UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Extended frequency amplification, speech recognition and functional performance in children with mild to severe sensorineural hearing loss

by

Claudia Müller

A dissertation submitted in fulfillment of the requirements for the degree M Communication Pathology
In the Department of Communication Pathology at the

UNIVERSITY OF PRETORIA
FACULTY HUMANITIES

SUPERVISER: Dr L. Pottas
CO-SUPERVISER: Mrs T.E. le Roux

March 2012

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Acknowledgements

I would like to thank Dr Lida Pottas and Mrs Talita le Roux for all their valuable inputs and patience.

Thank you to all my colleagues and friends at Siemens Hearing Solutions.

My friends supporting and helping me with references, statistics and tables: Deidre, Amelia and Marié.

My mother, for always being there and all her unconditional support - without her this would not have been possible.

My father: 12 October 1941 - 17 September 2010

Psalm 103:4-5

"Praise the Lord Who crowns you with love and compassion, Who satisfies your desires with good things so that your youth is renewed like the eagle's."

Abstract

TITLE:	Extended frequency range amplification, speech recognition and functional performance in children with mild to severe sensory neural hearing loss
NAME:	Claudia Müller
SUPERVISOR:	Dr L Pottas
CO-SUPERVISOR:	Mrs TE le Roux
DEPARTMENT:	Communication Pathology
DEGREE:	M Communication Pathology

A substantial body of research points to the benefits of fitting hearing instruments that provides extended high frequency amplification. Most published research were done on adults or in controlled laboratory settings. It is therefore necessary for peadiatric audiologists to critically assess the effects that this extended high frequency amplification has on the individual child fitted with hearing instruments.

A quantitative research method was selected to explore the possible correlations between extended high frequency amplification and the influence this extended high frequency amplification has on speech recognition and functional performance in children with mild to severe sensory neural hearing loss. A quasi-experimental design was selected. This design accommodated a one-group (single-system) pre-test versus post-test design. Baseline assessments were done and all participants were subjected to pre- and post-intervention assessments.

Six participants were fitted with hearing instruments which provided extended high frequency amplification. A baseline assessment was done with current hearing instruments after which participants were assessed with the hearing instruments with extended high frequency amplification. Aided audiological assessments were done without the extended high frequencies after which participants were evaluated with the added high frequencies. Speech recognition testing and functional performance questionnaires were used to compare the outcomes obtained with and without the extended high frequency amplification. A t-test was used for hypothesis testing to determine if extended range amplification increased speech recognition abilities and functional performance, and if these increases were statistically significant.

Results were varied where some participants performed better and some performed worse with the added extended range amplification during speech recognition testing and functional performances observed at home. These varied results were statistically insignificant. However, statistically significant evidence was obtained to indicate that extended high frequency amplification increased the functional performance observed at school. The study concluded that the paediatric audiologist should know the effect fitting hearing instruments capable of extended high frequency amplification have on speech recognition abilities and functional performances. Fitting hearing instruments with extended high frequency amplification should however be done with caution because not all children benefited from extended bandwidth amplification. This underlines the importance of following a strict evidence-based approach that incorporates objective and subjective assessment approaches. This will provide the paediatric audiologist with real world evidence of the success of the amplification strategy that is followed.

Keywords:
TEACH (Teacher's Evaluation of Aural/Oral Performance of Children), PEACH (Parent's Evaluation of Aural/Oral Performance of Children), WIPI (Word Intelligibility by Picture Identification Test), extended high frequency amplification, evidence-based approach, hearing instruments, speech recognition, functional performance, children with mild to severe sensory neural hearing loss, peadiatric audiologist

Table of content

3. Method

4. Results and discussion

List of tables

List of figures

CHAPTER 1

Introduction and orientation

1.1 Introduction

Early intervention in children with hearing loss requires an accurate diagnosis and the provision of appropriate amplification (Kuk & Marcoux, 2002:504). Hearing is the most effective modality for the teaching of spoken language, reading and cognitive skills (Cole & Flexer, 2007:2). Paediatric audiology is in an exciting era of transition (Cole & Flexer, 2007:2). Everything audiologists knew about deafness has changed dramatically with the advent of newborn infant hearing screening programs and innovative hearing instrument technologies which have allowed access to critical auditory brain centres during times of maximum neuroplasticity. Because of neuroplasticity, infants and young children diagnosed with hearing loss at a very young age have implausible possibilities for achieving higher levels of spoken language, reading skills and academic competencies than were available to most children in previous generations (Cole & Flexer, 2007:2).

1.2 Background and rationale

Permanent disabling hearing impairment (>40dB HL) is a significant contributor to the global burden of disease on individuals, families, communities and countries affecting about 250 million people worldwide (Olusanya, Swanepoel, Chapchap, Castillo, Habib, Mukari, et al., 2007:2). Congenital hearing loss is identified in two to three out of every 1000 infants in developed countries and is known to be the most frequently occurring birth defect (Vohr, 2003:62). According to Smith, Bale and White (2005:881) it is estimated that one in every 1000 infants are born with bilateral sensorineural hearing loss of at least 40dB HL and four profoundly deaf infants per every 10000. This data is consistent with findings of universal newborn hearing screening programs in other developed countries that report identification of two to four infants per 1000 with sensorineural hearing loss (Smith et al., 2005:882). Although available preliminary data from less developed countries is limited, existing data suggest that the incidence of congenital sensorineural hearing loss is much higher in these countries (Smith et al., 2005:882).

As a result of Early Hearing Detection and Intervention (EHDI), children with hearing loss have access to early use of hearing instruments and therefore auditory centres of the brain could be stimulated during times of critical neuroplasticity (Cole & Flexer, 2007:80). Infants and children diagnosed with a mild to profound degree hearing loss (identified during the first six months of life) and who are provided with immediate and appropriate intervention, have significantly better speech and language outcomes than later-identified infants and children (Joint Committee on Infant Hearing, 2007:162). These improved outcomes are observed in vocabulary development, receptive and expressive language, syntax, speech production and social-emotional development (Joint Committee on Infant Hearing, 2007:162). Children who enrol in early intervention within the first year of life have also shown to have language development within the normal range of development at five years of age (Joint Committee on Infant Hearing, 2007:162). According to Yoshinago-Itano, Sedey, Coulter and Mehl (1998:1169) children whose hearing loss are identified by six months of age demonstrate significantly better receptive and expressive language skills than children whose hearing loss is identified at a later age. This language advantage is evident across age, gender, socio-economic status, ethnicity, cognitive status, degree of hearing loss, mode of communication and the presence or absence of other disabilities (Yoshinago-Itano et al., 1998:1169).

Development of oral language highly depends on what an infant can hear (Eisenberg, 2007:766). The primary goal of amplification is to make audible to the infant / young child those elements of the acoustic spectrum, which contain important information for the identification of speech sounds (Boothroyd & Medwetsky, 1992:151). Thus, for the appropriate acquisition of speech and language, amplification should make all speech sounds audible to the infant /ʃ/ young child in a variety of listening contexts (Ching, Dillon & Katsch, 2001:149). Although oral communication is the goal when infants and young children with hearing loss are fitted with hearing instruments, they should first utilize their amplification in order to acquire necessary speech and language skills, which also include the accurate production of speech (Pittman, Stelmachovicz, Lewis & Hoover, 2003:649).

Hearing instrument technology has come a long way since the body-worn models and linear circuits with peak clipping of the 1970's (Stelmachovicz, 2004:27). Progress in hearing instrument processing technology has been made during the past 35 – 40 years. Compression in hearing instruments was available since the 1930s, but during those times it was not considered a routine feature. Today a variety of compression is available and the choice is rather between what type of compression is needed (Bentler & Mueller, 2009:781). Currently Automatic Gain Control: Output (AGCo) and Automatic Gain Control: Input (AGCi) are the two most common types of amplitude compression. AGCo is a replacement for peak clipping (peak clipping can introduce distortions that reduce speech intelligibility and quality for loud speech), and is used to maintain high inputs below uncomfortable loudness thresholds. With AGCo the signal is analyzed and compressed after it has been fully amplified. The primary goal for AGCo is therefore output limiting (Bentler & Mueller, 2009: 781). AGCi, on the other hand, is the alternative to linear processing and is used to reduce the dynamic range of the output signals in order for these signals to fit within the boundaries of the hearing instrument wearers' residual dynamic range. The input signal to a hearing instrument is analyzed and compressed before that signal reaches the final amplifier section. The goal is to 'reshape' and 'repackage' the input signal to allow a wide range of intensities to fit into the restricted residual dynamic range of the infant / young child with hearing loss (Bentler & Mueller, 2009:781). The shift toward digital hearing instrument technology has also expanded the signal processing capabilities to include single microphone noise reduction, frequency compression or transposition, adaptive directional microphone and feedback cancellation (Stelmachovicz, 2004:28).

These technological advances have not been accompanied by the methodologies needed to evaluate the efficacy of new hearing instrument technology in infants and young children (Stelmachovicz, 2004:28). According to Stelmachovicz (2004:31) in the late 1990s it was for example concluded that the provision of high frequency gain may not improve and in some cases degrade speech recognition for listeners with sensorineural hearing loss. These studies were conducted on adults with well-developed language systems and sufficient linguistic knowledge to compensate for a loss of audibility in the high frequencies (Stelmachovicz, 2004:32). Unfortunately, the concept that amplification in the high frequencies was not necessary was also applied to infants / young children in clinical practice (Stelmachovicz, 2004:32). A study by Kortekaas and Stelmachovicz (2000:658) however revealed that young children with hearing loss actually do require a wider signal bandwidth than adults in order to perceive [s] correctly when presented in noise.

In order for early identification programs to have maximum impact on speech and language acquisition, it is important that the fitted hearing instruments provide appropriate amplification. Therefore the monitoring of amplification, as well as the long-term validation of the appropriateness of the individual intervention program, requires ongoing audiological assessment along with electro-acoustical, real-ear and functional assessments of the hearing instruments (Joint Committee on Infant Hearing, 2007:167). Because these assessments are complex it is unlikely that a single outcome measure or a single approach to fit children with hearing loss with hearing instruments can provide adequate means by which to determine efficacy for all types of hearing instrument signal processing (Stelmachovicz, 2004:28).

Living in an era of early hearing detection and having access to advanced technology hearing instruments, children with mild to severe sensorineural hearing loss still present with speech production errors. The performance scores of word recognition are relatively high for children with mild to severe sensorineural hearing loss when compared to children with profound hearing loss, but not as high as scores for children with normal hearing (Eisenberg, 2007:766). Again the articulation of children with mild to severe sensorineural hearing loss are not severely affected, the most common errors being omissions and substitutions, particularly for fricatives and affricates (Eisenberg, 2007:766).

Speech information is carried by the changing patterns of sound energy and is measured in intensity (dB SPL or dB HL), frequency (Hz) and time (seconds). These acoustic characteristics of speech are important for children with hearing loss to be able to hear and discriminate speech sounds. Hearing these acoustic characteristics enable children with hearing loss to discriminate speech sounds for the understanding of vocabulary, syntax and grammatical markers and is necessary for spoken language development.

Table 1 summarizes the importance of hearing different frequencies because of the speech information carried by these frequencies.

Table 1: Speech information carried by the key speech frequencies (Cole & Flexer, 2007:25):

Frequencies from 250 Hz – 4000 Hz				
250 Hz	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**
• First formant of vowels [u] and [i] • Fundamental frequency of females' and children's voices • Nasal murmur associated with the phonemes [m]. [n] and [ng] • Prosody • Suprasegmental patterns like stress, rate, inflection and intonation • Male voice harmonics Voicing cues	• First formants of most vowels • Harmonics of all voices (male, female, child) • Voicing cues • Nasality cues • Suprasegmentals • Some plosive bursts associated with [b] and [d]	• Important acoustic cues for manner of articulation • Second formants of back and central vowels • Consonant-vowel and vowel-consonant transition information • Some plosive bursts • Voicing cues • Suprasegmentals • Unstressed morphemes	• Important acoustic cues for place of articulation • Key frequency for speech intelligibility • Second and third formant information for front vowels • Consonant-vowel and vowel-consonant transitions information • Acoustic information for the liquids /r/ and [l] • Plosive bursts • Affricate bursts • Fricative turbulence	• Key frequency for [s] and [z] audibility that is critical for language learning: plurals, idioms, possessives, auxiliaries, third person singular verb forms, questions, copulas, past perfect • Consonant quality

As depicted form Table 1, frequencies between 250Hz and 4000Hz are of particular importance for the perception of speech (Cole & Flexer, 2007:24). The acoustic phonetic audiogram (Northern & Downs, 2002) represents the typical intensities and frequencies of the different phones of the English language and is presented in Figure 1.

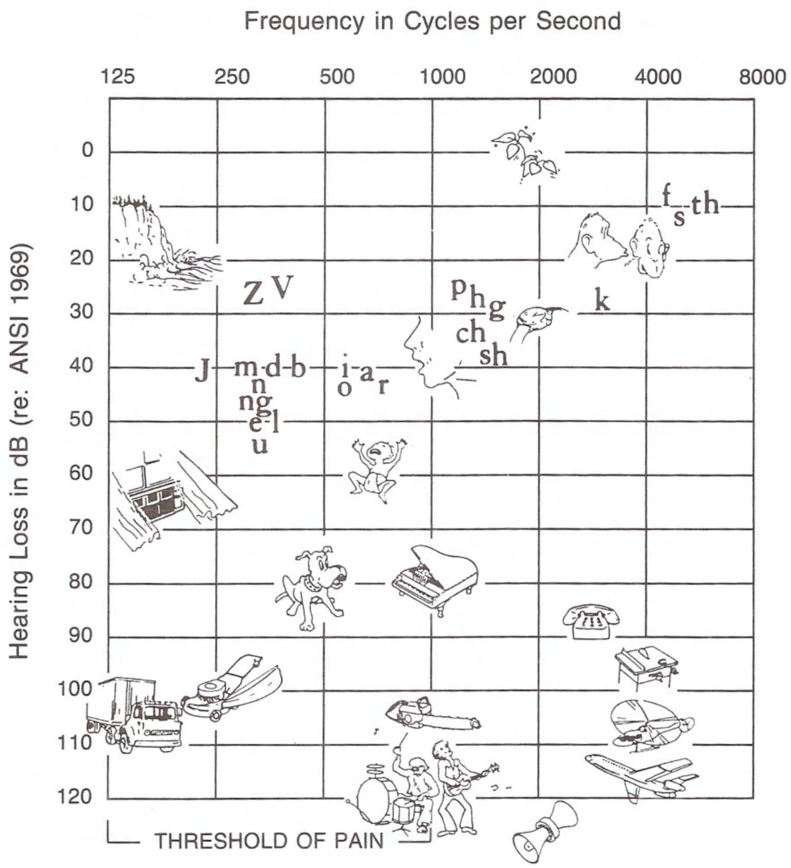


Figure 1: Acoustic phonetic audiogram (Northern & Downs, 2002)

Northern and Downs (2002), developed a widely used acoustic phonetic audiogram which represents the typical acoustic properties of numerous environmental and speech sounds. It displays the different intensities and frequencies of the different phonemes of the English language.

With reference to Table 1 and Figure 1 it can be concluded that most speech sounds and speech information are available between 250Hz and 4000Hz. Only the high-frequency low-intensity consonants such as [f], [s] and [th] are situated at higher frequencies than 4000 Hz.

The most common speech production error in children with a mild to severe hearing loss is the substitution or omission of phonemes (Elfenbein, Hardin-Jones & Davis, 1994:223). These errors are especially likely to occur with fricatives such as [f] and [s] and unstressed components of speech for example [t] indicating past tense of verbs ending in voiceless consonants, as in the word 'walked' (Elfenbein et al., 1994:223). It is also noted that, as hearing loss increases both in degree and affected frequencies, the number and type of phonemes of which production is affected, also increases (Elfenbein et al., 1994:223). It is likely for the fricatives mentioned above to be inaudible because of their low intensity and high frequency components. Therefore, children with mild to severe sensorineural hearing loss have difficulty perceiving the acoustic energy necessary for learning the proper use of information provided in the pronunciation of these phonemes (Elfenbein et al., 1994:223).

Results of an analysis by Stelmachovicz et al. (2004:558), which scored plural words spoken by a male and female speaker, revealed that mid frequency audibility (2000Hz – 4000Hz) appeared to be most important for perception of the fricative noise produced by a male speaker, whereas a somewhat wider frequency range (2000Hz – 8000Hz) was important for the perception of a female speaker. Boothroyd and Medwetsky (1992:156) further support this finding by emphasizing gender differences in that male speech averaged 4300Hz and female speech 7200Hz. The spectral levels of speech vary considerably across the frequency region of 125Hz to 8000Hz. These variations are based on differences in gender, age and vocal effort of the talker (Olsen, Hawkins & Van Tasell, 1987:101s). Comparison in the spectral characteristics of male and female speech showed virtually identical spectra over the frequency range 250Hz to 5000Hz, but for 6300Hz and higher, the female levels exceeded those of the males for every country, although only marginally in some instances (Byrne et al., 1994:2117). This implies that children whose hearing instruments amplify up unto only around 5000Hz will not be able to hear certain speech sounds produced, especially by female speakers. As a result, this can impact children's speech and language development in a negative manner, given the fact that children with hearing loss spend most of their time with female caregivers, teachers and other children (Stelmachovicz, 2001:171).

There is also evidence that young children with hearing loss need high frequency amplification more than older children and adults with hearing loss (Stelmachovicz, 2001:168; Kortekaas & Stelmachovicz, 2000:646). The first argument in favour of this statement is based on the concept of co-articulation. Co-articulation is the pervasive aspects of spoken language and refers to a production process in which a speaker adjusts the production of a word segment to accommodate the surrounding segments (Connine & Darnieder, 2009:412). Adult listeners use this high frequency co-articulation information of the transition from vowel to consonant to discriminate the correct consonant. Another argument is that adults use syntactical and semantic information to guide them to the correct consonant (Kortekaas & Stelmachovicz, 2000:646). However, children who are in the process of acquiring knowledge of speech and language rules still need to obtain knowledge about the language rules involving these sounds prior to using the abovementioned skills. In order to acquire this knowledge, the sounds should first be made consistently audible to them (Kortekaas & Stelmachovicz, 2000:646). As a result, children with hearing loss may experience inconsistent exposure to certain speech sounds across different speakers, situations and contexts. This inconsistent audibility of important speech sounds will delay the construction of linguistic rules (Stelmachovicz et al., 2004). It is probable that in order to learn structures that are dependant on minimal acoustic information, extensive exposure to speech sounds is required.

Aided audibility of high frequency speech sounds is problematic, even for children with mild to moderate hearing loss because it influences the ability to adequately monitor their own speech (Stelmachovicz et al., 2004:559). There are two aspects that may interact to influence the self-monitoring of speech in children with hearing loss. Firstly, the acoustic characteristics of a speaker's own voice are different when measured at the ear compared to at the speaker's mouth. The spectrum at the ear contains more energy below 1000Hz and less energy above 2000Hz than the spectrum in face-to-face conversation (0 degrees azimuth) (Stelmachovicz et al., 2004: 559). Cornelisse, Gagne and Seewald (1991:48) support this by stating that high frequency band levels are attenuated (reduced) when the input signal is moved from zero degrees azimuth to 90 degrees (at the side of the talker). They stated that this could be due to the directional radiation characteristics of the mouth. This reduction in high frequency energy may limit the audibility of important speech sounds produced by the children with hearing loss themselves (Stelmachovicz et al., 2004). Secondly, the overall amplitude level of children's speech are approximately 5dB SPL to 6dB SPL lower than that of adults, and there is a 8dB SPL to10dB SPL reduction in signal amplitude for frequencies higher than 4000Hz (Stelmachovicz et al., 2004:560). This supports the view that children with hearing loss may not be able to monitor high frequency fricative production adequately. Since roughly 50% of consonants in the English language are fricatives, this reduced ability to monitor high frequency fricative production is likely to have a substantial influence on speech and language development (Stelmachovicz et al., 2004:561).

Traditionally, the majority of infants and young children with hearing loss have been fitted with hearing instruments that provide amplification within a limited frequency range because of transfer difficulties associated with tubing of behind-the-ear hearing instruments, as well as acoustic feedback (frequency transfer characteristics of transducers and ear moulds) (Stelmachovicz, et al., 2004:561; Kortekaas & Stelmachovicz 2000:646). As a result infants and young children with mild to severe hearing losses did not have constant access to high frequency amplification and therefore had inconsistent access to important speech sounds, resulting in the omission and/or substitution of certain phonemes (Elfenbein et al., 1994:223). In order to address this critical limitation, hearing instruments with an increased frequency bandwidth were developed, since the primary goal in the development of hearing instruments is to ensure audibility of all sound properties that are essential for the perception of speech, including high frequency cues (Smith, Dann & Brown, 2009:64).

Bandwidth refers to the range of frequencies which are amplified by a specific hearing instrument (Stach, 2003:38). Although the bandwidth of current hearing instruments is wider than ever before, the high frequency gain in most instruments is rapidly reduced above 5000Hz, which is well below the frequencies of the peak energy of [s] in both children and adult female speakers (Pittman, et al., 2003:653; Stelmachovicz, et al., 2004:558). Reduced high frequency gain in combination with high frequency hearing loss may result in insufficient amplification in this region.

Children with hearing loss may benefit from increased high frequency amplification when learning new words and for other long-term auditory processes as well (Pittman, 2008:785). Regardless of degree of hearing loss, the children learn words significantly faster when they are provided with a speech signal that includes a bandwidth similar to that of normal hearing. Conversely, children with hearing loss learn words more slowly when they are provided with limited speech signals. It is therefore clear that sufficient high frequency amplification for children with hearing loss may be necessary to promote optimal word learning (Pittman, 2008:795).

It is important for children with hearing loss to acquire specific open set perceptual recognition skills and knowledge of phonological contrast in order to acquire language skills, because speech recognition skills significantly correlate with language skills in young children (DesJardin, Ambrose, Martinez & Eisenberg, 2009:255). This is explained by Eisenberg (2007:766) as precepts of speech stimuli that are internally represented as linguistic patterns: ‘phonemes – syllables – words – phrases – sentences' that carry meaning about the physical and social world. Auditory recognition of a speech stimulus requires decision criteria that are based on the acoustic-phonetic properties of the stimulus, lexical access from long-term memory and the listener's estimate of its probability of occurrence. The spoken response reflects the listener's set of phonemic and lexical recognition categories. Therefore, speech recognition and production are integrally related in the development of spoken communication. Infants and young children must first be able to detect speech before they are able to discriminate and recognize speech (Eisenberg, 2007:766).

Since it was indicated that children with mild to severe sensorineural hearing loss need high frequency amplification more than older children and adults (Stelmachovicz, 2001:168; Kortekaas & Stelmachovicz, 2000:646), hearing instruments with extended frequency bandwidth were developed to ensure audibility of all speech sounds, especially the fricatives and unstressed components of speech.

In the light of the above this study will focus on the effect that a hearing instrument with an extended bandwidth (>100Hz – 7000Hz) may have on the speech recognition abilities of children with mild to severe sensorineural hearing loss. For the purpose of this study high frequency amplification that increases bandwidth will be utilized. High frequency extension through 7000Hz – 9000Hz has been shown to improve speech recognition in children with mild to moderate hearing loss (Johnson, Ricketts & Hornsby, 2009:354). Also, speech recognition for the phoneme [s] increase with bandwidth extensions through 9000Hz when listening to child and female speakers (Johnson et al. 2009:354).

As stated in the Pediatric Amplification Guidelines Protocol (2004) there are basic evidence based requirements that need to be followed when providing amplification to children with hearing loss. According to this protocol, the main aim when fitting children with hearing loss should be to provide audibility of speech regardless of input level or vocal efforts.

Verification is the stage in the hearing instrument fitting process at which the hearing instrument's performance is measured in order to determine that it is doing what it is supposed to do in areas such as frequency shaping, compression, output limiting and directional microphone performance (Scollie, 2003: 10). Efficacy of amplification in children with hearing loss is complex and problematic when introducing a new signal-processing strategy to a child, because immediate changes in speech production or language skills cannot be expected (Stelmachowicz, 2004:28). Because the evaluation of device efficacy in the paediatric population is complex, it is unlikely that a single outcome measure or a single approach to the quandary can provide a means for determining efficacy for all types of signal processing (Stelmachowicz, 2004:28). Therefore, the Joint Committee on Infant Hearing (2007:167) recommend that monitoring of amplification, as well as the long-term validation of the appropriateness of the individual habilitation program, require ongoing audiological assessment along with electro-acoustic, real-ear and functional assessments of the hearing instruments.

In order to assess the effect that hearing instruments with an extended bandwidth has on the speech recognition abilities of children with moderate to severe sensorineural hearing loss, electro-acoustic and real-ear measurements have to be conducted in order to verify that the amplification targets are met. In order to provide evidence of the efficacy of this amplification strategy speech recognition measurements are necessary as well as functional performance tools completed by teachers and parents.

1.3 Rationale and research question

Due to the fact that, in the past, many hearing instruments only had a cut-off frequency of only around 5000Hz and as a result, children fitted with these instruments were not exposed to extended high frequency auditory stimuli. Because of advances in hearing instrument technology like extended high frequency amplification, more research needs to be done on the effect this extended high frequencies have on speech discrimination in background noise and speaker distance in naturalistic learning environments (Pittman, 2008:795).

Research conducted on the effect of limited and extended bandwidth in children with hearing loss have been conducted in a highly controlled environment using high fidelity earphones in sound treated rooms (Pittman, 2008:795). Such contexts are far removed from the natural environment that children with hearing loss are usually exposed to (Pittman, 2008:795). Children with hearing loss are, on a daily basis, exposed to background noise and varying distances from speakers and it is possible that the effects of extended bandwidth may be enhanced or reduced by such situations (Pittman, 2008:795). A study by Stelmachovicz, Lewis, Choi and Hoover (2007:483) evaluated the effects of stimulus bandwidth on the auditory skills of normal-hearing and hearing-impaired children. Results indicated significant improvements for the perception of the phonemes [s] and [z] by the hearing-impaired children exposed to a 10000Hz bandwidth condition. This study was done in a controlled laboratory setting, not in real life like the home or school environment. A more recent study by Mlot, Buss and Hall (2010:56) investigated the bandwidth effects on speech recognition in school-aged children and adults and concluded that younger children require more bandwidth than adults in order to recognize speech. Unfortunately, a limitation of this study is that the research was conducted in a laboratory setting with children and adults with normal hearing. A study by Horwitz, Ahlstrom and Dubno (2008:811) indicated that speech recognition improved with additional high-frequency speech bands, although most improvements were smaller than predicted. These results suggest that, although listeners with hearing loss may not take advantage of audible speech cues to the same extent as listeners with normal hearing, high frequency amplification increased speech audibility and improved speech recognition. Again, a limitation of the mentioned study is that data was gathered from adult listeners and not children. Also, data was collected in a controlled environment, namely in a laboratory setting (Horwitz, et al, 2008:811). These authors also suggested that the determination of the benefits of high frequency amplification should be based on research conducted under more realistic conditions outside of the laboratory and in real life conditions. A study done by Plyler and Fleck (2006:616) where hearing instruments with high frequency amplification were fitted indicated that in the laboratory setting significant improvements was noted with extra high frequency amplification. However within noisy and real world listening conditions some subjects preferred the extra high frequency amplification while others did not. Yet again, the participants of this study were adult listeners.

It can be concluded that a great deal of published research indicate that the fitting of hearing instruments with extended range high frequency amplification is beneficial to adult listeners. These studies were administered in a highly controlled environment and not in the real world where children are typically exposed to different challenging listening conditions (Plyler & Fleck, 2006:616). This emphasizes the need for clinical audiologists to critically assess the benefit that high frequency amplification has on the individual child fitted with hearing instruments. Not only should the outcomes of extended high frequency amplification on speech recognition abilities be determined, but these outcomes should also be determined in environments representing the day to day lives of children (Pittman, 2008:795; Stelmachovicz et al., 2007:483; Mlot, et al. (2010:56). Therefore it is also important that the influence of extended high frequency amplification should be assessed in real life environments such as the school and home environment.

Collectively, the discussed research indicates the importance of audibility of high frequency sounds**,** and this study aim to expand the knowledge of fitting children with mild to moderate sensorineural hearing loss with hearing instruments with extended high frequency amplification,. Therefore the question arises: *Will the fitting of hearing instruments with extended high frequency range amplification improve speech recognition abilities and functional performance of children with mild to severe sensorineural hearing loss?*

1.4 Definition of terms

AGCo: Automatic gain control: output
AGCi: Automatic gain control: input
dB HL: Decibel measured in hearing level
dB SPL: Decibel measured in sound pressure level
EHDI: Early hearing detection and intervention
Extended range amplification/High frequency amplification
Hz: Hertz
TEACH: Teacher's Evaluation of Aural/Oral Performance of Children
PEACH: Parents' Evaluation of Aural/Oral Performance of Children
WIPI: Word Intelligibility by Picture Identification Test

1.5 Outline of chapters

Chapter 1: The background to and rationale for the importance of extended frequency amplification and speech understanding in children with moderate to severe sensorineural hearing loss is discussed. The outline of the chapters is presented as well as definitions of terms used in this study.

Chapter 2: The second chapter provides a literature overview of communication development in children with hearing loss and the effects hearing loss has on auditory, speech and language development and the direct effect this have on the education of the child with a hearing loss. Evidence is provided of the necessity of early detection of hearing loss together with the prevalence, incidence and aetiology thereof, with the focus on developing versus developed countries. Lastly, the importance of evidence based practise in the intervention process is discussed, as well as the crucial role of hearing instrument technology in this process.

Chapter 3: The method used to conduct this study is discussed in Chapter 3. The main aim and sub aims are stated. The research design, ethical procedures, subject selection, data collection and analysis procedures are discussed in detail.

Chapter 4: In this chapter the results of the study are presented and discussed. This is done according the sub-aims as stated in Chapter 3, in order to realize the main aim. A conclusion of the obtained results is given at the end of the chapter.

Chapter 5: In this final chapter conclusions of the results are drawn and its clinical implications are discussed. Lastly, a critical evaluation of the study is provided, as well as recommendations for future research.

1.6 Conclusion

Development of oral language is highly dependent upon what an infant can hear (Eisenberg, 2007:766). The primary goal of hearing instruments is to make audible those parts of the acoustic spectrum which contain important information for the identification of speech sounds (Boothroyd & Medwetsky, 1992:151). Therefore speech recognition skills closely correlate with language skills in young children (DesJardin, Ambrose, Martinez & Eisenberg, 2009:255).

Hearing instruments with an increased frequency bandwidth have been developed to ensure the audibility of all speech sounds that are crucial for the perception of speech, including high frequency perceptual cues (Smith, et al., 2009:64).

This study will therefore focus on the possible effects that hearing instruments with extended high frequency amplification may have on the speech recognition abilities in children with moderate to severe sensorineural hearing loss.

CHAPTER 2

Literature review

> 'Although it is true that mere detection of a sound does not ensure its recognition, it is even more true that without detection the probability of correct identification is greatly diminished' (Olsen, et al., 1987:1067s)

2.1 Introduction

According to Cole and Flexer (2007:2) audiology is in an era of exciting transition and everything audiologists thought they knew about deafness, has changed dramatically. This change came about through newborn hearing screening programmes and new hearing instrument technologies which allow early auditory access to critical auditory brain centres during times of maximum neuroplasticity. As a result of neuroplasticity, infants and young children with hearing loss nowadays have incredible possibilities for achieving higher levels of spoken language, reading skills and academic competencies compared to children in previous generations (Cole & Flexer, 2007:2).

Hearing is the most effective modality for the teaching of spoken language, reading and cognitive skills (Cole & Flexer, 2007:2). Therefore, to better understand the impact of recent hearing instrument technology and especially added high frequency amplification on speech recognition skills, a brief overview of auditory and communication development in children with normal hearing is presented. With normal development as reference, the influence of hearing loss on the development of children's auditory, language, speech, socio-emotional and literacy skills will henceforth be discussed. Furthermore, the importance of early hearing detection and intervention and to the critical role that hearing instrument technology and the accurate fitting procedure play in the acquisition of speech and language will be discussed.

2.2 Development of the auditory system

Listening experience in infancy is critical for adequate language development of which speech recognition skills forms an integral part (Cole & Flexer, 2007:4). The development of adequate auditory skills is necessary for the recognition of sound. This view is supported by Eisenberg (2007:766), who states that children should first be able to detect speech before they will be able to discriminate and recognize speech. Therefore, the auditory system needs to be developed prior to speech being recognized in order for language development to take place.

The constituting levels of the development of auditory skills are described in terms of its fundamental elements by Flexer (2004:132) and are summarized below in Table 2:

Table 2: Auditory skill development (Flexer, 2004:132)

Detection
This is the lowest, least sophisticated level of auditory skill development. Detection refers to the noticing the presence and absence of sound.
↓
Discrimination
This involves distinguishing between two speech sounds. An example of a discrimination task would be noting if [p] and [b] in [pa] and [ba] are the same or different sounds.
↓
Recognition
This involves selecting a target from a known list of alternatives; recognition is a closed-set task.
↓
Comprehension
This is the highest level of auditory skill development. Comprehension is achieved when one can answer questions, follow directions and maintain conversations.

Table 2 indicates that auditory development begins with the detection of sound stimuli. Before discrimination, speech recognition and comprehension of speech can occur, it is crucial that sound should adequately be detected. Without detection, none of the higher auditory skills can develop. Brown (2009:945) describes this hierarchy of auditory skills development in more detail as is reflected in Table 3.

Table 3: Hierarchy of auditory skills (Brown, 2009:945)

Stage of auditory development	**Definition**
Awareness and meaning of sounds	The child is aware that an auditory stimulus is present. The child further demonstrates that sound is meaningful by associating a variety of auditory stimuli with their sound source.
Auditory feedback and integration	The child changes, notices, and monitors his/her own vocal productions. Furthermore, the child uses auditory information to produce a spoken utterance that approximates or matches a spoken stimulus.
Localizing sound source	The child searches for and/or finds the auditory stimulus. Searching is a prerequisite skill for localizing.
Auditory discrimination	The child distinguishes the characteristics of different sounds as being the same/different, including environmental sounds, suprasegmental characteristics of speech (e.g., intensity, duration, pitch).
Auditory comprehension	The child demonstrates understanding of linguistic information by identifying what is said, identifying critical elements in the message, and following directions.
Short-term auditory memory	The child can hear, remember, repeat, and recall a sequence of units (e.g., digits, unrelated words, sentences, etc.). This skill is developmentally appropriate for children who are 2 years of age and older.
Linguistic auditory processing	The child uses auditory information to process language. This category measures the ways in which audition is used to sequence language, to learn and use morphemes, to learn and use syntactic information, and to understand spoken language.

In this model, the detection and awareness of the sound is the first essential step towards auditory development. At this stage a sound is detected and meaning is associated with a particular sound. The following phases of auditory development that takes place after awareness of sound that are discussed in Table 3 are: auditory feedback, localization of sounds and discriminating between different sounds, followed by the understanding of what is being said, (what the sound means), short-term auditory memory (remembering what has been said) and linguistic auditory processing where auditory information is used.

In both the above models it is critical to note that without the basic detection of sound none of the higher levels of auditory processing skills are possible (Flexer, 2004:132). Both models also recognize the sequence of auditory development namely detection, discrimination, (before sound recognition can occur), followed by comprehension. The main difference between the models is that in Table 2 auditory development is divided into the further basic steps, whereas in Table 3 there are seven levels in the development of auditory skills. Brown (2009:945) identified that, together with sound detection, an infant also detects and monitors its own vocalizations and learn to localize where sounds are coming from. Detection is therefore more that just ‘hearing’ the sound, but an awareness of sounds in the environment. It is at this stage that auditory discrimination abilities (distinguishing between different sounds) starts to develop. According to Brown’s hierarchy of auditory skills (Table 3), comprehension are also the last auditory skill to develop, although Brown (2009:945) also mentions that short-term auditory memory develops after comprehension, as well as linguistic auditory processing (using auditory information to process language).

Internal (genetic) and external (sensory) instructions underlie the development of the central auditory system and associated auditory skills (Illing, 2004:9). The course of development of cortical as well as sub-cortical regions is susceptible to sensory stimuli and therefore they reveal neural plasticity (Illing, 2004:9). Neural plasticity refers to the dynamic changes in the structural and functional characteristics of neurons in the auditory cortex that occur as a consequence of altered auditory input (Irvine, 2007:159). This is supported by Flexer (2004:132), who mentions that sensory stimulation influences the actual growth and organization of the auditory pathways.

There is a critical age for neural plasticity (Sharma, Dorman & Spahr, 2002:532). The latency of the first positive peak (P1) of cortical auditory evoked potential is considered a biomarker for maturation (vary as a function of age) of the auditory cortical areas, and is therefore considered as an index of cortical auditory maturation (Sharma, Cardon, Henion & Roland, 2011:99). A study done by Sharma et al (2002:538) indicates that auditory deprivation of more than seven years substantially alters the latency of the P1 cortical response to sound. These authors concluded that the auditory system appears maximally plastic for a period of approximately 3.5 years (Sharma et al. 2002:538).

Harrison (2001:5) explains auditory system development by stating that what one see, hear and feel are actually portrayals of the outside world within the cerebral cortex. These representations are only as good as the ability of our sensory organs to transduce the external stimuli, and the ability to transfer this sensory information to the cerebral cortex. Therefore, those acoustic signals that activate the sensory epithelium of the cochlea, and which produce a pattern of neural activity that is faithfully transmitted to central auditory areas, can be heard (Harrison, 2001:3). Neural activity patterns generated along the sensory epithelium of the cochlea are re-represented at all levels within the auditory pathway up to and including the primary auditory cortex and areas beyond (Harrison, 2001:5).

These central (cortical) tonotopic maps are not present at birth or during the early stages of development. Whilst the human cochlea is completely functional at birth, the central auditory brain is very immature (Harrison, 2001:8). During infancy and adolescence there is a continuing maturation of the central auditory pathways as revealed for example, by the change in properties of the auditory evoked potentials (Harrison, 2001:8). The same author further explains that auditory brainstem evoked responses take up to five years to ‘mature’. Middle latency responses and other potentials from the auditory cortex are not adult-like for 12 – 15 years. Much of this maturation is paralleled by anatomical developments (Harrison, 2001:8). This is supported by Moore and Linthicum Jr (2007:461) who state that the auditory system develops from the embryonic period and well into later childhood. This maturation is important in order to learn and become aware of the complexities of language development in, for example, the areas of phonology, semantics, syntax and morphology. This may explain why development occurring after the 27th foetal week, during the perinatal period and early childhood, could be negatively impacted by an absence of sound-driven activity (Moore & Linthicum Jr, 2007:471).

2.3 Communication development in children with normal hearing

Normal language and speech development will be discussed as part of communication development in children with normal hearing.

2.3.1 Language development

Language learning and use are determined by the intervention of biological, cognitive, psychosocial and environmental factors (Owens, 1996:9). Effective use of language for communication requires a broad understanding of human interaction including such associated factors as nonverbal cues, motivation and socio-cultural roles (Owens, 1996:9). Language development is varied and complex (Shipley & McAfee, 1992:169) and can be divided into three major components, namely form (syntax, morphology, phonology), content (meaning) and use (pragmatics) (Owens, 1996:17). The aforementioned facets are subsequently discussed in terms of their definitions:

- Form

Syntax refers to sentence structure (Shipley & McAfee, 1992:199). The form or structure of a sentence is governed by the rules of syntax and these rules specify word order, sentence organization and the relationships between words, word classes and other elements of the sentence (Owens, 1996:18).

Morphology is the study of how morphemes (smallest units of meaning) are combined to form meaning (Owens, 1996:20). There are free morphemes (e.g. boy, house), bound morphemes (e.g. -s, -ing), grammatical morphemes (e.g. a, the), prepositions (e.g. in, at) and grammatical word segments (e.g. -ing, -ed) (Shipley & McAfee, 1992:209).

Phonology refers to the speech sounds component of language and the study of sounds systems (Wehmeier, McIntosh, Turnbull & Ashby, 2005:1090). A phoneme is the smallest linguistic unit of a sound that can signal a difference in meaning (Owens, 1996:21).

- Content (meaning)

Semantics is the system of rules governing the meaning or content of words and word combinations (Owens, 1996:22).

- Use

Pragmatics is used when we want to affect others or to relay information. It is therefore concerned with the way language is used to communicate context (Owens, 1996:23).

Early research efforts reflected the view that language is hierarchically organized which, in principle, described language in terms of how acoustic properties map onto phonetic segments (phonetic level), how the phonetic segments map to particular phonemes (phonemic level), how the phonemes are combined to form morphemes (morphemic level), and eventually how the morphemes are combined to form sentences (syntactic level) (Jusczyk & Luce, 2002:2). Although these earlier efforts to understand how language is learned (Cohort Theory, Trace theory, Shortlist model, Neighbourhood Activation Model (NAM) and PARSYN models) continue to be of importance in language and speech research, the primary focus of research concerning infants and adults has shifted somewhat toward understanding how our speech perception capacities are used in segmenting and recognizing words in fluent speech (Jusczyk & Luce, 2002:2). Thus, although the primary focus of earlier research included questions about our speech perception capacities, current investigations focus more sharply on how these capacities are used in understanding and learning language (Jusczyk & Luce, 2002:32). Table 4 reflects core issues that receive a great deal of attention in current research and theory on the acquisition of spoken word recognition capacities. These issues concern the development of lexical segmentation, lexical representation and knowledge of linguistic units beyond the word (Jusczyk & Luce, 2002:27).

Table 4: Acquisition of spoken word recognition (Jusczyk & Luce, 2002:27)

Segmenting words/lexical segmentation: Only about 7% of speech consists of one-word utterances. Therefore, to learn the words of a native language, infants must have some ability to segment words from fluent speech.
↓
Lexical representation: Once infants start segmenting words from fluent speech they are in a position to store information about the sound patterns of possible words and begin building a lexicon in which sound patterns are linked to specific meanings. There are indications that infants store information about sound patterns of words that they hear frequently, even when they do not have a specific meaning to link them to (Jusczyk & Luce, 2002:29). This view is however challenged by a growing body of evidence suggesting that infants' representations of words are detailed from the outset. Researchers interpreted this as an indication that infants' representations of such words might be very detailed, including enough detail to distinguish an item that differs only by a single phonetic feature in its initial consonant (Jusczyk & Luce, 2002:30).
↓
Knowledge on linguistic units beyond the word/Learning about larger units of linguistic organization: A critical task for language learners is to detect major constituents and how they are related in utterances. Accomplishing this requires that learners divide the signal into the right sized units. Infants are also sensitive to the information in speech that marks important units of linguistic organization. Although sensitivity for such information in not sufficient to ensure the acquisition of grammatical structure, the ability to group words into units corresponding to clauses and phrases is an important step towards discovering the specific syntactic organization of the native language (Jusczyk & Luce, 2002:31).

Table 4 summarized one theory surrounding core issues of research efforts to understand the acquisition of spoken word recognition. Even here there is evidence of contrasting results, which indicates that more research is necessary in this field.

Another more recent theory that explains language acquisition is described by Cole and Flexer (2007:188). Firstly, a frequency, intensity, and time analysis is done by the peripheral ear, with transformation of the input into representative neural patterns. Brief sensory memory storage should occur at this stage in order for the analysis and transformation to take place. Secondly, it is known that some preliminary auditory processing occurs in the brainstem related to localization and separations of competing messages (i.e., selective listening or selective attention). Finally, when the auditory cortex receives the input, higher levels of analysis occur of which the least certain knowledge is available and, consequently, the most theorizing exists. This type of processing presumably includes phonetic, phonological, syntactic, semantic and pragmatic/contextual processing. It may very well require hypothesized cortical activities such as discriminating from close cognates, identifying (categorizing or associating) with other similar items, and comprehending (integrating or interpreting) as meaning is derived. Clearly, both short and long term memory and retrieval are essential to this higher level processing of auditory linguistic messages (Cole & Flexer, 2007:188).

2.3.2 Speech development

Speech refers to the verbal means of communicating or conveying meaning (Owens, 1996:7). It is a dynamic neuromuscular process of producing speech sounds for communication (Owens, 1996:464). Speech is the result of planning and executing specific motor sequences and is a process that requires very precise neuromuscular coordination (Owens, 1996:7). Each spoken language has specific sounds (phonemes) and sound combinations that are characteristic of that language. Speech involves components such as voice quality, intonation and rate (Owens, 1996:7). The sounds (phonemes) of the child's speech reflect the language of the child's environment (Owens 1996:8). This is supported by Stokes and Surendran (2005:577) who states that that children's early phonologies should comprise consonants that reflect a predictable set of contrasts which, in turn, reflect underlying gradual development of control of the oral motor system.

It is generally agreed that age ranges exists in which normal consonant development occurs. Figure 2 provides the average age estimates and upper age limits of consonant production (Sanders, 1972, in Shipley & McAfee, 1992:151). In Figure 2 the solid bar corresponding to each sound starts at the median age of customary articulation and it stops at an age level at which 90% of all children are customarily producing the sound.

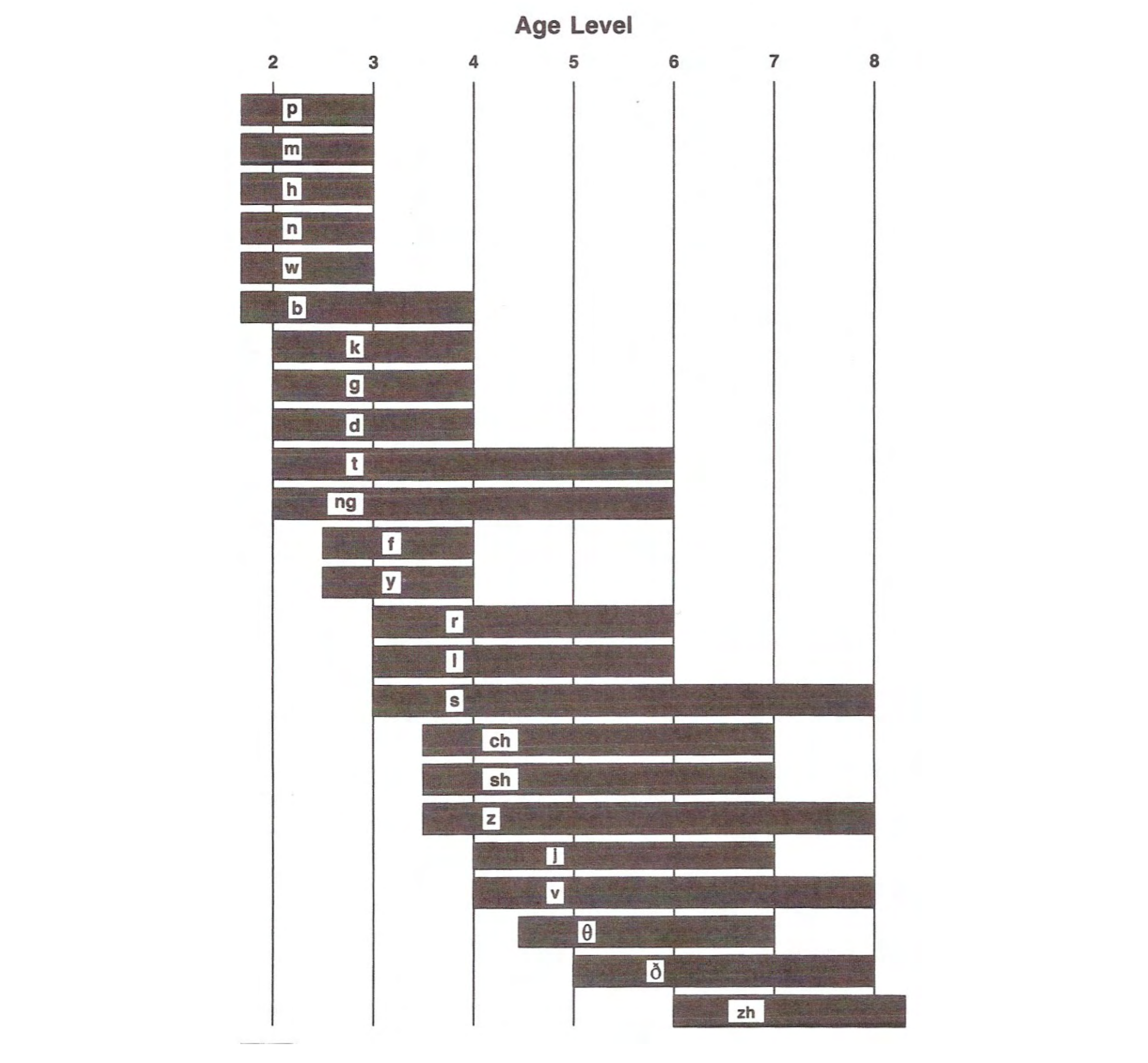


Figure 2: Average age estimates and upper age limits of consonant production (Sanders, 1972, in Shipley and McAfee, 1992:151).

Initially, sound production passes through a period of marginal babbling (Owens, 1996:87). At first the child's repertoire of consonants is restricted to bilabial and alveolar plosives such as [p], [b], [t] and [d]; nasals; and the approximant [j]. The phonemes are not fully formed or matured and are produced slowly (Owens, 1996:87). In contrast, the resonant quality and timing of reduplicated babbling more closely approximate mature speech (Owens, 1996:87) Reduplicated babbling is characterized by repetition of syllables consisting of a consonant (C) and a vowel (V) – CV-CV-CV – in which the vowel duration is very brief. Initially, reduplicated babbling is self-stimulatory in nature and is not used when communicating with adults and gradually the child start using this reduplicated babbling in more contexts (Owens, 1996:87). The developmental progression of speech production in infants begins with primitive vocalizations (crying, vegetative sounds, cooing, undifferentiated vocalizations and vocal play) that represent the earliest sounds uttered within the first six months of life (Eisenberg, 2007:768).

Complex vocal utterances (canonical babbling characterized by one or more consonant and vowel syllable sequences, reduplicated babbling, variegated babbling, and adult-like jargon) occur between six and fourteen months (Eisenberg, 2007:768). At around eight months, many changes occur in the infant's speech and interactional patterns. Initially the infant imitates gestures and intonation followed by sound imitation which will later be used to expand and modify the speech sound repertoire (Owens, 1996:88).

In the second half of the first year, infants begin to notice contrasts in pitch contours, in vowels, and in the initial consonants of CV syllables. Infants of seven to ten months of age are sensitive to prosodic cues that help them segment speech into perceptual units corresponding to clauses (Owens, 1996:88). The infant's babbling gradually resembles the prosodic pattern of the language to which the infant is exposed to. Babbling patterns become shorter and phonetically more stable. The prosodic features will develop into speech. Words and utterances are acquired as a 'whole tonal pattern' (Owens, 1996:89). Many speech sounds will develop sound-meaning relationships (phonetically consistent forms or PCFs). PCFs may be a link between babbling and adult-like speech in that they are more limited than babbling but not as structured as adult speech (babbling sounds used meaningfully) (Owens, 1996:89).

With the acquisition of words, the child's sound production becomes more controlled by the linguistic context. The order of appearance of the first sounds that children acquire – [m], [w], [b], [p] – cannot be explained by the frequency of their appearance in English. These are not the most frequently appearing English sounds, but they are the simplest consonants to produce. After acquiring one word, the child will usually learn a few more within a short time and then reach a plateau (Owens, 1996:90). Phonemic or syllabic speech patterns are manifested by broad phonetic and phonemic inventories associated with the child's native language. During this developmental stage spoken words emerge between twelve and fifteen months (Eisenberg, 2007:768).

To summarize normal speech development, Nip, Green, and Marx, (2009:286), suggest that normal speech development is a non-linear process marked with steep increases, plateaus and regressions. These changes are thought to reflect environmental influences as well as developmental interactions among emerging skills for cognition, language and motor control (Nip, Green & Marx, 2009:286).

2.4 Hearing loss in children

A prerequisite for normal communication development in children is access to detailed sound. A primary difficulty of hearing loss is that it interferes with the brain's access to sound (Cole & Flexer, 2007:36). In order to provide appropriate amplification, and therefore make the auditory signal audible to children with hearing loss, it is important to understand the prevalence and aetiology of hearing loss and the effect hearing loss has on communication, literacy and socio-emotional development. The importance of newborn hearing screening within the South African context is also discussed and motivated.

2.4.1 Prevalence and incidence of permanent childhood hearing loss

Permanent disabling hearing impairment (>40dB HL) is a significant contributor to the global burden of disease on individuals, families, communities and countries affecting about 278 million people worldwide (Olusanya, Wirz & Luxon, 2008:956). According to Smith, et al. (2005:881) one in 1000 infants are born with bilateral sensorineural hearing loss of at least 40dBHL and four profoundly deaf infants per every 10000. This data is consistent with findings of universal newborn hearing screening programs in other more developed countries that report identification of two to four infants per 1000 with sensorineural hearing loss (Smith et al., 2005:882). Although available preliminary data from less developed countries is limited, existing data suggest that the incidence of congenital sensorineural hearing loss in these countries is much higher (Smith et al., 2005:882).

Disabling hearing impairment affected 120 million people in 1995. It is clear that this estimate has more than doubled in a decade, with two thirds of people with hearing impairment living in developing countries and about 25% of these impairments present onset in early childhood (Olusanya et al., 2007:2). A more recent study (Olusanya & Somefun, 2009:1267) revealed that an overall crude prevalence rate of seven out of 1000 is almost double the estimate of the two to four per 1000 derived from universal newborn hearing screening programmes in developed countries. At least 90% of children born with hearing loss during the neonatal period are in developing countries like South Africa (Olusanya et al. 2008:956).

In order to understand the differences of incidence and prevalence of hearing loss existing between developing and developed countries, it is crucial to understand the aetiology of permanent childhood hearing loss. This should explain why the incidence is higher in developing countries like South Africa.

2.4.2 Aetiology of permanent childhood hearing loss

Challenges in managing childhood hearing loss begin with determining the precise aetiological factors involved (Lasisi, Ayodele & Ijaduola, 2006:625). Determining and understanding these factors may guide audiologists in establishing the course that intervention should take, because it is known that certain aetiologies present with certain types of hearing losses (Ohlms et al., 1999:161; Morzaria, Westerberg, & Kozak, 2004:1193). According to Lasisi et al. (2006:626) the aetiology of permanent childhood hearing loss includes numerous factors. More than 50% are hereditary factors, others are considered to be congenital factors, while other factors involve early onset hearing loss (prenatal, perinatal and postnatal). Therefore it can be summarized that permanent hearing impairment is an aetiologically heterogeneous trait attributable to genetic and environmental causes (Olusanya et al., 2007:2).

It is important to note that the significance of each aetiological factor varies with the population (Smith et al. 2005:879). In Sub-Saharan Africa, environmental factors such as infections, poverty and poor access to healthcare tend to play a more prominent role than familial factors (Lasisi et al., 2006:626), whereas the incidence of acquired sensorineural hearing loss in children living in more developed countries has fallen as a result of more improved neonatal care and the widespread implementation of immunization programmes (Smith, Bale & White 2005:879). This decrease was, however, accompanied by an increase of the inherited forms of sensorineural hearing loss (Smith et al., 2005:879). These changes in the incidence of sensorineural hearing loss have not been reported in children living in less developed countries, where the prevalence of consanguinity is high in many areas, and both genetic and acquired forms of sensorineural hearing loss are more common, particularly among children who live in poverty (Smith et al., 2005:626). This statement is corroborated by Morzaria, Westerberg and Kozak (2004:1193) who mentioned that the most common aetiology in their study population is unknown and they based the remaining 56% to genetic non-syndromic hearing loss because of the high rate of consanguine marriage in their study population.

The causes and incidence of mild to severe permanent childhood hearing loss (<90dB) is summarized below in Figure 3.

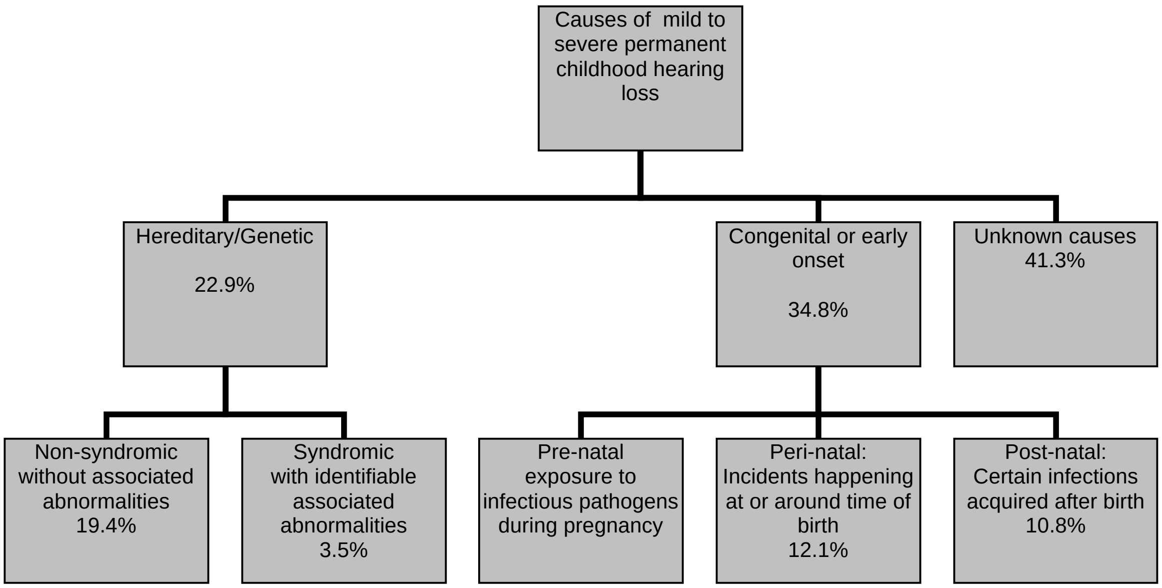


Figure 3: Causes of mild to severe permanent childhood hearing loss (Smith et al., 2005:882; Lasisi et al., 2006:626; Morzaria, Westerberg and Kozak, 2004:1194)

In Figure 3 the causes of hearing loss are divided into hereditary causes and congenital/early onset causes (Smith et al. 2005:882). Hereditary causes of hearing loss can either be non-syndromic or syndromic, where congenital / early onset can be pre-natal, perinatal or post-natal. The aetiology of permanent childhood hearing loss will be discussed accordingly.

2.4.2.1: Hereditary causes of permanent childhood hearing loss

According to Morzaria et al. (2004:1197), 22.9% of the causes of hearing loss are considered to be hereditary, of which 3.5% is syndromic hearing loss with identifiable associated abnormalities, whilst the remaining 19.4% is assumed to be non-syndromic hereditary hearing loss without associated abnormalities.

Examples of syndromic hearing loss are: Waardenburg, Velocardiofacial, Down, Goldenhar, Brancio-oto-renal (BOR), and Pendred (Morzaria, Westerbery & Kozak, 2004:1196). Shipley and McAfee (1992:52) describe additional syndromes that can be associated with hearing loss: Alport, Apert, Cornelia de Lange, Cri du Chat, Crouzon, Hunter, Turner and Usher. Genetic non-syndromic hearing loss is highly heterogeneous (Morzaria et al., 2004:1193) and is significantly more common in individuals with hearing loss greater that 90dBHL (Morzaria et al., 2004:1196).

Knowledge about a hearing loss being syndromes or non-syndromic provides insight into its causes and thereby guides the audiologist towards a more precise, individualized rehabilitation programme, taking into account previous experiences with a similar syndrome (Morzaria et al., 2004:1193).

Smith et al. (2005:883), further divide the causes of hearing loss into early onset/ congenital causes.

2.4.2.2: Congenital / early onset causes of permanent childhood hearing loss

As stated previously, permanent hearing impairment aetiologically can involve any person living in different places with different cultures (Olusanya et al., 2007:2). Hearing loss may also be acquired prenatally, perinatally or postnatally and the significance of each factor varies with the population (Lasisi et al., 2006:626).

Among the environmental causes are infectious diseases that account for substantial infant mortality in developing countries and which are currently addressed through various global health programmes. However, a significant proportion of hearing impairment is not preventable (Olusanya et al., 2007:2).

- Prenatal

Women are, for the duration of pregnancy, exposed to infectious pathogens and some of these infections may cause damage to the placenta and foetus Smith, et al., 2005:882). These infections are caused by the cytomegalovirus, lymphocytic choriomeningitis virus, rubella virus, measles virus, mumps virus, toxoplasmosis gondii and tremonema pallidum (Smith, et al. 2005:883). Ingestion of ototoxic medications, drugs, or alcohol, especially during the 6th and 7th week of pregnancy may be a risk factor for hearing loss in children (Smith et al., 2005:883).

It is interesting to note that the incidence of congenital rubella has been greatly decreased in more developed countries by the introduction of the rubella vaccine in the late 1960's (Smith et al. 2005:883). However, the worldwide burden of sensorineural hearing loss secondary to rubella syndrome remains high and in countries without a rubella vaccination programme, congenital rubella syndrome continues to rank as the most important cause of congenital sensorineural hearing loss (Smith et al., 2005:883).

- Perinatal

'Perinatal' refers to incidents that happened at or around the time of birth (Wehmeier et al., 2005:1081). Treatment in a neonatal intensive care unit (NICU) alone (in the absence of an identifiable syndrome or family history of sensorineural hearing loss in childhood) increases the likelihood of significant bilateral sensorineural or mixed hearing loss in a neonate by at least ten times (Smith et al., 2005:884). Events such as hypoxia, prematurity and oto-toxic drugs are also associated with the development of hearing loss (Ohlms et al., 1999:159). Kernicterus, asphyxia, prematurity, time spent in a NICU and drugs during the perinatal period can also be associated with an increased risk for sensorineural hearing loss (Morzaria et al., 2004:1196).

- Postnatal

Certain infections acquired after birth during the postnatal period can also be associated with an increased risk for sensorineural hearing loss. They include borrelia burgdorferi, Epstein - Barr virus, haemophilus influenza, Lassa virus, measles virus, mumps virus, neisseria meningitis, non-polio enterovirusses, plasmodium falciparum, streptococcus pneumonia, varicella zoster virus. (Smith, et al. 2005:883). Trauma and chemotherapy may also increase the risk for sensorineural hearing loss (Morzaria et al., 2004:1196).

Other post-natal infections that need to be taken into consideration, especially in developing countries, are HIV (human immunodeficiency virus)/ AIDS (acquired immune deficiency syndrome) and cerebral malaria (Newton, 2006:11; Mackenzie, 2006:14). These post-natal infections are implicated in studies as causes of hearing impairment, but the evidence for a causative role is confused by the occurrence of opportunistic infections and the use of ototoxic drugs in treatment (Newton, 2006:1).

HIV/AIDS is a significant health dilemma worldwide, with approximately 38 million adults and 2.3 million children under the age of fifteen years living with this infection (Newton, 2006:11). In South Africa alone it is estimated that an average of 17.8% (5.6 million people) of the total population lived with HIV at the end of 2009 (South Africa HIV & AIDS statistics). The following factors may be responsible for hearing loss in children living with HIV/AIDS (Newton, 2006:12, 13):

- Higher frequency of recurrent acute otitis media
- Co-infection with HIV may accelerate the development of otosyphilis.
- Ramsay Hunt Syndrome, which is a herpes zoster virus infection associated with unilateral hearing loss and impaired balance mechanisms
- Some medications are ototoxic and may result in a sensorineural hearing loss.

- HIV itself affects the central nervous system and may potentially affect the 8th cranial nerve directly causing a sensorineural hearing loss.
- Opportunistic infections like CMV, extrapulmonary, cryptococcal meningitis and invasive aspergillosis
- HIV related malignancy like Kaposi's sarcoma, and lymphoma of the tympanic membrane

Hearing loss is a recognized complication of cerebral malaria. Hearing loss associated with cerebral malaria is usually sensorineural, suggesting damage to the cochlea itself or somewhere along the eighth nerve pathway. Ototoxicity and neurotoxicity have been implicated with anti-malarial medicine like, quinine, metloquine and chloroquine (Newton, 2006:14). This implicates that in developing countries malaria can also be a major cause of hearing loss.

The knowledge referred to above regarding the aetiological factors of permanent childhood hearing loss enables the audiologist to identify risk factors associated with hearing loss. Intervention programmes can be adjusted on the basis of knowledge about specific issues in a certain risk population. The Joint Committee on Infant Hearing (2007:179) has identified the risk indicators associated with permanent congenital, delayed-onset of progressive hearing loss in childhood. They have summarized the most important risk factors to help identify children with hearing loss as early as possible. These risk factors are summarized as follows:

- Caregiver concern regarding hearing, speech, language or developmental delay
- Family history of permanent childhood hearing loss
- Neonatal intensive care of more than 5 days, or any of the following regardless of length of stay: extracorporeal membrane oxygenation (ECMO), assisted ventilation, exposure to ototoxic medications (gentamycin and tobramycin) or loop diuretics, hyperbilirubinemia requiring exchange transfusions

- In-utero infections such as cytomegalovirus virus, herpes, rubella, syphilis and toxoplasmosis
- Craniofacial anomalies, including those involving the pinna, ear canal, ear tags, ear pits, and temporal bone anomalies
- Physical findings such as white forelock, associated with a syndrome known to include a sensorineural or permanent conductive hearing loss
- Syndromes associated with hearing loss or progressive of late-onset hearing loss such as neurofibromatosis, osteopetrosis, and Usher syndrome; other frequently identified syndromes include Waardenburg, Alport, Pendred, and Jervell and Lange-Nielson.
- Neurodegenerative disorders, such as Hunter syndrome, or sensory motor neuropathies such as Friedreich ataxia and Charcot-Marie-Tooth syndrome
- Culture-positive postnatal infections associated with sensorineural hearing loss including confirmed bacterial and viral (especially herpes viruses and varicella) meningitis
- Head trauma, especially basal skull/temporal bone fracture requiring hospitalization
- Chemotherapy

Knowledge of these risk factors and causes of hearing loss in children not only assists audiologists in identifying children with hearing loss, but also assists them in planning culturally appropriate intervention and habilitation programmes.

2.4.3 Consequences of permanent childhood hearing loss

The design of human beings is such that hearing is a first order event for the development of language, reading, and academic skills, and therefore, as shown in Figure 4, it is not an isolated activity (Cole & Flexer, 2007:13)

Hearing

Access to sound results in enhanced auditory receptive skills (Stacey, Fortnum, Barton & Summerfield, 2006:162)

↓

Spoken language

Once access to meaningful sound, the better opportunity the child will have to develop spoken language.

↓

Reading and writing

Reading centres of the brain are located in the auditory cortex, and children with hearing loss who do not have access to auditory input tend to have great difficulty reading.

↓

Academic performance

Educational deficits experienced by the average hearing impaired child are directly related to delays in the development of language and verbal skills (Davis, Elfenbein, Schum, & Bentler, 1986:60)

↓

Professional flexibility

Enhanced educational qualifications provide enhanced opportunities in further education and therefore benefits employment (Stacey et al., 2006:162)

Figure 4: Hearing as a first order event (Cole & Flexer, 2007:13)

Figure 4 outlines the critical role that auditory development has on development of language, reading, and academic skills. Sound should first be audible before it can be utilized to develop spoken language. Consequently, spoken language must develop before language itself can be used for reading and writing. The basis of academic programmes are reading and writing, without which optimal academic development is therefore not possible (Stacey et al., 2006:162). Once academic achievements are attained they can be used to benefit employment in the professional world. It is clear from Figure 4 that spoken language, reading and writing and therefore academic performance cannot develop appropriately if a child does not have adequate hearing. For this reason, hearing is viewed as a first order event (Cole & Flexer, 2007:13; Stacey, et al. 2006:162).

Listening experience in infancy is critical for the development of both speech and language in young children and a strong language base is essential for acquiring reading skills (Cole & Flexer, 2007:3/4).

The first three years in a child's life are critical for acquiring information about the world, communicating within the family and developing a cognitive and linguistic foundation which forms the basis of all further development unfolds (Nicholas & Geers, 2006:286). If a child is able to develop age-appropriate spoken language skills, he/she is more likely to be prepared to enter into a pre-school setting, ready to participate fully in all activities and to engage in meaningful social interactions with teachers and peers (Nicholas & Geers, 2006:286). It has been shown that children who are deprived of adequate, good quality language input in their earliest years are at risk for poor outcomes in both language and subsequent academic endeavours later in childhood (Nicholas & Geers 2006:286). It is also indicated that poor language skills and/ or poor parent-child communication interaction early in life are associated with concurrent socio-emotional and behavioural problems; it is also associated with later deficits in language development, reading difficulties, lower verbal intelligence, poorer social-emotional development, poor self-esteem and certain psychiatric conditions (Nicholas & Geers, 2006:286).

Permanent hearing impairment that stems from birth (neonatal period) is of special interest because of its adverse consequences for speech, language, cognitive and psycho-social development and the subsequent impact late detection has on educational and vocational attainment, especially in developing countries (Olusanya et al., 2007:2). Failure in early identification and early management of children with congenital or early onset hearing loss may result in lifelong deficits in speech and language acquisition, poor academic performance, personal-social maladjustments and emotional difficulties (Attias et al; 2006:529).

Detailed discussions of the influence of early childhood hearing loss on auditory development, language and speech development, socio-emotional development and literacy follow in the sections below.

2.4.3.1 Hearing loss and auditory development

Sininger, Grimes and Christensen (2010:166) state that the development of mature spoken communication depends on the capacity of the auditory channel to receive and transmit information to the central nervous system early during development. Spoken communication is learned primarily through the auditory modality, and therefore early-onset hearing loss results in reduced ability to perceive and produce intelligible speech (Sininger et al., 2010:166). Therefore, identification of newborn hearing loss should be considered to be a neuro-developmental emergency (Cole & Flexer, 2007:5-6).

Major changes in auditory processing occur during infancy and early childhood, most notably the acquisition of receptive speech (Moore & Linthicum Jr., 2007:460). Moore and Linthicum (2007:474) agree that infant and childhood deafness have a more devastating effect on hearing and receptive language than hearing loss acquired in the teenage adult years. This implies that sound deprivation interferes with early developmental processes (Moore & Linthicum Jr, 2007:474). These authors also state that hearing loss during the perinatal months could negatively impact the two hallmarks of infant hearing, namely acoustic discrimination and attention to sound stimuli. In contrast, sound deprivation during early childhood and, particularly in the first two years of life, could lead to deficits in cortical perceptual processes and ultimately affect word learning (Moore & Linthicum Jr., 2007:475).

Disturbance of synaptic organization with resultant impairment of stimulus analysis could underlie the defects in discrimination observed in early deaf children. Children with normal hearing respond to a wide variety of changes that occur when a syllable is repeated; this includes the vowel and consonant contrasts. Young users of hearing instruments respond consistently only to vowel height (Moore & Linthicum Jr., 2007:471). Furthermore, neural imaging has shown that the same brain areas – the primary and secondary auditory areas – are most active when a child listens and when a child reads. That is, phonological or phonemic awareness, which is the explicit awareness of the speech sound structure of language units, forms the basis for the development of literacy skills (Cole & Flexer 2007:5/6).

A marked delay in maturation of higher brainstem structures occurs due to reduced auditory input during infancy (Tibussek et al., 2002:123). The correlation differs notably from results of comparable studies of adults. This leads to the assumption that the developing human brain is particularly sensitive to auditory deprivation. These results indicate the importance of a normal acoustic environment during sensitive periods in early childhood to ensure normal hearing and speech development. These authors state that deprivation of sound stimulation can negatively influence the central structures of the auditory system. Acoustic stimulation is therefore necessary during early infancy to ensure normal neural development. If auditory input is missing, auditory processing in the brainstem may be disturbed in relation to the severity of the hearing loss (Tibussek et al., 2002:128).

Cole and Flexer (2007:5-6) critically emphasize that anything should be done to access and 'programme' the critical and powerful auditory centres of the brain with acoustic detail, thereby expanding children's abilities to listen to and learn spoken language. These authors also emphasize that in order for auditory pathways to mature, acoustic stimulation must occur early and often because normal maturation of central auditory pathways is a precondition for the normal development of speech and language skills in children. Neuroplasticity is at its greatest during the first three and a half years of life. The younger the infant, the greater the neuroplasticity (Cole & Flexer, 2007:5-6). This view is supported by Harrison (2001:22) who states that there appears to be considerable plasticity in the whole pathway during early development, but in the adult subject plasticity at a lower level is considerably reduced, even perhaps lost. Clinically this data indicates that the early postnatal period is very important for the establishment of auditory pathways that can accurately represent complex sounds at the cortical level. There appears to be a critical period of plasticity (Harrison, 2001:22).

The above can be summarized by stating that rapid infant brain growth requires prompt intervention, typically including amplification and a programme that promotes the development of auditory skills development (Cole & Flexer, 2007:5-6). This is supported by Tibussek et al. (2002:123) who state that early intervention has been shown to be highly effective in the prevention of the speech, language and cognitive deficits that result from hearing loss (Tibussek et al., 2002:123). In the absence of sound, the brain reorganizes itself to receive input from other senses, primarily vision; this process is known as cross-modal reorganization and reduces auditory neural capacity. Early amplification stimulates a brain that is in the initial process of organizing itself, and is therefore more receptive to auditory input, resulting in greater auditory capacity (Cole & Flexer, 2007:6). This highlights the importance for the audiologist to ensure that appropriate amplification is provided to make all speech sounds audible.

2.4.3.2 Hearing loss and the development of language and literacy skills

More than two-thirds of children with a hearing loss have moderate, severe, or profound degrees of hearing loss bilaterally (Brown, 2009:938). Since access to sound is compromised, the development of functional auditory skills is compromised as well. In turn, both receptive and expressive language learning and spoken language are affected (Brown, 2009:938). Poor oral language abilities are the basis of reading difficulties (Moeller et al., 2007:748),

- Influence of hearing loss on language

The influence of hearing loss on the development of the different components of language is discussed below in terms of language form (syntax, morphology, and phonology), language content (meaning) and language use (pragmatics).

Form

Syntax:

Syntactic development refers to the way that words and phrases are put together to form sentences in a language (Wehmeier et al., 2005:1502), and grammar is the set of rules of language for changing the form of words and joining them into sentences (Wehmeier et al., 2005:648). The frequency of grammatical errors was related to the degree of hearing loss and it was found that the overall patterns of language development were delayed (Moeller et al., 2007:745). Therefore hearing loss negatively affects the development of syntax and grammar. Children with hearing loss, to varying degrees, exhibit a shorter mean length of utterance, tend to use simpler sentence structure, overuse the subject-verb-object sentence pattern, and demonstrate infrequent use of specific word forms (e.g., adverbs, auxiliaries, conjunctions) (Brown, 2009:938). A curious observation about the language of children with more severe degrees of hearing loss is their use of inappropriate syntactic patterns. For example, a child may say, 'I want you go get eat things'. In this example, the message is understood, but the syntactic patterns do not follow the rules of English (Brown, 2009:939).

Morphology:

Challenges in this language domain lead to difficulties in reading and writing. When a child has a low literacy level, graduation from high school and later vocational opportunities are adversely affected (Brown, 2009:938). Even children with mild to severe hearing loss experience delays in morphological development (Moeller, 2007:743). Children with hearing loss do not demonstrate a simple delay in morphological development; rather, the order of accuracy for various rules differs from normal hearing children. The order of development for the children with hearing loss is similar to that observed in second language learners, suggesting that auditory experience (input) may play a role in delayed morphological development. The most challenging morphemes for children with hearing loss (3rd person singular -s, past tense -ed and possessive form -s) are those that are reported least frequently in the input. It is suggested that limited perceptual access to fricatives may influence morphological development. Restricted bandwidth of hearing instruments limits the audibility of [s], especially for female and child speakers. It is concluded that children who wear hearing instruments may hear final [s] when spoken by a male, but not by a female or child speaker. Such perceptual access differences could result in inconsistent input regarding morphological rules (Moeller, Tomblin, Yoshinago-Itano, McDonald & Jerger, 2007:744).

Phonology

The phonological system includes all of the sounds of language, the ways of combining these sounds to form words, and the conventional ways in which the language uses prosodic features such as intonation, stress and rhythm to express meaning (Cole & Flexer, 2007:212). Phonology also refers to the ability to segment and discriminate phonemes from incoming speech, as well as acquire knowledge of sound patterns of a language (Briscoe, Bishop & Norbury, 2001:329). Early hearing loss can have an impact on phonological processing development (Moeller, Tomblin, Yoshinaga-Itano, McDonald & Jerger, 2007:748). Children with hearing loss are frequently reported to have an inadequate/defective phonological system (Huttunen, 2001:80). Other phonological difficulties experienced by children with hearing loss are impaired coding of phonologically similar items, for example syllable pairs that are differentiated by one rather than multiple features, and they also demonstrate difficulty with word repetition tasks (Briscoe, et al, 2007:329).

<u>Content</u>

Meaning/Semantics:

Even the mildest degree of hearing loss delays vocabulary development (Moeller et al., 2007:741). This is supported by Nott et al. (2009:528) who states that the average child with hearing loss is slower to acquire words than hearing children. Despite the apparent advantage in vocabulary ability that is evident in an early identified, cognitively normal group, these children still appear to be delayed relative to hearing children. Thus, although the early identified children demonstrated significantly improved expressive vocabulary skills relative to children who were identified later they were, on average, delayed compared with their normal hearing peers (Mayne, 1998:11).

Children with hearing loss demonstrated receptive vocabulary skills that were equivalent to those achieved by five to seven year old hearing children (Mayne, 1998:2). The difference between receptive vocabulary age and chronological age was greatest in the oldest age groups, with a plateau in vocabulary development evident at twelve to thirteen years (Mayne, 1998:2). Children with hearing loss have problems accessing constant and consistent information from the environment; these difficulties result in poor early learning experiences which phonological in turn create a weak foundation for formulating language rules and developing knowledge and vocabulary skills (Mayne, 1998:2). Most of the children used in a study (Mayne, 1998:11) were identified with hearing loss before six months. It is possible that, though still delayed in comparison with normal-hearing children, the average receptive vocabulary development of this group is more advanced than would have been expected prior to the development of universal newborn hearing screening (Mayne, 1998:11).

Results (Moeller et al., 2007:742) indicate that children with hearing loss showed delayed, though typical patterns of word learning strategies and that the strategy they use is closely tied to vocabulary development. Children with normal hearing learned and retained more words than children with hearing loss (Moeller et al., 2007:742). Receptive vocabulary development (word understanding) in a child's native spoken language proceeds expressive vocabulary development in the process of vocabulary acquisition. Vocabulary (store of words), is the building blocks of language and the basis for syntactic and morphological development.

Children with hearing loss frequently present with reduced language skills because of their auditory deprivation; especially, the onset of speech production is delayed and vocabulary is diminished compared with their hearing peers (Watkin et al., 2008:619).

Use

Pragmatic skills:

Pragmatic characteristics of language are usually also affected. Most pragmatic skills are accomplished by hearing children by the time they reach preschool. However, a sample of children with all degrees of hearing loss demonstrates challenges in their use of pragmatics during the preschool years. Children with hearing loss have the most success in language use when they make requests and express their feelings. As a group they demonstrate moderate success initiating and maintaining topics in conversation, giving directions, making polite commands, expressing their state of mind and asking questions to obtain information. The children demonstrated the greatest difficulty when apologizing for or explaining their behaviour, revising an unclear message or asking for clarifications of a message that was not understood, offering and supporting their own opinion, providing biographical information and explaining cause and effect (Brown, 2009:938).

From the discussion above it is concluded that hearing loss have an impact on all the major components of language.

- Development of literacy skills in children with hearing loss

Literacy skills consist of writing skills, which is the appreciation of various genres of written forms, and reading skills, which refers to the use of orthographic information provided through text to construct a meaning of the author's intent

(Moeller et al, 2007:746). Poor oral language abilities serve as the basis for reading difficulties (Moeller et al. 2007:748). Early literacy (the knowledge of reading and writing) that a child acquires before formal exposure in school, begins in a child's natural surroundings like home and pre-school and has been shown to predict children's academic success in school (Most, Aram & Andorn, 2006:6). Early literacy incorporates various skills, including linguistic knowledge, phonological awareness and orthographic awareness. According to these authors there are a correlation between pre-schoolers' language knowledge (vocabulary size and success in word recognition tasks) and their phonological awareness (Most et al., 2006:6). Phonological awareness skills serve as mediation between the sound segments of spoken language and the orthographic segments of written language. Children with hearing loss exhibit lower academic achievement than do their age-matched hearing peers. School aged children with hearing loss showed a lower performance on writing tasks than their hearing peers, including simpler and shorter sentences and the repeated usage of the same sentence pattern. The large gaps between children with hearing loss and their hearing peers appears to result from the effects of the hearing loss on different aspects of language acquisition – in particular deficits in the area of spoken language (Most et al., 2006:7).

A critical developmental expectation of children with hearing loss is that they become literate and that they succeed in acquiring at least basic academic skills (Moeller et al., 2007:746). Poor oral language abilities form the basis for reading difficulties (Moeller et al., 2007:746). Comprehension and production of advanced syntax is known to support discourse participation, reading comprehension and social reasoning. It is also an important skill for reading and literacy (Moeller et al., 2007:745).

Before newborn hearing screening was universally instituted, children with severe to profound hearing loss on average completed the 12th grade with a third to fourth grade reading level and language levels of a nine to ten year old hearing child. More recent evidence indicates that children with hearing loss seem to be at risk for poorer reading achievement and particularly at risk for poor phonological processing skills, which are generally regarded as important to support the acquisition of decoding skills. The degree of this risk is not as high as it is in children with more severe hearing losses, and many children with mild hearing losses are normal readers (Moeller et al., 2007:749).

2.4.3.3 Hearing loss and speech development

Speech development is highly dependent upon what an infant can hear Eisenberg, (2007:766). Although the human ear can hear frequencies ranging from 20 to 20000Hz, frequencies between 250 and 4000Hz are of particular importance for the perception of speech (Cole & Flexer, 2007:24). Speech recognition and production are integrally related in the development of spoken communication.

Before speech production can be accurate, the sounds of speech must be correctly recognized. In order to understand the effect that hearing loss may have on speech recognition and production, it is important to understand the spectral characteristics of speech. The spectral characteristics of speech explain why certain speech sounds are more difficult to hear than others, and show a higher rate of incorrect production. The spectral characteristics of speech are subsequently discussed, followed by the effect hearing loss has on speech perception, recognition and production.

- <u>Spectral characteristics of speech</u>

Speech information is carried by die changing patterns of sound energy and is measured in intensity (dB SPL / dB HL), frequency (Hz) and time (second). Psychological attributes are loudness/intensity (measured in dB HL / dB SPL) and pitch (high and low frequencies) (Cole & Flexer 2007:21; Abrams & Kraus, 2009:612). Pitch/Fundamental frequency is the number of times the vocal folds open and close in a second (Cole & Flexer, 2007:327). Hertz (Hz) is the standard unit for measuring and describing the frequency of a sound. A unit of frequency measurement equals one cycle per second. The more cycles per second the higher the frequency (pitch) and the fewer the cycles per second, the lower the frequency (pitch) (Cole & Flexer, 2007:22). Formants are series of discrete peaks in the frequency spectrum of speech that are the result of an interaction between the frequency of vibration of the vocal folds and the resonances within a speaker vocal tract (Abrams & Kraus, 2009:612). Table 5 represents speech information carried by die key speech frequencies and explain the important speech information each frequency carries.

Table 5: Speech information carried by the key speech frequencies of 250-400Hz (+/- one-half octave) (Cole & Flexer, 2007:25)

250Hz	500Hz	1000Hz	2000Hz	4000Hz
• First formant of vowels [u] and[i] • Fundamental frequency of females' and children's voices • Nasal murmur associated with the phonemes [m. [n] and [ng] • Prosody • Suprasegmental patters like stress, rate, inflection and intonation • Male voice harmonics Voicing cues	• First formants of most vowels • Harmonics of all voices (male, female, child) • Voicing cues • Nasality cues • Suprasegmentals • Some plosive bursts associated with [b] and [d]	• Important acoustic cues for manner of articulation • Second formants of back and central vowels • Consonant-vowel and vowel-consonant transition information • Some plosive bursts • Voicing cues • Suprasegmentals • Unstressed morphemes	• Important acoustic cues for place of articulation • Key frequency for speech intelligibility • Second and third formant information for front vowels • Consonant-vowel and vowel-consonant transitions information • Acoustic information for the liquids /r/ and /l/ • Plosive bursts • Affricate bursts • Fricative turbulence	• Key frequency for [s] and [z] audibility that is critical for language learning: plurals, idioms, possessives, auxiliaries, third person singular verb forms, questions, copulas, past perfect • Consonant quality

Northern and Downs (2002:18), developed a widely used acoustic phonetic audiogram which represents the typical acoustic properties of many environmental and speech sounds. It displays the different intensities and frequencies of the different phonemes of the English language.

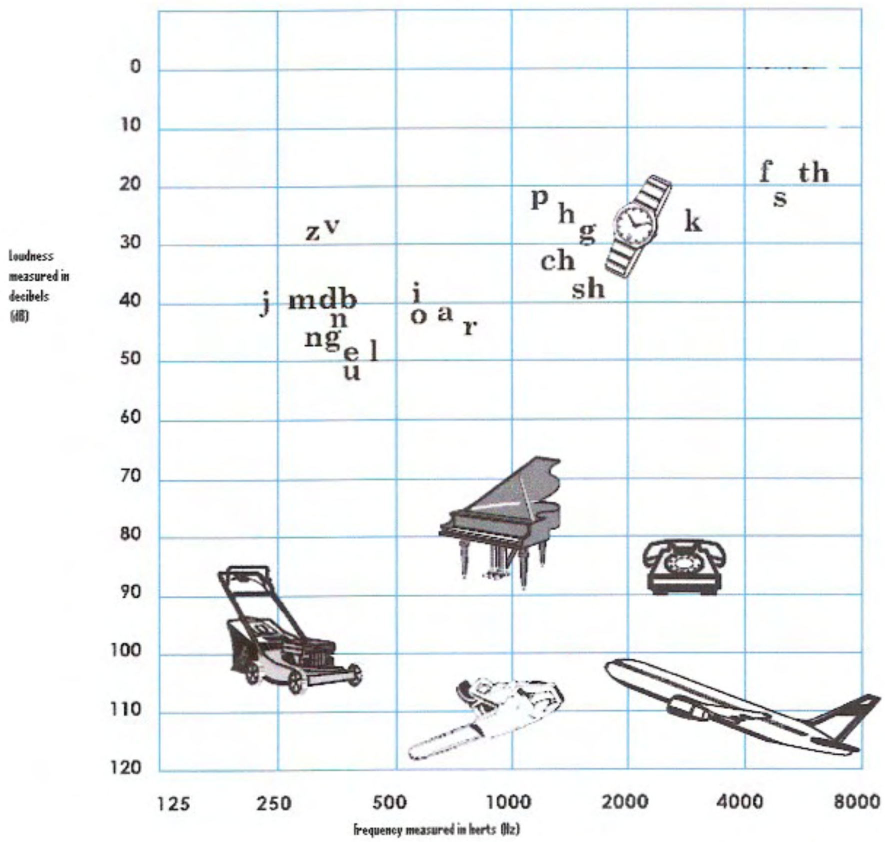


Figure 5: Acoustic phonetic audiogram (Northern & Downs, 2002:18)

Table 5 and Figure 5 it can be seen that most speech sounds and speech information are available between 250Hz and 4000Hz. Only the soft high frequency consonants [f], [s] and [th] are higher than 4000Hz.

The spectral levels of speech vary considerably across the frequency region of 125Hz to 8000Hz. These variations are based on differences in gender, age and vocal effort of the speaker (Olsen, Hawkins & Van Tasell, 1987:101s). Byrne, et al. (1994:2117) stated that the comparison in the spectral characteristics of males and females showed virtually identical spectra over the frequency range from 250Hz to 5000Hz, but for 6300Hz and higher frequencies the female levels exceeded those of males for every country, although only marginally in some instances (Byrne et al., 1994:2117). These authors also mention that although different languages use different vowels (formant structures) and the frequency of occurrence of various phonemes differs, these factors appear to have only a minor effect on the spectral characteristics of males and females (Byrne et al., 1994:2120).

The most intense components of speech occur in the region of 250Hz to 4000Hz (Cole & Flexer, 2007:24). Importantly, it is in this frequency region where normal hearing sensitivity is optimal. It is also in this frequency region that most of the intelligibility of speech is carried (Olsen et al., 1987:106s). 'Intelligibility of speech' refers to the ability to hear word-sound distinctions clearly (Cole & Flexer, 2007:27). These authors explain that there is a big difference between an audible and an intelligible signal (Cole & Flexer, 2007:27). Speech is audible if the person is able simply to detect its presence. However, for speech to be intelligible the person must be able to discriminate the word-sound distinctions of the individual phonemes of speech sounds. Consequently, speech might be audible but not consistently intelligible to a child with even a minimal hearing loss. Vowels sounds (such as [o], [u], [i], etc.) have strong low-frequency energy, at about 250Hz to 500Hz. These sounds are the most powerful sounds in English. Vowels carry 90% of the energy of speech. On the other hand, consonant sounds like [f] and [s] lack power, with high frequencies and energy focused at 2000Hz to 4000Hz and above. Consonants carry only 10% of the energy of speech but 90% of the information needed to perceive the differences among the sounds. For speech to be heard clearly, both vowels and consonants must be acoustically available. Persons with hearing loss typically have the most difficulty hearing the weak, unvoiced, high frequency consonant sounds (Cole & Flexer, 2007:27). This information is important when hearing amplification instruments are considered. The frequencies that are provided to the listener have an effect on the amount of speech information that is auditorily available.

- Effects of hearing loss on speech perception and recognition

Results of an analysis done by Stelmachovicz et al. (2004:558) revealed that mid frequency audibility (2000Hz – 4000Hz) appeared to be most important for the perception of the fricative noise produced by a male speaker, whereas a somewhat wider frequency range (2000Hz – 8000Hz) is important for the female speaker. Boothroyd and Medwetsky (1992:156) support this finding by stating that gender differences exist, where male speech averaged at 4300Hz and female speech at 7200Hz. This implies that children fitted with hearing instruments that amplify only around 5000Hz will not be able to hear some of the speech sounds produced by especially female speakers. This can have a major impact on children's speech and language development, given the fact that children with hearing loss spend most of their time with female caregivers, teachers and other children (Stelmachovicz, 2001:171).

There is also evidence that young children need high frequency amplification more than older children and adults (Stelmachovicz, 2001:168; Kortekaas & Stelmachovicz, 2000:646). The first argument centres around co-articulation; it seems that adult listeners use the co-articulation information of the transition from vowel to consonant to identify the correct consonant. Another argument is that adults use syntactical and semantic information to guide them to the correct consonant. However, children who are in the process of acquiring knowledge of speech and language rules still need to acquire knowledge about the language rules of these sounds, prior to using the skills mentioned above. In order to acquire this knowledge, the speech sounds should first be made consistently audible to them (Kortekaas & Stelmachovicz, 2000:646), since they may experience inconsistent exposure to certain speech sounds across different speakers, situations and contexts. This inconsistent audibility of imperative speech sounds will delay the formulation of linguistic rules (Stelmachovicz et al., 2004:559). It is probable that, in order to learn structures that are dependent on minimal acoustic information, consistent exposure to these speech sound structures are required (Stelmachovicz et al., 2004:559).

Aided audibility of high frequency speech sounds is problematic, even for children with mild to moderate hearing loss because it influences the ability to adequately monitor their own speech (Stelmachovicz et al., 2004:559). There are two aspects that may interact to influence the self-monitoring of speech in children with hearing loss. The first is the acoustic characteristics of a speaker's own voice received and measured at the ear that differ from the acoustic characteristics measured at the mouth. The spectrum at the ear contains more energy below 1000Hz and less energy above 2000Hz than the spectrum in face-to-face conversation (0 degrees azimuth) (Stelmachovicz et al., 2004:559). Cornelisse, Gagne and Seewald (1991:48) support this by stating that high frequency band levels are attenuated when the input signal is moved from zero degrees azimuth to 90 degrees (side of the speaker). They state that this could be due to the directional radiation characteristics of the mouth. This reduction in high frequency energy may limit the audibility of important speech sounds produced by the children with hearing loss themselves (Stelmachovicz et al., 2004:559). The second aspect that influences the ability to adequately monitor one's own speech is that the overall amplitude level of children's speech are approximately 5dB to 6dB lower than that of adults and there are a 8dB to10 dB reduction in signal amplitude for frequencies higher than 4000Hz (Stelmachovicz et al., 2004:560). This supports the view that children with hearing loss may not be able to monitor fricative production adequately. Since roughly 50% of consonants in English are fricatives, this delay is likely to have a substantial influence on speech and language development (Stelmachovicz et al., 2004:561). To support the above and to emphasize the importance of hearing speech, von Hapsburg and Davis (2006:820) indicate that inadequate auditory access to speech results in different speech development patterns emphasizing the co-dependence of auditory perceptual factors and speech production factors in early speech acquisition.

- Effects of hearing loss on speech production

As hearing loss increases both in degree and the frequencies that are affected, the number and type of incorrectly produced also increases (Elfenbein et al., 1994:223). It is likely for these fricatives to be inaudible because of their low intensity and high frequency components. Therefore, children with hearing loss have difficulty perceiving the acoustic energy necessary to learn the proper use of information provided by these phonemes (Elfenbein et al., 1994:223).

Children with a more severe hearing loss show a higher proportion of errors than children with a less severe hearing loss. For manner of articulation, the order of consonants correctly produced (from highest to lowest), were glides and laterals, nasals, stops, fricatives and affricates. The number and type of phoneme errors were shown to increase with increasing hearing loss. The most common articulation error was substitution, particularly for fricatives and affricates (Eisenberg, 2007:770). The most common speech production error in children with a mild to severe hearing loss is the substitution or omission of phonemes (Elfenbein, et al., 1994:223). These errors are especially likely to occur with fricatives like [f] and [s] and unstressed components of speech for example [t] indicating past tense of verbs ending in voiceless consonants, as in *walked*. (Elfenbein et al.,1994:223). Hendrick and Younger (2003:637) agree by stating that children with hearing loss have difficulties perceiving place of articulation for consonant sounds, particularly consonants having high frequency energy. The following properties affect perception of fricative place of articulation for listeners with normal hearing: frication duration; frequency of the frication spectral peak; formant transitions; spectral prominence or relative amplitude (Hendrick & Younger, 2003:637). Children with hearing loss have difficulties perceiving place of articulation of consonant sounds, particularly of consonants with high frequency energy.

Pittman, et al. (2003:649) state that a child's own voice through a hearing instrument contain lower energy at frequencies above 2000 Hz, relative to speech originating in front of the speaker. These authors also mention that the child's own speech would contain even more energy above 2000 Hz because of the adult-child difference in overall amplitude. Frequency regions important to normal speech development (like high frequency energy in phonemes like /s/), may therefore not be amplified sufficiently by many hearing instruments (Pittman et al., 2003:649).

Because speech recognition and production are significantly correlated with language skills in young children (DesJardin, et al., 2009:255), it is vitally important to make these speech sounds consistently intelligible and not only audible to children with hearing loss (Cole & Flexer, 2007:27). This again emphasizes the need for extended high frequency amplification in hearing instruments, especially in children.

2.4.3.4 Hearing loss and socio-emotional development

A study done by Petrou et al. (2007:1044) provide evidence of an association between bilateral permanent childhood hearing loss, diminished health status and health related quality of life. Quality of life is defined as the impact hearing loss has on daily functioning and the ability to participate in developmental routines and activities (Moeller 2007:730). When language development is delayed, there is a cascading effect on many aspects of a child's psychosocial development (English, 2009:977). Moeller (2007:730) describes psycho-social development as the quality of life which includes family-child issues, child specific issues like concept of self-concept and identity formation and child-peer issues like social access. These different aspects of psychosocial development will be discusses separately below.

- <u>Family-child issues:</u>

Family and child issues emphasize the importance of the social-emotional contact in which early learning takes place. A healthy emotional climate support navigation of unclear symbolic communication, resulting in reduced frustration for the child/infant and maintains a positive context (Moeller, 2004:732). There are, however, factors that influence the stress levels in family-child interactions; they are low family income, presence of additional disabilities, extent of child's language delay, and extent of family support (Moeller, 2007:731-732).

- Child specific issues like self-concept and identity formation:

Self-concept or self-esteem is defined as a stable set of attitudes about the self, including a description and an evaluation of one's attributes and behaviours (Moeller, 2007:734). Individuals are not born with their self-concepts intact; rather, self-concept is learned by absorbing the input and feedback and reactions from those around us (English, 2009:977). Children with hearing loss are at risk for developing a relatively poor self-concept, most likely from negative reactions regarding their communication difficulties and also from being perceived differently as hearing instrument users (English, 2009:977).

When language development is delayed due to hearing loss, children are often less accurate in identifying others' emotional states and have a poorer understanding of affective words than children with normal hearing (English, 2009:978). Affective vocabulary describes how one feels, including adjectives such as *frustrated, confused, overwhelmed, insecure, confident, satisfied,* and *reluctant* (English, 2009:978). Davis, Elfenbein, Schum and Bentler (1986:57) described the effects that a mild and moderate hearing loss have on the psychosocial behaviour of hearing impaired children. They mention that these children scored significantly higher than the norm on scales of aggression. The parents of these children also described their children with hearing loss as having behavioural problems characterized by aggression, impulsiveness, immaturity and resistance to discipline and structure (Davis et al., 1986:60).

Stevenson et al. (2009:77) undertook a study to determine the relationship between language development and behavioural problems in children with hearing loss. They found that the receptive and expressive language aggregates were highly significant predictors of the behaviour aggregate, and they concluded that hearing loss is related to an increased rate of behavioural problems only because hearing loss in itself is a risk factor for low language competence (Stevenson, 2009:82). This explains that the high prevalence of psychopathology in adolescents with hearing loss is not due to hearing loss as such, but rather that communication problems, physical health problems, adverse living conditions and other factors, may increase the risk of psychiatric disorders in this population (Stevenson et al., 2009:77).

- Child-peer issues:

Child-peer issues involve the influence of school experiences on feelings about self as an individual with hearing loss. Relationships with peers are important because they contribute to social development, emotional development, cognitive as well as academic growth (Moeller, 2007:735). Mainstream education can lead to feelings of insecurity, isolation and poor self-confidence (Moeller, 2007:734). Although children with hearing loss had sufficient linguistic competence to compete academically in the mainstream, they reported less social confidence in expressing feelings or presenting arguments than peers with normal hearing (Moeller, 2007:734). As children grow up, their social world expands to include same-age peers. Because of their delay in developing communication skills, children with hearing loss have fewer opportunities for peer interactions, making it difficult to learn the social rules governing communication (English, 2009:978).

The influence hearing loss has on the socio-emotional development (and therefore quality of life), emphasizes the need for early intervention and appropriate amplification; Stacey et al. (2006:162), for instance, concluded that a cascade of benefits flow from the provision of appropriate amplification which is associated with improvements in speech perception and spoken language abilities.

2.4.4 Education for children with hearing loss

Any educational environment where the child with hearing loss has to rely on any form of auditory information delivered through spoken language may prove to be difficult, especially in a noisy classroom (Brown, 2009:949). Flexer (2004:132) agrees by stating that typical mainstream classrooms are auditory-oral environments where instruction is presented through the teacher's spoken communication. Children in mainstream classrooms, whether or not they have hearing problems, have to be able to hear the teachers for learning to occur. It is important to note that without basic detection, none of the higher levels of auditory processing is available. Therefore comprehension, the goal of the classroom instruction, is completely dependent on the initial detection of individual phonemes that comprise the spoken message. Challenging acoustic environments, hearing loss and inappropriate amplification compromise detection. Without detection, there can be no comprehension (Flexer, 2004:132).

As already explained, hearing loss interferes with a child's detection and recognition of speech. A delay in early development of auditory skills caused by a hearing loss negatively impacts a child's ability to learn and use an auditory-oral language system. The filtering effects of a hearing loss, coupled with immature auditory skills caused by hearing impairment, typically impact the development of oral language in all domains (Matkin & Wilcox, 1999:143). For school aged children learning problems related to hearing loss typically manifest as poor performance in language-based subjects, class tests, class participation and verbal interaction with peers and teachers. The impact of these difficulties leads to reduced academic achievement and often school failure, especially in the lower grades. Until a child with hearing loss learns to read for new information, most classroom learning is through the auditory channel (Matkin & Wilcox, 1999:143).

A common challenge to children with hearing loss is the inability to hear speech and language adequately in a typical listening situation like a classroom (Brown, 2009:934). Therefore, the primary nemeses of children with hearing loss are classroom noise levels, reverberation (reflected sounds that add delayed versions of the original sound) and large speaker-to-listener distances that interfere with distance hearing (Ricketts & Tharpe, 2004:143; Dillon, 2000:58; Flexer, 2004:134)). Classroom noise levels tend to be more intense at low frequencies and less powerful at high frequencies (Cole & Flexer, 2007:27; Brown, 2009:934). Another obstacle that interferes with children's abilities to hear soft high frequency speech sounds, are the fact that the weaker, high frequency consonant sounds are more affected by noise than the louder vowel sounds (Cole & Flexer, 2007:27). In noisy situations, the intelligibility of speech (the ability to hear word-sound distinctions clearly) is compromised even though the sounds might still be audible (Cole & Flexer, 2007:27).

For much of the day in a primary school classroom, young children are exposed to the noise of other children producing 'classroom babble' at levels typically of around 65dB, while the typical overall exposure level of a child at primary school has been estimated at around 72dB (Shield & Dockrell, 2007:133) with a signal-to-noise-ratio (SNR) typically from -1dB to +5dB, rather than the +15dB which is optimal for children with hearing loss (Pittman, Vincent & Carter, 2009:1483). Pittman et al. (2009:1477) noted that with amplification and when listening in quiet, few differences between children with hearing loss and their hearing peers are observed. However, significant effects of hearing loss re-emerge when speech is presented in noise (like in a classroom), suggesting that elevated hearing thresholds alone do not fully account for the effects of hearing loss (Pittman et al., 2009:1477). These results indicate that when contextual information was provided, the presence of hearing loss was not a determining factor; however, when the same words were presented in nonsense sentences, perception was no longer as simple. These authors mentioned that it is important to note that children with hearing loss are often required to perceive more complex materials in more difficult listening conditions. In a learning environment such as the classroom, children are expected to perceive new and more complex phrases every day (Pittman et al., 2009:1483). Although prescriptive hearing instrument gain and output procedures typically result in appropriate audibility and comfort of the speech signal, ensuring that the intensity level of speech is presented well above that of interfering background noise remains a significant problem (Ricketts & Tharpe, 2004:143).

In Deaf Education in South Africa, there is currently a mismatch between needs and the provision of special education. According to the Education White Paper 6 (2001:14), this is a direct result of previous apartheid policies that allocated facilities on a racial basis. These policies also centralized provision within the Western Cape and Gauteng with the result that the vast majority of learners today attend residential special schools in a province other than their own since no facilities are available in their province of residence (Education White Paper 6, 2001:14). For example, the Western Cape has 5.47% of the disabled population, but has 21, 58% of the special schools (Education White Paper 6, 2001:14). The national total incidence figure for disabilities of all ages is 6.55% and the total number of learners currently in special schools is 0.52% (Education White Paper 6, 2001:15).

However, it is stated in the Education White Paper 6 (2001:14) that government will make it its obligation to provide basic education to all learners. Government will focus specifically on learners who experienced barriers to learning and development and have dropped out of learning because of the inability of the education and training system to accommodate the diversity of learning needs (Education White Paper 6, 2001:10). The National Disability Strategy condemns the segregation of persons with disabilities from the mainstream society. They further emphasize the need for including persons with disabilities in the workplace, social environment, political sphere and sports arenas. The ministry supports this view and sees the establishment of an inclusive education and training system as a cornerstone of an integrated and caring society and of an education and training system for the 21st century (Education White Paper 6

2001:10). This inclusive education system is positive, but also challenging, and emphasizes the importance of optimal hearing instrument fitting as the basis for auditory learning; instruction as part of an inclusive educational setting will, to a certain extent, be done auditorily. A study done by Pottas, (2004:240) about inclusive education in South Africa and the challenges thereof, indicates that regardless of certain challenges (child-related, teacher related and environment related), inclusive education can be an appropriate academic option for children with hearing loss in South Africa (Pottas, 2004:240).

2.4.5 Early hearing detection and intervention (EHDI)

EHDI provides access for children with hearing loss to early use of hearing instruments, allowing stimulation and growth of auditory centres of the brain during times of critical neuroplasticity (Cole & Flexer, 2007:80).

Currently, EHDI programmes are being implemented worldwide. In the following few pages the importance of early hearing detection and intervention are discussed, local and international position statements regarding EDHI are mentioned, and, finally, EDHI in South Africa as a developing country will be addressed.

2.4.5.1 Importance of early intervention

Early intervention became possible with hearing screening in newborns and has been shown to be efficient and cost effective, with a sensitivity range of 80%-90%, a false positive rate smaller than 2% and a positive predictive value of 17% (Lasisi et al., 2006:627). The significant importance is that significantly better language scores (vocabulary development, receptive and expressive language, syntax, speech production and socio-emotional development) are associated with early diagnosis and early intervention that actively involve children’s families (Watkin et al., 2008:624; Joint Committee on Infant Hearing, 2007:161-162). At this point it is worth pointing out that the literature has now defined six months as the definite cut off point for early diagnosis (Watkin et al., 2008:624). This is considered a first world benchmark. According to research done by Yoshinago-Itano, et al. (1998:1169), a group of children whose hearing loss was identified by 6 months of age demonstrated significantly better receptive and expressive language skills than did children whose hearing loss was identified after the age of 6 months. This language advantage was evident across age, gender, socio-economic status, ethnicity, degree of hearing loss, mode of communication and presence/absence of other disabilities.

A variable that has received attention with regards to its impact on language development in hearing children is the mother's level of education (Mayne, 1998:4). It is explained by Cole and Flexer (2007:5) that the extra talk of parents in professional families and of the most talkative parents in working-class families contained more of the varied vocabulary, complex ideas and positive feedback thought to be important to cognitive development. The first 3 years of experience put in place a vocabulary growth and the foundations of analytic and symbolic competencies that make a lasting difference to how children perform in later years (Cole & Flexer, 2007:5). Maternal communicative skills is a strong aspect of parental involvement, and according to studies done by Moeller (2008:1), are the most successful when early identification is paired with early intervention that actively include families (Moeller, 2008:1).

2.4.5.2 Position statements regarding EHDI

- Internationally (developed countries)

The Joint Committee on Infant Hearing Position Statement (2007:143) endorses early detection of and intervention for infants with hearing loss. The goal is to maximize the outcome for infants who are deaf or hard of hearing; the hearing of all infants should be screened no later than at one month of age. Those who do not pass screening should have a comprehensive audiological evaluation no later than at three months of age. Infants with confirmed hearing loss should receive appropriate intervention by health care and education professionals with expertise in hearing loss and deafness in infants and young children no later than at six months of age.

- South Africa (developing country)

The Health Professions Council of South Africa (HPCSA) early hearing and detection and intervention programmes in South Africa Position Statement (2007:3) advocates early detection of and intervention for infants with hearing loss through integrated provincial and district service delivery mechanisms which include all role players, be they from relevant government or private and non-governmental organization/s. Following first world benchmarks, the goal of early hearing detection and intervention (EHDI) is to provide children with hearing loss optimal and timely opportunities to develop linguistic, literary and communicative competence in keeping with their full potential. Diagnostic audiological and, if necessary, medical evaluations should be in progress before three months of age and diagnosis confirmed by no later than four months of age. Those infants with confirmed hearing loss should receive intervention before six months of age and no later than at eight months. In a developing country such as South Africa, early intervention programmes should be family centred within a community based model of service delivery that is the same for all cultures (Van der Spuy & Pottas, 2008:S31; EHDI Position Statement HPCSA 2007:4). All children with hearing loss and their families should have access to appropriate early identification services, despite financial limitations or restriction.

2.4.5.3: EHDI in South Africa

South Africa is uniquely positioned in terms of its health care infrastructure (training of audiologists and otolaryngologists) leading the way in sub-Saharan Africa for implementing EHDI services (Swanepoel, Storbeck & Friedland, 2009:786). Newborn hearing screening is the only way to ensure early identification and early access to amplification (Swanepoel et al., 2009:783) Various barriers exists that are hampering the implementation of EHDI service delivery, support and education in South Africa (Van der Spuy & Pottas, 2008:s30). Some of these hindrances include poor socio-economic circumstances such as inaccessibility to basic services (including intervention centres for children with disabilities) due to transport problems, inaccessible roads, violence, crime, cultural differences, malnutrition and unemployment (Van der Spuy & Pottas, 2008s31). Taken the above into account, it is comprehensible that service delivery to infants with hearing loss and their families remain a tremendous challenge for the paediatric audiologist working within and implementing intervention services in South Africa (Van der Spuy & Pottas, 2008: s31).

A study conducted in South Africa by Swanepoel, et al. (2009:784) indicates that the average age of diagnosis is almost two years, while enrolment in intervention programmes takes place at over two and a half years of age, meaning that the critical period of intervention before six to nine months of age is not accessed. Newborn hearing screening in the private health care sector is mostly dependent on individual initiatives from audiologists in private practice in hospitals, but is not mandated by hospital management and therefore remains mostly unstructured, unsystematic and only available in certain hospitals (Swanepoel et al., 2009:785). Pilot programmes of infant hearing screening in the public health care sector, supported by provincial government, have been initiated at two immunization clinics in the city of Cape Town, Western Cape (Swanepoel et al., 2009:785). Much more initiatives are however needed and without the support from the Department of Health very little progress can be made in the public health care sector where the majority of infants with hearing loss are born (Swanepoel et al., 2009:785).

Newborn hearing screening programmes should result in the diagnosis of hearing loss in children before the age of four months. In comparison to other African countries, the mean age of diagnosis in South Africa is 23 months. South Africa is the only country in sub-Saharan Africa with tertiary training in audiology. This is why statistics indicate earlier identification in South Africa than in other sub-Saharan African countries where the absence of newborn hearing screening lead to significantly delayed identification and intervention of hearing loss, starting from two years of age and well into adolescence (Van der Spuy & Pottas, 2008: s33). The Joint Committee on Infant Hearing (2007) indicates identification of hearing loss at three months, and intervention at six months of age. The mean age of enrolment in early intervention programmes in South Africa is 31 months of age, which is relatively late compared to the recommended age of six months stated above. (Van der Spuy & Pottas, 2008: s33).

Newborn hearing screening is a silent (global) revolution which is an achievable and important goal for all nations (Olusanya et al., 2007:3). Hospital based screening programmes are essential in all countries but it is also necessary to have complementary community based programmes, especially in countries like South Africa where a significant proportion of births occur outside hospitals (Olusanya & Somefun, 2009:961). Most community based programmes are linked to visits to primary maternal and child clinics for routine immunization in the first 3 months of life (Olusanya et al., 2007:10). It is possible to implement EDHI at these primary clinics using the community health workers (Olusanya, et al., 2008:961).

The reality is that the majority of South Africans (85%) rely on the public health sector (Theunissen & Swanepoel, 2008:s24). These authors also mention that private sector hospitals benefit from world class medical staff and use state-of-the art equipment for service delivery, while public sector hospitals often still render a ‘developing world’ type of service (Theunissen & Swanepoel, 2008:s24). The availability of adequate resources in terms of equipment and trained staff affects the ability of the public healthcare sector to implement and manage early detection and intervention programmes for hearing loss in South Africa (Theunissen & Swanepoel, 2008: s24).

In summary, it is clear that paediatric audiology in South Africa faces many challenges. It is however positive to note the changes in policy regarding hearing instrument provision for children under six years (Van der Spuy & Pottas, 2008:s33). Another positive is that South Africa is fortunate to have Audiology as a health profession (Van der Spuy & Pottas, 2008:s34); furthermore, position statements like the EDHI Programmes in South Africa provides strong motivation for starting to improve current services.

2.5 Hearing instrument technology, extended range amplification and paediatric hearing instrument fitting

In order to optimize the use of residual hearing it is important to make sure that correct hearing instruments are fitted, that the correct fitting algorithms are used and, most importantly to verify that the child with hearing loss is benefiting from the amplification provided. This is emphasized by Cox (2004:10), who states that current best practice refers to well designed, patient centred clinical research on the efficacy and effectiveness of rehabilitative treatments for hearing loss. This includes prescriptive fitting methods, technological innovations and audiological rehabilitation (Cox, 2004:10). To gain an understanding of these issues, the following discussion includes: hearing instrument technology; extended range amplification; the stages of hearing instrument fitting.

2.5.1 Hearing instrument technology

Hearing instruments have been developed to partially overcome the deficits associated with hearing loss (Dillon, 2001:1). To understand where hearing instrument technology came from, a brief historical overview of the development of hearing instruments are presented in Table 6.

Table 6: Historical perspective of hearing instrument technology development (Dillon, 2001:13-16)

Date:	Hearing instrument technology development:
1652-1692	The trumpet, horn, funnel and speaking tube was used.
1899	Invention of the carbon amplifier leads to the first carbon hearing instrument.
1920	The vacuum tube electronic amplifier leads to vacuum tube hearing instruments.
1953	Hearing instruments started to use transistors rather than valves which resulted in reduction of hearing instrument size.
1964	In this era multiple transistors and resistors were could be combined into a single component that was similar in size to any one of the individual transistors that it replaced. This integrated circuit was applied to hearing instruments.
1968	Piezoelectric microphones were invented, which was a small microphone with a reasonably smooth and wide frequency response. Directional microphones also first appeared.
1970	Improved size reductions of microphones and receivers.
1986	Application of digital control circuits and digital memories to hearing instruments.
1996	The first fully digital hearing instrument became commercially available.

In Table 6 it can be seen that hearing instrument technology development is closely linked to overall development in technology. As can be expected the most development occurred during the last few decades.

Sensorineural hearing loss are a multifaceted loss of hearing ability and in most cases decreased audibility, decreased dynamic range, decreased frequency resolution, decreased temporal resolution, and/or a combination of these, are involved (Dillon, 2001:2). Taken together, all these auditory deficits mean that any child with a sensorineural hearing loss needs a signal-to-noise ratio greater than normal in order to communicate effectively, even when sounds have been amplified by a hearing instrument (Dillon, 2001:1).

Ensuring consistent audibility is therefore an important objective when fitting children with hearing instruments (Kuk & Marcoux, 2002:503). The primary goal in hearing instrument development is to ensure audibility for all sounds that are important for the perception of speech, including high frequency speech information (Smith, et al., 2009:64; Boothroyd & Medwetsky, 1992:151). In other words, for optimal acquisition of speech and language, the amplification should be able to make all speech sounds audible in a variety of listening contexts (Ching, et al., 2001:149). Although communication is the primary goal, young children with hearing loss must first use the amplification to acquire the necessary communication skills – which include the accurate production of speech (Pittman, et al., 2003:649).

To be able to choose the correct hearing instrument, it is important to understand the basic components and technology of today's hearing instruments. Hearing instruments have basic components like microphones which convert sound waves into electrical signals, amplifiers which increase the strength of the electrical signal, and receivers which convert amplified signals back into an acoustical signal. Even though these components are basic, it is uncommon to fit hearing instruments that have these basic features only (Bentler & Mueller, 2009:780). According to these authors, there are numerous additional features and digital algorithms available in modern hearing instrument technology. This is supported by Kuk, Damsgaard, Bulow and Ludwigsen (2004:40), who state that hearing instruments today use far more sophisticated algorithms to process sounds than a few years ago. Some examples are modern algorithms for compression, consistent improvements in feedback management, noise reduction, control of directional microphones and multiple channels, all of which are summarized in Table 7.

Table 7: Basic features of modern hearing instrument technology (Bentler & Mueller, 2009:781)

Hearing instrument feature	**Description of hearing instrument feature**
Compression	The two most common types of amplitude compression are: AGCo (Automatic Gain Control: Output): AGCo is a replacement for peak clipping (introduced distortions that can reduce speech intelligibility and quality for loud speech) and is used to maintain high inputs below the uncomfortable loudness thresholds of the child with hearing loss. Here the signal is analyzed and compressed after it has been fully amplified. The primary goal is therefore output limiting. Research evidence has shown that the clinical procedure of adjusting the hearing instrument output using AGCo to ensure that loud sounds are not uncomfortable, improves satisfaction. AGCi (Automatic Gain Conrol: Input): This is the alternative to linear processing and is used to reduce the dynamic range of the output signals, fitting these signals within the boundaries of the patient's residual dynamic range. The input signal to a hearing instrument is analyzed and compressed before that signal reaches the final amplifier section. The goal is to 'reshape' and 'repackage' the input signal to allow a wide range of intensities to fit into the patient's restricted residual dynamic range. This is important for loudness recruitment, typically experienced with cochlear hearing loss.
Feedback management	To manage the whistling sound that occurs when the gain of the hearing instrument (at a particular frequency) is greater than the occlusion at the ear mould (at that frequency)
Noise reduction	Algorithms distinguish between speech and noise in the listener's immediate environment and reduce the 'noise' component.
Microphone technology	Directional microphones in its basic design operate on the principle that the microphone is more sensitive to forward-facing inputs, than to inputs from other azimuths.
Multiple channels	In many cases hearing instrument users require different degrees of signal processing in different frequency regions.

Table 7 provides a brief summary of basic technology that is available in hearing instruments today. The paediatric audiologist should know about these advances in technology and what type of technology is important for children with hearing loss for optimal speech recognition. Hearing instrument companies are constantly developing new features in order to improve audibility. These companies base their new developments on research results and hearing instrument user specifics (Cox, 2004:10). Research applicable to the current study indicates that the bandwidth of current behind-the-ear hearing instruments is inadequate to accurately represent the high frequency sounds of speech (Stelmachovicz et al., 2004:556) and it is suggested that children with hearing loss may benefit from extended high frequency amplification (extended range amplification) when learning new words (Pittman, 2008:785).

2.5.2 Extended range amplification

Bandwidth refers to the range of frequencies which are amplified by a specific hearing instrument (Stach, 2003:38). Extended range amplification for the purpose of this study refers to a wider bandwidth, specifically referring to additional high frequency amplification.

Survey data suggests that, when it comes to hearing instrument technology, hearing instrument users rank speech intelligibility and sound quality as the two most important areas in need of improvement (Ricketts, Dittberner & Johnson 2009:161). These authors found that audible bandwidth was the one factor that greatly affected sound quality. Improvements were found in speech recognition with increasing bandwidth, also in listeners with high frequency hearing thresholds as poor as 85dB HL (Ricketts et al., 2009:161). It is concluded that high frequency speech information, up to approximately 8000 Hz, may be necessary for optimal speech and language development in children with hearing loss (Ricketts et al. 2009:161). This is supported by Stelmachovicz et al., (2004:556), who mentioned that the bandwidth of current behind-the-ear hearing instruments is inadequate to accurately represent the high frequency sounds of speech, particularly for female speakers.

Although the bandwidth of current hearing aids is wider than ever before, the high frequency gain in most instruments is reduced rapidly above 5000 Hz, which is well below the frequencies of the peak energy of [s] in both children and adult female speakers (Pittman et al., 2003:653). This statement is supported by Stelmachovicz et al., (2004:558). According to Kortekaas and Stelmachovicz (2000:646), this is due to the frequency transfer characteristics of transducers and ear moulds. Reduced high frequency gain in combination with high frequency hearing loss, may result in insufficient amplification in this region. This limited high frequency amplification may have a negative influence on the development of speech and language skills in children with hearing loss and it may limit the audibility of important high frequency speech sounds (Stelmachovicz et al., 2004:559).

Traditionally, the majority of children have been fitted with hearing instruments with a limited frequency range. The result of this practice was that children with mild to severe hearing loss did not have constant access to high frequency amplification and therefore had inconsistent access to important speech sounds as well, resulting in the omission and/or substitution of certain phonemes (Elfenbein et al., 1994:223). The primary goal in the development of new hearing instruments is to ensure audibility for all speech sounds that are crucial for the perception of speech, including high frequency cues that are important for speech recognition (Smith, et al., 2009:64).

Children with hearing loss may benefit from increased high frequency amplification when learning new words and for other long-term auditory processes (Pittman, 2008:785). This author also states that this increased bandwidth can be perceived as an increase in sound quality and that it can have a quantitative effect in children who use their hearing primarily to learn. In the same study by Pittman (2008:795), the author suggested that, regardless of the degree of hearing loss, the children learned words significantly faster when they were provided with a speech signal that included a bandwidth similar to that of normal hearing. Conversely, the children learned the words more slowly when they were provided with limited speech signals. In summary, these results indicate that sufficient high frequency amplification for children with hearing loss may be necessary to promote optimal learning of words (Pittman, 2008).

From the above discussion it is clear that constant input of all speech sounds and therefore accurate speech recognition is fundamental to the acquisition of speech and language. Hearing instruments with extended frequency bandwidths have been developed to ensure audibility of all speech sounds, especially the fricatives and unstressed components of speech (Smith, et al., 2009:64). This study will therefore focus on the possible effect that such a hearing instrument with extended high frequency range amplification may have on the speech recognition abilities of children with mild to severe sensorineural hearing loss.

On the other hand, expansion of the signal bandwidth is problematic in this type of instruments because of resonances associated with the tubing (Stelmachovicz et al., 2004:561). As a result, providing adequate gain in the 6000Hz - 8000Hz range is difficult, particularly for infants and young children where acoustic feedback is common. One potential solution to this problem is to widen the hearing aid bandwidth (Stelmachovicz et al., 2004:561). High frequency bandwidth extension of approximately 10000Hz has been made available as a direct result of recent improvements in feedback management that provides increased gain in the high frequencies, before audible oscillations occur (Johnson, et al., 2009:354).

An alternative approach might be the use of frequency compression or transposition schemes, whereby high-frequency signals are shifted to lower frequencies to provide adequate audibility (Stelmachovicz, 2004:561). Glista, Scollie, Polonenko and Sulkers (2009:20) mentioned that frequency-lowering technology can also be used in hearing instrument signal processing to present high frequency information to a lower frequency region. According to these authors frequency lowering is a logical solution to the limits of gain, feedback or high frequency clarity that are encountered when fitting hearing instruments (Glista et al. 2009:20). Two frequency-lowering schemes are currently available: frequency transposition and frequency compression. *Frequency transposition* refers to the shifting of the upper frequency band of energy by a fixed amount to a lower frequency place; it typically results in a mixing of transposed and non-transposed energy (Glista et al., 2009:20; Glista, Scollie, Bagatto, Seewald, Parsa & Johnson 2009:633). *Nonlinear frequency compression* is applied to the high frequency band, narrowing it in bandwidth but not mixing it with low frequency energy (Glista et al., 2009:20). If this compression is applied across the entire frequency range of the device, frequency compression can alter the positions of vowel formants in the frequency domain (Glista et al., 2009:633).

These frequency-lowering schemes may be a solution for persons with hearing loss greater than 70dB, because there is the possibility of cochlear dead regions that may not respond as expected to traditional amplification, especially in the high frequencies (Miller-Hansen, Nelson, Widen & Simon, 2003:106). Cochlear dead regions are associated with a ‘dead’ region of the cochlea, defined as a complete loss of inner hair cell and/or neural function over the basal region of the cochlea (Smith, Dann & Brown 2009:63)

Positive outcomes according to Glista et al. (2009:20) in terms of significant overall benefit with frequency compression are that children are more likely to benefit than adults, and participants with greater hearing loss that is more confined to the high frequencies are also more likely to benefit. Children with severe hearing loss showed significantly improved aided thresholds and word recognition (Miller-Hansen et al., 2003:107). There is also a need for a better understanding of candidacy and training requirements when acclimatizing to this type of signal processing (Glista et al., 2009:20), because some studies showed that providing high frequency information where the hearing loss is severe, carries little or no speech recognition benefit in itself (Glista et al., 2009:632).

In summary of the above studies it is clear that there is a great deal of focus on successful provision of high frequency amplification and how to develop technology in hearing instruments that provide this type of amplification. It is also clear that a great deal of research is needed on the outcomes of high frequency amplification in children with hearing loss.

For the purpose of this study traditional high frequency amplification by increasing the bandwidth will be used. High frequency extension through 7000 Hz – 9000 Hz has been shown to improve speech recognition in children with mild to moderate hearing loss (Johnson, et al., 2009:354).

2.5.3 Paediatric hearing instrument fitting

Bentler et al. (2004:49) state in the Pediatric Amplification Guidelines Protocol that there are basic evidence based requirements that need to be followed when providing amplification to children with hearing loss. According to these authors, the primary goal when fitting children with hearing loss is to provide audibility of speech regardless of input levels and vocal effort. They also state that the target values for gain and output should be determined through the use of a prescriptive formula by using hearing sensitivity data and real ear to coupler difference (RECD) data (Bentler et al., 2004:50). This prescriptive formula should be scientifically based according to Current Best Practice (Cox, 2004:10). A validation process should follow once amplification is provided, to ensure that optimal speech input is received (Bentler et al., 2004:51).

The process of fitting children with hearing loss with hearing instruments are discussed below in six stages: prescription of amplification, selection of amplification, verification of the fitting, orientation and training, validation of the fitting and follow-up.

2.5.3.1 Prescription of amplification

An objective prescription should be used to compute recommended electro-acoustic settings for the hearing instruments, which should result in appropriate detection, loudness, and intelligibility of amplified speech (Strauss & Van Dijk, 2008:s62). Because children with hearing loss will wear their hearing instruments at a fixed, clinically determined setting for months/years before they are able to clearly express their preferences, it is crucial that the determined hearing instrument settings are valid and done in an objective manner (Scollie, 2004:91). Objective hearing instrument prescriptions uses computational algorithms that prescribe specific amplification characteristics, typically based on the diagnostic status of the hearing instrument wearer. These prescriptions are used to compute recommended electro-acoustic settings for hearing instruments that should result in appropriate detection, loudness and intelligibility of amplified speech (Scollie, 2004:91). Such an objective approach is important, because it results in consistent treatment across children, clinicians and clinics. This consistency not only facilitates communication and collaboration between clinical sites, but also allows individual clinicians to note trends of successful and/or unsuccessful outcomes (Scollie, 2004:91).

The Desired Sensation Level Multistage input/output (DSL m[i/o]) method will be used because it has always been, and still is, focused specifically on paediatric amplification (Scollie, 2006:10). The primary goal of the DSL m[i/o] is to fit the normal range of speech into the child's residual dynamic range in order to optimize audibility of speech across both frequency and level (Stelmachowicz & Hoover, 2009:831). The DSL m[i/o] provides audiologists with a systematic, science-based approach to paediatric hearing instrument fitting that ensures audibility of amplified speech by accounting for factors that are uniquely associated with the provision of amplification to infants and young children with hearing loss (Moodie et al. 2007:2). DSL m[i/o] describes the electro-acoustic goal as the provision of frequency/gain characteristics that would deliver amplified speech to a child that is audible, comfortable and undistorted across the broadest relevant frequency range possible (Moodie et al., 2007:3). The DSL m[i/o] is multistage and provide amplification in four input/output stages: expansion, linear, wide dynamic range compression (WDRC), and limiting (Scollie, 2006:10). Calculations across frequencies can also be grouped according to the number of channels in the hearing instrument, which resulting in target compression ratios per channel, rather than one per audiometric frequency as was done in the previous version (Scollie, 2006:10). Lastly, the DSL m[i/o] has been developed to work more effectively with modern hearing instrument technologies, and it also recognizes that real-ear-to-coupler (RECD) measurements are critical components of the fitting process (Scollie, 2006:12).

Recently, another aspect of the hearing instrument fitting process came under the spotlight, namely cochlear dead regions. Dead regions in the cochlea are areas where inner hair cells and/or neurons are absent or functioning so poorly that the tone producing maximum vibration is detected via a different place in the basilar membrane, with a characteristic frequency different from that of the tone. The presence of a dead region can have a significant effect on the perception of speech, and can have several perceptual consequences like abnormal pitch perception, rapid growth of loudness, and distorted perception (Malicka, Munro & Baker, 2010:238). When a dead region is present, the audiogram will give a misleading impression of the amount of hearing loss for a tone of which the frequency falls in the dead region (Moore, 2001:154). Appropriate diagnosis of dead regions of the cochlea may be particularly important, but also particularly difficult in children (Moore, 2001:163). Psycho-acoustic measurements in children tend to be more variable than those in adults, and masked detection thresholds are often higher than in adults; therefore, application of tests such as the TEN test is more difficult (Moore, 2001:163). This author also mentions that these tests are difficult to apply in cases of severe to profound loss, and their applicability in children with congenital hearing loss remains to be established. This is supported by Munro (2007:15) who states that what little information there is about children with high frequency dead regions suggests that some may not benefit from the provision of amplification well within a high frequency dead region; importantly, so far none have shown a reduction in performance. Therefore, for the purpose of this study, cochlear dead regions of subjects will not be assessed, and therefore amplification will be provided as if no cochlear dead regions exist.

2.5.3.2 Selection of amplification

The Paediatric Amplification Guideline (Bentler et al., 2004:49) also provide guidelines as to what to consider when selecting hearing instruments for children. It is recommended that hearing instruments should have the following basic requirements to ensure optimized speech recognition (Bentler et al., 2004:49):

- Avoid distortion
- Allow frequency/output shaping to provide audibility based on an appropriate prescriptive method
- Allow frequency/output shaping to avoid tolerance issues based on an appropriate prescriptive method
- System should employ amplitude processing that ensures appropriate audibility over a range of typical speech sounds from soft to loud
- Output limiting: independent of the signal processing that is provided in the dynamic range, because compression output limiting provides superior sound quality when compared with peak clipping output limiting
- System should include sufficient electro-acoustic flexibility to allow for changes in required frequency/output characteristics related to growth of the child (e.g. larger ear canal will result in a smaller RECD)

The following are current and future processing schemes that should be considered viable for paediatric hearing instrument fitting (Bentler et al., 2004:50).

- Automatic feedback control (caution when hearing instrument requires gain reduction)
- Multiple channels to allow finer tuning for an unusual audiogram
- Expansion to reduce low-level noise (e.g. microphone noise, over-amplification of soft sounds associated with low threshold compression)
- Compression to allow fitting a large variation of input levels found in speech and environment into the dynamic range of the child's hearing loss
- Frequency transposition, frequency compression

Background noise reduction and/or speech enhancement is not recommended until data relative to its effectiveness become available (Bentler et al., 2004:50).

2.5.3.3 Verification of the fitting

Verification is the stage in the hearing instrument fitting process when the the hearing instrument's performance is measured to determine whether it is doing what it is supposed to do in areas such as frequency shaping, compression, output limiting and directional microphone performance (Scollie, 2003:10).

It is recommended not to rely on functional gain to learn what the hearing instrument is, because it can be misleading. Measuring RECD's and using the corrected coupler targets and verifying hearing instruments with a speech-like signal to make paediatric fittings more accurate are recommended instead (Scollie, 2003:15).

- <u>Functional gain/aided threshold</u>

The aided threshold (functional gain) is a perceptual response. Because its value is dependent on the subjective response of the user it cannot be predicted from insertion gain measures (Kuk & Ludvigsen, 2003:95). Because real ear measures and aided thresholds provide different and important information, these measures should be used together in the verification on non-linear hearing instruments. Real ear measures and aided thresholds (functional gain), serve a complementary purpose rather than an exclusive purpose (Kuk & Ludvigsen, 2003:95). Sound field thresholds cannot be used to estimate the degree of hearing instrument gain for supra-threshold signals such as speech; this is particularly true of non-linear hearing instruments (Stelmachovicz & Hoover, 2009:832), but if a aided sound field threshold is 20db HL or better, then this is indicative that the child can hear the softest component of speech (Valente & Valente, 2009:867)

- Real Ear to Coupler Difference

Because valid an reliable probe-tube microphone measures may not always be possible with infants and young children with hearing loss due to the lack of cooperation, excessive movement and vocalization, a clinically feasible technique to predict real-ear measures of hearing instrument gain output was developed (Stelmachovicz & Hoover, 2009:832). This is the RECD which is the difference between the SPL measured in the occluded ear canal relative to the 2cc coupler clinical protocol for measure. The RECD uses an insert earphone/ear mould to deliver the signal and compares the SPL generated in the real ear with the SPL generated in the HA2 2cc coupler. The difference between the two measurements is the RECD (Munro, 2004:71). After the RECD is obtained, all subsequent measures of hearing instrument performance are obtained by adding the RECD to 2cc coupler measures; it does not require that the child is present, since it is not feasible to expect infants and young children to sit in front of a loudspeaker for the length of time required for conventional probe microphone measures. RECD is relatively easy to perform and takes less than a minute per ear. If the child is too active or noisy to complete the RECD measurement, it is possible to use predicted values for each frequency using normative data stored in the real ear measurement system (Rousch, 2004:109). If the small size of the infant's ear canal is not accounted for by the RECD measurement during hearing instrument fitting, the resulting SPL at the eardrum can be as much as 20dB higher than expected (Rousch, 2004:110). RECD is a critical component of the fitting process (Scollie, 2006:12). Because children's RECD measurements change rapidly across ages, particularly in the first two years it is recommended to measure individual RECDs whenever possible, though the DSL m[i/o], has specific built in correction factors to accommodate the rapidly changing ear canals (Scollie, 2006:12).

- Speech mapping

Probe-microphone measures provide a unique opportunity to easily quantify the audibility of speech across a range of input levels (Stelmachowicz, 2004:29).

Recent investigation illustrated that the most accurate representation of a hearing instrument's response will be through the use of a speech-like signal. Because audibility of speech is fundamental when fitting children with hearing loss, speech was selected as the signal for evaluating hearing instrument output (Strauss & van Dijk, 2008:s63). Therefore, if the audiologist does not verify the performance of the hearing instrument with a real-ear measurement system referenced to ear canal sound pressure level (SPL), it cannot be assumed that speech will be audible (Strauss & van Dijk, 2008:s69). This is supported by Scollie (2003:14) who states that the more the test signal is like real speech, the more accurately it estimates the gain for speech.

The more complex the processing of the hearing aid, and the more automatic, adjustable, and adaptive features it has, the more important it is to determine how this hearing instrument is functioning in the real ear for different input levels (Mueller, 2005:22). Hearing instruments with multiple channels of compression and digital noise reduction made probe-microphone measures more of a necessity than a luxury (Mueller, 2005:26). When real speech is used, the hearing instrument output is commonly displayed in the real ear aided response (REAR) mode, and often the procedure is referred to as speech mapping (Mueller, 2005:26).

Hearing instrument verification is not an isolated evaluation, but rather a combination of different types of assessments.

2.5.3.4 Orientation and training

To promote appropriate use of hearing instruments, parents/caregivers and educators need information regarding the use and handling of hearing instruments. Orientation and training sessions are recommended that is customized for parents/caregivers, educators and the child's abilities to perform the required tasks (Bentler et al., 2004:51). An orientation and training session should include the following (Bentler et al., 2004:51).

- Maintenance and care of hearing instrument (moisture, cleaning, drying, storage, use of provided cleaning tools)
- Suggested wearing schedule and retention
- Insertion, removal, switching on and off, working with assistive listening devices and telephones
- Batteries (removal, insertion, storage, disposal, battery life, flat battery indicators)
- Basic trouble shooting (listening checks, battery testing, plugged tube/ear mould, feedback)

2.5.3.5 Validation

Validation of auditory function is a demonstration of the benefits and limitations of aided hearing abilities (Bentler et al., 2004:51). Current evidence based practice refers to well-designed, patient centred clinical research and the effectiveness of rehabilitative treatments for hearing loss. It is important that not only the effectiveness of hearing instrument amplification is verified, but also the audiological rehabilitation (Cox, 2004:10).

Efficacy of amplification in children with hearing loss is complex and problematic when introducing a new signal-processing strategy to a child because it cannot be expected to see immediate changes in speech production or language skills (Stelmachowicz, 2004:28). Because of this complexity, it is unlikely that a single outcome measure or a single approach to the problem can provide a means to determine efficacy for all types of signal processing (Stelmachowicz, 2004:28). Therefore it is recommended in the Paediatric Amplification Guideline (Bentler et al. 2004:51) that in addition to ongoing monitoring of the hearing instrument, *objective measures of aided performance in controlled clinical environments* and *functional assessments in real-world environments* should be done. King (2010:s67) agrees by recommending use of a combination of functional assessments (informal teacher and parent reports) and objective testing (speech recognition and aided pure tone audiometry) tests. There is growing recognition for the value of validating the benefits of audiological habilitation for a child in the clinical setting as well as in the child’s typical listening environment by using a range of tools including subjective measures and structured clinical tests (Ching, Hill & Dillon, 2008:472).

2.5.3.6 Follow-up

Hearing instrument fitting in a child is an ongoing process. It is recommended that audiologists should see the child every three months during the first two years of using hearing instruments, and every four to six months thereafter (Bentler et al., 2004:52). It is stated in the Pediatric Amplification Guideline that follow-up appointments should include the following (Bentler et al., 2004:52):

- Behavioural audiometric evaluations
- Assessments of communication abilities and needs
- Adjusting amplification based on new audiometric information and communication needs
- Evaluating the working of hearing instrument (fitting of moulds, electro-acoustic evaluations, listening checks, probe-microphone measurements with each mould change)
- Validation through objective speech perception testing and functional assessments from time to time
- Long-term follow-up including academic progress

Fitting a child with hearing loss with hearing instruments requires ongoing support, verification and validation. This is the basis for evidence based practice which refers to 'well-designed, patient centred clinical research on the efficacy and effectiveness of rehabilitative treatments for hearing loss, which includes prescriptive, fitting methods, technologic innovations, and audiological rehabilitation.' (Cox, 2004:10).

2.6 Conclusion

There is an imperative need for more research in paediatric audiology (Stelmachowicz, 2004:37). Especially, effectiveness of innovative new hearing instrument technology on the acquisition of speech and language in children needs to be investigated.

Currently there is strong emphasis on making high frequency sounds audible to children who still need to acquire speech and language skills. Stelmachovicz et al., (2004:559) state that limited high frequency amplification has a negative influence on the development of speech and language skills, because it limits the audibility of important high frequency sounds. In order to support this statement the purpose of this study is to determine the effect extended range amplification has on children with mild to severe hearing loss.

The goal of current hearing instrument development is to ensure audibility for all speech sounds that are crucial for the perception of speech, including high frequency cues (Smith, Dann & Brown, 2009:64). According to current best practice, evidence of efficacy of amplification is important (Cox, 2004:10). In order to verify the efficacy of hearing instrument amplification, it is not recommended to use a single outcome measure, due to the complexities of the paediatric population (Stelmachovicz, 2004:28). Therefore, the Joint Committee on Infant Hearing (2007:167) recommends that the monitoring of amplification, as well as the long-term validation of the appropriateness of the individual habilitation programme, require ongoing audiological assessments along with electro-acoustic, real-ear and functional checks of the hearing instruments. Validation for the purpose of this study in order to determine the effect extended range amplification has on children with mild to severe hearing loss, objective testing (speech recognition) and subjective assessments (functional questionnaires) will be used.

2.7 Summary

This chapter orientates the reader with regards to the topics of relevance of fitting children with hearing loss with hearing instruments with an extended bandwidth, and provides a critical evaluation and interpretation of recent and relevant literature. In order to achieve this understanding of the effect extended bandwidth has on children with hearing loss, normal auditory, speech and language development are discussed. This knowledge provides better insight into the detrimental effects that hearing loss has on children's auditory, speech and language development, as well as on other aspects of their life.

A discussion of hearing instrument technology, amplification protocols and verification, in its turn, provides insight into the importance of evidence based practice. This should lead to a better understanding of the importance of developing new hearing instrument technologies and the importance of having evidence to support these developments.

CHAPTER 3
Method

3.1 Introduction

Chapter 1 explained that development of oral language is highly dependent upon what an infant can hear (Eisenberg, 2007:766) and that the primary goal of amplification is to make those elements of the acoustic spectrum containing important information for the identification of speech sounds audible to the young child (Boothroyd & Medwetsky, 1992:151).

Chapter 2 provided the theoretical background explaining why children with hearing loss still presented with speech errors and proposed that the probable answer is that hearing instruments do not provide sufficient high frequency amplification and that children would actually benefit from additional extended range amplification (Stelmachovicz, 2001:171; Pittman, 2008:785).

The essence of successful practice lies in the ability to demonstrate that the applied intervention strategy has worked (Strydom, 2005:148). In other words, for the purpose of this study, did the speech recognition abilities and functional performance of children with hearing loss improve by providing them with hearing instruments with an extended bandwidth? Therefore, the audiologist needs to be able to determine to what extent the intervention has been effective (Strydom, 2005:149). Clinical research enables the therapist to readily integrate evidence of assessments, intervention and evaluation into clinical management and to lay the foundation of evidence based practise (Irwin, et al., 2008:3). These authors further mentioned that evidence based practice increased professionalism, accountability to clients and other professionals, and the social relevance of the health services delivered in an economy with increased costs and decreased resources (Irwin, et al., 2008: 3). This is especially true in the South African context, because most research is done in the developed world, making it necessary that these methods be examined and adapted for the South African context which is economically and culturally diverse (Grobbelaar, 2009:94).

This chapter aims to explain the method used to conduct the research in this study. This will be discussed in terms of the aims for this study, the research design, ethical procedures, participant selection, data collection and analysis, as well as the reliability and validity of the research.

3.2 Research aims

3.2.1 Main aim

The main aim of this study was to determine the effect of extended range amplification on the speech recognition abilities and functional performance of children with mild to severe sensorineural hearing loss.

3.2.2 Sub-aims

The following sub aims were formulated to realize the main aim:

- To determine speech recognition scores and functional performance of children using their own, standard hearing instruments which did not incorporate an extended high frequency range.

- To determine speech recognition scores and functional performance of children using hearing instruments that did incorporate extended high frequency, *without* using the extended high frequencies.

- To determine speech recognition scores and functional performance of children using hearing instruments that did incorporate extended high frequency *while using* the extended high frequencies.

- To compare the speech recognition scores and functional performance of each child as obtained with and without extended high frequency amplification.

3.3 Research design

Research is defined by Leedy and Ormrod (2005:2) as a systematic process of collecting, analyzing and interpreting data in order to increase our understanding of the phenomenon in which we are interested in and to communicate what is discovered to the larger scientific community. Before research can commence, the researcher needs a research design. According to Babbie and Mouton (2001:74) a research design is a plan or a blueprint of how the researcher intends conducting the research.

Quantitative, correlational research explores the possible correlations among two phenomena (Leedy & Ormrod 2005:179). For the purpose of this study the two phenomena which were explored were the extra high frequency amplification on the one side and the influence this extended high frequency amplification had on speech recognition in children with mild to severe sensorineural hearing loss. In experimental research, the researcher manipulates the independent variable and examines its effects on another, dependent variable (Leedy & Ormrod 2005:222). In this study the independent variable was the hearing instruments with the extra high frequency amplification, while the hearing impaired children's speech recognition abilities constituted the dependent variable.

A quasi-experimental design was used because a non-randomized participant selection procedure was followed (Scott & Berkeljon, 2010). Such a design does not control for all the confounding variables and therefore cannot completely rule out some alternative explanations for the obtained results (Leedy & Ormrod, 2005:227; Scott & Berkeljon, 2010). Because lack of availability of participants that fitted the selection criteria, all participants that did fit the criteria were selected, and therefore a non-randomized selection procedure was used.

This design accommodated a one-group (single-system) pre-test versus post-test design (Fouché & De Vos, 2005:139), which had a built-in strategy for comparing pre-tests results with post-tests results. This concept of a baseline (pre-test) is unique to the single-system data collection period which immediately precedes the implementation of treatment (providing extended bandwidth amplification). For the purpose of this study were all participants assessed with their own hearing instruments which served as the baseline.

'Single-system design' refers the study of a single participant on a repetitive basis, and this single participant can be an individual or a group or any client system (Strydom, 2005:144; Irwin, et al., 2008:119). This design was selected because each participant was assessed three times during the data capturing period. Because this study, studied the effect of the provision of extra high frequency amplification as part of intervention for children with hearing loss, were single-system designs the ideal way to evaluate the effectiveness of these treatment interventions. (Strydom, 2005:145). This design also enabled the researcher to measure the progress of the intervention programme (provision of extended high frequency amplification), and to thereby establish a link between research and practice based on the possibility of clinical application (Strydom, 2005:145; Irwin, Pannbaker & Lass, 2008:121; Drummond, 2003:35). Single-participant designs are structured around two core elements that distinguish them form a case study or group studies, namely repeated measurement and design phases (Irwin, et al., 2008:119). The three assessments were the repeated measurement, and three phases which consisted each out of intervention, adaptation and assessment. Single-system designs can be used to compare several types of treatment or intervention (Irwin, et al., 2008:119). This single-system design also involves the planned comparison of observations in a pre-intervention period (baseline) with observations during the intervention period, or even during a post-intervention phase. Pre- and post-test comparisons are the essence of all scientific research (Strydom, 2005:150).

This baseline (pre-test) serves as a control phase having the same function as a control group in experimental research. Collected data were used to initially measure the problem and this served as a basis for comparison with data collected during the treatment and follow-up sessions (Strydom, 2005:147). Kazdin (1982:105) agrees with this statement by emphasizing that this initial or baseline assessment provides information about the level of behaviour before a special intervention begins. The intervention in this study is the fitting of hearing instruments with extra high frequency amplification. Strydom (2005:149) mentions that a baseline can be compared to a normal pilot study and entails the planned collection of data before the independent variable is implemented.

According to Irwin, Pannbaker and Lass (2008:121) the advantages of a single-system design are that causal relationships can be established and that it can accommodate a small number of participants. Other important and practical, therapist-centred advantages mentioned by Strydom (2005:154-155) are that whenever research involves testing the success of an intervention, an ethical question arises about placing some participants into a control group who will not benefit from the intervention programme. The single-system approach allows for all the participants to be treated and evaluated, thereby avoiding this particular ethical issue. All participants in this study received treatment and therefore there were no control group. These authors also mention that the single-participant design should be standard practice. Every therapist should start thinking more scientifically about problem areas in their clients' lives and about which interventions would be appropriate and how solutions should be evaluated. This view is also supported by Horner and Spaulding (2010), who state that single-participant design research holds promise as one approach for documenting evidence-based practice, since there is a need for research standards that can be used for documenting an intervention as 'promising'. It is, however, also important to state the disadvantages of the single-system design. Irwin, et al. (2008:121) mention that it limits generalization and control of extraneous variables.

Making use of a control group would certainly rule out other possible explanations for the obtained results (Leedy & Ormrod 2005:223). Unfortunately, for this study, using a control group is not possible because of a lack of available participants. The researcher can, however, use each participant as his/her own control (Leedy & Ormrod, 2005:223) and therefore, in this study, this strategy is used instead. To control for individual differences, the researcher exposed all participants to all treatments and subsequently assessed the effects of each treatment independently (Leedy & Ormrod, 2005:223).

The research phases in this study are summarized in Table 8

Table 8: Overview of the research phases

	Phase	Data capturing process
←10 weeks→	**Phase 1**	Baseline audiometry, optimal fitting and verification of own hearing instruments ↓ 12 days acclimatization period ↓ Participative and objective assessments of own hearing instruments ↓
	Phase 2	Optimal fitting and verification of new hearing instruments without extended high frequencies ↓ 12 days acclimatization period ↓ Participative and objective assessments of new instruments without extended high frequencies ↓
	Phase 3	Optimal fitting and verification of new hearing instruments with extended high frequencies ↓ 12 days acclimatization period ↓ Participative and objective assessments of new instruments with extended high frequencies

This research project intended to address issues that are of immediate relevance to current practices and procedures in fitting children with hearing loss with hearing instruments. This type of research is therefore applied research, because it may inform human decision making about practical problems (Leedy & Ormrod 2005:43), (Irwin, et al., 2008:121).

3.4 Ethical considerations

Strydom (2005a:57) defines ethics as a set of moral principles which are widely accepted. These rules and behavioural expectations provide the basis for correct conduct towards experimental participants, employers, sponsors, other researchers, assistants and students. Drummond (2003:18) states that ethical principles are essentially a combination of law and professional convention. These principles are applied within the healthcare context and also in the studies that support the development and improvement of healthcare (Drummond, 2003:18).

There are two basic categories of ethical responsibilities, namely the researcher's responsibility towards the participating people, and an ethical obligation to the discipline of science, for it to be accurate and honest in its reporting (Strydom, 2005a:56). The responsibilities mentioned above are discussed in more detail below.

3.4.1 Responsibility towards people

- Protection from harm

According to Leedy and Ormrod (2005:101), the risk of physical or psychological harm should not be more than that of normal day-to-day living and the participants should not be exposed to unusual stress, embarrassment or loss of self-esteem. Participation in this study did not exceed the normal risk of day-to-day living, in that the fitting and evaluation procedures were exactly the same as what the participants were exposed to in their school environment. These participants periodically go through the same hearing instrument fitting, verification and hearing testing procedures at the school they are attending. Therefore, none of the assessment procedures are unfamiliar to, or inappropriate for the participants.

Fitting procedures proposed by the American Academy of Audiology were followed (Bentler, et al., 2004). This ensured that the participants received optimal amplification according to the international recommended standard.

- Voluntary participation and withdrawal

'Participation in a study should always be voluntary' (Strydom, 2005a: 59). In this study, participation was voluntary and the participants' parents/legal guardians were informed that they had the right to withdraw from the study at any given time. Verbal assent was obtained from each participant before testing (Appendix E).

- Informed consent

The principle of informed consent according to Oliver (2003:28) states that participants should be fully informed about a research project before they decide to take part. Therefore, a clear account must be provided of what might be in store for anyone participating in the research (Herrera, 2010). Because the participants in this study were all children (minors), the parents/legal guardians of each child will act in his/her the best interest. Written informed consent was obtained by providing the parents/legal guardians with a letter that explained the following (Appendix B):

- the purpose of the study
- the procedures to be followed during data collection by the researcher, the child as well as the parent/legal guardian
- the possible advantages and disadvantages of participation
- strict confidentiality
- storing of information

- Right to privacy / confidentiality

The participants' right to privacy was protected and all information was handled with confidentiality (Strydom, 2005a:61). Permission was obtained from the centre for hearing impaired children to use information in the participant's school files for selection procedures (Appendix A)

- Deception of participants

'No form of deception should ever be inflicted.' (Strydom, 2005a:61). The real goal and function of the study were not hidden from participants, neither the experiences the participants went through. The participants were informed of what was expected of them during each evaluation procedure.

- Debriefing of participants

Debriefing the participants is one way to minimise possible harm done during the study by interviewing the parents/legal guardians. Possible misperceptions that have arisen were addressed (Strydom, 2005a:66); an overview of their child's performance with the hearing instruments was also provided. This enabled an informed decision on which hearing instruments were best for the child.

- Competence of the researcher

A researcher is ethically obliged to ensure that he/she is adequately skilled to undertake the intended investigation (Strydom, 2005a:63; Drummond, 2003:20). The researcher of this study is qualified to conduct research due to her qualification and experience in the field of Audiology. The researcher is registered with the Health Professions Council of South Africa (STA 0023345).

3.4.2 Responsibility toward science

- Honesty with professional colleagues

It is the responsibility of the researcher to report findings in a complete and honest manner (Leedy & Ormrod, 2005:102). The researcher will not intentionally mislead others about the nature of the findings.

- Release of publication of the findings

The findings of this research will be introduced to the public in written form. The information obtained during the research will be conveyed as clearly and accurately as possible (Strydom, 2005a:65).

3.5 Participants

3.5.1 Sampling method

The sampling method used in this study can be described as non-probability sampling, because the researcher had no way of guaranteeing that each element of the population was represented in the sample (Leedy & Ormrod, 2005:206).

Purposive sampling was used because the sample consisted of elements that contain the typical characteristics of the targeted population (Strydom, 2005:202). Availability of participants was dependent on clinical incidence and prevalence, and the number of participants depended on the design of the study (Drummond, 1996:41). According to Neuman (2003:213), purposive sampling methods are appropriate when participants are members of a special, difficult-to-reach population. Children with binaural mild to severe sensorineural hearing loss, who have never been exposed to high frequency amplification, can be seen as such a difficult-to-reach population because of limited availability of such participants.

3.5.2 Criteria for participant selection

The criteria for the selection participants are stipulated in Table 9.

Table 9: Selection criteria for participants

Criteria	Justification
Degree of hearing loss: Participants had to have a bilateral mild to severe sensorineural hearing loss as classified by Northern and Downs (Schlauch & Nelson, 2009:39), which did not progress more than 10dB at two consecutive frequencies or 15dB at one frequency during the last year.	This degree of hearing loss was found to be a good indicator for a child to benefit from increased high frequency amplification (Stelmachovicz et al. 2007:485). This degree of hearing loss fits into the fitting range of the specific model hearing instrument that was used.
Middle ear functioning: Participants had to present with normal middle ear functioning.	Children with conductive hearing losses experience different amplification needs and because of middle ear pathology these children need different amplification from children with sensorineural hearing loss (Stelmachovicz & Hoover, 2009:840). Middle ear pathology will also result in fluctuating hearing loss, which will result in under-amplification for periods of time during the study, which will negatively influence results (Schlauch & Nelson, 2009:45)
Age: Participants had to be between the ages of 3 years 0 months and 10 years 11 months at commencement of the study.	The children in this age group were developmentally mature enough to understand (Louw, Van Ede & Louw 1998:258) what was expected of them during tasks and to cooperate well during the extended

	assessments (Louw, et al., 1998:318). Children with hearing loss who are older are not accommodated at the Centre for hearing impaired children and are placed in schools with different language approaches which are not aural-oral.
Language: Participants had to be mother tongue speakers of either English or Afrikaans.	English and Afrikaans are the two languages in which the researcher is proficient. These two languages were used in order to communicate with participants without any language barriers.
Current hearing instruments: • Participants should be fitted with binaural conventional hearing instruments set according to the amplification targets prescribed by the DSL m[i/o]. • Participants had to use their hearing instruments on a regular, daily basis. • Participants should have no experience of feedback during normal use.	• The child's current hearing instruments had to be optimized to reflect the current best practice. The DSL m[i/o] was designed for modern hearing instruments with multiple channels and several stages of compression (Scollie, 2006:10). • Being enrolled in an aural-oral programme means that the children had to wear their hearing instruments most of the time to be able to develop active listening and spoken language (Brown, 2009:949). • Optimum amplification is compromised when a hearing instrument has feedback (Bentler & Mueller, 2009:790).
Educational environment: Participants had to attend the selected centre for children with hearing loss for at least three months prior to commencement of the study.	Participants should have been subjected to the same educational environment that focuses on spoken language and active listening (Brown, 2009: 949) and where uniform opportunities for growth in these areas are created.

According to Table 9 it can be seen that the configuration and degree of hearing loss, middle ear functioning, age, language, current hearing instruments and educational environment was taken into account when participants were selected.

3.5.3 Material and apparatus for participant selection

Table 10 gives an outline of the material and apparatus that were used to select the participants.

Table 10: Material and apparatus for participant selection

Materials and apparatus	Rationale
School audiograms	Were used to determine if the participants' hearing loss complied with the selection criteria
School files	Were used to determine age and language of participant. Information on current hearing instruments and duration of hearing instrument use were obtained. Duration of school attendance were also documented.
Heine Mini 2000 Otoscope	Condition of the external meatus and the tympanic membrane, as well middle ear functioning were determined.
GSI 38 Autotymp (calibrated 08/05/2009)	Middle ear functioning was determined.
Audioscan Verifit with DSL m[i/o] software	It was verified that hearing instruments were providing optimal amplification according to the DSL m[i/o] fitting rationale, and it was checked if distortion on hearing instruments were within acceptable limits.
Sterilization equipment (*Milton*, sterilizing solution, alcohol swabs, alcohol hand sanitizer)	To ensure audiologist conformed to hygiene standards when working with children.

Additional to the participant selection criteria, each participant's middle ear functioning was determined. Information from the school files were used to determine if the participants fit the selection criteria.

3.5.4 Procedures for participant selection

- Audiograms were obtained to make sure that hearing losses complied with the selection criteria.
- A statistician was consulted before the selection of participants in order to determine an adequate sample size.
- Permission to perform the planned study at the centre for hearing impaired children was requested from the principal (Appendix A).
- Consent was obtained from the involved State Hospital.
- Letters requesting informed consent to participate in the study were given to the identified children's parents/legal guardians (Appendix B).
- After informed consent was granted, the children's school files were obtained and their personal and audiological information were used to verify whether the child qualified for participation.

- Information regarding their current hearing instruments was obtained to determine if the hearing aids had a limited frequency bandwidth.
- Letters requesting participation were also given to the class teachers of all the participants (Appendix C).

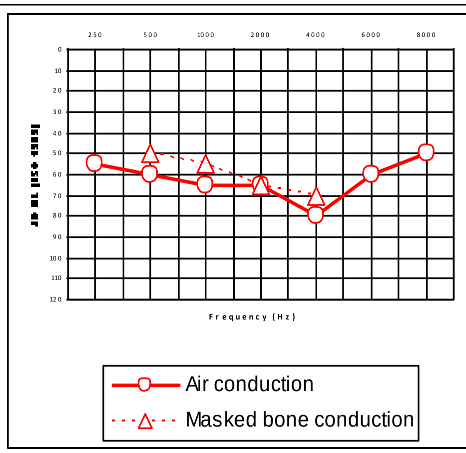
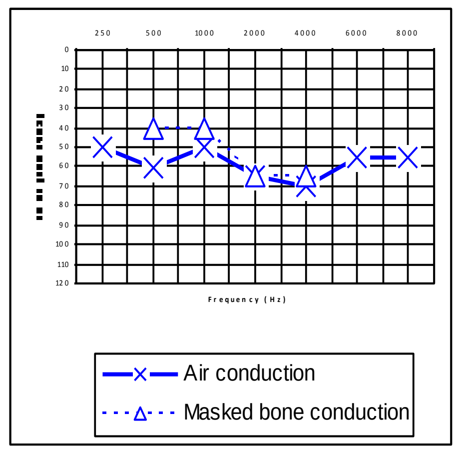
3.5.5 Description of participants

Audiograms were obtained to make sure that the hearing loss complied with the set selection criteria.

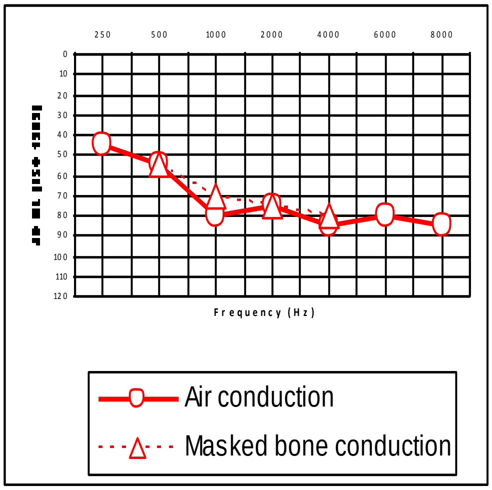
- **Audiograms of participants**

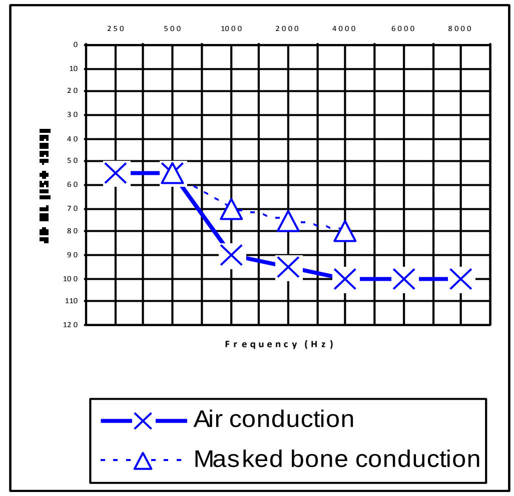
The participants' unaided audiograms are displayed in Table 11.

Table 11: Unaided audiograms of participants

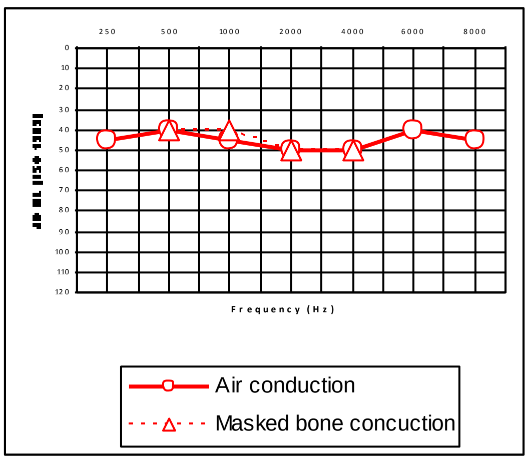
Participant	Audiogram: Right ear	Audiogram: Left ear
1		

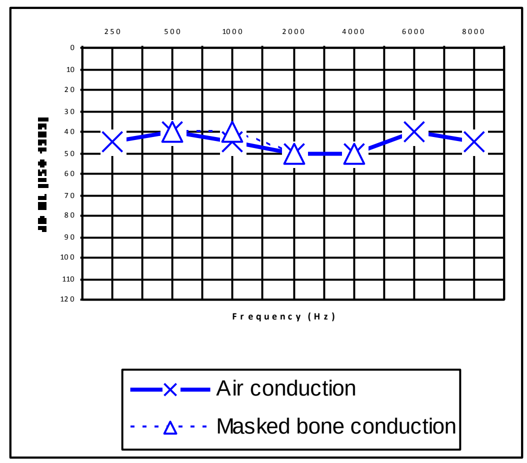
2


250 500 1000 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80 90 100 110 120
Frequency (Hz)
Air conduction
Masked bone conduction

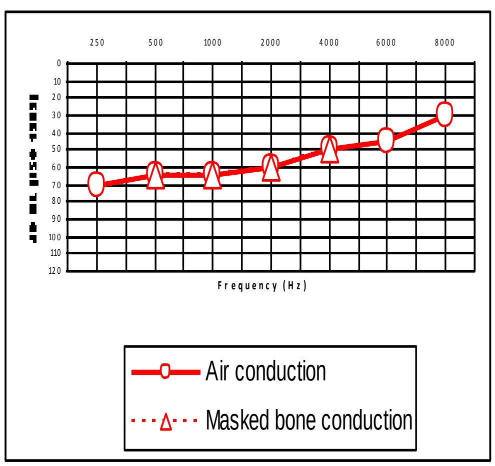

250 500 1000 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80 90 100 110 120
Frequency (Hz)
Air conduction
Masked bone conduction

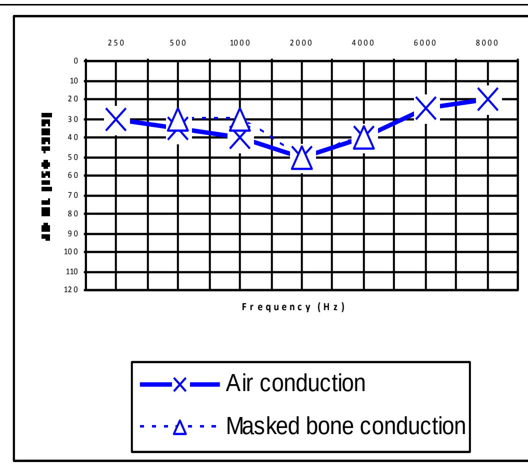
3

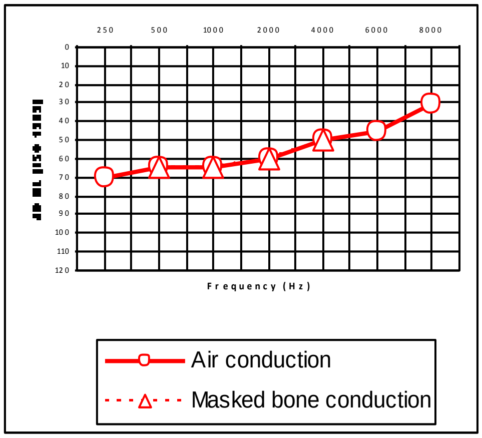
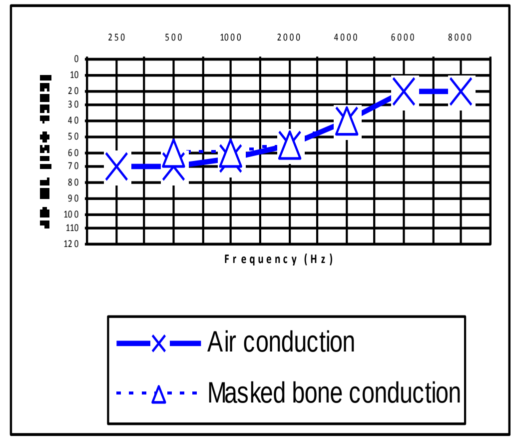
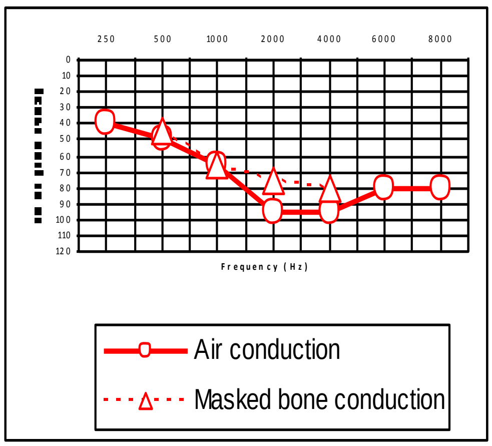
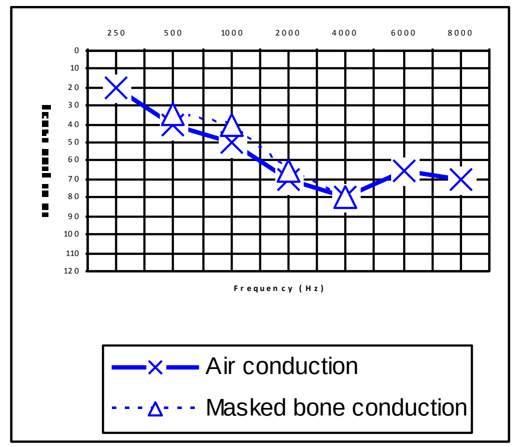

250 500 1000 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80 90 100 110 120
Frequency (Hz)
Air conduction
Masked bone concuction


250 500 1000 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80 90 100 110 120
Frequency (Hz)
Air conduction
Masked bone conduction

4


250 500 1000 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80 90 100 110 120
Frequency (Hz)
Air conduction
Masked bone conduction


250 500 1000 2000 4000 6000 8000
0 10 20 30 40 50 60 70 80 90 100 110 120
Frequency (Hz)
Air conduction
Masked bone conduction

5		
6		

As shown in Table 11, all participants displayed mild-to-moderate to moderate-severe sensorineural hearing loss. Participant 1 displayed a binaural moderate to severe sensorineural hearing loss. Participants 2 and 6 displayed moderate to severe sloping sensorineural hearing loss binaurally. Participant 3 had a binaural mild-to-moderate sensorineural hearing loss. Participants 4 and 5 displayed moderate to severe reversed sloped sensorineural hearing loss, while participant 4 displayed better low frequency hearing of a mild degree.

- **Biographical information of participants**

Table 12 summarizes the relevant biographical information of each participant.

Table 12: Summary of participants' biographical information

P#[1]	**Chronological age during period of study**	**Gender**	**Age of diagnosis**	**Home language**	**Age of hearing instrument fitting**	**Duration of hearing instrument use**	**Time in educational program**	**Frequency range of own hearing instrument**	**Technology of own hearing instrument**
1	6 yrs[2] 2 mnths - 6 yrs 5 mnths[3]	M[4]	3 yrs 0 mnths	Eng.	4 yrs 4 mnths	1 yr 10 mnths	1 yr 5 mnths	100Hz-5600Hz	Digital
2	9 yrs 0 mnths - 9 yrs 3 mnths	F[5]	8 yrs 1 mnth	Eng.	8 yrs 6 mnths	0 yrs 5 mnths	0 yrs 4 mnths	100Hz-5000Hz	Digital
3	3 yrs 6 mnths - 3 yrs 9 mnths	F	2 yrs 8 mnths	Afr.	2 yrs 10 mnths	0 yrs 7 mnths	0 yrs 6 mnths	100Hz-6600Hz	Digital
4	4 yrs 0 mnths - 4 yrs 3 mnths	F	2 yrs 0 mnths	Afr.	2 yrs 2 mnths	1 yr 10 mnths	1 yrs 9 mnths	120Hz-6800Hz	Digital
5	10 yrs 1 mnth - 10 yrs 4 mnths	F***	2 yrs 0 mnths	Afr.	6 yrs 5 mnths	1 yr 10 mnths	7 yrs 5 mnths	100Hz-6800Hz	Digital
6	6 yrs 2 mnths - 6 yrs 5 mnths	M	5 yrs 9 mnths	Eng.	6 yrs 2 mnths	0 yrs 7 mnths	1 yr 1 mnth	100Hz-5600Hz	Digital

[1] Participant number
[2] year/s
[3] month/s
[4] Male
[5] Female

As displayed in Table 12 it can be seen that none of the participants were early identified. Three of the participants wore hearing instruments for one year and ten months, where the other three participants have not been exposed to hearing instruments for more than seven months at the time the study commenced.

3.6 Data collection

The materials, apparatus and procedures that were followed for the collection of data are discussed in the following section.

3.6.1 Materials for data collection

- Word Intelligibility by Picture Identification Test (WIPI) (Ross & Lerman, 1970)

The participants' aided speech recognition abilities were assessed by using the Word Intelligibility by Picture Identification Test (WIPI) (Ross & Lerman, 1970:44). This is a standardized test and can be used to determine the difference in speech recognition abilities between a participant's two ears as well as the difference between hearing instruments or acoustical changes in the same hearing instruments (Ross & Lerman, 1970:52). As stated by these authors, the WIPI has a sufficient number of discrimination tasks to permit the measurement of a baseline speech recognition score, and they also mention that the WIPI has high test-retest reliability.

Speech recognition testing was used because it plays an important role in estimating the adequacy of rehabilitation efforts, which included the selection and fitting of hearing instruments (McArdle & Hnath-Chisolm, 2009:75). The WIPI uses monosyllabic words presented in a closed-set format, and comprises of words expected to be within the receptive vocabulary of the participants, which is important to consider during speech recognition testing (McArdle & Hnath-Chisolm, 2009:75).

- Teachers' Evaluation of Aural/Oral Performance of Children (TEACH) (Ching & Hill, 2001)

This questionnaire provided important information for determining if the provided amplification was optimally effective for a child. This functional assessment approach is also useful in indicating which frequency response are the most effective for the individual child (Ching & Hill, 2001:2). The TEACH also provides information about the real-life functional performance of the participants in the classroom context (Ching, Hill & Dillon, 2007:427).

- Parents' Evaluation of Aural/Oral Performance of Children (PEACH) (Ching & Hill, 2001)

This questionnaire provides important information for determining the effectiveness of provided amplification as well for determining the effectiveness of different frequency responses (Ching & Hill, 2001:2). The PEACH also provides information about the real-life functional performance of the participants in the home environment (Ching, et al., 2007:427).

3.6.2 Apparatus for data collection

The apparatus used for data collection is listed in Table 13.

Table 13: Apparatus for data collection

APPARATUS	RATIONALE
Heine Mini 2000 Otoscope	For performing otoscopy to examine the external auditory ear canal and tympanic membrane for any abnormalities.
GSI 38 Autotymp (calibrated 08/05/2009)	Tympanometry will be performed to detect any abnormalities in the middle ear system as this may influence the accuracy of the planned assessments.
Interacoustics Clinical Audiometer AC40 with Eartone 3A insert-earphones and a Radio Ear B-17 bone conducter (calibrated 08/05/2009)	Pure tone (air and bone conduction) and speech audiometry will be performed to determine hearing thresholds. Unaided and aided thresholds will be determined.
Peg 'n Play and PegBoard Combo (Smile Puzzles)	To provide an engaging activity for play audiometry.
Siemens Explorer 500P hearing Instruments connected to a standard #13 tubing attached to a full concha acrylic mould.	This hearing instrument has been selected to be used in this study as the amplification device. The bandwidth of the instrument is <100 Hz – 7000 Hz (IEC 118 – 0/A1).
Mecer Celeron personal computer and a GN Otometrics NOAHlink system.	To programme the hearing instruments with the cables provided by hearing instrument company. Initial amplification values will be calculated using the software also provided by the hearing instrument companu.
Audioscan Verifit with DSL m[i/o] sofware	To verify the output from the hearing instruments according the amplification targets prescribed by the DSL m[i/o] with the individual RECD values added. Distortion levels of the hearing instruments will also be checked to make sure they are within acceptable limits.
Stethoclip	To perform listening checks on the hearing instruments.
Sterilization equipment (Milton, alcohol swabs, alcohol hand sanitizer)	To ensure audiologist conforms to the appropriate standards of hygiene when working with children.

It was ensured that all data collection apparatus were available, in good working condition, and were last calibrated on the 6 April 2009 where appropriate. Next calibration was due 7 May 2010.

3.6.3 Data collection procedures

Assessments with each participant were done over a period of three days. According to Roeser, Valente and Hosford-Dunn (2000:314) a child may quite often not cooperate or be able to concentrate for a complete audiometric assessment. This three-day assessment period ensured that the participants did not get tired, and therefore led to better cooperation and more reliable results. The participants were taken out of their class only when they were needed for the assessment. This kept the interruption of classroom activities to a minimum. Each participant was assessed three times: once with their current hearing instruments, then with the new hearing instruments without the extra high frequencies, and the third and last time with the new hearing instruments with the extra high frequency amplification. Each day's assessment was completed within 30 to 45 minutes. Specific procedures are the following:

3.6.3.1 Pure-tone audiometry

Pure-tone audiometry was performed using ear moulds with insert-earphones (Schlauch & Nelson 2009:34), as well as conditioned play audiometry in a sound treated room in order to establish unaided air conduction thresholds. Conditioned play audiometry is the most consistent behavioural technique to determine ear-specific hearing thresholds in young children from three years of age (Northern & Downs, 2002:184). Thresholds were established by using the modified Hughson-Westlake up-down procedure (Schlauch & Nelson, 2009.38). This procedure was slightly adjusted for conditioned play audiometry. The participants were asked to sit at a table with a motivational game on the table in front of him/her (Peg 'n Play or PegBoard Combo). The participant was seated between two free field speakers, at a distance of 1.5 metres away from the speakers. The participant was instructed to put one of the pegs in the board every time a sound is heard. This was practiced a few times via the free field speakers to make sure that the procedure was understood. Insert-earphones were placed in both ear canals, and testing began by presenting 2000Hz warble-tones 40 to 50dB (Northern & Downs 2002:186) above the estimated threshold. If the participant responded to the sound, the testing descended and stimulus intensity commenced in 10 dB steps until the child responded again. Thresholds were established as soon as the participant responded twice on the ascending presentation as recommended by the ASHA guidelines 2005 which state that a threshold should correspond to the level at which responses were obtained for two ascending runs (Schlauch & Nelson 2009:38). This procedure was repeated for the frequencies 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, 6000Hz and 8000Hz in both ears. This testing procedure was done for each ear separately and thresholds were recorded on an audiogram.

After the thresholds were established, both insert-earphones were taken out and a bone-conductor was placed on the mastoid process behind the ear. The same procedure was followed as for the unaided air conduction thresholds for the frequencies 500Hz, 1000Hz, 2000Hz and 4000Hz.

Aided thresholds of the participants were determined by also using the modified Hughson-Westlake up-down method (Schlauch & Nelson, 2009:38) with conditioned play audiometry and narrowband noise as a stimulus. This procedure only used an ascending method for establishing thresholds. The hearing instruments were placed in the child's ear and, in order to determine ear-specific information, only one hearing instrument was switched on at a time. The hearing instrument that was switched on first was the one that was fitted on the better ear. The narrow band noise stimulus was presented via the free field speaker on the side of the hearing instrument being tested. The stimulus started at 10 dB below the estimated threshold and increased in 5dB increments until the participant responded. The stimulus decreased again in 5dB steps until the child did not respond. A threshold was again established as soon as the child responded twice to the same level on the ascending presentation. Aided thresholds at 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz and 6000Hz were established. This procedure was followed for each ear independently and the obtained aided thresholds were recorded on an audiogram. A test assistant was used who sat inside the sound proof booth with the children and assisted them with the tasks (Ross & Lerman 1970:47).

3.6.3.2 Hearing instrument check and DSL m[i/o] verification

The participants' hearing instruments were checked to ensure that they in excellent working condition with no distortion or intermittence. The participant's current hearing instrument was removed from his/her ear and connected to the 2cc-coupler in the test chamber of the Audioscan Verifit. A distortion test was run to detect any harmonic distortion at the frequencies 250 Hz to 4000 Hz. Total harmonic distortion of less than 5% at all frequencies was accepted (Dillon 2001: 87).

A listening check with a stethoclip was performed. Real-ear measurements were done to objectively verify the hearing instrument's output to comply with the amplification targets set by the DSL m[i/o] (Scollie 2006). A real-ear-to-coupler-difference (RECD) transducer was connected to the 2-cc coupler of the Audioscan Verifit and the coupler response to a given signal was measured. The RECD transducer was taken off from the 2-cc coupler and connected to a foam tip, and both the foam tip and the probe tube were inserted into the child's ear canal with the probe tube at a depth of +/- 2-5mm from the tympanic membrane. A real-ear response was measured and the difference calculated as the RECD. The RECD was required for the verification of hearing instrument performance, and to make sure that there was a close match to the target when the hearing instrument was worn by the participant with his/her individual ear canal characteristics taken into account (Munro 2004:74). Adjustments to the gain output of the hearing instruments were made, if necessary, in order to match the amplification targets set by the DSL m[i/o]. This was done for each ear individually.

3.6.3.3 Speech audiometry

The Word Intelligibility by Picture Identification (WIPI) (Ross & Lerman 1970:44) was administered to the child with both hearing instruments switched on at the same time. This was done in the same sound treated booth already described. The participant faced the one speaker (0° azimuth), and the other speaker was facing the back of the participant (180°). The speakers were approximately 1.5 metres away from the participant's head. The pre-recorded test stimuli were presented through the 0° azimuth speaker. (Stelmachovicz, Lewis, Choi & Hoover, 2007:487). After a word was presented, it was expected of the participant to point to a picture out of the set of pictures in front of him/her. The word lists were rotated for the different assessments to prevention familiarisation with the lists (Ross & Lerman, 1970:47). The word lists were presented at 65dB SPL, which is consistent with average conversational speech (Pittman, 2008:790), with a signal-to-noise ratio of +15dB to simulate typical listening environments and the reduced audibility of the low-amplitude components of speech experienced by listeners with hearing loss (Stelmachowicz, Nishi, Choi, Lewis, Hoover, Dierking & Lotto, 2008:1373). The speech noise was presented through the speaker at 180°. Results of a study by Papso and Blood, (1989:236), indicated that the introduction of background noise to speech test materials reduced the recognition scores and increased test sensitivity. A test assistant was used who sat inside the soundproof booth and assisted the participants with the task (Ross & Lerman, 1970:47).

3.6.3.4 Fitting of hearing instruments with increased high frequencies

The new hearing instruments were connected to the computer and fitted using the manufacturer's software and cables. The output of the hearing instruments were verified using probe-tone measurements (already described) and fine-tuned to match the DSL m[i/o] targets. A period of 12 days was allowed for the participants to acclimatize to their new hearing instruments; one week was actually found to be sufficient time (Marriage, Moore, Stone & Baer, 2005:36)

3.6.3.5 TEACH and PEACH questionnaires

The TEACH questionnaires were completed by each participant's teacher, after training by the researcher on how the questionnaire should be completed. The PEACH questionnaires were completed by the participants' parents/legal guardians together with their parent guidance teacher, again after training by the researcher on how the questionnaires should be completed. These questionnaires were designed to record observations of children's functional performance with their current hearing instruments (Ching & Hill, 2001:1). Responses to both questionnaires were studied and scores were allocated according to the provided TEACH and PEACH scoring keys 1 and 2. Raw scores were first determined and subsequently a percentage value was calculated for the total score. This is not a test and therefore the percentage values indicate if frequency of behaviour observed has occurred more (percentage increase), the same, or less (percentage decrease).

The schedule for the assessments is shown in Table 14.

Table 14: Schedule for assessments

WEEK		MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
1	Phase 1	-Otoscopy + immittance -Unaided air + bone conduction audiogram -Unaided speech reception thresholds	-Otoscopy + immittance -Unaided air + bone conduction audiogram -Unaided speech reception thresholds	-Otoscopy + immittance -Unaided air + bone conduction audiogram -Unaided speech reception thresholds		
2	Phase 1	-Otoscopy + immittance -Fitting + verifying hearing instruments RECD measurements	-Otoscopy + immittance -Fitting + verifying hearing instruments -RECD measurements			
3	Phase 1	**Acclimatisation Period**				
4	Phase 1	-Otoscopy + immittance -Unaided audiogram air conduction -Aided audiogram + speech reception thresholds -WIPI	-Otoscopy + immittance -Unaided audiogram air conduction -Aided audiogram + speech reception thresholds -WIPI	-Otoscopy + immittance -Unaided audiogram air conduction -Aided audiogram + speech reception thresholds -WIPI	TEACH	PEACH
5	Phase 2	-Otoscopy + immittance -Fitting + verifying Siemens Explorer 500P without extra high frequencies	-Otoscopy + immittance -Fitting + verifying Siemens Explorer 500P without extra high frequencies			
6	Phase 2	**Acclimatisation Period**				
7	Phase 2	-Otoscopy + immittance -Unaided air conduction -Aided audiogram + speech reception thresholds -WIPI	-Otoscopy + immittance -Unaided air conduction -Aided audiogram + speech reception thresholds -WIPI	-Otoscopy + immittance -Unaided air conduction -Aided audiogram + speech reception thresholds -WIPI	TEACH	PEACH
8	Phase 3	-Otoscopy + immittance -Fitting + verifying Siemens Explorer 500P with extra high frequencies	-Otoscopy + immittance -Fitting + verifying Siemens Explorer 500P with extra high frequencies			
9	Phase 3	Acclimatization Period				
10	Phase 3	-Otoscopy + immittance -Aided audiogram + speech reception thresholds -WIPI	-Otoscopy + immittance -Aided audiogram + speech reception thresholds -WIPI	-Otoscopy + immittance -Aided audiogram + speech reception thresholds -WIPI	TEACH	PEACH

Table 14 indicates the three phases in which data was collected and also clearly indicates, on a weekly basis, what data was to be collected. In this table it is also clear that the three data collection phases were identical in terms of procedures and time allocated.

Three mornings were allocated during each phase for assessing the participants. The goal was to assess each participant in full at one time. If poor cooperation were obtained, testing resumed the following day. Two mornings were allocated for verification and fitting of hearing instruments during each phase. One morning provided too little time.

3.7 Data analysis

Materials which were used and procedures followed for data analysis are stipulated in the following sections.

3.7.1 Materials for data analysis

The data was captured in Microsoft Excel and the statistical analysis was done by an actuary associated with the Department of Statistics at the University of Stellenbosch.

3.7.2 Data analysis procedures

Quantitative data analysis was used for this study. Data analysis of a single-system design relies mainly on visual analysis of changes in the participant's behaviour (Horner & Spaulding, 2010). Literature advises that the researcher should examine each phase of a single-case design by assessing the level, trend and variability of the data within each phase (Horner & Spaulding, 2010). Visual representations were constructed by means of simple graphics or plotting, and not in the form of complex statistics (Strydom, 2005:147). Continuous measurements (WIPI, TEACH and PEACH) were collected for each participant. Graphic representations of the data included bar charts. Graphic presentation is visually effective and easy to interpret (Strydom, 2005:227).

Researchers are interested in the relationship between variables (bivariate analysis). In other words, they are interested in whether a relationship between two variables really exist and if such a relationship does exist, in whether it is a positive or a negative relationship, and finally, in how strong that positive or negative relationship is (Strydom, 2005: 238).

Inferential statistics allow the researcher to make inferences about large populations from relatively small samples, and to test statistically based hypotheses (Leedy & Ormrod, 2005:267). Tests for statistical significance have been developed to determine whether the results obtained through data analysis are meaningful and not merely the result of chance (Irwin, et al., 2008:145). The final step in all statistical analyses is testing for statistical significance (Strydom, 2005:242). For the purpose of this study a 0.05 level of significance was used, which indicated that there was a 95% chance that the results were due to the influence of the independent variable (Strydom, 2005:242). This enabled the researcher to make probability statements concerning the populations from which the samples were drawn (Strydom, 2005:243). The t-test for testing hypotheses was used. This test determines whether a statistically significant difference exists between two means (Leedy & Ormrod, 2005:274).

3.8 Reliability and validity

According to Leedy and Ormrod (2005:27), the reliability and validity of a study are influenced by the extent to which one can learn something about the phenomenon being studied, the probability of obtaining statistical significance in the data analysis, and the extent to which one can draw meaningful conclusions from the data.

Reliability refers to the consistency with which measuring instruments yield a certain result when the entity being measured has not changed (Leedy & Ormrod, 2005:29). The measuring instrument that was used in this study has already been tested as reliable in terms of test-retest reliability (Ross & Lerman, 1970:50; Ching & Hill, 2001:2). The measuring instrument (WIPI) has been standardized and can be used to determine the difference in discrimination ability between a participant's two ears as well as the difference between acoustical changes in the same hearing instruments (Ross & Lerman, 1970:44). The manner in which the testing instrument was used could also influence the reliability (Leedy & Ormrod, 2005:29). The researcher in this study was responsible for filling in the WIPI and thereby ensured that it was done in a reliable manner (Ross & Lerman 1970:47). Proper training of the classroom teachers took place before commencement of the study to ensure valid and accurate responses when filling in the TEACH questionnaires (Ching et al., 2008:465). The PEACH questionnaire was filled in together with the parents/legal guardians as well as their parent guidance teacher where applicable (Ching et al., 2008:464).

According to Irwin, et al. (2008:105), validity implies that a measurement is relatively free from error. For a study to have internal validity, it should rule out all variables that might affect the dependent variable so that it can be concluded that the independent variable (in this case extra high frequency amplification) was ultimately responsible for any change in the dependent variable (participants' speech understanding abilities). According to Leedy & Ormrod (2005:220) there are a few steps that can be taken to increase internal validity. For the purpose of this study, the following was done in this regard:

- The participants continued with their normal day-to-day activities, where the only change was the different frequency amplification strategies they received

- The time period between testing the different amplification strategies was exactly the same

- Pre-testing the participants was done to obtain a baseline before intervention took place

- All participants were exposed to the same experimental conditions

- A three-day assessment was done to ensure that the participants did not get tired; this ensured better cooperation and more reliable results.

External validity, according to Leedy and Ormrod (2005:99), refers to the extent to which the conclusions drawn can be generalized to other contexts. This study had too few participants to generalize conclusions, but the following two ways were implemented to increase external validity:

- To do research in a real life setting (Leedy & Ormrod, 2005:99). The participants in this study were assessed during their normal daily activities.

- The participants should be representative of the intended population about which conclusions will be drawn (Leedy & Ormrod, 2005:99). The researcher believes that the participants in this study constituted a representative sample of children with mild-severe sensorineural hearing loss who learn speech and language in a structured oral-aural orientated school.

3.9 Conclusion

Chapter 3 summarizes the method used to conduct this research project. The main aim of the research is provided as well as the sub-aims which were set to realize the main aim. A single-system design was used because it enabled the researcher to draw conclusions about the effect of extended high frequency amplification on the speech recognition abilities and functional performance of children with moderate to severe sensorineural hearing loss in a South African context. As Irwin, et al. (2008:3) states: "….effectiveness in research is defined as the benefits and use of the procedure under 'real-world' conditions". Single-system designs are one way of enhancing a linkage between practice and research (Strydom, 2005:144). This design is similar in form to the design of therapy and is the best, if not the only, appropriate strategy to advance clinical knowledge and to apply evidence-based practice (Irwin, Pannbaker & Lass, 2008:121). Ethical considerations were addressed in terms of the researcher's responsibility towards humans and towards science. Procedures for participant selection, the materials used as well as data capturing and data analysis were explained in detail in this chapter.

CHAPTER 4

Results and discussion

4.1 Introduction

Research emphasizes the need for high frequency amplification to make all speech sounds audible for children with hearing loss in a variety of contexts including the higher frequency speech information of child and female voices (Stelmachovicz et al., 2004:558). Research together with technological advances in the development of hearing instruments and the provision of additional high frequency bandwidth amplification (Smith, Dann, & Brown 2009:64) emphasize the importance of assessing the effect of these exciting developments on the speech recognition abilities of children with hearing loss. Validation of such developments form the basis for evidence-based practice which is an obtainable goal for all forms of patient centred rehabilitation.

Chapter 3 described and motivated the research design that was followed in this project as well as the procedures for the collection, analysis and interpretation of data in order to increase our understanding of the main aim of the project. The main aim of the study was to determine the effect of extended range amplification on the speech recognition abilities and functional performance of children with mild to severe sensorineural hearing loss. In order to realize this aim various sub-aims were formulated. It is hoped that the overall results of this investigation will bring audiologists closer to the ideal of evidence-based practice stated above. Figure 6 schematically describes how the sub-aims will provide adequate information in order to attain the main aim.

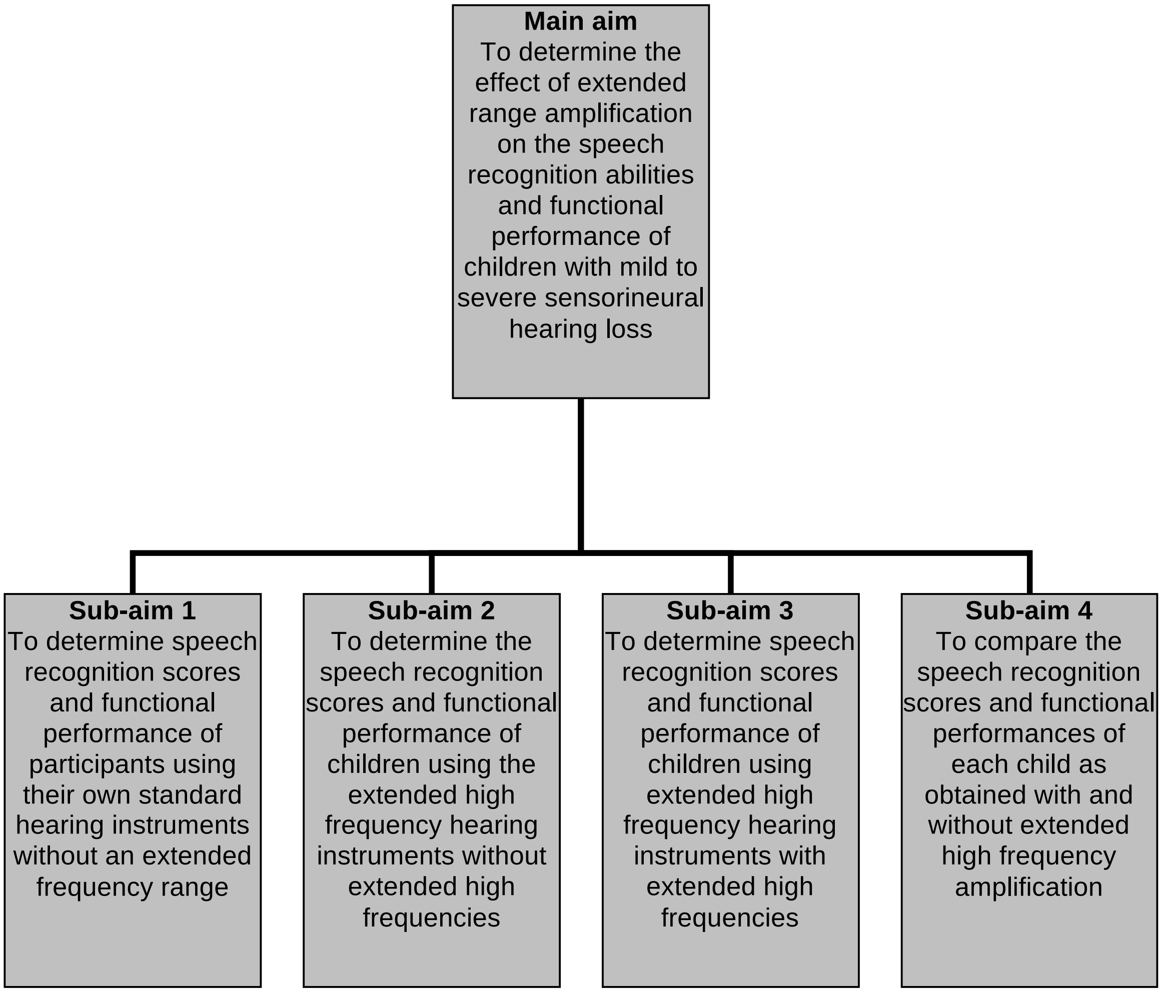


Figure 6: Presentation of sub-aims in relation to achieving the main aim

Results will be discussed in two parts. Results of sub-aims 1, 2 and 3 will firstly be provided, followed by the results of sub-aim 4. Discussion and interpretation of these results will be given in the second part. Each participant will be compared to him or herself as discussed in 3.3.

4.2 Results and discussion: Sub-aims 1, 2 and 3

The results are presented to correspond with the sub-aims.

4.2.1 Results of sub-aims 1, 2 and 3

Raw data of sub-aim 1, 2 and 3 are first provided in the form of figures. Interpretation and discussion of these results follow in **4.2.2**.

4.2.1.1 Sub-aim 1: Speech recognition scores and functional performance of participants using their own, standard hearing instruments which are without an extended frequency range

- **Speech recognition scores**

The speech recognition abilities of the participants using their own standard hearing instruments were evaluated first. These scores were obtained using the first word list on the Word Intelligibility Identification Test (WIPI) as explained in 3.6.3.5 (Ross & Lerman 1970:44). The speech recognition scores obtained by the participants while wearing their own hearing instruments are indicated in Figure 7.

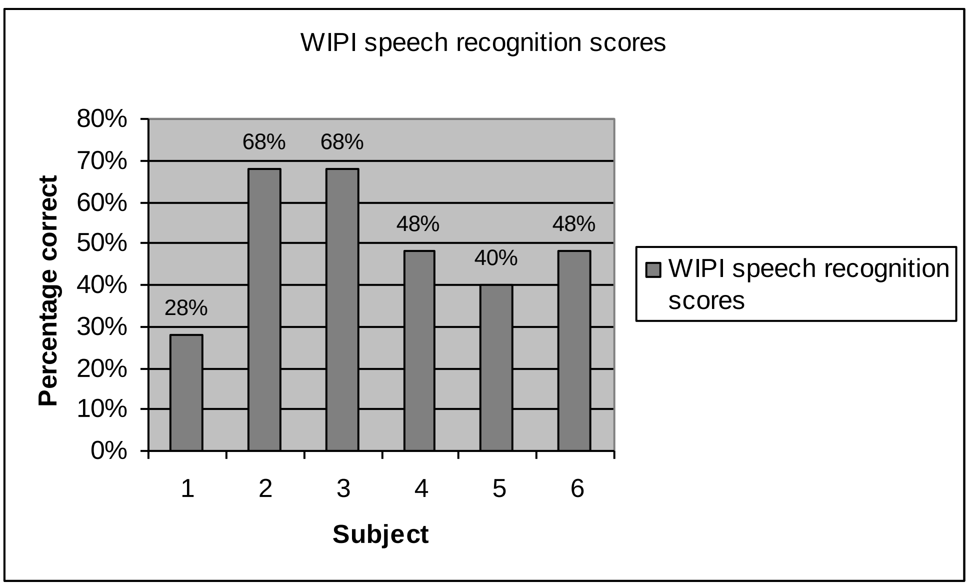


Figure 7: Speech recognition scores with participants wearing their own hearing instruments (n=6)

Results indicate that the individual scores vary among the participants. Participant 1 only obtained 28%. Participants 4, 5 and 6 obtained 48%, 40% and

48% respectively. Both participants 2 and 3 obtained 68%. Speech recognition testing was done in the presence of background noise, and therefore these scores are indicative of various degrees of ability to recognize speech in noisy situations.

- **Functional performance**

Functional performance scores were obtained as explained in **3.6.3.7**. Results of the TEACH and PEACH questionnaires were processed and raw scores were allocated. These raw scores were first determined using the provided scoring Key 1 and 2, after which a percentage value was calculated of the total score. This is not a test and therefore the percentage value only indicates if frequency of the observed behaviour was higher (percentage increase), the same, or less (percentage decrease) (Ching & Hill, 2001).

Participants' performance on the TEACH questionnaire with their own hearing instruments is presented in Figure 8.

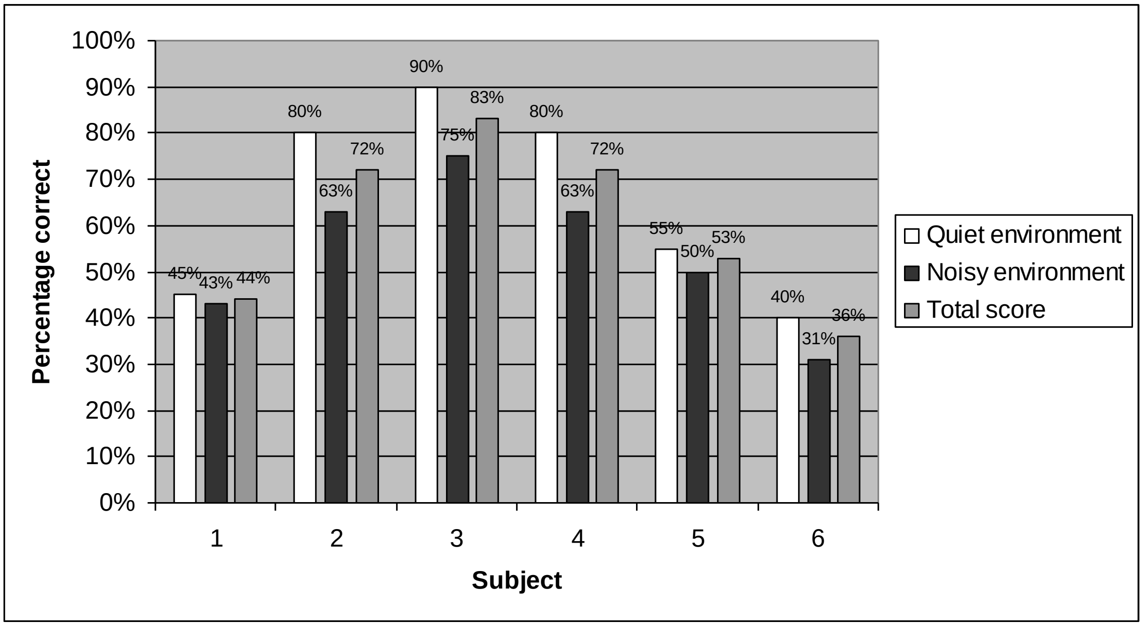


Figure 8: TEACH scores with participants' own hearing instruments (n=6)

Figure 8 indicates that the scores varied among the individual participants (n=6). The results obtained form the TEACH questionnaire provide information of the participants' functioning in their real classroom environment; it is clear that all participants performed poorer in the noisy environments than in the quiet environments.

Performance on the PEACH questionnaire

Figure 9 represents the scores obtained on the PEACH questionnaire while participants were wearing their own hearing instruments.

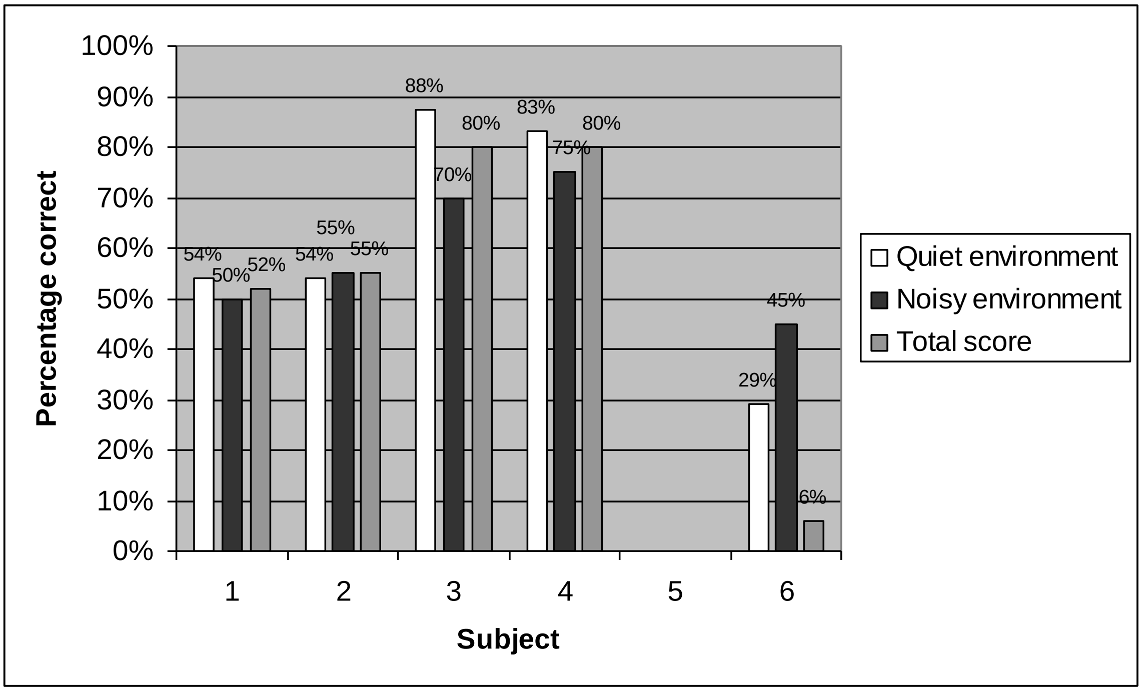


Figure 9: PEACH scores with own hearing instruments (*n*=5)

No results were obtained for Participant 5 because no feedback was provided by the parents/legal guardian. No conclusion can be made yet, but Participants 3 and 4 both received a total score of 80%, whereas Participants 1, 2 and 6 (*n*=5) performed worse. Figure 9 indicates that noisy environments was again more difficult than quiet environments, except for Participant 2 who performed marginally (1%) worse in the quiet environment, and Participant 6 who, according the parents/legal guardians, performed 16% better in a noisy environment than in a quiet environment.

4.2.1.2 Sub-aim 2: Speech recognition scores and functional performance of participants using the extended high frequency hearing instruments *without* the extended high frequencies

Raw scores are provided first, with a discussion to follow in **4.2.2**

- **Speech recognition scores**

The speech recognition abilities of the participants using the extended range frequency hearing instruments *without* the extended high frequencies were investigated; the second word list of the Word Intelligibility Identification Test (WIPI) as explained in **3.6.3.5** was used for this purpose (Ross & Lerman, 1970:44). The results are presented in Figure 10.

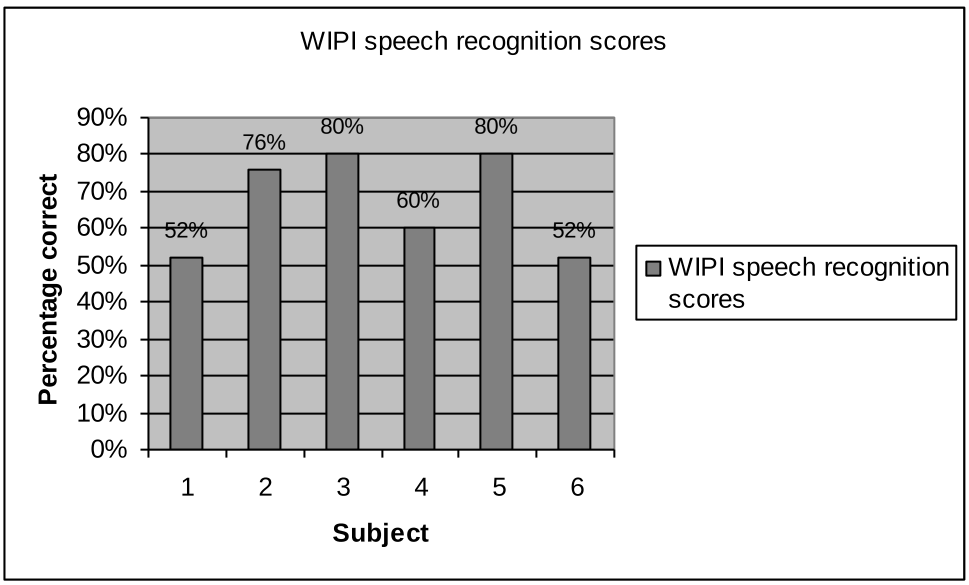


Figure 10: Speech recognition scores with the new hearing instruments *without* extended high frequencies (n=6)

According to the results reflected in Figure 10, the individual scores vary among the participants. Because the study compares each participant with him/herself, no conclusion can yet be made. Participants 1, 4 and 6 scored respectively 52%, 60% and 52%. Participants 2, 3 and 5 reached higher scores, i.e. 76%, 80% and 80% respectively; it can therefore be assumed that they have better speech recognition abilities.

- **Functional performance**

Functional performances were obtained as explained in **3.6.3.7**. The scores are followed by a discussion.

Participant's performance on the TEACH questionnaire with the extended high frequency hearing instruments without the extended range high frequencies are presented in Figure 11.

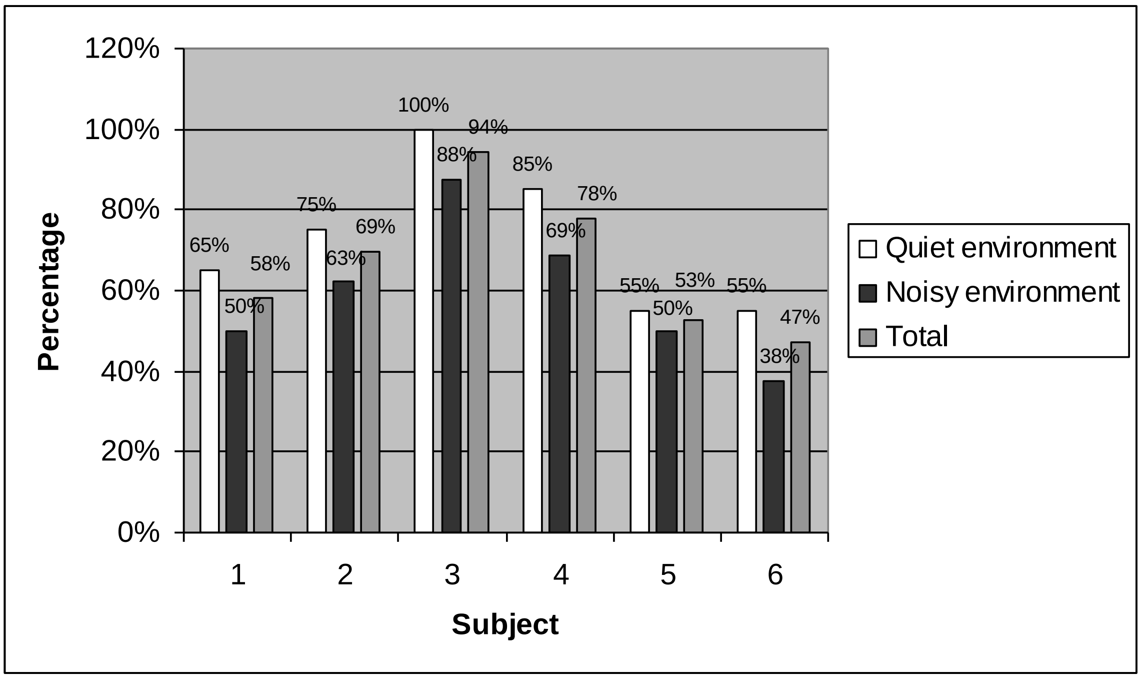


Figure 11: TEACH scores with new hearing instruments without extended high frequencies (*n*=6)

According to the results displayed in Figure 11, participants 5 and 6 performed the poorest in terms of the total score for this questionnaire. Participants 1 and 2 scored 58% and 69% respectively; participants 3 and 4 showed the best total scores for this questionnaire (94% and 78% respectively). No conclusions can be made yet, but once again all the participants performed poorer in the noisy situations than in the quiet situations.

Figure 12 presents the scores obtained for the PEACH questionnaire while participants were wearing the new hearing instruments without the extended high frequencies.

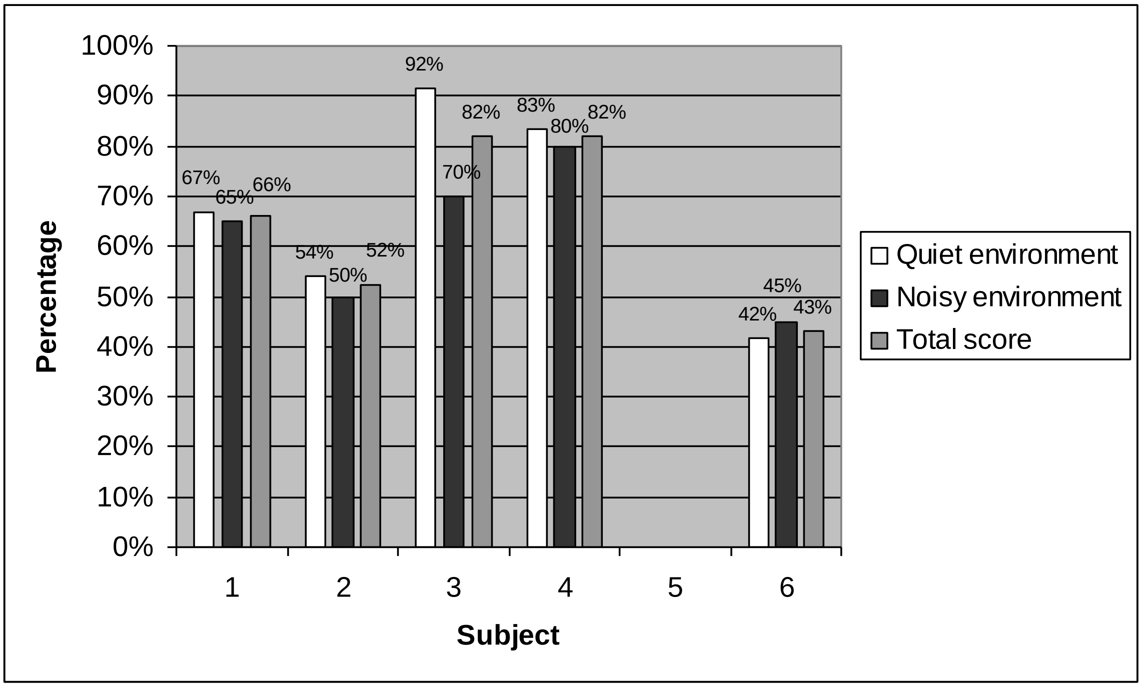


Figure 12: PEACH scores with new hearing instruments without extended high frequencies (*n*=5)

According to the parents' questionnaire, participants 1, 3 and 4 obtained the highest total scores (66%, 82% and 82%) with the new hearing instruments although no extended high frequencies were provided. Participant 2 and 6 obtained total scores of only 52% and 43% respectively.

All the participants, except for participant 6 performed worse in the noisy environment. The possible reason for the poor performance in noise is mentioned by authors Johnson et al. (2009: 354) who state that increasing amounts of reverberation and noise have been shown to have detrimental effects on speech recognition.

No results were obtained for participant 5, because no feedback was provided from the parents and therefore no PEACH questionnaire were filled in.

4.2.1.3 Sub-aim 3: Speech recognition scores and functional performance of participants using the extended high frequency hearing instruments *with* the extended high frequencies

Raw scores are provided first, after which a discussion of the results follows in **4.2.2**

- **Speech recognition scores**

The speech recognition abilities of the participants using the extended high frequency hearing instruments *with* the extended high frequencies were investigated; the third word list of the WIPI as explained in **3.6.3.5** was used for this purpose (Ross & Lerman, 1970:44). Raw data of the results are presented first, followed by a discussion.

Figure 13 therefore represents speech recognition scores obtained while the participants were wearing the new hearing instruments with extra high frequency amplification.

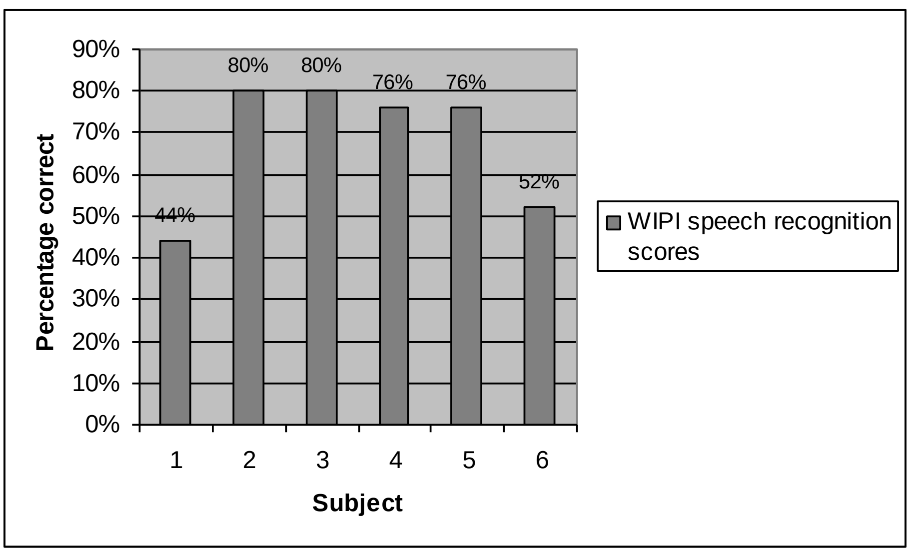


Figure 13: Speech recognition scores with new hearing instruments with extra high frequencies (n=6)

According to the results shown in Figure 13 participants 2 and 3 both scored 80% and both participants 4 and 5, scored 76%. Participants 1 and 6 scored 44% and 52% respectively.

Four of the six participants displayed fairly good speech recognition abilities. Although speech recognition abilities of participants 2, 3, 4 and 5 were better, it was still not within normal limits. A score of 88% - 100% indicates speech recognition abilities that are within normal limits (Papso & Blood, 1989:236).

- **Functional performance**

Functional performance scores were obtained as explained in **3.6.3.7**. Scores are followed by a discussion.

Results obtained by the participants' performance on the TEACH questionnaire with the new hearing instruments with the extra high frequencies are presented in figure 14.

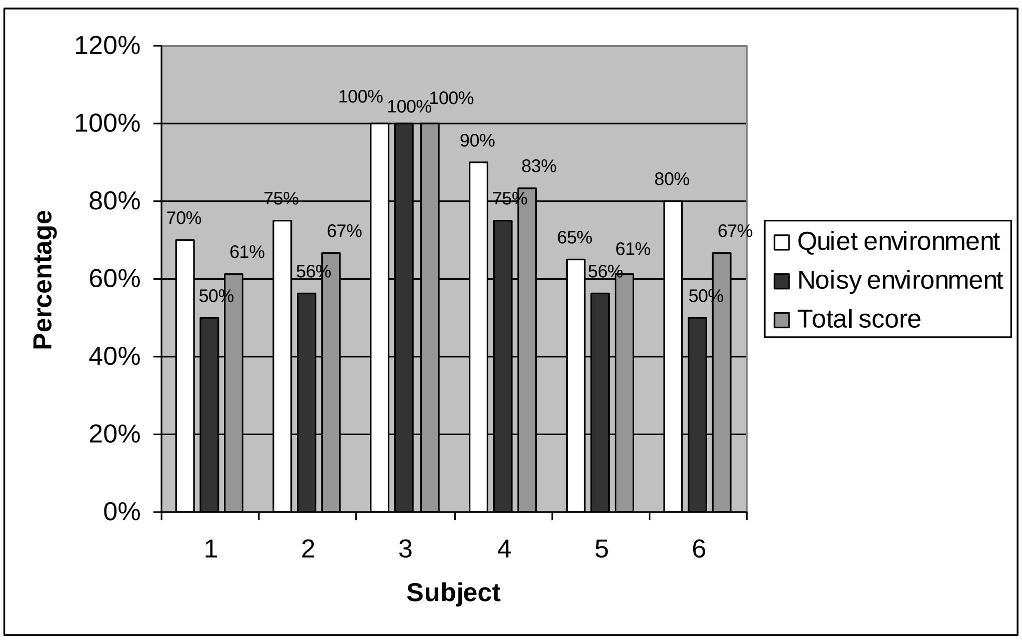


Figure 14: TEACH results with new hearing instruments with extra high frequency amplification (*n*=6)

Participants 3 and 4 achieved the highest scores with the new hearing instruments with the extra high frequency amplification. All participants obtained total scores of above 60%. No conclusion can be made before these results are compared to previous scores. Once again, the only salient result is the poorer performance in noisy environments for all participants. Even though the participants received extra high frequency amplification, they still performed poorer in noisy environments.

A discussion on the TEACH scores obtained for sub-aims 1, 2 and 3 will follow.

Figure 15 represents the participants' scores on the PEACH questionnaire with the new hearing instruments with the extra high frequency amplification.

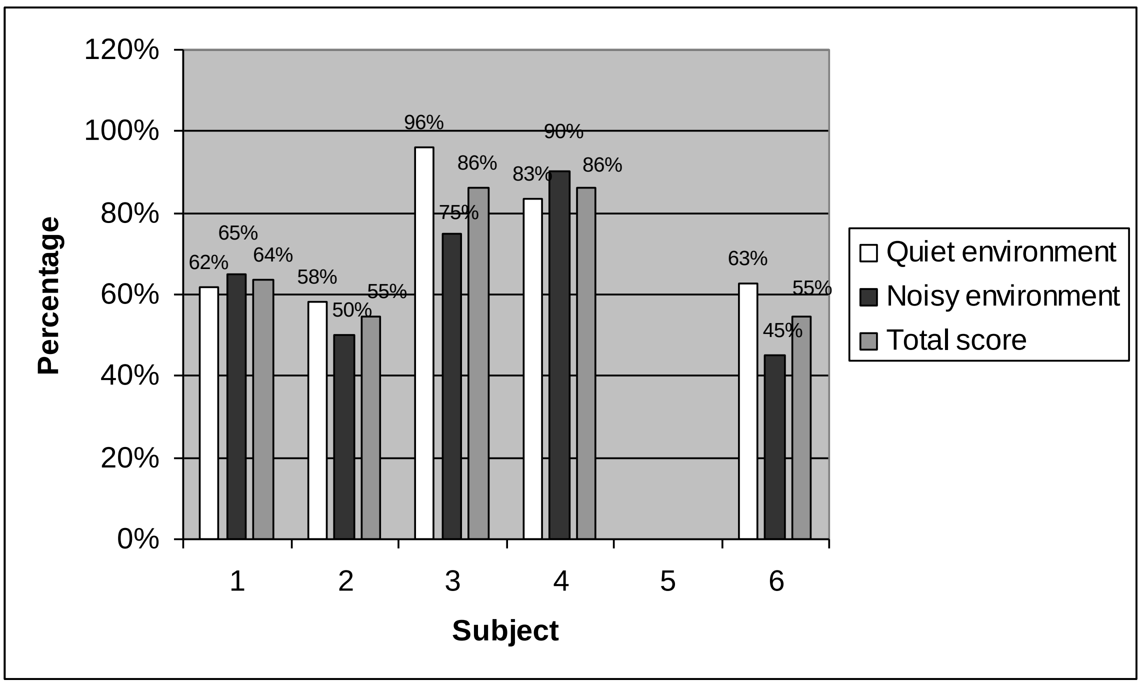


Figure 15: PEACH scores with new hearing instruments with extra high frequency amplification (*n*=5)

No conclusion can be made, but according to the total scores in Figure 15 it is clear that Participants 3 and 4 obtained the highest scores (86% for both participants) on the PEACH questionnaire, and that Participants 1, 2 and 6 scored respectively 64%, 55% and 55%, which are indicative that these participants still experience communication difficulties in the home environment.

No results were obtained for Participant 5 because of lack of cooperation from the parents/legal guardians.

4.2.2 Discussion of results of sub-aims 1, 2 and 3

A discussion of the presented raw scores regarding sub-aims 1, 2 and 3 follows.

4.2.2.1 Speech recognition scores

Speech recognition testing was done in the presence of background noise and therefore these scores are indicative of various degrees of ability to recognize speech in noisy environments. Raw scores obtained for sub-aims 1, 2 and 3 indicate that most participants still experience some degree of difficulty recognizing speech in noise, despite wearing the hearing instrument with extended high frequencies.

This is of some concern, because the background noise that was presented mimicked the classroom situations (Stelmachovicz et al., 2008:1373) in which these participants are functioning daily. For much of the day young children in primary schools are exposed to the noise of other children producing “classroom babble” at levels of typically around 65dB, while the typical overall exposure level of a child at primary school has been estimated at around 72dB (Shield & Dockrell, 2007:133). The optimal signal-to-noise ratio for optimal speech perception in a classroom is +15dB, but unfortunately a ratio of -1dB to +5dB is the reality (Pittman et al., 2009:1483). This background noise and classroom babble can have a detrimental influence on this participant’s speech and language acquisition because background noise has a greater negative effect on speech recognition by children with hearing loss than on children with normal hearing (Hicks & Tharpe, 2002:582). Background noise in a room compromises speech perception by masking the acoustic and linguistic cues available in the message (Smaldino, et al., 2009:746). A reduction on consonant information can have a significant impact on the speech perception because approximately 80% to 90% of the acoustic information important for speech perception comes from the consonants (Smaldino et al., 2009:746). Background noise levels increase when reverberation (reflected delayed versions of original sounds) is present (Dillon, 2000:58). Classroom babble, background noise and reverberation add to increased background noise in classrooms, and therefore interfere with the ability for children to perceive speech (Brown, 2009:934). Pittman, et al. (2009:1477) noted that, with amplification, few differences between children with hearing loss and their hearing peers are observed when listening in quiet. However, significant effects of hearing loss re-emerge like perceiving the soft weaker consonants of speech, when speech is presented in noise, like in a classroom with signal to noise ratios between +10dB and +20dB (Hicks & Tharpe, 2002:577). Therefore, children with hearing loss have more difficulty than children with normal hearing to recognize speech in the presence of background noise.

Although no comparison of results are made yet, results of sub-aims 1,2 and 3 indicate that noisy environments do have a detrimental effect on the participant's abilities to recognize speech which is widely supported in the literature as explained above.

These results also emphasize the importance of testing speech recognition in the presence of background noise with hearing instruments to get an idea of how well children with hearing loss function in a noisy classroom situation (Stelmachovicz et al., 2008:1373). This will provide evidence and guidance for further treatment options. It can be speculated that the provision of extra high frequency amplification can be beneficial for speech recognition, but not necessarily for everyone. This underlines the fact that audiologists cannot assume that extra high frequencies will necessarily provide enough speech information; thereby showing the importance of evidence based audiological practice once again. If the assessed outcome is not desired, a new recommendation based on evidence should be formulated (Cox, 2005:419).

4.2.2.2 Functional performance

According to the results obtained from all TEACH questionnaires it is clear that, despite the hearing instrument worn, noisy situations are still more difficult than quiet situations. Background noise makes speech less audible for children with hearing loss than for children with normal hearing; children with hearing loss also expend more effort in listening in difficult listening conditions than children with normal hearing (Hicks & Tharpe, 2002:582). Horwitz et al. (2008:811) explain that, when listening in noise, fewer of the redundant speech cues are available in the lower frequency range where hearing is best for most children with hearing loss. It is also explained that additional high frequency amplification provides more speech cues, resulting in better speech recognition (Horwitz, et al., 2008:811). For children in academic settings, it is critical to hear the teacher in order to learn (Hicks & Tharpe, 2002:573); it is therefore important to use the information obtained from the TEACH questionnaires to optimize speech recognition in the classroom environment. The TEACH questionnaire will provide information for example how children respond to verbal instructions, story reading, environmental sounds in noisy situations and in quiet situations (Ching & Hill, 2001).

There is evidence in the research that states that providing high frequency information can significantly improve speech understanding, especially in noisy listening environments (Glista et al., 2009:633). Johnson et al. (2009:354) mention that increasing the amounts of reverberation by adding extra high frequencies may, on the other hand, have a detrimental effect on speech recognition. When the results of sub-aims 1, 2 and 3 are considered, the only deduction that can be made at this stage is that speech recognition is more difficult in noisy environments than in quiet listening situations, despite the hearing instruments worn and despite the provision of extra high frequency amplification.

Literature (Johnson et al., 2009:354) emphasizes the importance of evidence on how children perform with a hearing instrument. The importance of minimizing background noise in a classroom should never be underestimated, and more effort should go into providing better signal to noise ratios in classroom situations. This reminds the audiologist that even though good amplification is provided, there is still a need for improvement of classroom acoustics. The importance of FM usage for children provide signal to noise ratios for optimum learning performance in the classroom and emphasizes the reality of classroom noise and states that children, especially those with hearing loss, need a quieter environment and a louder signal than adults for learning purposes (Flexer, 2004:135).

Finally, the filling in of a questionnaire by the teachers, provided valuable information regarding the participants' performance in the classroom. This information provided evidence on how a child functions in a classroom situation, and this enabled the teacher and the audiologist to work together to customize options for maximum performance for each individual participant.

As noted from the TEACH questionnaires, the participants performed poorer in the noisy environments than in quiet environments, irrespective of which hearing instrument was worn. At this stage the only conclusion that can be made is that background noise does have a great influence on speech recognition abilities in children with hearing loss, and that great effort should be put into lessening it by fitting children with hearing instruments with extended bandwidths (Stelmachovicz et al., 2007:487) and considering improving classroom signal to noise ratios. Signal to noise ratios can be improved by acoustic modifications of the classroom and providing personal and group amplification systems (Smaldino, Crandell, Kreisman, John & Kreisman, 2009:750). The importance of evidence to measure the effectiveness of amplification should not be underestimated.

Most participants performed poorer in noisy situations in the home environment (PEACH questionnaire), emphasizing the fact that children are not exposed to detrimental background noise in the school environment only, but also at home. This indicates that children not only need to be able to recognize speech better at school, but also at home. Noisy situations at home diminish opportunities for overhearing and therefore compromise communication abilities and, ultimately, academic performance and psychosocial behaviour as well (Stelmachovicz et al., 2004:556).

The above results provided the researcher with important information on how the participants performed in the home environment and also gave her an idea of how the parents/legal guardians perceived the performance of the individual participants. No conclusions can yet be drawn because results of sub-aim 2 and 3 should first be compared (sub-aim 4), but it is important to note that the benefit of high frequency amplification provided by hearing instruments should be managed under more realistic conditions, such as the home environment (Horwitz, Ahlstrom & Dubno 2008:811). Therefore audiologists should take more time and assess the outcomes of children wearing hearing instruments not only based on objective testing in the office, but should also make use of functional questionnaires to determine outcomes in the home environment.

Because of contrasting literature stated earlier regarding benefit of extended high frequency amplification (Glista, et al., 2009:633; Johnson et al., 2009:854) it is important that the above results should remind audiologists to assess the outcomes of all children fitted with hearing instruments. These outcomes should be measured not only in a laboratory or consulting room setup, but also in real world environments (like the home and school environment) in order to learn how the child is functioning in these environments. This view is supported by Horwitz, et al. (2008:811) who recommend that the benefit of extended high frequency amplification should be based on performance in real life conditions. The TEACH and PEACH questionnaires are designed to assess children's functional auditory performance in daily life by using parents and teachers observations (Ching, et al., 2008:462).

4.3 Results and discussion regarding sub-aim 4

Comparison of the speech recognition scores and functional performances of each participant as obtained with and without the extra high frequencies are provided in the form of figures and an interpretation of the results. Results of statistical analyses are provided. Speech recognition scores will first be discussed followed by a discussion of functional performance results.

4.3.1 Speech recognition scores

The speech recognition scores presented in 4.2.2 and 4.2.3 were compared to determine the effect the extra high frequency amplification had on the participants (*n*=6) speech recognition scores. Figure 16 displays the compared recognition scores.

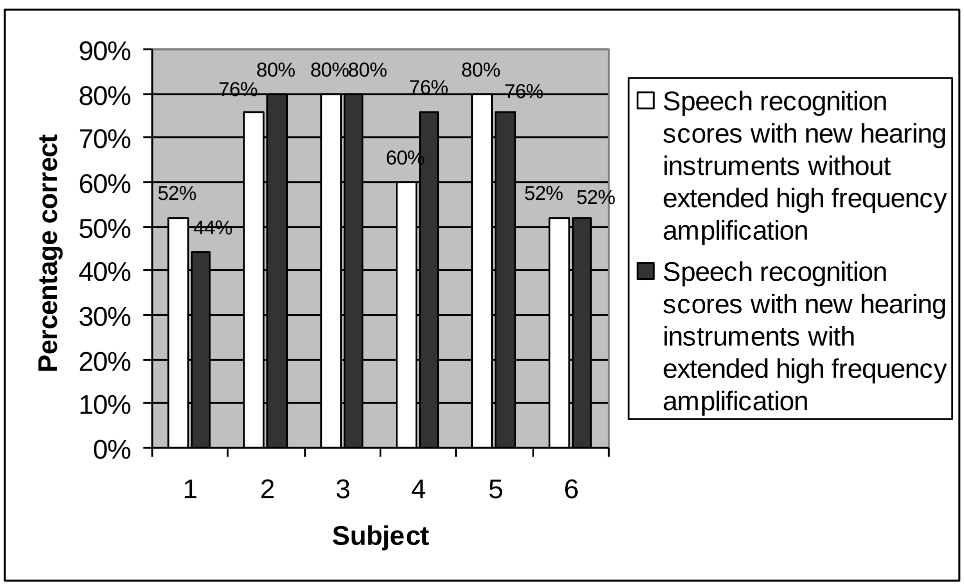


Figure 16: Comparison of speech recognition scores

According to the results presented in Figure 16 participants 1 and 5 obtained worse scores for speech recognition abilities with the hearing instruments with the extra high frequency amplification, whereas participants 3 and 6 showed no improved speech recognition abilities. Participants 2 and 4 showed a 4% and 16% improvement in speech recognition abilities respectively. These results may impact the current debate regarding the use of providing high frequency amplification (Stelmachovicz & Hoover, 2009:837). These authors also mention that current studies with adults show conflicting results in that, for some adults, amplification fail to improve but actually decrease speech perception scores, where on the other hand, other studies show improvement for some listeners in some conditions (Stelmachovicz & Hoover, 2009:837). The only study involving children was done by Stelmachovicz et al. (2001:2183), where cut-off frequencies of 4000 Hz-5000 Hz for males and 6000-9000 Hz for females were needed for maximum performance (Stelmachovicz et al., 2001:2188). It should be emphasized that the study mentioned above investigated hearing-impaired children's perception of [s] in quiet, and that in the current study the speech recognition scores were obtained in a noisy environment where the speech was presented at 65dB, and the background noise at 50dB.

Literature also indicates that individual performance with hearing instruments can be influenced by both the audibility of high frequency signals as well as the listener's proficiency in extracting useful information from the audible signal (Glista et al., 2009:633). These authors also suggest that providing audibility at frequencies where a hearing impairment is severe offers little or no speech recognition benefit, which is thought to be due to limitations in the perceptual abilities of the listener to extract information from high frequencies (Glista et al., 2009:633).

A possible explanation for the performance of participants 1 and 5 could be that either experienced difficulty in the noisy environment, or that they were unable to extract useful information from the audible signal. Another reason for the decreased performance of participant 1 could be recurrent otitis media which was present for the two week period of data capturing (Schlauch & Nelson, 2009:45). Regarding participant 5, it is strongly speculated that the background noise had a detrimental effect on speech recognition abilities because of the reverse sloped hearing loss. Horwitz, et al. (2008:799) mention that the provision of high frequency amplification would not necessarily restore the contribution of the cochlea for lower frequency cues, and therefore would be of no benefit to participant 5. They further suggest that the benefit of high frequency amplification could have been influenced by whether lower frequency speech cues were largely available (as when listening in quiet) or largely unavailable (as when listening in noise) (Horwitz, et al., 2008:799).

Participants 3 and 6 showed no improvement with the extra high frequencies added. In terms of participant 3 it can be speculated that the background noise that was presented during the speech recognition task had a negative effect on recognition because the effects of background noise can be exacerbated by the further addition of amplified high frequency sounds (Johnson et al., 2009:354). The reason for this phenomenon is provided by Horwitz, et al. (2008:799) who explain that high frequency speech must be amplified to high levels to make it audible, which could create unwanted distortion or masking. This excessive downward spread of masking could reduce the audibility of lower frequency speech information, thus reducing any benefit of amplification (Horwitz, et al., 2008:799). It was found that listeners needed a bigger signal to noise ratio as the bandwidth of their hearing instruments increased in order to overcome the downward spread of masking effect referred to above (Johnson et al., 2009:354).

Participants 2 and 4 showed an improvement of respectively 4% and 16% in their speech recognition scores. It is possible that the extra high frequencies that were provided made more speech sounds audible for improved speech recognition abilities. Another explanation could be that an even wider bandwidth is needed to make more high frequency sounds audible. Stelmachovicz et al., (2001:2183) mentioned that a bandwidth of up to 9000 Hz may be necessary to hear the sounds [s] and [f] when spoken by a female or a child.

The obtained varied results again shows the importance of evidence-based research and practice because the results for each participant differ and therefore it **cannot** be assumed that the same intervention strategies, like providing extra high frequency amplification, would be beneficial for all children with a hearing loss. It is strongly recommended that each individual child with a hearing loss should be assessed and treated independently and according to that specific child's performance and results. New outcomes should be targeted if the desired results are not attained. It also indicates that one single testing procedure is not enough for evaluating a child's performance. Objective measurements are important, but it is equally important to incorporate the use of functional assessment tools to assess outcomes in the real environments like the home and school (King, 2010:66).

Referring statistically to Figure 16, only two participants showed an improvement in their speech recognition scores. The average difference was 0.01 (1%), with a standard deviation of 0.08. It was expected that the exposure to extended/additional high frequency amplification would improve the participants' speech understanding abilities by ensuring consistent audibility of soft high frequency speech sounds. To determine the statistical significance of the scores obtained in speech recognition, a *t*-test of paired samples was performed using the data of Figure 16 (Leedy & Ormrod, 2005:274). A left-sided test was done.

H_0 represents the true mean of the speech recognition scores with extended/additional high frequency where this mean is lower than or equal to the true mean of the speech recognition scores without extra high frequencies. H_a is the true mean of the speech recognition scores with extra high frequencies where this mean is higher than the true mean of the speech recognition scores without extra high frequencies. The *p*-value is 0.3545. The *p*-value is higher than 0.05, therefore one cannot reject H_0. This indicates that there is not sufficient evidence that extra high frequency amplification increases the speech recognition scores.

4.3.2 Functional performance

Functional performance scores obtained in **4.2.4** and **4.2.6** were compared to determine the effect that additional high frequency amplification had on the participants' (*n*=6) functional performance in the classroom and at home.

- <u>Performance on the TEACH questionnaire</u>

Figure 17 displays the compared TEACH scores and will be followed by a discussion.

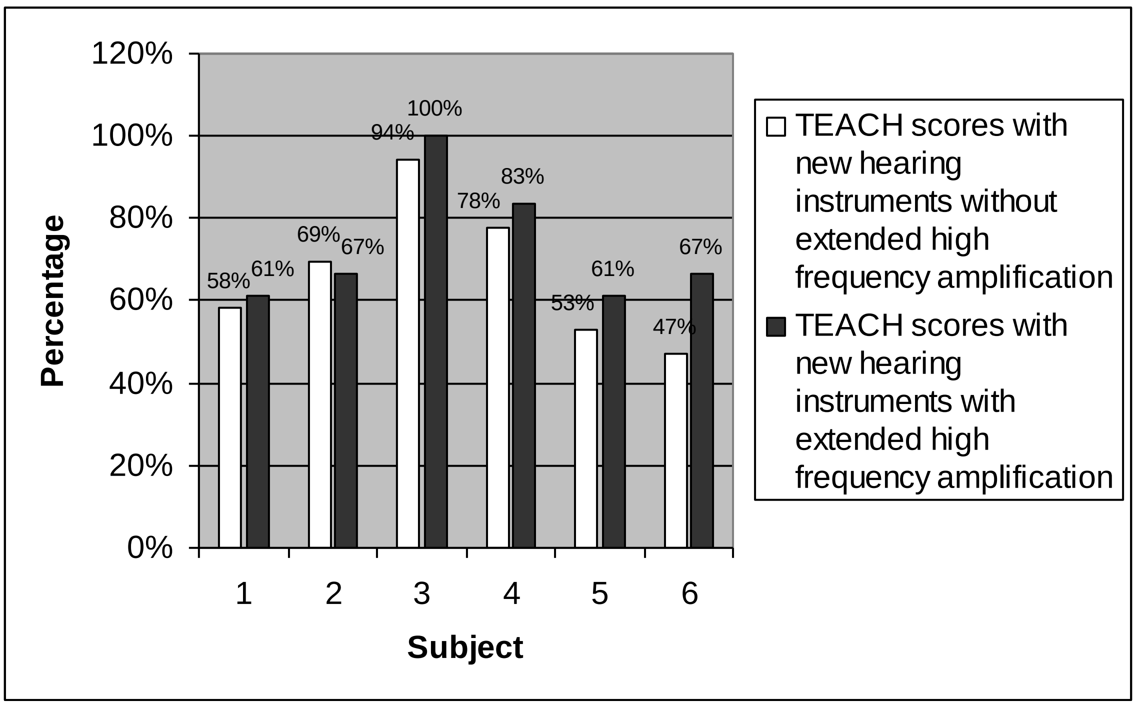


Figure 17: Comparison of TEACH scores with and without extended high frequency amplification

According to Figure 17 all participants (*n*=6) except participant 2 performed better when the additional high frequencies were provided. This correlates with the study done by Stelmachovicz et al. (2001:2188) in which results indicate that children with mild to moderately severe hearing loss are at a great disadvantage of perceiving [s] for female speakers under filtered conditions. These authors found that the mean performance on perceiving the [s] of female speakers continued to improve as more high frequency amplification were provided (Stelmachovicz et al., 2001:2188). These findings are consistent with the fact that the peak energy of [s] is in the 5000-6000Hz region for adult male speakers and 6000-8000Hz for adult female speakers, and is therefore critical because young children tend to spend most of their day with adult female caregivers and/or other children. The importance of additional high frequency amplification is supported by a study by Mlot, et al. (2010:61); their results indicate that children with hearing loss require a wider bandwidth than adults to achieve the same speech recognition results.

Participant 2 performed worse when the additional high frequencies were added. Stelmachovicz and Hoover (2009:837) mentions that in some instances high frequencies fail to improve in some adult listeners; they actually lead to a decrease in performance. These authors also mention that in the case of a severe to profound high frequency hearing loss results have been varied and may be dependent on participants' characteristics like the degree and slope of hearing loss (Stelmachovicz & Hoover, 2009:838). It is speculated that in participant 2 the negative influence of the additional high frequencies could be ascribed to the severe degree of hearing loss in the high frequencies, and that either the hearing instrument did not provide enough amplification in that frequency region, or that the provision of additional high frequencies actually degraded the speech signal (as was found in some of the adult studies) (Stelmachovicz & Hoover, 2009:837; Horwitz, et al., 2008:799). This is also supported by Pittman et al. (2009:1478) who state that speech perception in children with hearing loss cannot be predicted solely on the basis of age and stimulus audibility. They mention that supra threshold selectivity like poor frequency selectivity, poor temporal resolution and loudness recruitment could also explain the difficulty that children with hearing loss experience in noise (Pittman et al., 2009:1278).

Assessing each child individually and verifying performance of hearing instrument fittings need to be done regularly. New intervention strategies need to be worked out and assessed when current strategies do not provide the desired results. These results also indicate that performance should be assessed subjectively and objectively (Hind & Davis, 2002:200).

Statistically analyzed, five participants showed an improvement in their functional performance scores. The average difference was 0.06 (6%) with a standard deviation of 0.07. It was expected that exposure to additional high frequency amplification would improve the participants' speech understanding abilities by ensuring consistent audibility of soft high frequency speech sounds. It was also expected that this improved speech understanding would be noticed in the school environment.

To determine the statistical significance of the scores obtained during functional performance testing, a t-test of paired samples was performed (Leedy & Ormrod, 2005:274).

H_0 is the true mean of the functional performance observed at school with additional high frequencies lower than or equal to the true mean of the functional performance observed at school without additional high frequencies. H_a is the true mean of the functional performance observed at school with additional high frequencies higher than the true mean of the functional performance observed at school without additional high frequencies. A *p*-value of 0.0421 was determined. The *p*-value is lower than 0.05, therefore one can reject H_0 and accept H_a.

Statistically there is sufficient evidence that additional high frequency amplification increase the functional performance observed at school. This implicate that children performed better on the TEACH questionnaire when extended range amplification were provided.

• <u>Performance on the PEACH questionnaire</u>

Figure 18 displays the compared PEACH scores.

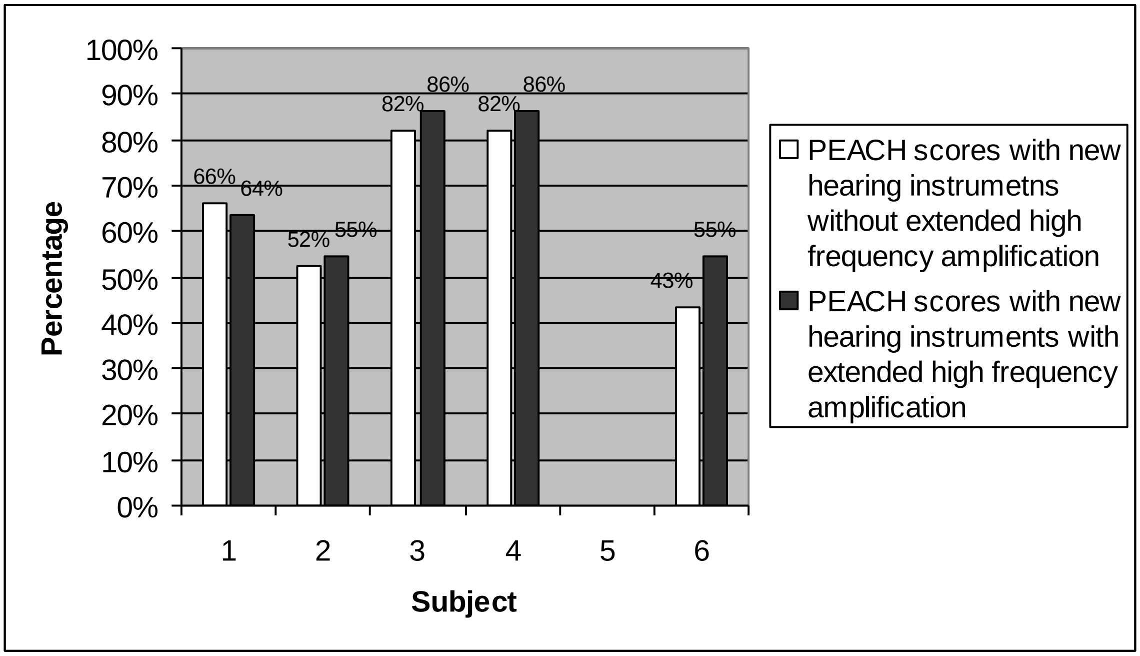


Figure 18: Comparison of PEACH scores with and without extended high frequency amplification.

It is clear from Figure 18 that participants 1, 2, 4 and 6 (*n*=5) performed, according to their parents, better with the additional high frequencies. Participant 1, however, performed worse. It is speculated that this decreased performance can be contributed to the fact that this participant had otitis media during the last week of data capturing. Hearing assessment during that period indicated an added conductive component to his current hearing status (Schlauch & Nelson, 2009:45). For this reason the results of participant 1 are taken to be unreliable and therefore the focus will be on the remaining participants.

Participants 2, 3, 4 and 6 performed better on the total score of the PEACH questionnaire when additional high frequencies were provided. This is consistent with findings of Plyler and Fleck (2006:624) who state that increasing the amplification bandwidth provided listeners with additional information that was used to improve recognition of speech cues that are necessary for accurate feature identification, thereby improving speech recognition.

It is speculated that by providing additional high frequencies more high frequency speech information was available, which improved the participants' speech recognition abilities and therefore resulted in improved functional performance in the home environment (Plyler & Fleck, 2006:624).

Statistically, four participants showed improved functional performances (Participant 5 did not participate in this part of the test). The average difference was 0.04 (4%) with a standard deviation of 0.05. It was expected that the exposure to additional high frequency amplification would improve the participants' speech understanding abilities by ensuring consistent audibility of soft high frequency speech sounds. It was also expected that this improved speech understanding would be noticeable in the home environment.

To determine the statistical significance of the scores obtained during speech recognition and functional performance testing, a *t*-test of paired samples was performed (Leedy & Ormrod, 2005:274).

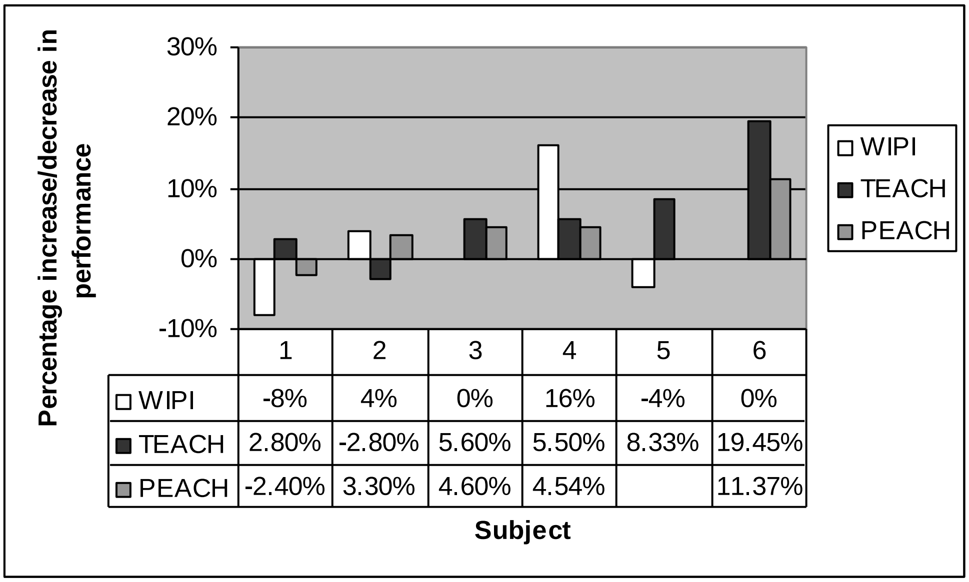
H_0 is the true mean of the functional performance observed at home with additional high frequencies lower than or equal to the true mean of the functional performance observed at home without additional high frequencies. H_a is the true mean of the functional performance observed at home with additional high frequencies higher than the true mean of the functional performance observed at home without additional high frequency. The *p*-value=0.0685. The *p*-value is higher than 0.05, therefore one cannot reject H_0.

There is not sufficient evidence that additional high frequencies increase the functional performance observed at home. Therefore statistically not all participants performed better in the home environment when extended high frequencies were provided. The implication of these results is that the audiologists cannot assume that extended high frequency amplification would be beneficial.

4.3.3 Individual comparison of scores

Comparison of individual scores were done to compare each participant with him/herself in order to see how each participant performed on the different assessment tasks when extended high frequencies were provided. This would render subjective and objective information on how each participant performed when additional high frequency amplification was provided.

The individual scores of the participants for the speech recognition task and the functional performance questionnaires were taken and the percentage increase and/or decrease between the scores of the new hearing instruments without the additional high frequencies and the new hearing instruments with the additional high frequencies were calculated. This was done to compare the results of the different test procedures. Figure 19 displays the percentage increase and/or decrease in performance of the different testing procedures.



	1	2	3	4	5	6
WIPI	-8%	4%	0%	16%	-4%	0%
TEACH	2.80%	-2.80%	5.60%	5.50%	8.33%	19.45%
PEACH	-2.40%	3.30%	4.60%	4.54%		11.37%

Figure 19: Comparison of the percentage increase / decrease in performance for the different testing procedures (*n*=6)

In Figure 19 it can be seen that participants 3, 4 and 6 performed better on the TEACH and PEACH questionnaires when the additional high frequency amplification was added. Participants 3 and 6 did not show any improvement or decrease in performance on the WIPI speech recognition task when the additional high frequency amplification was added. Participant 2 and 4 did show an improvement in performance on the WIPI speech recognition task when additional high frequencies were added.

Participants 1, 2 and 5, showed varied results where the performance on some tasks showed an increase and on other tasks a decrease when the additional high frequencies were provided. Participant 1 showed a decrease in performance on two of the tasks; it could be attributed to the otitis media this participant had during the last week of data capturing which contributed to an additional conductive component to this participants hearing loss which resulted in under amplification (Schlauch & Nelson, 2009:45). Participant 2 showed an increase in performance on the WIPI and the PEACH questionnaire, but a decrease on the TEACH questionnaire. It can only be speculated that the degree of hearing loss in the high frequency region may be too severe to amplify the high frequencies successfully with the current hearing instruments.

Participant 5 showed a decrease in the speech recognition task of the WIPI when additional high frequency amplification was provided. However, this participant's teacher indicated on the TEACH questionnaire that this participant performed better in the classroom when the additional high frequencies were provided. Unfortunately, in this case, no PEACH questionnaire results were obtained due to no feedback from the parents/legal guardians.

To summarize the above results, it can be seen that some participants performed better when high frequency amplification were provided and some participants showed varied results while some participants did better in some of the tasks and other did worse in other tasks. This is supported by a study by Glista et al., (2009:633) who states that the relationship between audibility and speech recognition suggest that providing audibility at frequencies where a hearing impairment is severe, provides little or no speech recognition benefit, and on the other hand, these authors mention that other studies have demonstrated that providing high frequency information to listeners with sloping sensorineural hearing losses can significantly improve speech understanding (Glista et al., 2009:633).

This is consistent with the view of Stelmachovicz and Hoover (2009:837) regarding the debate on the usefulness of providing high frequency amplification. They mention that most of the studies done were on the adult population and the only one on children was that by Stelmachovicz et al. (2001). Stelmachovicz et al (2001) found that high frequency amplification up to 6000 Hz-8000 Hz was needed for maximum performance, which is consistent with the fact that the peak energy of [s] is in the 5000 Hz - 6000 Hz region for adult male speakers, and in the 6000 Hz - 8000 Hz region for adult female speakers. Pittman (2008:795) also mentions that studies on the effect of limited and extended bandwidth in children with hearing loss were done in a controlled environment through high fidelity earphones in a sound treated room, which is far from the natural environment children with hearing loss are mostly exposed to.

Possible reasons for varied results when additional high frequency amplification was provided are as follows: The degree of hearing loss and the amount of high frequency sound provided cannot by themselves predict the speech perception abilities in children (Pittman, et al., 2009:1478). Studies by these authors suggest that the full effect of hearing loss is not captured by estimates of hearing threshold, but that supra-threshold psychophysical deficits like poor frequency selectivity, poor temporal resolution and loudness recruitment may also explain why children with hearing loss have difficulty hearing in difficult situations like noisy environments (Pittman, et al., 2009:1478). Horwitz, et al. (2008:799) provide several explanations for the limited benefit provided by high frequency amplification. These authors mention that high frequency speech must be amplified to high levels to make it audible, which could create unwanted distortion or masking, which reduces audibility of lower frequency speech information. Another reason they mention, is that amplification of high frequency speech would not necessarily restore the contribution at the base of the cochlea for lower frequency cues, and lastly, they suggest that thresholds greater than about 60dB HL reflect not only loss of outer hair cells but also some loss of inner hair cells and diminished afferent input, which would in all likelihood not result in improved speech recognition (Horwitz, et al., 2008:799). The lack of plasticity of the central auditory system can also explain why some of the participants did not show any benefit from extended high frequency amplification (Sharma et al., 2002:532). There is a sensitive period at 3.5 years where the central auditory system is maximally plastic. If the auditory centres are deprived of sound during this first 3.5 years, it can lead to abnormal cortical response latencies to speech (Sharma et al., 2002:532)

Although Ricketts, et al. (2008:161) mention that improved speech recognition with bandwidth increased to 7000.Hz has been shown in listeners with high frequency thresholds as poor as 85dB HL, still suggest that children with a mild to severe sensorineural hearing loss are not a homogenous group. As a result they propose that some listeners will prefer additional high frequency amplification, some will have no preference, and others will prefer less high frequency amplification (Ricketts, et al., 2008:161).

Taking into account the literature and the results displayed in Figure 16, it can only be speculated that providing additional high frequency amplification to improve speech recognition abilities do prove to be beneficial to some children. There is still a debate going on about why not all children benefit from this type of amplification. This emphasizes the importance of assessing the outcomes of each individual child. Outcomes should also be assessed in a subjective and an objective manner to reach a more holistic picture of the child's performance. These outcomes guide the audiologist in terms of the next step of intervention.

The results mentioned above were statistically analyzed. An Analysis of Variance (ANOVA) single factor test was done. Participant 6 (in addition to participant 1) was not included as part of this hypothesis. The average difference was 0.02 (2%) with a standard deviation 0.05. A *p*-value of 0.740663 was obtained that indicated that there is not sufficient evidence that the increase in performances on the WIPI, TEACH and PEACH were due to the extended high frequency amplification.

4.4 Conclusion

"The bandwidth of current hearing instruments is inadequate to accurately represent the high-frequency sounds of speech, particularly for female speakers, and data on phonological development in children with hearing loss suggest that the greatest delays occur for fricatives, consistent with predictions based on hearing aid bandwidth" (Stelmachovicz et al., 2004:556).

Taking the above information into account, the provision of additional high frequency amplification should improve the audibility of high frequency speech sounds. If these high frequency speech sounds become audible it has been shown to improve speech recognition in children with hearing loss (Johnson et al., 2009:354). Some contrasting results have shown limited benefit through high frequency amplification and that it may, in fact, contribute to poorer speech recognition (Horwitz, Ahlstrom & Dubno, 2008:799).

The most important conclusion that can be made is that the paediatric audiologist should know the importance of fitting hearing instruments capable of high frequency amplification and make audible as many speech cues as possible. This should, however, be done with caution because not all children benefit from extended bandwidth amplification, and this underlines the importance of following a strict outcomes-based approach that incorporates objective and subjective assessment approaches. This will provide the audiologist with real world evidence of the success of the amplification strategy that is followed.

CHAPTER 5

Conclusions and recommendations

5.1 Introduction

Bandwidth refers to the range of frequencies which are amplified by a specific hearing instrument (Stach, 2003:38). Although the bandwidth of current hearing instruments is wider than ever before, the high frequency gain in most instruments is rapidly reduced above 5000Hz, which is well below the frequencies of the peak energy of [s] in both children and adult female speakers (Pittman et al., 2003:653). This limited high frequency amplification can have a negative influence on the development of speech and language skills in children with hearing loss and it may limit the audibility of important high frequency speech sounds (Stelmachovicz et al., 2004:559).

Results of an analysis done by Stelmachovicz et al., (2004:558), revealed that mid frequency audibility (2000 – 4000Hz) appeared to be most important for perception of the fricative noise of the male speaker, whereas a somewhat wider frequency range (2000 – 8000Hz) was important for such perception of the female speaker. This implies that children whose hearing instruments amplify only around 5000Hz will not be able to hear some of the speech sounds produced especially by female speakers. This can have a major impact on children's speech and language development given the fact that children with hearing loss spend most of their time with female caregivers, teachers and other children (Stelmachovicz, 2001:171).

Traditionally the majority of children have been fitted with hearing instruments with a limited frequency range. This resulted in children with mild to severe hearing losses not having constant access to high frequency amplification and therefore had inconsistent access to important speech: this resulted in the omission and/or substitution of certain phonemes (Elfenbein et al., 1994:223). The primary goal in the development of new hearing instruments is to ensure audibility for all speech sounds that are crucial for the perception of speech, including high frequency cues (Smith, et al., 2009:64). Hearing instruments with an increased frequency bandwidth have been developed, because the primary goal in the development of hearing aids is to ensure audibility for all speech sounds that are crucial for the perception of speech which include high frequency cues (Smith, et al., 2009:64).

Because the constant input of all speech sounds, and therefore accurate speech recognition, are fundamental in the acquisition of speech and language, hearing instruments with extended frequency bandwidths have been developed to ensure audibility of all speech sounds, especially the fricatives and unstressed components of speech. This study therefore focused on the possible effect that such a hearing instrument with extended high frequency range amplification may have on the speech recognition abilities in children with moderate to severe sensorineural hearing losses.

5.2 Conclusions

Speech recognition scores with and without extended range amplification were determined in a group of children (aged between 3 years, 0 months and 10 years, 11 months) with a bilateral mild to severe sensorineural hearing loss and results indicated that there was not sufficient statistical evidence that extra high frequency amplification increased the speech recognition scores. Varied results between participants indicate the importance of evidence based research and practice because the results for each participant differ and therefore it cannot be assumed that the same intervention strategies, like providing extra high frequency amplification, would benefit all children with hearing loss. It is strongly recommended that each individual child with a hearing loss should be assessed and treated independently and according to his/her performance and results. New outcomes should be targeted if the desired results are not attained.

Functional performance results as assessed with and without extended high frequency amplification obtained from the TEACH questionnaire indicated that subjects performed better on the TEACH questionnaire when extra high frequency amplification was provided. Statistically there was enough evidence to support the hypothesis that extended high frequency amplification improved the subjects' daily performance in the school environment.

Performance on the PEACH functional assessment questionnaire indicated that four subjects attained higher scores when extra high frequency amplification was provided. This suggested that the provision of extra high frequency amplification improved most of the subjects' daily functional performance in the home environment. However there was not sufficient statistical evidence to indicate that extended high frequency amplification improved their functional performance at home.

Lastly, a comparison of percentage increase/decrease in performance of speech recognition scores and functional performances with and without the extended high frequencies were lastly done in order to compare each participant with himself/herself. Although objective measurements like speech recognition testing are important, it is equally important to incorporate the use of functional assessment tools (such as TEACH and PEACH) for assessing the outcomes in real environments like home and school (King, 2010:66).

The most important clinical finding when speech recognition scores and functional performances percentage increase/decrease in performance were compared with each other, are discussed below:

Three participants performed the same or showed increases in performance on the speech recognition scores as well as on the TEACH and PEACH functional assessments. This important finding suggests that these three subjects definitely performed better when extended range amplification was provided. The remaining three participants showed varied results performing better in some of the assessments, and worse in the others when extended range amplification was provided. For these subjects it was recommended that they were monitored and assessed again by following the recommended outcomes based approach. Statistically there was not sufficient evidence to show that extended high frequency amplification improved speech recognition scores and functional performances.

Summarized, the most important conclusion is that all children with moderate to severe sensorineural hearing loss should be fitted with hearing instruments with an extended amplification range, because it benefitted speech recognition and functional performance in three out of six subjects. Until proven that extended range amplification is not beneficial (and in actual fact detrimental for a particular child through outcomes based assessments that include functional assessments), hearing instruments with extended high frequency bandwidth should be fitted. This will provide more audible high frequency speech cues. It is however also emphasized that a strict evidence based protocol should be followed to assess the outcomes and ensure that the extra high frequencies does indeed improve speech recognition and not deteriorate it.

5.3 Clinical implications

An important implication regarding fitting children with hearing instruments are the outcomes based approach. This prompts the audiologist to critically evaluate not only the objective verification of the hearing instruments, but also assess the functional performance of each individual child with his/her hearing instruments. This forces the audiologist to make use of available assessment tools to gain evidence that the prescribed amplification is providing sufficient audibility for optimum functioning. In this study, for example, new hearing instruments with extended range high frequency amplification were provided, but it was of critical importance to assess each child to make sure that this was the best choice for each individual subject. The only way to determine if it was the best option was to follow an outcomes based approach and assess each child's daily functioning. According to the results of the functional assessments all of the subjects kept the new hearing instruments with the extended range amplification, except Subject 3 who preferred super power hearing instruments.

Another important clinical implication is the use of more than one assessment tool to determine outcomes. The use of more that one tool, such as the use of both the TEACH and PEACH questionnaires, proved to be useful. This gave the researcher insight of daily functioning of each subject in the classroom and in the home environment. If these functional assessments are used in conjunction with objective measurements like the WIPI, it can provide substantial evidence in terms of the performance of a child with hearing instruments.

A great implication for audiologists and children living in a developing country like South Africa is the fact that the assessment tools are easily accessible. The PEACH and TEACH are questionnaires which can be ordered and the WIPI can be done in a soundproof booth.

These outcomes based functional measurements together with objective verification methods (speech mapping, RECD measurements), should be the cornerstone of each individual hearing instrument fitting.

5.4 Critical evaluation of the study

The main strength of the study is that it attempted to provide evidence of the effect of extended range amplification on the speech recognition abilities and functional performance of children within the unique South African context. The fact that both objective (WIPI) and subjective measurements (TEACH and

PEACH) were used, provides more evidence in a wider context of the effect extended range amplification has on speech recognition abilities and functional performance.

To date only a few studies are available on the subject of children with mild to severe sensorineural hearing losses and extended range amplification to enhance their speech recognition abilities and functional performance in real world environments and not in laboratory settings. This study contributes towards the knowledge in this field.

The sample size of the subjects was small and is a drawback. A larger sample size would have increased the statistical significance of this study. The small sample size was due to the dependence on donated hearing instruments, specific criteria in terms of hearing loss and the high frequency bandwidth of the subjects' own hearing instruments.

Due to the fact that these subjects were representative of a heterogeneous population and have been diagnosed and fitted with hearing instruments at different ages, could have accounted for unwanted variability. They have been exposed to audiology services within the public as well as the private sector. Therefore, these subjects have been exposed to different levels of amplification technology and intervention services depending on their socio-economic circumstances. Some subjects used Afrikaans and other English as their primary language, and they come from different backgrounds and cultures. All of the above mentioned variables created a heterogeneous subject group, but fairly representative of the multi-cultural diversity of the developing South African population.

The absence of a control group was noted. The ideal would have been to be able to compare the experimental group with a control group to completely rule out the influence of normal learning: and furthermore, to determine what the extent of the increased performance was due to extended high frequency amplification and what the role of normal development was.

Lastly, it can be argued that the acclimatization period was not sufficient and that longer periods of time were necessary. Parents and teachers were also pressurized to fill in the booklet within the given time frame. However, literature indicates that this may be sufficient to effectively evaluate outcomes, but that further effects might have be seen had the child been wearing the hearing instruments for a longer period of time (Marriage et al., 2005:45).

5.5 Recommendations for future research

The following recommendations are made for future studies:

- A similar study with a large sample size may give conclusive evidence regarding the efficacy of extended range amplification on speech recognition abilities.
- A similar study, but providing hearing instruments with even a wider range of high frequency amplification.
- The same study, but with the addition of a control group.
- More in depth training of parents and teachers in terms of listening environments. This will help parents fill in the questionnaires more comprehensively.
- A longitudinal study with a control group.
- Longer acclimatization periods between different amplification settings.

5.6 Closing statement

Extended range amplification may increase, decrease or have no influence on speech recognition abilities and functional performance of children with a moderate to severe sensorineural hearing loss. It is important to include as much as possible high frequency amplification (extended range amplification) to make high frequency speech sounds audible. An outcomes based protocol should be included whenever children are fitted with hearing instruments. This will provide important evidence of performances with hearing instruments, thereby guiding the audiologist to the next best step in terms of habilitation.

“Hearing is a first order event…one can reasonably focus on developing listening skills and strategies only after acoustic events have been made available to the brain – not before” (Cole & Flexer, 2007:12).

REFERENCE LIST

Abrams, D.A., & Kraus, N. (2009). Auditory pathway representations of speech sounds in humans. In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 611-626). USA: Lippincott Williams & Wilkens.

Attias, J., Al-Masri, M., AbuKader, L., Cohen,G., Merlov, P., Pratt, H. et al. (2006). The prevalence of congenital and early-onset hearing loss in Jordanian and Israeli infants. *International Journal of Audiology.* 45, 528-536.

Babbie, E., & Mouton, J. (2001). *The Practice of Social Research.* Oxford:University Press.

Bentler, R., Eiten, L., Gabbards, A., Grimes, A., Johnson, C.D., Moodie, S., et al. (2004). Pediatric amplification guideline. *Audiology Today.* 6(2), 10-17.

Bentler, R.A., & Mueller, H.G. (2009). Hearing aid technology. In J.Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 776-793). USA: Lippincott Williams & Wilkens.

Boothroyd, A., & Medwetsky, L. (1992). Spectral Distribution of /s/ and the Frequency Response of Hearing Aids. *Ear and Hearing, 13*(3)*, 150-157.*

Briscoe, J., Bishop, D.V.M., & Norbury, C.F. (2001). Phonological processing, language, and literacy: a comparison of children with mild to moderate sensorineural hearing loss and those with specific language impairment. *Journal of Child Psychology and Psychiatry*, 42(3), 329-340.

Brown, A.S. (2009). Intervention, education and therapy for children who are deaf or hard of hearing. In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 934-953). USA: Lippincott Williams & Wilkens.

Byrne, D., Dilllon, H., Tran, K., Arlinger, S., Wilbraham, K., Cox, R. et al. (1994). An international comparison of long-term average of speech spectra. *Journal of Acoustical Society, 96*(4), 2108-2120.

Ching, T.Y.C., Dillon, H., & Katsch, R. (2001). Do children require more high frequency audibility than adults with similar hearing losses? In: R.C. Seewald & J.S. Gravel (eds.), *A sound foundation through early amplification 2001: Proceedings of the second international conference* (pp. 141-152). Stäfa, Switzerland: Phonak AG.

Ching, T.Y.C., & Hill, M. (2001). Hearing aid outcome measures in children: How effective is amplification in real life? *Paper presented at the hearing aid outcome meeting, CHARTT.* Indiana University. Retrieved July 20, 2009 from www.nal.gov.au/PEACH%20&%20TEACH/TC%20-Outcomes%20CHARTT%20paper.doc

Ching, T.C., Hill, M., & Dillon, H. (2008). Effect of variations in hearing aid frequency response on real-life functional performance of children with severe hearing loss. *International Journal of Audiology. 47*, 461-475.

Cole, E.B., & Flexer, C. (2007). *Children with hearing loss: developing listening and talking. Birth to six.* Oxford: Plural Publishing, Inc.

Connine, C.M., & Darnieder, L.M. (2009). Perceptual learning of co-articulation in speech. *Journal of Memory and Language*, *61*, 412-422.

Cornelisse, L.E., Gagné, J., & Seewald, R.C. (1991). Ear level recordings of the long-term average of speech. *Ear and hearing*, *12*(1), 47-54.

Cox, R.M. (2004). Waiting for evidence-based practice for your hearing aid fitting? It's here! *The Hearing Journal, 57*(8), 10-17.

Cox, R.M. (2005). Evidence-based practice in provision of amplification. *Journal of the American Academy of Audiology, 16*(7), 419-438.

Davis, J.M., Elfenbein, J., Schum, R., & Bentler, R.A. (1986). Effects of mild and moderate hearing impairments of language, educational, and psychosocial behaviour of children. *Journal of Speech, Language and hearing disorders, 51*, 53-62.

Department of Education. (2001). Education white paper 6: special needs education: building an inclusive education and training system. Pretoria: Department of Education.

DesJardin, J.L., Ambrose, S.E., Martinez, A.S., & Eisenberg, L.S. (2009). Relationships between speech perception abilities and spoken language skills in young children with hearing loss. *International Journal of Audiology, 48*, 248-259.

Dillon, H. (2001). *Hearing Aids.* Australia: Boomerang Press.

Drummond, A. (2003). *Research methods for therapists.* United Kingdom: Nelson Thornes Ltd.

Education White Paper 6

Eisenberg, L.S. (2007). Current state of knowledge: speech recognition and production in children with hearing impairment. *Ear and hearing, 28*(6), 766-772.

Elfenbein, J.L., Hardin-Jones, M.A., & Davis, J.M. (1994). Oral Communication Skills of Children Who are Hard of Hearing*. Journal of Speech and Hearing Research, 37,* 216-226*.*

English, K. (2009). Counselling: how audiologists can help patients adjust to hearing loss. In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 971-984). USA: Lippincott Williams & Wilkens.

Flexer, C. (2004). The impact of classroom acoustics: listening, learning, and literacy. *Seminars in Hearing, 25*(2), 131-140.

Fouché, C.B., & de Vos, A.S. (2005). Quantitative research designs. In. A.S. de Vos (Ed.). *Research at grass roots for the social sciences and human service professions* (3rd ed., pp. 132-143). Pretoria: Van Schaik.

Glista, D., Scollie,S., Bagatto, M., Seewald, R., Parsa, V., & Johnson, A. (2009). Evaluation of nonlinear frequency compression: clinical outcomes. *International Journal of Audiology, (48)*9, 632-644.

Glista, D., Scollie, S., Polonenko, M., & Sulkers, J. (2009). A comparison of performance in children with nonlinear frequency compression systems. *Hearing Review,* 20-24.

Grobbelaar, A. (2009). Linear frequency transposition and word recognition abilities of children with moderate-to-severe sensorineural hearing loss. Electronic theses and dissertations: University of Pretoria.

Harrison, R.V. (2001). Representing the acoustic world within the brain: normal and abnormal development of frequency maps in the auditory system. In R.C. Seewald & J.S. Gravel (eds.), *A sound foundation through early amplification 2001: Proceedings of the second international conference* (pp. 3-24). Stäfa, Switzerland: Phonak AG.

Health Professions Council of South Africa. (2007). Professional board for speech, language and hearing professions: early hearing detection and intervention (EDHI) programs in South Africa position statements year 2007, 1-42.

Hedrick, M.S., & Younger, M.S. (2003). Labelling of /s/ and /ʃ/ by listeners with normal and impaired hearing, revisited. *Journal of Speech, Language and Hearing Research, 46*, 636-648.

Herrera, C. (2010). Ethics in the Research Process. *Encyclopaedia of Research Design. SAGE Publications.* Retrieved 16 Jul. 2011 from: http://0-www.sage-ereference.com.innopac.up.ac.za/view/researchdesign/n134.xml

Hicks, C.B., & Tharpe, A.M. (2002). Listening effort and fatigue in school-age children with and without hearing loss. *Journal of Speech, Language and Hearing Research, 45*, 573-584.

Hind, S., & Davis, A. (2000). Outcomes for children with permanent hearing impairment. In: R.C. Seewald & J.S. Gravel (eds.). *A sound foundation through early amplification: Proceedings of the third international conference* (pp. 199-212). Stäfa, Switzerland: Phonak AG.

Horner, R.H., & Spaulding, S.A. (2010). Single-subject design. In. *Encyclopedia of Research Design.* Retrieved from: http://0-www.sage-ereference.com.innopac.up.ac.za/researchdesign/Article_n424.html

Hornsby, B.W.Y. (2004). The speech intelligibility index: what is it and what's it good for? *The Hearing Journal, (57)*10, 10-17.

Horwitz, A.R., Ahlstrom, JB., & Dubno, J.R. (2008). Factors affecting the benefits of high-frequency amplification. *Journal of Speech, Language and Hearing Research, 51*, 798-813.

Huttunen, K.H. (2001). Phonological development in 4 – 6 year old moderately hearing impaired children. *Scandinavian Audiology, 53*(30), 79-82.

Illing, R. (2004). Maturation and plasticity of the central auditory system. *Acta Otolaryngoly,* 552, 6-10.

Irvine, D.R.F. (2007). Auditory cortical plasticity: Does it provide evidence for congnitive processing in the auditory cortex? *Hearing Research, 299*, 158-170.

Irwin, D.L., Pannbaker, M., & Lass, N.J. (2008). *Clinical research methods in speech-language pathology and audiology.* San Diego: Plural publishing.

Joint committee on infant hearing. (2007). Joint committee of infant hearing, year 2007 position statement: principles and guidelines for early hearing detection and intervention programs. *The Volta Review, 107*(2), 141-189.

Johnson, E., Ricketts, T., & Hornsby, B. (2009). The effect of extending high frequency bandwidth on the acceptable noise level (ANL) of hearing instrument listeners. *International Journal of Audiology, (48)*6, 353-362.

Jusczyk, P.W., & Luce, P.A. (2002). Speech perception and spoken word recognition: past and present. *Ear and Hearing, 23*(1), 2-40.

Kazdin, A.E. (1982). *Single-case research designs: Methods for clinical and applied settings.* Oxford: Oxford University Press.

King, A. (2010). The national protocol for paediatric amplification in Australia. *International Journal of Audiology, (49),* s64-s69.

Kortekaas, R.W.L., & Stelmachovicz, P.G. (2000). Bandwidth Effects on Children's Perception of the inflectional Morpheme /s/: Acoustical Measurements, Auditory Detection, and Clarity Rating*. Journal of Speech, Language and Hearing Research, (43), 645-660.*

Kuk, F., Damsgaard, A., Bulow, M., & Ludvigsen, A. (2004). Using digital hearing aids to visualize real-life effects of signal processing. *The Hearing Journal, 57*(4), 40-49.

Kuk, F.K., & Ludvigsen, C. (2003). Changing with times: re-examining the aided threshold. Understanding the role of functional gain, real-ear response, and insertion gain in linear and non-linear fittings. *The Hearing Review, 10*(3), 28-95.

Kuk, F., & Marcoux,A. (2002). Factors ensuring consistent audibility in pediatric hearing aid fitting. *Journal of the American Academy of Audiology, 13*(9), 503-520.

Lasisi, O.A., Ayodele, J.K., & Ijaduola, G.T.A. (2006). Challenges in management of childhood sensorineural hearing loss in sub-Saharan Africa, Nigeria. *International Journal of Pediatric Otorhinolaryngology, 70*, 625-629.

Leedy, P.D., & Ormrod, J.E. (2005). *Practical research: planning and design* (8th ed.). New Jersey: Pearson Merrill Prentice Hall.

Louw, D.A., Van Ede, D.M., & Louw, A.E. (1998). *Menslike ontwikkeling* (derde uitgawe). Kaapstad: Kagiso Uitgewers.

Mackenzie, I.J. (2006). Malaria and deafness. *Community Ear and Hearing Health, 3*, 1-16.

Malicka, A.N., Munro, K.J., & Baker, R.J. (2010). Diagnosing cochlear dead regions in children. *Ear and Hearing, (3)*2, 238-246.

Marriage, J.E., Moore, B.C.J., Stone, M.A., & Baer, T. (2005). Effects of three amplification strategies on speech perception by children with severe and profound hearing loss. *Ear and Hearing, 26*(1), 35-47.

Matkin, N.D., & Wilcox, A.M. (1999). Considerations in the education of children with hearing loss. *Pediatric Clinics of North America, 46*(1), 143-152.

Mayne, A.M. (1998). Receptive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review.* 100(5), http://0-web.ebscohost.com.innopac.up.ac.za/ehost/detail?vid=3&hid=9&sid=e1ff12c3-d731-4fd6-a2fe-ef74ec3930b6%40sessionmgr14&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#db=aph&AN=3274898

McArdle, R., & Hnath-Chisolm, T. (2009). Speech Audiometry. In J. Katz (Ed.). *Handbook of Clinical Audiology* (6th ed., pp. 64-79) USA: Lippincott Williams & Wilkens.

Miller-Hansen, D.R., Nelson, P.B., Widen, J.E., & Simon, S.D. (2003). Evaluating the benefit of speech recoding hearing aids in children. *American Journal of Audiology, 12*, 106-113.

Mlot, S., Buss, E., & Hall, J.W. (2010). Spectral Integration and Bandwidth Effects on Speech Recognition in School-Aged Children and Adults. *Ear and Hearing, 31*(1), 56-62

Moeller, M.P. (2007). Current state of knowledge: psychosocial development in children with hearing impairment. *Ear and hearing, 28*(6), 729-739.

Moeller, M.P., Tomblin, J.B., Yoshinaga-Itano, C., Connor, C.M., & Jerger, S. (2007). Current state of knowledge: language and literacy of children with hearing impairment. *Ear and Hearing, 28*(6), 740-753.

Moodie, S., Scollie, S., Seewald, R., Bagatto, M., & Beaulac, S. (2007). The DSL method for pediatric and adult hearing instrument fitting: version 5. *Phonak Focus,* 37.

Moore, B.C.J. (2001). Dead regions in the cochlea: implications for the choice of high frequency amplification. In: R.C. Seewald & J.S. Gravel (eds.), *A sound foundation through early amplification 2001: Proceedings of the second international conference* (pp. 53-165). Stäfa, Switzerland: Phonak AG.

Moore, J.K., & Linticum Jr, F.H. (2007). The human auditory system: a timeline of development. *International Journal of Audiology, 46*, 460-478.

Morzaria, S., Westerberg, B.D., & Kozak, F.K. (2004). Systematic review of the etiology of bilateral sensorineural hearing loss in children. *International Journal of Pediatric Otorhinolaryngology,* 68, 1193-1198.

Most, T., Aram, D, & Andorn, T. (2006). Early literacy in children with hearing loss: a comparison between two educational systems. *The Volta Review, 106*(1), 5-28.

Mueller, G.H. (2005). Probe-mic measures: Hearing aid fitting's most neglected element. *The Hearing Journal, 58*(10), 21-30.

Müller, L. (2010). Unpublished class notes.

Munro, K.J. (2007). Integrating cochlear dead regions diagnosis into the hearing instrument fitting process. *Phonak Focus,* 38.

Munro, K.J. (2004). Update on RECD measures in children. In: R.C. Seewald & J.M. Bamford (eds.), *A sound foundation through early amplification 2004: Proceedings of the third international conference* (pp. 71-89), Stäfa, Switzerland, Phonak AG.

Neuman, W.L. (2003). *Social research methods: Qualitative and Quantitative Approaches* (5th ed.), United States: Allyn and Bacon.

Newton, P.J. (2006). The causes of hearing loss in HIV infection. *Community Ear and Hearing Health, 3*, 1-16.

Nicholas, J.G., & Geers, A.E. (2006). Effects of early auditory experience on the spoken language of deaf children at 3 years of age. *Ear and Hearing, 27*(3), 286-298.

Nip, S.B., Green, J.R., & Marx, D.B. (2009). Early speech motor development: cognitive and linguistic considerations. *Journal of Communication Disorders, 42*, 286-298.

Northern, J.L., & Downs, M.P. (2002). *Hearing in Children* (5th ed.). USA: Lippincott Williams & Wilkins.

Nott, P., Cowan, R., Brown, M., & Wigglesworth, G. (2009). Early language development in children with profound hearing loss fitted with a device at a young age: part 1 – the time period taken to acquire first words and first word combinations. *Ear and Hearing, 30*(5), 526-540.

Ohlms, L.A., Chen, A.Y., Stewart, M.G., & Franklin, D.J. (1999). Establishing the etiology of childhood hearing loss. *Otolaryngology – Head and Neck Surgery, 120*(2), 159-163.

Oliver, P. (2003). *The Student's Guide to Research ethics.* United Kingdom: Open University Press.

Olsen, W.O., Hawkins, D.B., & Van Tassell, D.J. (1987). Representations of the long-term spectra of speech. *Ear and Hearing, 8*(5), 100S-108S.

Olusanya, B.O., Wirz, S.L., & Luxon, L.M. (2008). Community-based infant hearing screening for early detection of permanent hearing loss in Lagos, Nigeria: a cross-sectional study. *Bulletin of the World Health Organization, 86*(12), 956-963.

Olusanya, B.O., & Somefun, A.O. (2009). Place of birth and characteristics of infants with congenital and early-onset hearing loss in a developing country. *International Journal of Pediatric Otorhinolaryngology, 73*, 1263-1269.

Olusanya, B.O., Swanepoel, D., Chapchap, M.J., Castillo, S., Habib, H., Mukari, S.Z., et al. (2007). Progress towards early detection services for infants with hearing loss in developing countries. *BMC health services research,* 7. Retrieved 2010, from http://www.biomedcentral.com/1472-6963/7/14

Owens, R.E. (1996). Language development: An Introduction (4th Edition). *Allyn & Bacon, Boston, United States of America.*

Papso, C.F., & Blood, I.M. (1989). Word recognition skills of children and adults in background noise. *Ear and Hearing, 10*(4), 235-236.

Petrou, S., McCann, D., Law, C.M., Watkin, P.M., Worsfold, S., & Kennedy, C.R. (2007). *Pediatrics, 120*(5), 1044-1052.

Pittman, A.L. (2008). Short-term word-learning rate in children with normal hearing and children with hearing loss in limited and extended high frequency bandwidths. *Journal of Speech, Language and Hearing Research, 51*, 785-797.

Pittman, A.L., Stelmachovicz, P.G., Lewis, D.E., & Hoover, B.M. (2003). Spectral characteristics of speech at the ear: implications for amplification in children. *Journal of Speech, Language, and Hearing Research,* 46(3), 649 (9).

Pittman, A., Vincent, K., & Carter, L. (2009). Immediate and long-term effects of hearing loss on the speech perception of children. *Journal of acoustical society America, 126*(3), 1477-1484.

Plyler, P.N., & Fleck, E.L. (2006). The effects of high frequency amplification on the objective and subjective performance of hearing instrument users with varying degrees of high frequency hearing loss. *Journal of Speech, Language and Hearing Research, 49*, 616-627.

Pottas, L. (2004). Inclusive education in South Africa: the challenges posed to the teacher of the child with a hearing loss. Retrieved November 2011, from: http://upetd.up.ac.za/thesis/available/etd-09072005-105219/

Ricketts, T.A., Dittberner, A.B., & Johnson, E.E. (2009). High frequency amplification and sound quality in listeners with normal through moderate hearing loss. *Journal of Speech, Language and Hearing Research.* 51, 160-172.

Ricketts, T.A., & Tharpe, A.M. (2004). Potential for directivity-based benefit in actual classroom environments. In R.C. Seewald & J.M. Bamford (eds.), *A sound foundation through early amplification 2004: Proceedings of the third international conference,* (pp. 143-153). Stäfa, Switzerland: Phonak AG.

Roesner, R.J., Valente, M., & Hosford-Dun. (2000). *Audiology: Diagnosis.* New York: Thieme.

Ross, M and Lerman, J. (1970). A picture identification for hearing impaired children. *Journal of Speech and Hearing Research, 13*(1), 44-53.

Roush, P.A. (2004). Hearing aid fitting in infants: practical considerations and challenges. In: R.C. Seewald & J.M. Bamford (eds.), *A sound foundation through early amplification 2004: Proceedings of the third international conference,* (pp. 105-113). Stäfa, Switzerland: Phonak AG.

Scollie, S. (2006). The DSL method: improving with age. *The Hearing Journal, 59*(9), 10-16.

Scollie, S. (2003). Heairng aid test signals: what's new and what's good for kids? *The Hearing Journal, 56*(9), 10-15.

Scott, B. and Berkeljon, A. (2010). Quasi-experimental design: Encyclopedia of Research Design. SAGE Publications. Retrieved 6 may 2011: http://0-

www.sage-ereference.com.innopac.up.ac.za/researchdesign/Article_n353.html

Schlauch, R.S., & Nelson, P. (2009). Puretone Evaluation. In J.Katz (Ed.), *Handbook of Clinical audiology* (6th ed., 30-49). USA: Lippincott Williams & Wilkens.

Sharma, A., Droman, M.F. and Spahr, A.J. (2002). A sensitive period for the development of the central auditory system in children with cochlear implants: implications for age of implantation. *Ear and Hearing, 23*(6), 532-539.

Sharma, A., Cardon,G., Henion,K. and Roland, P. (2011). Cortical maturation and behavioral outcomes in children with auditory neuropathy spectrum disorder. *International Journal of Audiology, 50*, 98-106.

Shield, B.M., & Dockrell, J.E. (2008). The effects of environmental and classroom noise on the academic attainments of primary school children. *Journal of Acoustical Society America, 123*(1), 133-144.

Shipley, K.G., & McAfee, J.G. (1992). *Communicative disorders: an assessment manual.* London: Chapman & Hall.

Sininger, Y.S., Grimes, A., & Christensen, E. (2010). Auditory development in early amplified children: factors influencing auditory-based communication outcomes in children with hearing loss. *Ear and Hearing, 31*(2), 166-185.

Smaldino, J., Crandell, C., Kreisman, B., John, A. & Kreisman, N. (2009). Room acoustics and auditory rehabilitation technology. In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 745-775). USA: Lippincott Williams & Wilkens.

Smith, R.J.H., Bale Jr, J.F., & White, K.R. (2005). Sensorineural hearing loss in children. *The Lancet,* 365, 879-890.

Smith, J., Dann, M., & Brown, P.M. (2009). An evaluation of frequency transposition for hearing impaired school-age children. *Deafness and Education International, 11*(2), 62-82.

South Africa HIV and AIDS Statistics. http://www.avert.org/safricastats.htm retrieved 25 April 2011

Stacey, P.C., Fortnum, H.M., Barton, G.R., & Summerfield, A.Q. (2006). Hearing impaired children in the United Kingdom I: auditory performance, communication skills, educational achievements, quality of life, and cochlear implantation. *Ear and hearing, 27*(2), 161-186.

Stach, A.B. (2003). *Comprehensive Dictionary of Audiology: Illustrated (2nd ed).* Canada: Singular Publishing.

Stelmachovicz, P.G. (2004). Pediatric amplification: past, present and future. In: R.C. Seewald & J.M. Bamford (eds.), *A sound foundation through early amplification 2004: Proceedings of the third international conference* (pp. 27-40). Stäfa, Switzerland: Phonak AG.

Stelmachovicz, P.G. (2001). The Importance of High-Frequency Amplification for Young Children. In:R.C. Seewald & J.S. Gravel (eds.), *A Sound Foundation Through Early Amplification 2001: Proceedings of the second international conference.* (pp. 167-175). Stäfa, Switzerland: Phonak.

Stelmachovicz, P.G., Lewis, E.L., Choi, S., & Hoover, B. (2007). Effect of Stimulus Bandwidth on Auditory Skills in Normal-Hearing and Hearing-Impaired Children. *Ear and Hearing, 28*(4), 483-494.

Stelmachovicz, P., & Hoover, B. (2009). Hearing instrument fitting and verification for children. In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 827-845). USA: Lippincott Williams & Wilkens.

Stelmachovicz, P.G., Pittman, A.L., Hoover, B.M., & Lewis, D.E. (2001). Effect of stimulus bandwidth on the perception of /s/ in normal- and hearing impaired children and adults. *Journal of Acoustical Society of America, 110*(4), 2183-2190.

Stelmachovicz, P.G., Pittman, A.L., Hoover, B.M., Lewis, D.E., & Moeller, M.P. (2004). The importance of High-Frequency Audibility in the Speech and Language Development of Children with Hearing Loss. *Arch Otolaryngology on Head and Neck Surgery, 130, 556-562.*

Stelmachowicz, P.G., Nishi, K., Choi., Lewis, D.E., Hoover, B.M., Dirking, D., & Lotto, A. (2008). Effects of stimulus bandwidth on the imitation of English fricatives by normal-hearing children. *Journal of Speech, Language and Hearing Research, 51*, 1369-1380.

Stevenson, J., McCann, D., Watkin, P., Worsfold, S,. Kennedy, C. (2009). The relationship between language development and behavior problems in children with hearing loss. *Journal of Child Psychology and Psychiatry, 51*(1), 77-83.

Stokes, S.F., & Surendran, D. (2005). Articulatory complexity, ambient frequency, and functional load as predictors of consonant development in children. *Journal of Speech, Language, and Hearing Research, 48*, 577-591.

Strauss, S., & van Dijk, C. (2008). Hearing instrument fittings of pre-school children: do we meet the prescription goals? *International Journal of Audiology, 47*(suppl. 1), s62-s71.

Strydom, H. (2005). Single-system design. In. A.S. de Vos (Ed.). *Research at grass roots for the social sciences and human service professions* (3rd ed. 144-158). Pretoria: Van Schaik.

Strydom, H. (2005a). Ethical aspects of research in the social sciences and human service profession. In. A.S. de Vos (Ed.). *Research at grass roots for the social sciences and human service professions* (3rd ed. pp. 56-70). Pretoria: Van Schaik.

Swanepoel, D., Storbeck, C., & Friedland, P. (2009). Early hearing dtection and intervention in South Africa. *International Journal of Pediatric Otorhinolaryngology,* 1-4.

Theunissen, M., & Swanepoel, D. (2008). Early hearing detection and intervention services in the public health sector in South Africa. *International Journal of Audiology, 49*(suppl 1), s23-s29.

Tibussek, D., Meister, H., Walger, M., Foerst, A., & von Wedel, H. (2002). Hearing loss in early infancy affects maturation of the auditory pathway. *Developmental Medicine and Child Neurology, 44*, 123-129.

Valente, M., & Valente, M. (2009). Hearing aid fitting for adults: selection, fitting, verification and validation . In J. Katz (Ed.), *Handbook of Clinical Audiology* (6th ed., pp. 846-870) USA: Lippincott Williams & Wilkens.

Van der Spuy, T. (2010). Unpublished class notes.

Van der Spuy, T., & Pottas, L. (2008). Infant hearing loss in South Africa: Age of intervention and parental needs for support. *International Journal of Audiology, 47* (suppl 1), s30 – s35.

Von Hapsburg, D., & Davis,. B.L. (2006). Auditory sensitivity and the prelinguistic vocalizations of early-amplified infants. *Journal of Speech, Language, and Hearing Research, 49*, 809-822.

Vohr, B. (2003). Overview: infants and children with hearing loss – part 1. *Mental Retardation and Developmental Disabilities Research Reviews. 9*, 62-64.

Watkin, P., McCann, D., Law, C., Mullee, M., Petrou, S., Stevenson, J. et al. (2008). Language ability in children with permanent hearing impairment: the influence of early management and family participation. *Pediatrics, 120*(3), e694-e701.

Wehmeier, S., McIntosh, C., Turnbull, J., & Ashby, M. (Eds.). (2005). *Oxford advanced learner's dictionary of current English* (7th ed.). Oxford: University Press.

Yoshinaga-Itano, C., Sedey, A.L., coulter, D.K., & Mehl, A.L. (1998). Language of early and later identified children with hearing loss. *Pediatrics, 102*(5), 1161-1171.

Appendix A:
Permission letter from Principal of Carel du Toit Centre

100
1908 - 2008

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Dept of Communication Pathology
Speech, Voice and Hearing Clinic
Tel: +27 12 420 2814
Fax : +27 12 420 3517
Email: catherine.vandijk@up.ac.za

Date: 13 October 2009

Dear Principal,

RE: REQUEST FOR PARTICIPATION IN RESEARCH PROJECT ON FITTING CHILDREN WITH HEARING INSTRUMENTS WITH EXTRA HIGH FREQUENCY AMPLIFICATION

I am a postgraduate, Masters of Communication Pathology student at the Department of Communication Pathology, University of Pretoria. My research project entails fitting children with moderate to severe sensory neural hearing losses with extended high-frequency-amplification hearing instruments and to assess the influence these extra–high-frequency sounds have on their speech-understanding abilities. The project will be submitted for approval to the Ethics Committee of the University of Pretoria. Approval will also be requested from Tygerberg Hospital before the research commences. I would like to request that you consider allowing me to conduct my study at your school.

The research will focus on fitting children with bilateral, moderate to severe sensory neural hearing losses with hearing instruments that will provide extra-high-frequency amplification. In the research it is indicated that children who wear hearing instruments with a limited bandwidth do not have consistent exposure to the softer high-frequency sounds. This results in inconsistent exposure to these speech sounds. It is also indicated that hearing instruments with extra-high-frequency amplification allow for the improved audibility of these softer high-frequency sounds.

The aim of this study is to see whether extra-high frequency amplification has an effect on the children's speech-understanding abilities.

The data collection procedures will be done as follows:

Data collection will be done over a total period of 10 weeks. This will include the three, 12-day acclimatisation periods between assessments.

Pure tone audiometry will be performed to obtain unaided air- and bone conduction thresholds. Immittance measurements will also be done to assess middle ear functioning. The children's own hearing aids will be verified according to their audiograms to make sure that they receive optimal amplification with them. After 12 days of acclimatisation, their performance will be assessed using the WIPI (Word Intelligibility by Picture Identification Test), TEACH (Teachers' Evaluation of Aural/Oral Performance of Children) and PEACH (Parents' Evaluation of Aural/Oral Performance of Children) questionnaires.

The WIPI will be done by me, the teachers will complete the TEACH and the parent/primary caregiver together with the researcher and parent guidance teacher will complete the PEACH.

After another pure tone audiogram and immittance measurement, the children will be fitted with Siemens Explorer 500P hearing instruments without the extra-high frequency amplification. After 12 days of acclimatisation, the children's performance with the new hearing instruments will be assessed, again with the WIPI and the TEACH and PEACH and using the same procedures.

The third and last pure tone audiogram and immittance measurements will be done, after which the Siemens Explorer 500P will be fitted and verified with all the extra-high frequencies. Final assessments will be done, using the WIPI, TEACH and PEACH.

The children will therefore be exposed to hearing assessments and hearing aid verification procedures known to them. The same evaluation protocols used by Carel du Toit, will be used in the study.

After the study, the parents/primary caregivers have the choice to keep the hearing aids used in the study. The aids will be free of charge.

Informed-consent letters will be given to the parents of children who fall within the selection criteria. It would be appreciated if the consent letters could be given to the individual classroom teachers to be distributed to the individual parents. Assessments will commence as soon as the letters of consent have been returned by the parents.

The assessments will be free of charge. The parents will have the right to withdraw the child from this study at any time without any negative consequences. All information and the child's identity will be treated as confidential. Applicable data will be destroyed should a parent or child decide to withdraw. Results will be published in the final thesis report. The data will be stored for a minimum of 15 years in accordance with University of Pretoria Regulations.

Contact me at 083 235 6603 or claudia.muller@vodamail.co.za should you require any additional information.

Kind Regards,

Ms Claudia Müller
Masters of Communication Pathology Student

Dr Catherine van Dijk
Research Supervisor

Professor Brenda Louw
HEAD: Department of Communication Pathology

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

INFORMED CONSENT:

Clinical trial of fitting children with hearing aids with extra-high-frequency amplification

Please complete the following:

I, ____, hereby agree to participate in the study outlined above and consent to the data being used for research purposes. I understand the conditions as stipulated in the accompanying letter.

________________________ ________________________

Signature Date

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Carel du Toit Centre / Sentrum

WHERE DEAF CHILDREN LEARN TO SPEAK / WAAR DOWE KINDERS LEER PRAAT

19130
TYGERBERG 7505
S.A.

(021) 938 5303
(021) 932 5104
cdthoof@pgwc.gov.za
www.careldutoit.co.za
Reg No./Reg Nr. 003-401 NPO

Ms C Müller,
Dept Communication Pathology,
University of Pretoria.

12.10.2009

Dear Ms Müller,

RE: RESEARCH PROJECT

Thank you for our letter requesting permission to conduct your research project at the Carel du Toit Centre.

The School Management Team has granted permission for this project to proceed and this includes access to the learners files.

We look forward to your involvement at the Centre.

Yours Sincerely,

Ruth Bourne
(Principal)

Appendix B:
Letters of consent (Parents)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

100
1908 - 2008

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Dept of Communication Pathology
Speech, Voice and Hearing Clinic
Tel: +27 12 420 2814
Fax : +27 12 420 3517
Email: catherine.vandijk@up.ac.za

Date:

Dear Parent,

RE: REQUEST FOR PERMISSION TO INCLUDE YOUR CHILD IN A RESEARCH PROJECT

I am a postgraduate, Masters in Communication Pathology student at the Department of Communication Pathology, University of Pretoria. My research project entails fitting children with binaural, moderate to severe sensory neural hearing loss with extended high–frequency-amplification hearing instruments. The goal is to assess the influence these extra-high frequencies may have on these children's speech recognition abilities. If you are interested in having your child partake in this study, the study details are as follows:

This project will specifically focus on children between the ages of 3 and 10 with binaural moderate to severe sensory neural hearing loss. The information gathered could be helpful for better hearing-instrument selection specifically for children in the future.

What will be expected of your child?

Test Type	Procedures	What is expected of your child?
Hearing test without hearing aids	Earphones will be placed on your child's ears. Sounds will be presented at a comfortable level.	Your child needs to indicate every time s/he hears a sound
Hearing test with hearing	Your child will sit in front of a	Your child needs to indicate

aids	speaker. Sounds will be presented at a comfortable level.	every time s/he hears a sound.
Speech-understanding test	Your child will wear his/her hearing aids. S/he will sit in front of a speaker where words will be presented.	Your child needs to point out a picture of the word s/he heard.
Testing of middle ear functioning	A small probe will be placed in the ear canal.	Your child does not have to do anything, except sitting quietly.
Hearing aid evaluation	A mould will be placed in your child's ear, and a measurement will be done.	Your child does not have to do anything, except sitting quietly.

The procedures mentioned are the routine procedures done by the audiologist at Carel du Toit to ensure your child hears optimally with his/her hearing aids. Your child will therefore be exposed to procedures already known to him/her.

What will be expected of the parent/primary caregiver?

It will be expected of the parent/primary caregiver to monitor the child's responses to speech and sounds at home with the hearing aids. The parents need to come to parent-guidance sessions 3 times over a period of 10 weeks to discuss the child's speech-understanding abilities and to fill in a questionnaire together with the researcher and the parent guidance teacher.

An information session will be held before the assessments start. A broad overview of the purpose of the study will be given, and questions will be answered. At the end of the study, a feedback session will also be held to report back on the findings of the study and to discuss which hearing instruments would be the most appropriate for your child. You will be given the choice of letting your child keep the hearing aids used in the study. The hearing aids will be given without any charge.

All assessments will be free of charge. The entire test-battery will be conducted during school hours.

You and your child have the right to withdraw from this study at any time without any negative consequences. All information will be treated as confidential and your child's name will not be used. Data will also be destroyed should you or your child decide to withdraw from the study. Results will be published in the final thesis report, but no identifying information will be used at any time. Coded data will be stored for a minimum of 15 years, in accordance with University of Pretoria Regulations.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Should you consent to have your child participate in the project, please complete the informed-consent receipt provided.

For any further information, you can contact me on 083 235 6603 or claudia.muller@vodamail.co.za.

Kind Regards,

Ms Claudia Müller

Masters of Communication Pathology Student

Dr Catherine van Dijk

Research Supervisor

Professor Brenda Louw

HEAD: Department of Communication Pathology

INFORMED CONSENT:

Clinical trial of fitting children with hearing aids with extra-high-frequency amplification

Please complete the following:

I, ______________________________________, hereby acknowledge and agree that my child may participate in the study outlined above and consent to the data being used for research purposes. I understand the conditions as stipulated in the accompanying letter.

Child's name: ____________________________

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Appendix C:
Letters of consent (Teachers)

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

100
1908 - 2008

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Dept of Communication Pathology
Speech, Voice and Hearing Clinic
Tel: +27 12 420 2814
Fax : +27 12 420 3517
Email: catherine.vandijk@up.ac.za

Date:

Dear Teacher,

RE: REQUEST FOR PARTICIPATION IN RESEARCH PROJECT ON HEARING INSTRUMENTS WITH EXTRA–HIGH-FREQUENCY AMPLIFICATION

I am a postgraduate, Masters of Communication Pathology student at the Department of Communication Pathology, University of Pretoria. My research project entails fitting children with binaural, moderate-to-severe sensory neural hearing losses with extended high-frequency amplification hearing instruments. The goal is to assess the influence that these extra-high frequencies may have on the children's speech-understanding abilities.

This project will specifically focus on children between the ages of 3 and 10 with binaural, moderate-to-severe sensory neural hearing loss. The information gathered may be helpful for better hearing instrument selection, specifically for children, in the future.

What will be expected of the child?

Test Type	**Procedures**	**What is expected of your child?**
Hearing test without hearing aids	Earphones will be placed on the child's ears. Sounds will be presented at a comfortable level.	The child needs to indicate every time that s/he hears a sound.
Hearing test with hearing aids	The child will sit in front of a speaker. Sounds will be presented at a comfortable level.	The child needs to indicate every time that s/he hears a sound.

Speech-understanding test	The child will wear his/her hearing aid. S/he will sit in front of a speaker where words will be presented.	The child needs to point out the picture of the word s/he has heard.
Testing of middle ear functioning	A small probe will be placed in the ear canal.	The child does not have to do anything, except sit quietly.
Hearing aid evaluation	A mould will be placed in the child's ear, and a measurement will be done.	The child does not have to do anything, except sit quietly.

The procedures mentioned are routine procedures done by the audiologist at Carel du Toit to ensure that children hear optimally with their hearing aids. The child will therefore be exposed to procedures already known to him/her.

What will be expected of the teacher?

It will be expected of the teacher to monitor the child's responses to speech and sounds during school hours while wearing the hearing aid. You will be provided with the TEACH (Teachers' Evaluation of Aural/Oral performance of Children) questionnaire which needs to be completed. The study will take 10 weeks, during which time the teacher will have to fill in three TEACH questionnaires.

An information session will be held before the assessments starts. A broad overview of the purpose of the study will be given, and questions will be answered. At the end of the study, a feedback session will also be held to report back on the findings of the study and to discuss which hearing instruments would be the most appropriate for the children. The parents will be given the choice for their child to keep the hearing aids used in the study. The hearing aids will be given without any charge.

All assessments will be free of charge. The entire test battery will be conducted during school hours.

Should you agree to participate in the project, please complete the informed-consent receipt provided.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

INFORMED CONSENT:
Clinical trial of fitting children with hearing aids with extra-high-frequency amplification

Please complete the following:

I, ______________________________________, hereby agree to participate in the study outlined above and consent to the data being used for research purposes. I understand the conditions as stipulated in the accompanying letter.

______________________ ______________________
Signature Date

Appendix D:
Ethical clearance letters

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Humanities
Research Ethics Committee

12 February 2010

Dear Dr van Dijk,

Project:	**Extended frequency range amplification and speech recognition in children with moderate to severe sensory neural hearing loss**
Researcher:	**C Müller**
Supervisor:	**Dr C van Dijk**
Department:	**Communication Pathology**
Reference number:	**97066682**

Thank you for the application that was submitted to the Research Ethics Committee, Faculty of Humanities.

I have pleasure in informing you that the Research Ethics Committee formally **approved** the above study on 4 February 2010. Please note that this approval is based on the assumption that the research will be carried out along the lines laid out in the proposal. Should your actual research depart significantly from the proposed research (as sometimes happens for a variety of possible reasons), it would be necessary to apply for a new research approval and ethical clearance.

The Committee requests you to convey this approval to Ms Müller.

We wish you success with the project

Sincerely

Prof John Sharp
Chair: Research Ethics Committee
Faculty of Humanities
UNIVERSITY OF PRETORIA
e-mail: john.sharp@up.ac.za

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot · your knowledge partner

05 May 2010 **MAILED**

Ms C Muller
Department of Communication Pathology
University of Pretoria
Pretoria
0002

Dear Ms Muller

Extended frequency range amplification and speech recognition in children with moderate to severe sensory neural hearing loss.

ETHICS REFERENCE NO: UP 1

RE : ACKNOWLEDGEMENT

We acknowledge receipt of documents pertaining to the above study and the approval letter from the University of Pretoria Humanities Research Ethics Committee, as well as the permission letter from the facility concerned for this project.

The approval of the University of Pretoria Humanities Research Ethics Committee is recognised by the Health Research Ethics Committee for this particular project. However please continue to keep us informed of the progress of the project, by submitting annual progress reports.

Yours faithfully

MR FRANKLIN WEBER
RESEARCH DEVELOPMENT AND SUPPORT
Tel: +27 (0)21 938-9657 / E-mail: fweb@sun.ac.za
Fax: +27 (0)21 931-3352

05 May 2010 11:12 Page 1 of 1

Fakulteit Gesondheidswetenskappe · Faculty of Health Sciences

Verbind tot Optimale Gesondheid · Committed to Optimal Health
Afdeling Navorsingsontwikkeling en -steun · Division of Research Development and Support
Posbus/PO Box 19063 · Tygerberg 7505 · Suid-Afrika/South Africa
Tel.: +27 21 938 9075 · Faks/Fax: +27 21 931 3352

Appendix E:
Questionnaires and score sheets

P.E.A.C.H Diary

Child's name:______________________________

Date of Birth:______________________________

Parent/Care giver completing PEACH:_______________

Date completed:______________________________

Developed by Teresa Ching & Mandy Hill

Australian Hearing
National Acoustic Laboratories

Pre interview checklist

Did you observe your child for at least one week? **Yes / No**

During that week:

Has your child been wearing his or her hearing aids and/or cochlear implant? **Yes / No**

Has your child been well/healthy? **Yes / No**

Have the hearing aids been working properly? **Yes / No**

If you answer No to any of the above questions, please contact your audiologist and re- schedule the appointment for your PEACH interview for:

____Date:_________________________Time:_____________________

Observation dates

Please observe your child from______________ to ______________

Guidelines for parents

What is the PEACH?

- The PEACH (Parents' Evaluation of Aural/oral performance of Children) is a questionnaire designed to record how your child is hearing and communicating with his/her hearing aids/cochlear implant at the moment. To complete the questionnaire you need to observe your child for at least one week, and record your observations for 13 questions. The topics covered include:
  - USE of amplification & Loudness DISCOMFORT
  - listening and communicating in QUIET
  - listening and communicating in NOISE
  - TELEPHONE usage
  - responsiveness to sounds in the ENVIRONMENT
- The PEACH is not a test. Remember even normal hearing people have some difficulty hearing in some situations. As the PEACH has been developed for use with babies, older children and children of different abilities, some of the questions may not be relevant to your child yet. Children's listening skills improve as they grow and develop and as they get more listening practice.

Why use it?

Your observations will be used to build a vivid picture of your child's auditory experience that helps your audiologist to evaluate the effectiveness of your child's hearing aids and fine tune them if necessary. It can also be used to track your child's progress.

How do I do it?

- Read through all the questions first so you know what you need to observe.
- Some of the questions have two alternatives. Use the alternative that gives examples that better describe your child's behaviour.
- Carry your booklet around with you and write down your observations as you notice them.

- Be as specific as you can when giving examples. For example, for Question 6 you might write:
  "Olivia stopped and crawled to me when I called her name from the kitchen (5 metres away)."
- Write down as many examples as you can for each question. Your audiologist will score each question based on the number of examples you give.
- If your baby/child doesn't respond record those examples too.
- If you have many examples of the same type of behaviour that's okay just record the behaviour every time it occurs.
- Only record examples of behaviour that you have observed during the time period designated by your audiologist.

Helpful Hints

- Identify certain noisy and quiet times of your day to observe your child and collect examples.
  - **Quiet** times may occur first thing in the morning and/or during story time.
  - **Noisy** times may occur during an activity such as kindy-gym, when having coffee with friends or when the TV/radio is on.
  - Write down the examples as soon as you observe them. Usually by the end of the day it is hard to remember exact details.
- Don't forget to carry the booklet with you.

What happens next?

- Your audiologist will arrange a time with you to collect the PEACH and go through it with you.
- They may ask further questions to help them to score accurately and to make sure they have a thorough understanding of the abilities and needs of your child.
- Results from the PEACH will enable you and your audiologist to gain a better understanding of specific difficulties your child may be experiencing. The information may then be used by your audiologist to fine tune your child's hearing aids.

USE OF DEVICE & LOUDNESS DISCOMFORT
Questions 1 & 2

1. I would like to know how often your child is wearing his/her hearing aids and/or cochlear implant. Can you tell me about your child's routine for wearing his/her hearing aids/cochlear implant in the last week?

___

___

___

___

___

___

___

___

___

___

___

2. Has your child complained about / or been upset by any loud sounds in the last week. (He or she may startle and/or cry, cover his/her ears, pull his or her hearing aids off, complain or show some other signs of discomfort)?

Please list examples of when your child has *<u>or has not</u>* displayed the above behaviour over the last week, describing when and where they occurred.

LISTENING IN DIFFERENT SITUATIONS

Questions 3-12

3. You are in a quiet place with your child (For example he/she may be sitting next to you, behind you or across the room when the TV is off). Does he or she respond to a **familiar voice** or to his or her **name** the first time you call, talk or sing when he/she is unable to see your face? For example, he/she may respond by smiling, looking up, by turning his/her head or by answering you verbally.

OR

You are in a quiet place with your child, (for example, he/she may be feeding with eyes closed or lying or sitting next to you when the TV is off). Does he or she respond to a **familiar voice** the first time you call, talk or sing when he/she is unable to see your face? For example when you talk or sing, he/she may respond by quietening, cessation of sucking, increasing rate of sucking, opening eyes, eye widening or by looking.

> **Quiet situations** may be when the TV, music or radio is off or when any other people in the house are in another area or doing quiet activities.

Please list examples of when your child has *<u>or has not</u>* displayed the above behaviour over the last week, describing when and where they occurred.

4. You are in a **quiet** place with your child (For example, he/she may be sitting next to you, behind you or across the room when the TV **is off**). When you ask him/her a **simple question** (For example, where's Mummy?), or to do a **simple task**, (For example, look, clap, wave, point, pick up a toy, go and get your shoes etc) does he or she respond the first time you ask?

> **Quiet situations** may be when the TV, music or radio is off or when any other people in the house are in another area or doing quiet activities.

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

5. You are in a **noisy** place with your child (for example he/she may be sitting next to you, behind you or across the room when the TV is **on**). Does he or she respond to a **familiar voice** or to his or her **name** the first time you call, talk or sing when he/she is unable to see your face? For example, he/she may respond by smiling, looking up or by turning his/her head or by answering you verbally.

OR

You are in a **noisy** place with your child, (for example, he/she may be feeding with eyes closed or lying or sitting next to you when the TV is on). Does he or she respond to a **familiar voice** the first time you call, talk or sing when he/she is unable to see your face? For example when you talk or sing, he/she may respond by quietening, cessation of sucking, increasing rate of sucking, opening eyes, eye widening or by looking.

Examples of noisy situations are: when the TV is on, or the dishwasher / radio / music / washing machine are on, other children are playing or talking in the same room, at family gatherings, in a shopping centre or restaurant.

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

6. You are in a **noisy** place with your child (For example, he/she may be sitting next to you, behind you or across the room when the TV is on). When you ask him/her a simple question (For example, where's Mummy?), or to do a simple task, (For example, look, clap, wave, point, pick up a toy, go and get your shoes, etc) does he or she respond the first time you ask?

Examples of noisy situations are: when the TV is on, or the dishwasher / radio / music / washing machine are on, other children are playing or talking in the same room, at family gatherings, in a shopping centre or restaurant.

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

7. When you are in a **quiet** place reading your child a story (or he/she is listening to stories/songs on the TV, video or cassette tape when there is no other background noise), does he or she pay close attention to/ follow the line of the story? (For example, your child may ask questions about the story, answer your questions, discuss the story with you, sing along with the song).

OR

When you are in a **quiet** place reading your child a story (or he/she is listening to stories, songs, nursery rhymes on TV, video or cassette tape when there is no other background noise) does he or she pay close attention to/follow the story? (For example, your child may look at the pictures or TV screen, turn the pages, lift the flaps, point to or label the correct picture, make the appropriate sounds for the object/animal depicted, or find objects, clapping, dancing, imitating, humming, or performing actions etc).

> **Hint:** Try showing the story book without reading or turning the TV volume right down to see if your child still responds when only the visual stimulus is present.

Please list examples that have occurred over the last week describing when and where they occurred.

8. When you are in a **quiet** place with your child how often does he or she initiate and participate in **conversation** with you and your family or with friends? (For example, does he/she need frequent repetition, does he/she respond to the topic appropriately, does he/she overhear conversation).

OR

When you are in a **quiet** place with your child how often does your child **vocalise** to get your attention/ to express need/ or in response to you or family members or familiar persons? (For example, by varying voice pitch, trying to imitate sounds or words, taking turns in vocalising, pointing to objects while vocalising or naming them)

Quiet situations may be when the TV, music or radio is off or when any other people in the house are in another area or doing quiet activities.

Please list examples that have occurred over the last week describing when and where they occurred.

Initiate (e.g. vocalising to get your attention or to express need):________

Participate (e.g. taking turns in vocalising):

9. When you are **in** a **noisy** place with your child how often does he or she initiate and participate in **conversation** with you and your family or with friends? (For example, does he/she need frequent repetition, does he/she respond to the topic appropriately, does he/she overhear conversation).

OR

When you are **in** a **noisy** place with your child how often does he or she **vocalise** to get your attention/ to express need/ or in response to you or family members or familiar persons? (For example, by varying voice pitch, trying to imitate sounds or words, take turns in vocalising, point to objects while vocalising or name them)

Examples of noisy situations are: when the TV is on, or the dishwasher / radio / music / washing machine are on, other children are playing or talking in the same room, at family gatherings, in a shopping centre or restaurant.

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

Initiate (e.g. vocalising to get your attention or to express need):

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Participate (e.g. taking turns in vocalising):

10. When you talk/sing to your child in the **car or in a bus or train**, does he/she respond to/follow what you are saying/singing? Responses may include quietening down, pointing, or looking towards something, or joining in with the song or responding verbally.

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

11. If you or a friend call your child when he or she is unable to see your face, does he/she **recognise** who is calling (For example, answer giving the persons name, or call out to the person using the person's name or say "...", is at the door).

OR

If you or a close family member speak/sing when your child is not looking, (For example, from the hallway or from behind) would he/she recognise who it was? (For example, they may quieten or calm down, gaze and smile or look animatedly for the speaker).

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

12. Does your child use the **telephone**? If yes, can he/she recognise the voice of a familiar person and/or have a conversation with the caller?

Please list examples of when your child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

ENVIRONMENTAL SOUNDS Question 13

13. What sounds, other than people's voices, has your child responded to or recognised in the last week? (For example, he/she may awaken to a door slamming or startle when something is dropped on the floor, stop sucking, quieten, look quizzical, search for the sound, imitate the sound or name the sound).

Please list examples that have occurred over the last week describing when and where they occurred.

T.E.A.C.H. Diary

Child's name:____________________

Date of Birth:____________________

Teacher completing TEACH:____________________

Date completed:____________________

Developed by Teresa Ching & Mandy Hill

Australian Hearing
National Acoustic Laboratories

Pre interview checklist

Did you observe the child for at least one week? **Yes / No**

During that week:

Has the child been wearing his or her hearing aids and/or cochlear implant?

Yes / No

Has the child been well/healthy? **Yes / No**

Have the hearing aids been working properly? **Yes / No**

If you answer No to any of the above questions, please contact the audiologist and re- schedule the appointment for your TEACH interview for:

____Date:________________________Time:_____________________

Observation dates

Please observe the child from_______________ to _______________

Guidelines for teachers

What is the TEACH?

- The TEACH (Teachers' Evaluation of Aural/oral performance of Children) is a questionnaire designed to record how the child is hearing and communicating with his/her hearing aids/cochlear implant at the moment. To complete the questionnaire you need to observe the child for at least one week, and record your observations for 11 questions. The topics covered include:
  - USE of amplification & Loudness DISCOMFORT
  - listening and communicating in QUIET
  - listening and communicating in NOISE
  - responsiveness to sounds in the ENVIRONMENT

- The TEACH is not a test. Remember even normal hearing people have some difficulty hearing in some situations. As the TEACH has been developed for use with babies, older children and children of different abilities, some of the questions may not be relevant to the child at this stage. Children's listening skills improve as they grow and develop and as they get more listening practice.

Why use it?

Your observations will be used to build a vivid picture of the child's auditory experience that helps the audiologist to evaluate the effectiveness of the child's hearing aids and fine tune them if necessary. It can also be used to track the child's progress.

How do I do it?

- Read through all the questions first so you know what you need to observe.
- Some of the questions have two alternatives. Use the alternative that gives examples that better describes the child's behaviour.
- **Carry your booklet around with you and write down your observations as you notice them.**
- Be as specific as you can when giving examples. For example, for Question 7 you might write:

  "When reading a story Olivia responded to, "Where's the plane?" and pointed out other objects as well on request the first time I asked."
- Write down as many examples as you can for each question. The audiologist will score each question based on the number of examples you give.
- If the baby/child doesn't respond record those examples too.
- If you have many examples of the same type of behaviour that's okay, just record the behaviour every time it occurs.
- Only record examples of behaviour that you have observed during the time period designated by the audiologist.

Helpful Hints

- Identify certain noisy and quiet times of the day to observe the child and collect examples.
  - **Quiet** times may occur when other children are working quietly and/or during story time.
  - **Noisy** times may occur during an activity such as art/craft, or in the playground or during sporting activities.
- Write down the examples as soon as you observe them. Usually by the end of the day it is hard to remember exact details.
- Don't forget to carry the booklet with you.

What happens next?

- The audiologist will arrange a time with you to collect the TEACH and go through it with you.
- They may ask further questions to help them to score accurately and to make sure they have a thorough understanding of the abilities and needs of the child.
- Results from the TEACH will enable you and the audiologist to gain a better understanding of specific difficulties the child may be experiencing. The information may then be used by the audiologist to finetune the child's hearing aids.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

USE OF DEVICE & LOUDNESS DISCOMFORT
Questions 1 & 2

1. I would like to know how often the child is wearing his/her hearing aids/cochlear implant. Can you tell me about the child's routine for wearing his/her hearing aids/cochlear implant in the last week?

2. Has the child complained about / or been upset by any loud sounds in the last week. (He or she may startle and/or cry, cover his/her ears, pull his or her hearing aids off, complain or show some other signs of discomfort)?

   Please list examples of when the child has *__or has not__* displayed the above behaviour over the last week, describing when and where they occurred.

LISTENING IN DIFFERENT SITUATIONS

Questions 3-10

3. You are in a **quiet** place with the child (For example he/she may be sitting next to you, behind you or across the room when the classroom is quiet). Does he or she respond to a familiar voice or to his or her name the first time you call, talk or sing when he/she is unable to see your face? For example, he/she may respond by smiling, looking up, by turning his/her head or by answering you verbally.

OR

You are in a **quiet** place with the child, (for example, he/she may be feeding with eyes closed or lying or sitting next to you in a quiet lounge/therapy room). Does he or she respond to a familiar voice the first time you call, talk or sing when he/she is unable to see your face? For example when you talk or sing, he/she may respond by quietening, cessation of sucking, increasing rate of sucking, opening eyes, eye widening or by looking.

Quiet situations may be when the other children are working quietly, or when any other people in the house/classroom are in another area or doing quiet activities.

Please list examples of when the child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

4. You are in a **quiet** place with the child (For example, he/she may be sitting next to you, behind you or across the room when the classroom/therapy room is quiet). When you ask him/her a simple question (For example, where's your foot?), or to do a simple task, (For example, look, clap, wave, point, pick up a toy, go and get your shoes etc) does he or she respond the first time you ask?

> **Quiet situations** may be when the other children are working quietly, or when any other people in the house/classroom are in another area or doing quiet activities.

Please list examples of when the child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

5. You are in a **noisy** place with the child (for example he/she may be sitting next to you, behind you or across the room when the classroom is noisy). Does he or she respond to a **familiar voice** or to his or her **name** the first time you call, talk or sing when he/she is unable to see your face? For example, he/she may respond by smiling, looking up or by turning his/her head or by answering you verbally.

OR

You are in a **noisy** place with the child, (for example, he/she may be feeding with eyes closed or lying or sitting next to you when other noise is present). Does he or she respond to a **familiar voice** the first time you call, talk or sing when he/she is unable to see your face? For example when you talk or sing, he/she may respond by quietening, cessation of sucking, increasing rate of sucking, opening eyes, eye widening or by looking.

Examples of noisy situations are: during group activities, in the playground, when music, radio or TV are playing in the background, during sport, when other children or family members are talking in the same room.

Please list examples of when the child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

6. You are in a **noisy** place with the child (For example, he/she may be sitting next to you, behind you or across the room when other children are talking). When you ask him/her a simple question (For example, where's your foot?) or to do a simple task, (For example, look, clap, wave, point, pick up a toy, go and get your shoes, etc) does he or she respond the first time you ask?

> **Examples of noisy situations** are: during group activities, in the playground, when music, radio or TV are playing in the background, during sport, when other children or family members are talking in the same room.

Please list examples of when the child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

7. When you read the child a story (or he/she listens to stories/songs on the TV, video or cassette tape), does he or she pay close attention to/ follow the line of the story? (For example, the child may ask questions about the story, answer your questions, discuss the story with you, sing along with the song).

OR

When you read the child a story (or he/she listens to stories, songs, nursery rhymes on TV, video or cassette tape) does he or she pay close attention to/follow the story? (For example, the child may look at the pictures or TV screen, turn the pages, lift the flaps, point to or label the correct picture, make the appropriate sounds for the object/animal depicted, or find objects, clapping, dancing, imitating, humming, or performing actions etc).

> **Hint:** Try showing the story book without reading or turning the TV volume right down to see if the child still responds when only the visual stimulus is present.

Please list examples of when the child has *<u>or has not</u>* displayed the above behaviour over the last week, describing when and where they occurred.

8. When you are in a **quiet** place with the child how often does he or she initiate and participate in conversation with you or with friends? (For example, does he/she need frequent repetition, does he/she respond to the topic appropriately, does he/she overhear conversation).

OR

When you are in a **quiet** place with the child how often does he or she vocalise to get your attention/ to express need/ or in response to you or family members or familiar persons? (For example, by varying voice pitch, trying to imitate sounds or words, taking turns in vocalising, pointing to objects while vocalising or naming them).

Quiet situations may be when the other children are working quietly, or when any other people in the house/classroom are in another area or doing quiet activities.

Please list examples of when the child has *<u>or has not</u>* displayed the above behaviour over the last week, describing when and where they occurred.

Initiate (e.g. vocalising to get your attention or to express need):________

____

____

____

____

____

____

____

____

____

____

Participate (e.g. taking turns in vocalising):________________

____

____

____

____

____

____

____

____

____

9. When you are in a **noisy** place with the child how often does he or she initiate and participate in conversation with you or with friends? (For example, does he/she need frequent repetition, does he/she respond to the topic appropriately, does he/she overhear conversation).

OR

When you are in a **noisy** place with the child how often does he or she vocalise to get your attention/ to express need/ or in response to you or family members or familiar persons? (For example, by varying voice pitch, trying to imitate sounds or words, take turns in vocalising, point to objects while vocalising or name them)

> **Examples of noisy situations** are: during group activities, in the playground, when music, radio or TV are playing in the background, during sport, when other children or family members are talking in the same room.

Please list examples of when the child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

Initiate (e.g. vocalising to get your attention or to express need): _______

____

____

____

____

____

____

____

____

____

Participate (e.g. taking turns in vocalising):______________________

____

____

____

____

____

____

____

____

____

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

10. If you or a family member call the child when he or she is unable to see your face, does he/she recognise who is calling (For example, answer giving the person's name, or call out to the person using the persons name or say "....", is at the door).

OR

If you or a close family member speak/sing when the child is not looking, (For example, from the hallway or from behind) would he/she recognise who it was? (For example, they may quieten or calm down, gaze and smile or look animatedly for the speaker).

Please list examples of when the child has *or has not* displayed the above behaviour over the last week, describing when and where they occurred.

ENVIRONMENTAL SOUNDS Question 11

11. What sounds, other than people's voices, has the child responded to or recognised in the last week? (For example, he/she may awaken to a door slamming or startle when something is dropped on the floor, stop sucking, quieten, look quizzical, search for the sound, imitate the sound or name the sound).

Please list examples that have occurred over the last week describing when and where they occurred.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Parents' Evaluation of Aural/Oral Performance of Children (PEACH)

Child's Name: ____________________

D.O.B: ____________________

Pre-Interview Questions

1	Child's use of hearing aids/cochlear implant*
2	Is your child upset by loud sounds

* If score ≤1 do not proceed, investigate cause.

PEACH Items

Compare current settings with previous settings (use scoring key 2)

No.	Scale	Item Description	Much worse	Worse	Same	Better	Much Better
3	Quiet	Respond to name in quiet	-2	-1	0	1	2
4	Quiet	Follow verbal instructions in quiet	-2	-1	0	1	2
5	Noise	Respond to name in noise	-2	-1	0	1	2
6	Noise	Follow verbal instructions in noise	-2	-1	0	1	2
7	Quiet	Follow story read aloud	-2	-1	0	1	2
8	Quiet	Participate in conversation in quiet	-2	-1	0	1	2
9	Noise	Participate in conversation in noise	-2	-1	0	1	2
10	Noise	Participate in conversation in transport	-2	-1	0	1	2
11	Quiet	Recognise voice of familiar persons	-2	-1	0	1	2
12	Quiet	Converse on the phone	-2	-1	0	1	2
13	Noise	Recognise sounds in the environment	-2	-1	0	1	2

	RAW Score	% Score
QUIET	(Q's 3+4+7+8+11+12) A	(A/24) x 100
NOISE	(Q's 5+6+9+10+13) B	(B/20) x 100
OVERALL	(A + B) C	(C/44) x 100

Comparison Conditions

Condition 1: ____________________

____

Condition 2: ____________________

____

AVERAGE Comparison Score (Add all scores, divide by 11)	

Comments: ____________________

Respondent: ______________________

Interviewer: ______________________

Date: ____________

Frequency of reported behaviour				
Never	Seldom	Sometimes	Often	Always
0	1	2	3	4
4	3	2	1	0

(Use scoring key 1)

Never	Seldom	Sometimes	Often	Always
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4

(Turn over for comparison scoring)

(See back for scoring keys)

PEACH Scoring Key 1

Frequency of Reported Behaviour

0 = Never no examples are given

1 = Seldom 1 or 2 examples are given and the behaviour occurs 25% of the time

2 = Sometimes 3 or 4 examples are given and the behaviour occurs 50% of the time

3 = Often 5 or 6 examples are given and the behaviour occurs 75% of the time

4 = Always more then 6 examples are given and the behaviour occurs >75% of the time

PEACH Scoring Key 2

Compare Current Settings with Previous Settings

- 2 = Much worse 2 or more examples to demonstrate why current amplification is much worse

- 1 = Worse 1 example to demonstrate why current amplification is worse

0 = Same no difference noted by parent

1 = Better 1 example to demonstrate why current amplification is better

2 = Much better 2 or more examples to demonstrate why current amplification is much better

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Teachers' Evaluation of Aural/Oral Performance of Children (TEACH)

Child's Name: ____________________

D.O.B: ____________________

Pre-Interview Questions

1	Child's use of hearing aids/cochlear implant*
2	Is the child upset by loud sounds

* If score ≤1 do not proceed, investigate cause.

TEACH Items

No.	Scale	Item Description
3	Quiet	Respond to name in quiet
4	Quiet	Follow verbal instructions in quiet
5	Noise	Respond to name in noise
6	Noise	Follow verbal instructions in noise
7	Quiet	Follow story read aloud
8	Quiet	Participate in conversation in quiet
9	Noise	Participate in conversation in noise
10	Quiet	Recognise voice of familiar persons
11	Noise	Recognise sounds in the environment

	RAW Score		% Score
QUIET	(Q's 3+4+7+8+10)	A	(A/20) x 100
NOISE	(Q's 5+6+9+11)	B	(B/16) x 100
OVERALL	(A + B)	C	(C/36) x 100

Comparison Conditions

Condition 1: ____________________

____

Condition 2: ____________________

____

Compare current settings with previous settings (use scoring key 2)				
Much worse	Worse	Same	Better	Much Better
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2
-2	-1	0	1	2

AVERAGE Comparison Score (Add all scores, divide by 9)	

Comments: ____________________

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Respondent: ______________________

Interviewer: ______________________

Date: ___________

Frequency of reported behaviour				
Never	Seldom	Sometimes	Often	Always
0	1	2	3	4
4	3	2	1	0

(Use scoring key 1)

Never	Seldom	Sometimes	Often	Always
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4
0	1	2	3	4

(Turn over for comparison scoring)

(See back for scoring key)

TEACH Scoring Key 1

Frequency of Reported Behaviour

0 = Never no examples are given

1 = Seldom 1 or 2 examples are given and the behaviour occurs 25% of the time

2 = Sometimes 3 or 4 examples are given and the behaviour occurs 50% of the time

3 = Often 5 or 6 examples are given and the behaviour occurs 75% of the time

4 = Always more then 6 examples are given and the behaviour occurs >75% of the time

TEACH Scoring Key 2

Compare Current Settings with Previous Settings

- 2 = Much worse 2 or more examples to demonstrate why current amplification is much worse

- 1 = Worse 1 example to demonstrate why current amplification is worse

0 = Same no difference noted by teacher

1 = Better 1 example to demonstrate why current amplification is better

2 = Much better 2 or more examples to demonstrate why current amplification is much better

Appendix F:
Verbal assent letters

Verbal Assent Form

- I am going to test your hearing.
- You do not have to participate
- You can stop any time during the test.

Test procedures:

1. When you hear a noise/sound through the earphones/speaker – even if the sound is very far away, you can put a block in the board.

2. When you hear me saying a word, you must show me the picture of the word you just heard.

3. I am going to put a soft tip in you ear. You do not have to do anything right now.

Verbale Toestemmingsvorm

- Ek gaan jou gehoor toets.
- Jy hoef nie as jy nie wil nie.
- Jy kan my stop gedurende die toets as jy nie verder wil deelneem nie.

Toets prosedures:

1. Wanneer jy ´n klank/muis wat piep hoor deur die oorfone/luidspreker – al is die klank baie sag, kan jy ´n blokkie insit.

2. Wanneer ek ´n woord sê, dan kan jy vir my wys na die prentjie van wat jy gehoor het.

3. Ek gaan nou ´n sagte spons in jou oor sit. Jy hoef nou niks te doen nie.