

A comparison of two non-linear prescriptive  
methods used with digital hearing instrument  
fittings in children.

**By**

**Michelle Reyneke**

Presented in partial fulfilment of the requirements for the degree  
M. Communication Pathology

**In the**

Department Communication Pathology  
Faculty of Humanities  
University of Pretoria

February 2004

## ACKNOWLEDGEMENTS

*“Thou wilt keep him in perfect peace, whose mind is stayed on thee: because  
he trusteth in thee”*

Isaiah 26:3 (King James Version)

*To my family and friends for their interest, encouragement and their  
reassuring belief in me. In particular, this thesis is in honour of my late mother  
– you will always be an inspiration.*

*Ms. Carina Avenant for your tutorial guidance and optimistic support in aid of  
this research project.*

*To Prof. Van der Linde and Mrs. Strydom for the statistical analysis and  
assistance with the interpretation of the results.*

*In appreciation of all the participants that participated in this study, and  
without whom this project would not have been possible.  
May you, and many others, benefit from the collective effort of research.*

## ABSTRACT

Advances in hearing instrument technology have permitted the development of non-linear prescriptive methods to prescribe amplification characteristics for the hearing-impaired individual. The dispenser's task in selecting the most appropriate prescriptive procedure for the young child is of utmost importance to ensure optimum hearing aid benefit for communication development. It was the aim of this study to compare and describe the effect of the two most widely used methods, DSL (i/o) and NAL-NL1, on speech recognition and loudness perception. An exploratory, descriptive research design was selected to realise this goal. Ten participants were selected using a convenient non-probability method of sampling. Articulation index calculations and a closed set speech recognition test were utilised in the evaluation of speech recognition, whereas functional gain results and loudness rating measurements provided an opportunity to describe loudness perception. The obtained results were analysed using the SAS (Statistical Analysis System). The study concluded that, although significant statistical differences existed in loudness perception, no statistical difference was observed in actual speech recognition measures. This effect may contribute to the individual amplification approaches of the two methods, which seem to reflect the uncertainties expressed by researchers as to the contribution of high frequency amplification to speech recognition in young children.

## KEY WORDS

non-linear, prescriptive methods, DSL (i/o), NAL-NL1, paediatric hearing aid fitting, digital hearing instruments

## OPSOMMING

Nie-lineêre versterkingstrategieë vir gehoorapparaat-instellings het hul ontstaan te danke aan die huidige ontwikkelinge in gehoorapparaat-tegnologie. Die selektering van die mees akkurate metode is van uiterste belang in die pediatriese populasie, aangesien goeie versterking essensieel is tot die ontwikkeling van kommunikasievaardighede. Hierdie studie het gepoog om die twee mees algemene strategieë, DSL (i/o) en NAL-NL1, te vergelyk en te beskryf in terme van hul effek op spraakherkenning en luidheidspersepsie. 'n Kwasi-eksperimentele, beskrywende navorsingsontwerp is geselekteer om hierdie navorsingsdoelstelling te bereik. 'n Nie-waarskynlike, gemaklikheid-steekproef is aangewend waartydens tien deelnemers geselekteer is. Spraakherkenning is geëvalueer deur die gebruik van die Artikulasie Indeks en 'n geslote spraak herkenningstoets. Funksionele wins resultate en 'n luidheidsbeskrywingstoets het die geleentheid gebied om luidheids-persepsie te evalueer en omskryf. Die resultate wat sodoende verkry is, is geanaliseer met die SAS (Statistiese Analisestelsel). Die studie het bevind dat alhoewel wesenlike verskille verkry is in terme van luidheidspersepsie, geen spraakherkennings-verskille opgemerk is nie. Hierdie verskynsel kan moontlik toegeskryf word aan die uiteenlopende versterkingsbenaderinge van die individuele strategieë. Dit reflekteer ook die huidige debat in resente navorsing wat die effek van hoëfrekwensie versterking spesifiek vir kinders betwis.

## SLEUTELWOORDE

Nie-lineêr, versterkingstrategie, DSL (i/o), NAL-NL1, pediatriese gehoorapparaatpassing, digitale gehoorapparate

## TABLE OF CONTENTS

|  |           |
|--|-----------|
| <b>1. INTRODUCTION.....</b>  | <b>7</b>  |
| <b>2. RESEARCH<br/>METHODOLOGY.....</b>  | <b>13</b> |
| 2.1 Aims.....  | 13        |
| 2.2 Research Design.....   | 13        |
| 2.3 Participants.....  | 15        |
| 2.3.1 Selection criteria<br>Figure 1. Mean value of hearing thresholds   |           |
| 2.4 Material and apparatus.....  | 17        |
| 2.4.1 Material and apparatus used for collection of data   |           |
| 2.4.2 Materials used for collection of data  |           |
| 2.4.3 Materials used for analysis of data  |           |
| 2.5 Procedure.....   | 22        |
| 2.5.1 Procedure for the collection of data   |           |
| 2.5.2 Procedure for recording of data  |           |
| 2.5.3 Procedure for analysis of data   |           |
| <b>3. RESULTS AND DISCUSSION.....</b>  | <b>28</b> |
| 3.1 The effect of DSL (i/o) and NAL-NL1 on speech recognition skills.....  | 28        |
| 3.1.1 Data obtained through predicted intelligibility measures<br>Table 3. Results of the t-test for predicted intelligibility |           |
| 3.1.2 Data obtained through speech recognition measures<br>Figure 2. Results of speech recognition measurement                 |           |
| 3.2 The effect of DSL (i/o) and NAL-NL1 on loudness perception.....  | 33        |
| 3.2.1 Functional gain tests results.....   | 33        |

Figure 3. Participant responses at 500Hz

Figure 4. Participant responses at 1kHz

Figure 5. Participant responses at 2kHz

Figure 6. Participant responses at 4 kHz

Table 4. Analysis of difference between DSL (i/o) and NAL-NL1 with respect to functional gain

|  |           |
|--|-----------|
| 3.2.2 Loudness rating<br>measures.....   | 38        |
| Figure 7. Results of loudness rating 45dB  |           |
| Figure 8. Results of loudness rating at 65dB   |           |
| Figure 9. Results of loudness rating at 90dB   |           |
| <b>4. SUMMARY AND CONCLUSION.....</b>  | <b>43</b> |
| 4.1 The effect of DSL (i/o) and NAL-NL1 prescriptions on speech recognition and<br>loudness<br>perception..... | 43        |
| 4.2 Evaluation of research<br>methodology.....   | 47        |
| 4.3 Research<br>implications.....  | 48        |
| <b>5. LITERATURE<br/>REVIEW.....</b>   | <b>52</b> |
| <b>6. APPENDIX.....</b>  | <b>60</b> |

## 1. INTRODUCTION

The importance of selecting the appropriate prescriptive procedure for especially children cannot be underestimated, as it remains the task of the dispenser to select the correct method based on the characteristics of the individual's hearing loss (Dillon, 2000). As hearing instrument technology develops, it is quite clear from past experience that prescriptive methods will develop in tandem. As Dillon (2000) points out, technological advances mean nothing unless the resulting characteristics can be matched to meet the needs of hearing-impaired individuals. Despite the continued developments in hearing instrument technology over the past years, there are often doubts that especially young children are appropriately fitted (Bess & Paradise, 1994). It seems that the availability of advanced technology does not necessarily imply optimum benefit to the young child. Ching (2002) points out that it is not the technology per se that ensures a successful fitting, but rather how dispensing audiologists program their instruments to deliver specified gain and output targets.

According to an earlier study by Hedley-Williams (1996), few dispensing audiologists use a systematic approach for selecting and fitting amplification for young children. Many also do not use current technologies in the fitting process. However, the current demands on the audiologist to provide an accountable service to young children, will continue to increase with improvements in early identification of hearing loss and changes in technology and amplification strategies (Stein, 1995; Bess & Paradise, 1994).

The task of selecting instruments for children seems challenging at best especially if one considers the well-documented contributing factors that have to be considered during the intricate rehabilitation process (Stach, 1998; Seewald, Ross & Spiro, 1985), one of which is the passive participation of the young child in the fitting process. In spite of the challenges, the dispensing audiologist is acutely aware of the importance of providing efficient amplification timeously for linguistic and psychosocial development, as it was described comprehensively in past and present literature (Martin & Clark, 2000; Stelmachowicz, 2000; Alpiner & McCarthy, 1993; Northern & Downs, 1991). This is especially true for young

children, as they will have to live with the prescribed fitting their audiologist decides on. The implicated long-term effect of this decision on a child's speech and language development is obvious.

Advances in hearing instrument technology have permitted the performance rendered by an individual's hearing aid to be much more closely matched to the desired amplification characteristics (Dillon, 2000). Individuals often present with hearing losses that vary widely in type, degree and configuration. Dispensers attempt to accommodate these individual audiological differences during the hearing aid selection process by matching the amplification characteristics of the instruments to the audiological characteristics of the individual. This calculated target amplification can be prescribed using a formula approach (Dillon, 2000).

These prescription formulae are often based on both threshold and supra-threshold audiometric data in its specification of gain and output requirements. More specifically, it calculates how much gain to provide at different frequencies and for different input levels. In addition to a gain prescription, it also specifies the output limitation characteristics of the instrument, in order to provide good audibility without causing discomfort (Cornelisse, Seewald & Jamieson, 1994; Ching, 2002). Especially considering the needs of hearing-impaired people, most prescriptive methods aim to amplify speech to a level where it is both audible and comfortable (Cornelisse, Seewald & Jamieson, 1995).

Continuous research into the amplification needs of people with hearing-impairment has led to the development of several prescriptive methods over the last twenty-five years (Dillon, 2000; Byrne, Dillon, Ching, Katsch & Keidser, 2001). One of the first attempts at prescribing amplification included a technique by Knudsen and Jones called mirroring of the audiogram as early as 1935 (Dillon, 2000). Since then, amplification strategies were significantly influenced by the advancements in hearing-instrument technology, typically characterized by a miniaturization of instruments and micro-processing (Bench, 1992), compression amplification (Lutermann, 1999) and multi-channel instruments (Staab & Lybarger, 1994). However, the undeniable breakthrough in technological development was



the introduction of digital signal processing, which allowed the user to take full advantage of residual hearing (Volanthen, 2000).

Both past and present technological developments were incorporated into modern day hearing instruments and prescriptive methods. Specifically the advantages that non-linear processing advocate currently (Moore, 1996, in Stelmachowicz, Dalzell *et al.*, 1996; Dillon, 1996, in Byrne, Dillon, Ching, Katsch & Keidser, 2001) has subsequently required the research and development of non-linear prescriptive methods. Non-linear prescription differs from its linear counterparts in that it usually specifies the gain-frequency response for several input levels (Dillon, 2000). The resulting effect will be that the average gain and configuration of the frequency response will vary depending on the input level, specifying an input-output (I-O) curve for several input levels. Despite the development of several non-linear prescriptive methods, the two most widely used methods (Ching, 2002) are Desired Sensation Level Input/Output (DSL i/o) and National Acoustics Laboratory Non-Linear 1 (NAL-NL1). Although the essential target of the two methods shows similarities, they differ in theoretical derivation and implementation (The DSL Report, 2001). Both of these methods will be discussed briefly, in an attempt to provide a clear overview of their respective rationales.

Seewald, Ross and Spiro initially described the DSL method in 1985 (Moodie, Seewald & Sinclair, 1994). This method served as the foundation of all the DSL versions that followed, with the main goal of amplifying speech to a level where it is intelligible, without being uncomfortable. The formulation was based on research with children, and although the DSL method may be applied as a prescriptive method suited to hearing-impaired persons of all ages, special considerations were implemented for use in the paediatric population (Seewald, 1994; <http://www.dslio.com>). The method attempted to take into account such factors as infant ear acoustics, audiometric assessment, electro-acoustic selection, fitting and verification (Moodie, Seewald & Sinclair, 1994).

In 1995 Cornelisse, Seewald, and Jamieson described a new DSL algorithm (Cornelisse, Seewald, Jamieson, 1995). This formula related to a wide range of input levels to the output of the instrument across frequencies, and was appropriately named the “ DSL

input/output formula". This formula corresponded to sensation levels originally described by previous DSL versions, and its use was recommended for both linear and non-linear circuitry, all hearing instrument types, and all ages (Cornelisse, Seewald, Jamieson, 1995).

In the DSL formulation, the desired sensation level of speech is calculated to approximate the most comfortable listening level contour (Cornelisse, Seewald & Jamieson, 1994). In its attempt to make the same range of sounds audible as for normal hearing individuals, it is necessary to both amplify and compress the acoustic signal at the same time. Through amplification the sounds below the auditory threshold of the individual is made audible. In contrast to amplification, the entire dynamic range of a normal hearing individual is made available to the hearing aid user by utilising compression (Cornelisse, Seewald & Jamieson, 1994). The input/output function will therefore typically display three areas: an area of linear gain, an area of compression and an area of output limiting (Cornelisse, Seewald & Jamieson, 1995). Conversely, the DSL (i/o) formula attempts to specify an output level within the hearing-impaired listener's dynamic range for each input level within the acoustic region of a normal hearing person. This means that the entire acoustic region that a normal hearing person will experience, is compressed into the residual auditory area of the hearing-impaired listener (Cornelisse, Seewald & Jamieson, 1995). Compression characteristics are applied to ensure that the upper limit of comfort is not exceeded. At the same time, minimal amplification is prescribed for high input levels that are below the input maximum (Cornelisse, Seewald & Jamieson, 1995).

According to the National Acoustics Laboratories (NAL) in Australia, most existing prescriptive methods for non-linear amplification strategies (for example DSL) are mainly based on the principles of *normalising loudness* (<http://www.nal.gov.au>). This means that the goal of these procedures is to amplify sounds for a hearing-impaired person to the same level on which it would be perceived by a normal hearing person. As this approach contradicts research from the National Acoustics Laboratory, the NAL-NL1 prescriptive method was devised in order to provide a gain-frequency response that intends to maximise speech intelligibility (<http://www.nal.gov.au>).

The earlier version of the well-validated NAL-R procedure provided a good estimate of the prescription which a non-linear method should provide for average input levels (Byrne, Dillon, Ching, Katsch & Keidser, 2001). NAL-NL1 was consequently intended as an extension of the established, validated NAL-R procedure (Byrne, Dillon, Ching, Katsch & Keidser, 2001) for application in non-linear instruments. NAL-NL1 shares the rationale of previous NAL methods, in that it attempts to maximise speech for a specified input level (Byrne, Dillon, Ching, Katsch & Keidser, 2001). It considers that variation in loudness levels is necessary to preserve the natural quality of speech, since speech amplified to the same level will probably be unacceptable (Byrne, Dillon, Ching, Katsch & Keidser, 2001). This non-linear prescriptive method adopted the approach to amplify speech to normal loudness, as a consequence of a lack of empirical data to indicate what loudness variation is desirable (Byrne, Dillon, Ching, Katsch & Keidser, 2001). Although loudness normalisation is therefore applied to overall speech levels, the formula does not attempt to normalise the levels of different frequency components of speech. It was also not designed to equalise loudness across frequencies as with the NAL-R method, but it does so only as a consequence of optimising the predicted speech intelligibility for a specified loudness (Byrne, Dillon, Ching, Katsch & Keidser, 2001). The gain prescribed for various input levels, is greatest for low level inputs and least for high level inputs. The amount of compression also varies with frequency and hearing loss, and compression additionally tends to be greater at high frequencies and larger hearing losses (Byrne, Dillon, Ching, Katsch & Keidser, 2001).

A distinctive characteristic of the NAL-NL1 method is that it may not prescribe amplification at the most extreme frequencies, as it is argued that the amplified signal at these frequencies contribute minimally to speech intelligibility. It furthermore tends to equalise loudness across frequencies only as a consequence of its aim to maximise speech understanding, while limiting overall loudness (Byrne, Dillon, Ching, Katsch & Keidser, 2001). This approach closely resembles the rationale of the NAL-R procedure.

From the description of the characteristics of DSL (i/o) and NAL-NL1, it is clear that they were designed with speech intelligibility and loudness considerations in mind. Although the formulation of both methods is well supported by research, very little comparative

evaluations are available to ascertain how well each of the methods works in practice. More specifically, the issue of which prescriptive method to use, specifically for children, is one that has not yet been resolved (Alpiner & McCarthy, 1993; Stelmachowicz, 2000; Byrne, Dillon, Ching, Katsch & Keidser, 2001).

Recent literature (Scollie, Seewald, Moodie & Dekok, 2000; Stelmachowicz, 2000; Byrne, Dillon, Ching, Katsch & Keidser, 2001) has clearly indicated the necessity for research on prescriptive methods, and their application in the hearing aid fitting of young children. In the words of Scollie, Seewald, Moodie & Dekok (2000: pp. 237): “Nonetheless, the relative success of alternative amplification strategies for young children with a hearing loss is a key issue, deserving of further study”. Seemingly due to the passive participation of young children in the fitting process, dispensing audiologists consequently require a more scientifically based approach in their attempts to set and achieve amplification targets.

The only way for the dispensing audiologist to make this formidable decision as to the best prescriptive method to use with the young child is by drawing conclusions from current research efforts. Conversely, this study will aim to compare DSL (i/o) and NAL-NL1 as two non-linear prescriptive methods used for fitting digital hearing instruments in children. The study will propose to determine and describe the difference in hearing aid fitting verification outcomes, when comparing DSL (i/o) and NAL-NL1 directly after the initial fitting of the hearing instruments.

## 2. RESEARCH METHODOLOGY

### 2.1 Aims

The main aim of this study is to determine and compare the effect of two non-linear prescriptive methods, for fitting digital hearing instruments in children, on aided verification and validation measures.

The following sub-aims are formulated in order to provide data in which the main aim can be realised:

- 2.1.1 To determine and compare the effect of two non-linear prescriptive methods on **speech-recognition skills**. This aim will be achieved by
  - i) Determining and comparing the effect of DSL (i/o) and NAL-NL1 on predicted speech intelligibility
  - ii) Determining and comparing the effect of DSL (i/o) and NAL-NL1 on actual speech recognition measures
  
- 2.1.2 To determine and compare the effect of two non-linear prescriptive methods on **loudness perception**. This aim will be realised in the following way
  - i) By determining and comparing the effect of DSL (i/o) and NAL-NL1 on functional gain measurements
  - ii) By determining and comparing the effect of DSL (i/o) and NAL-NL1 on loudness rating measurements

### 2.2 Research Design

Kerlinger (1970, in Smit, 1985) defines the research design concept as consisting of the plan, structure and strategy of the research. Researchers past and present (Smit, 1985; Leedy, 1997) furthermore pointed out that although the research design does not provide

answers to the research question, it equips the researcher to acquire the answers in a scientifically valid manner that has not been influenced by interference variables. Thus, the design of a study provides the “overall framework for collecting data” (Leedy, 1997: 94).

In order to achieve the aims of this study, an exploratory, descriptive research approach was selected. Neuman (1997) defines descriptive research as presenting an image of the particular traits of a situation, social setting or relationship. The purpose of descriptive research is therefore suited to achieve the main and sub-aims of this study, as it allows for a description of the verification and validation fitting results of the selected prescriptive methods. The study furthermore lends itself to an initial exploratory phase, as it deals with the phenomenon of cause and effect (Leedy, 1997: 230).

The study lends itself to a quasi-experimental design, as it lacks the key ingredient of a true experimental design, which is random assignment (Trochim, 2002).

Quantitative data collection methods were selected for this study, due to the nature of the data to be collected. During quantitative research, the variables to be studied are usually isolated, extraneous variables are controlled and standardized procedures are used to collect numerical data (Leedy & Ormrod, 2001). In addition, this type of data collection allows for statistical procedures to analyze and draw conclusions from the data.

It is of importance to consider the internal and external validity of any selected approach (Leedy, 1997). The internal validity is the extent to which the obtained data allows the researcher to draw accurate conclusions from it (Leedy & Ormrod, 2001). A controlled laboratory test environment, with uniformity in test equipment, is selected to control for environmental conditions. External validity is the extent to which the results apply to situations beyond the study. However, the opportunity to generalize the findings of this study to the total population is limited, due to the small sample size.

Guided by the selected research design described above, the methodology of the study is presented below.

## **2.3 Participants**

Ten participants were selected for this study, based on a non-probability convenience sampling approach (Leedy & Omrod, 2001). Participants were selected from both the clinical caseload at the Department of Communication Pathology, University of Pretoria, and learners from the Sonitus School for Hard of Hearing Children.

The selection was based on audiogram data obtained during hearing assessments. The case history information (revealing age and language proficiency), as well as audiological information was used in determining the candidacy of the participants for this study.

The following criteria for inclusion were set to ensure uniformity in the participant selection:

### **2.3.1 Selection criteria**

#### **2.3.1.1 Hearing loss configuration**

Participants with a bilateral, mild to moderately severe sensory-neural hearing loss were considered for the study. The specific criteria were selected in order to obtain uniformity in the hearing instrument selection, as all participants will be fitted with similar hearing instruments. Figure 1 provides an illustration of the mean values of hearing threshold from the selected participants.

#### **2.3.1.2 Age**

Children between the ages of three and fourteen years were selected for the study. In order to obtain reliability and consistency in audiometric data, it was decided to restrict the age group to an age where participation from the participants was possible.

The mean age of the participants was 7 years, 4 months, of which the youngest participant was 3 years, 7 months.

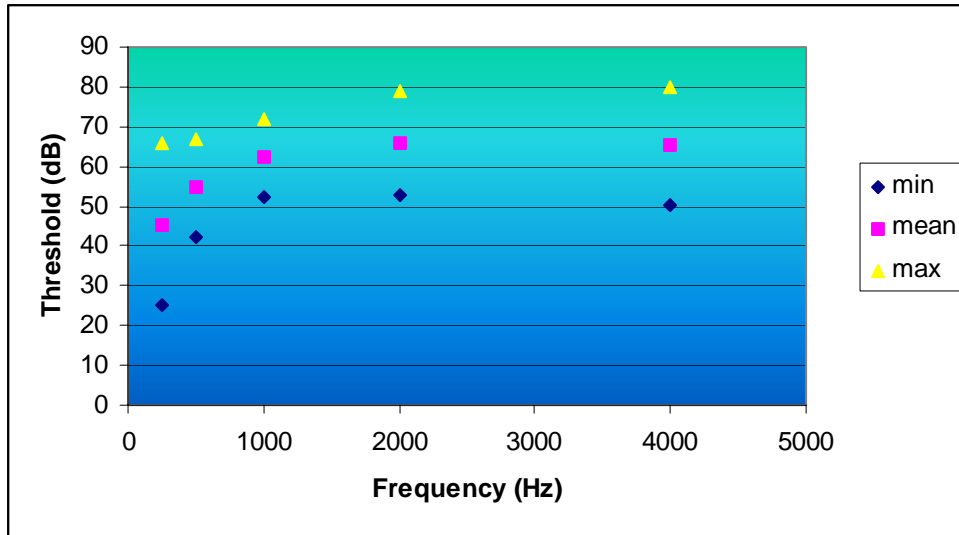


Figure 1: Mean value of hearing thresholds.

### 2.3.1.3 Language

Participants with some understanding of English were included in the study. Limited proficiency in the English language is considered necessary in order for the participant to understand the instructions given at the time of the assessment.

It is, however, a criterion with limitations in a multi-cultural country with subsequent multi-lingual clinical rehabilitation settings. Consequently, the use of a translator and/or the parents was considered in circumstances that necessitate the need. In addition, special care was taken to restrict the test measures to non-language-dependant material.

### 2.3.1.4 Cognitive Ability

In order to obtain consequent and reliable responses from the participants, normal cognitive ability was included in the selection criteria.

Normal cognitive ability was assumed, based on informally assessed adaptive behaviour, for example self-help and communication skills (Katz, 1994), observed during the initial audiometric testing.



## **2.4 Material and apparatus**

### **2.4.1 Material and apparatus used for collection of data**

#### **2.4.1.1 Test environment**

Aided sound field tests were measured in a double-walled audiometric sound booth with dimensions of 2.84m x 2.9m x 1.98m. One loudspeaker was mounted in each front corner of the test room. The test position was located at a height of 1m, 1.5m from the front of each speaker, such that the speaker orientation to the participants is 45° and 315° azimuth. Participants were seated on a standard office chair with a fixed height of 0.4m. Actual head position may have varied from participant to participant.

#### **2.4.1.2 Audiometer**

A clinical audiometer (Grason Stadler GSI-61) was used for the purpose of this study. The last date of calibration was January 2003, in accordance with ISO 389 specifications. The ambient noise level within the test chamber was less than 22dB.

#### **2.4.1.3 Hearing Instruments**

To achieve consistency in results and to minimize the influence of variables, it was decided that all participants were fitted with similar commercially available hearing instruments from one manufacturer. This multi-channel digital hearing instrument featured advance digital signal processing, speech sensitive processing techniques, multi-microphone technology, and high-resolution loudness and frequency response shaping methods.

Hearing instruments were fitted bilaterally, due to advantages like improved speech recognition in noise, better localization abilities and binaural summation (Northern & Downs, 1991; Mueller & Hawkins, 1990), and to ensure optimum fitting conditions. The instruments were fitted in accordance with the manufacturer's specifications, using a HIPRO box and multidimensional fitting software. The software automatically allows for compensations, due

to binaural summation and real-ear acoustics. The omni-directional microphone mode was used at the time of the evaluation. All automatic noise reduction systems were deactivated during the test procedure.

Custom-made ear moulds were provided to new users at the time of the fitting. Ear mould acoustics were selected for each participant, based on the individual audiological data available.

#### **2.4.1.4 Insertion Gain Analyzer**

A Fonix 6500 Insertion Gain Analyzer was used to obtain electro-acoustical verification of hearing instrument performance. This measure is used to ascertain that frequency-specific gain targets are met as calculated by the prescriptive method in use.

#### **2.4.1.5 Articulation Index Predictions**

An Articulation Index prediction for each of the test hearing instruments was calculated using aided real ear measurements from the FONIX 6500 Insertion Gain analyzer. This simple procedure is derived in accordance with the technique originally prescribed by Pavlovic (1989) and later supported by several researchers (Killion, Mueller, Pavlovic & Humes, 1993; Mueller & Killion, 1990).

This procedure provides a simple tool to assess the benefits of amplification to speech recognition. It is especially useful for predicting the relative amount of speech information available to the child in different listening conditions (for example unaided vs. aided) without having to perform repeated speech- recognition measures (Seewald, Hudson, Gagne & Zelisko, 1992).

The calculated index describes the available speech information without requiring word-recognition testing.

#### **2.4.1.6 Functional Gain Test**

Aided threshold sound field testing is a technique used to assess the amplification provided by a hearing aid by subtracting the participant's aided sound field threshold from his unaided sound field threshold (Macrae & Fraser, 1980). The limitations of this technique were documented in literature (Stelmachowicz & Lewis, 1988; Seewald *et al.*, 1987; Northern & Downs, 1991; Alpiner & McCarthy, 1993; Clark, 1996) but in most American clinical settings, it is still standard procedure (Martin & Clark, 2000).

It was decided to include this measurement in the study, as it is still widely used in South African practices. This measurement was used purely to demonstrate improvement in unaided versus aided conditions, thereby eliminating some of the disadvantages associated with this procedure, as described in literature (Macrae, 1982).

#### **2.4.1.7 Aided Speech Recognition Test**

As some of the participants were not English mother-tongue speakers, it was the aim of this test to evaluate aided speech recognition with not only words that are universal for different languages, but also words that do not require linguistic competence in this particular language.

Studies by Nelson (1973) and Gillham (1979) evaluated the early vocabulary of American and English babies. Similarities in not only the vocabulary of these babies were noted, but words with a high frequency were almost identical. The extent to which children brought up in different homes and in different countries use the same words, served as the rationale behind selecting these high frequency words as the basis for an aided test of speech recognition.

The words were selected in accordance with the developmental vocabulary list of The First Words Language Programme (Gillham, 1979). Ten words from the first-to-ten word stage, and words with the highest frequency of incidence, were selected for the test. The word list was administered in random order, using live voice. The words were preceded by an introductory phrase, in preparation of the word to follow. To ensure internal validity, the use

of live voice was monitored with VU-meter readings during the presentation of the word list to participants. Pictures and real-life objects were used to represent the selected words.

#### **2.4.1.8 Loudness Rating Measurement**

Setting appropriate output levels is especially difficult with young children, as obtaining thresholds of discomfort is often impossible due to the cognitive skill it requires to complete the task (Kawell, Kopun & Stelmachowicz, 1988; MacPherson *et al.*, 1991).

An adapted version of a technique designed by Kawell *et al.* (1988), using pictorial representation of loudness categories, was used to obtain loudness ratings at three input levels (45dB, 60dB and 90dB). This technique was modified slightly by reducing the number of pictures to three, in order to simplify the task.

The importance of this measurement can be demonstrated through the underlying rationale of both non-linear prescriptive methods, which is to restore loudness perception.

A summary of the main aim and sub-aims, described in relation to materials and procedures used for data collection, is presented in Table 2.

Table 2: Summary of aims

| <b>MAIN AIM:</b>   |   |   |  |
|--|---|---|--|
| <b>To determine and compare the effect of two non-linear prescriptive methods, for fitting digital hearing instruments in children, on aided verification and validation measures.</b>                                     |   |   |  |
| <b>SUB-AIMS:</b>   | <b>Material:</b>  |   | <b>Apparatus</b>   |
|  | Tests Utilized  | Stimulus Material   |  |
| <p>To determine and compare the effect of DSL (i/o) and NAL-NL1 on:</p> <p>1. Speech Recognition Skills</p> <p>i) Predicted intelligibility</p><br><p>ii) Speech recognition measures</p><br><p>2. Loudness Perception</p> | a. Articulation Index (AI) based on real ear measurements | Real-ear measurements obtained with a speech weighted composite noise signal will be used in calculations in accordance with the Pavlovic (1989) technique. | Fonix 6500 Insertion Gain Analyser   |
|  | b. Speech recognition testing                             | Ten words selected from First Words Language Programme (Gillham, 1979). Words will be presented in random order for each evaluation.                        | Grason-Stadler GSI-61 Audiometer with one loudspeaker each at a 45° and 315° azimuth to the participant. Five pictures and five real objects will be used to represent the selected words. |
|  | c. Functional gain testing                                | Pulsed pure-tone stimuli.   | Grason-Stadler GSI-61 Audiometer with one loudspeaker each at a 45° and 315° azimuth.  |
|  | d. Loudness rating measurements                           | Warble tones presented at 45dB, 65dB and 90dB. Three pictures are used for response indication.   | Grason-Stadler GSI-61 Audiometer with one loudspeaker each at a 45° and 315° azimuth.  |

## **2.4.2 Materials used for recording of data**

A Siemens-Fujitsu C series Notebook with the Microsoft Excel (Windows 2000) program was used for data recording.

## **2.4.3 Materials used for analysis of data**

The Statistical Analysis System (SAS) was used for qualitative analysis of the recorded data. All calculations were done using the SAS statistical package.

## **2.5 Procedure**

### **2.5.1 Procedures for the collection of data**

#### **2.5.1.1 Hearing Instrument Settings**

The initial hearing instrument settings were determined by the recommended fitting from the Connex version 4.3 (Siemens software) program. No modification was made for paediatric ear canal acoustics, as research has indicated that no systematic real ear to coupler differences are observed between values obtained with adults and children between the ages of 3 and 15 years of age (Nelson-Barlow, Auslander, Rines & Stelmachowicz, 1988). Furthermore, the greatest changes in ear canal length occur before 2 years of age (Bernstein & Kruger, 1986).

The software allowed for a 3 dB binaural summation compensation for bilateral hearing aid fittings. This compensation was allowed in the programming of the instruments. An acclimatization level adjustment was available in the software. This level-dependant feature allows for changes to frequency response and compression characteristics in order to facilitate first fit acceptance of the hearing instrument. However, due to the fact that changes were made to the original prescriptive methods during the activation of the acclimatization levels, this feature was excluded from the programmed settings.

Subsequently, an acclimatization level number four was selected which did not alter the chosen prescriptive method.

Application of the recommended settings from the Connexx programming software was employed to maintain a consistent fitting strategy across all participants. It was not necessary to allow for minimal changes in suggested settings typically associated with loudness discomfort and acoustical feedback.

### **2.5.1.2 Prescriptive method selection**

For the purpose of this study, an adapted manufacturer version of DSL (i/o) was used, specifically formulated with compatibility to multi-channel hearing instruments. This adapted version was approved by the author of the original DSL (i/o) prescriptive method, which was originally designed for use in single channel instruments.

NAL-NL1 was selected as the initial prescriptive method to be evaluated. Fitting data was stored in the software program for later analysis. After the first set of tests was performed, the instruments were reprogrammed in accordance with the DSL (i/o) prescriptive method, and the test battery repeated. The fitting parameters in accordance with the DSL (i/o) method were once again stored in the fitting software. A short break was allowed between test procedures for NAL-NL1 and DSL (i/o) to control for participant acclimatization and exhaustion. Furthermore, to ensure reliability of test results, the selection of a prescriptive method was in a reversed order for half the participants.

### **2.5.1.3 Real Ear Measurements**

Real ear-aided measurements (insertion gain) were obtained to verify electro-acoustically that the desired frequency response is achieved in accordance with the selected prescriptive method.

Prior to each test, an acoustic calibration of the probe tube microphone system was performed. Measurements were made using a speech-weighted composite noise signal

(Seewald, Hudson, Gagne & Zelisko, 1992) produced by the Fonix 6500 hearing aid analyzer. Ear canal sound pressure level (SPL) was measured using a probe tube microphone. The probe tube was inserted at a conservative depth of 10-15mm (Feigin, Kopun, Stelmachowicz & Gorga, 1989) for unaided measures, and 3mm in front of the ear mould for aided measures (Snik & Hombergen, 1993). The insertion depth of the probe was marked for an insertion reference. Participants were seated on their own while the tests were performed.

Data was analyzed by the Fonix 6500 system. Minor adjustments to the hearing instrument settings have not been necessary in order to achieve the optimal frequency response curve in accordance with the selected prescriptive method.

#### **2.5.1.4 Articulation Index (AI) Calculations**

The real ear insertion gain data (as obtained through the real ear measurements described previously) was used in Articulation Index (AI) calculations. No participation from the participants was required.

The index was calculated in accordance with the Pavlovic (1989) technique. The AI is an octave band procedure based on various approximations. One important approximation is that the speech peaks are all assumed to be 50dB HL, and the speech minima at 20dB HL. At each of the four frequency bands (500, 1000, 2000 and 4000 Hz) the speech peaks and speech minima values were increased by the amount of insertion gain at those frequencies. Neither of these values is allowed to exceed the discomfort level. The difference is then calculated between the speech peak and either the threshold, or the speech minima, whichever is the largest. Finally, the sum of the positive differences is divided by 120 in order to obtain the index.

For the purpose of this study, the index was calculated for both unaided and aided conditions, in order to obtain comparative data.



#### **2.5.1.5 Functional Gain Test**

Participants were seated in the test environment. Unaided sound field thresholds were obtained for five frequencies using the recommended ascending threshold determination procedure by ASHA (1978). Pulsed pure-tone stimuli were used as recommended by Berger, Hagberg & Rane in 1984. Stimuli were routed to both loudspeakers simultaneously. Aided sound field thresholds were subsequently determined with the hearing instruments in place.

#### **2.5.1.6 Aided Speech Recognition Test**

Participants remained seated in the test environment. Speech stimuli were presented to both ears at 65dB SPL in order to approximate the level of normal conversational speech (Berger *et al.*, 1984). The speech stimuli consisted of ten words from The First Word and Language Program (Gillham, 1979). The words were presented after the introductory phrase “Say the word...”. Speech recognition tests are only assessed in the aided condition, as it is the purpose of this study to compare aided hearing instrument fitting results.

#### **2.5.1.7 Loudness Rating Test**

Warble tones were presented at three intensities: 45dB, 65dB, and 90dB. The test signal was presented free field, and subsequently routed to both ears. After each presentation of the test signal, the participant was asked to rate the loudness of the signal in accordance with the pictorial representation thereof. Three pictures represented the following categorical scale: soft, average and loud.

Conditioning to the test material took place before the official testing. The aim of the conditioning was to demonstrate the procedure to the child, and to establish that the instructions were well understood.

### **2.5.2 Procedures for recording of data**

Data yielded for real ear measures in each participant were:

- Unaided Articulation Index (AI) for NAL-NL1
- Aided AI for NAL-NL1
- Unaided AI for DSL (i/o)
- Aided AI for DSL (i/o)

Data yielded for sound field measures in each participant were:

- Unaided free-field thresholds
- Aided free-field thresholds for NAL-NL1
- Aided free-field thresholds for DSL(i/o)
- Percentage correct speech discrimination for NAL-NL1
- Percentage correct speech discrimination for DSL(i/o)
- Loudness rating at three intensity levels for NAL-NL1
- Loudness rating at three intensity levels for DSL(i/o)

### **2.5.3 Procedures for analysis of data**

Results of all participants were analyzed as a group. The collected data was initially tabulated using the Microsoft Excel (Windows 2000) program.

A series of analyses of variance for repeated measures (ANOVA-R) is usually selected as data analysis procedure for similarly designed studies. During these procedures, all the test conditions of a study are taken into consideration (Leedy & Ormrod, 2001). In addition, the ANOVA-R reveals statistical significance for correlation coefficients using the 0.05 level of significance.

However, due to the small sample size of this study, it was necessary to make use of a non-parametric, distribution free method (Steyn, Smit, Du Toit & Strasheim, 1994). For this reason, a t-test of paired variables was selected. This type of statistical data analysis method lends itself to less strict assumptions regarding the distribution of the underlying

population from which the samples were drawn (Steyn, Smit, Du Toit & Strasheim, 1994). The t-test indicates exceedence probability (p) values, which is indicative of significant statistical differences when comparing variables. An exceedence probability (p) less than 0.01 is considered highly significant, and a p-value  $<0.05$  as significant (Neuman, 1997).

### 3. RESULTS AND DISCUSSION

The results of the study are described and discussed in accordance with the formulated sub-aims.

It was the aim of this study to determine and compare the effect of DSL (i/o) and NAL-NL1 on specifically speech recognition skills and loudness perception during hearing instrument verification measures.

Visual representations are used where possible, in order to provide a clear interpretation of the described results.

#### 3.1 The effect of DSL (i/o) and NAL-NL1 on speech recognition skills

##### 3.1.1 Data obtained through predicted intelligibility measures

The articulation index (AI) was used to evaluate the extent to which the two prescriptive methods (DSL i/o and NAL-NL1) contribute to predicted intelligibility of the speech spectrum.

The articulation index (AI) was determined in the unaided and aided condition for both DSL (i/o) and NAL-NL1. A t-test of paired variables was used in the statistical analysis to firstly compare unaided and aided AI results with DSL (i/o) prescriptions, secondly unaided and aided AI results with NAL-NL1 prescriptions, and finally aided AI results with DSL (i/o) with aided AI results with NAL-NL1 prescriptions.

The data of the right ear was treated independently from the data of the left ear. Since real-ear measurements were used in the AI prediction, differences in the unaided and aided response values of the two ears could have a significant effect on the final calculation, and for this reason it was taken into account.

Table 3 illustrates the difference in mean value, the t-value and exceedence probability obtained in the comparison of AI data.

**Table 3: Results of t-test for predicted intelligibility**

| <b>Variable</b>  | <b>Mean Value</b> | <b>t-Value</b> | <b>Exceedence Probability</b> |
|--|-------------------|----------------|-------------------------------|
| <b>Unaided and aided DSL (i/o) results for the left ear</b>  | -0.364            | -11.95         | < .0001                       |
| <b>Unaided and aided DSL (i/o) results for the right ear</b> | -0.4              | -9.53          | < .0001                       |
| <b>Unaided and aided NAL-NL1 results for the left ear</b>    | -0.245            | -7.09          | < .0001                       |
| <b>Unaided and aided NAL-NL1 results for the right ear</b>   | -0.239            | -5.24          | 0.0005                        |
| <b>Aided DSL (i/o) and NAL-NL1 results for the left ear</b>  | 0.119             | 2.71           | 0.0240                        |
| <b>Aided DSL (i/o) and NAL-NL1 results for the right ear</b> | 0.161             | 3.85           | 0.0039                        |

In the comparison of AI values for DSL (i/o), **highly significant statistical differences between unaided and aided AI results** were found. This illustrates that the articulation index prediction was significantly lower for the unaided condition than for the aided condition, which is expected from any effective amplification strategy. Similarly to the DSL (i/o) results, the articulation index for the unaided condition is significantly different from the aided condition with NAL-NL1 prescriptions. The significant difference in the predicted AI between results obtained in the aided and unaided condition is once again expected from effective amplification.

In addition, a **significant statistical difference** between aided DSL (i/o) and NAL-NL1 articulation index (AI) results was noted. Although the difference in exceedence probability is larger for comparisons of DSL (i/o) and NAL-NL1 in the aided condition than previous comparisons, the statistical difference is still highly significant and in favour of DSL (i/o).

The described results provide the opportunity to draw the following conclusions:

Firstly, in light of the determined articulation index data, it is clear that significant amplification is obtained with both DSL (i/o) and NAL-NL1 as prescriptive methods for hearing instrument performance. This conclusion can be drawn from the fact that highly significant statistical differences were noted from data obtained in both the unaided and aided condition.

Secondly, the difference in the aided AI results for DSL (i/o) and NAL-NL1 was significantly in favour of DSL (i/o) prescriptions. This is demonstrated through the negative value obtained. Conversely, the AI calculations predict that speech will be more intelligible with DSL (i/o) prescriptions than with NAL-NL1 prescriptions.

However, the AI values are based on real ear measurements of insertion gain. In turn, the target gain is prescribed by the selected prescriptive method. The more gain the selected method prescribed, the higher the value of the real ear insertion gain that could result in a higher AI value. Thus, a method prescribing an increased amount of gain could positively influence the AI results.

It is clear from the available literature that the two methods prescribe completely different amplification strategies (Byrne, Dillon, Ching, Katsch & Keidser, 2001). It is evident that NAL-NL1 prescribes the most gain for the mid-frequencies and least for the low frequencies (<500 Hz) and high frequencies (>3 kHz). In contrast, DSL (i/o) recommends significantly more gain than NAL-NL1 for the low and high frequencies. It is consequently not surprising to find differences in AI predictions, as the two methods vary significantly in terms of the prescribed target gain. The predicted AI in this instance indicates that DSL (i/o) will contribute more towards the intelligibility of speech than NAL-NL1. AI results are clearly influenced by the respective gain prescriptions of the individual formulas.

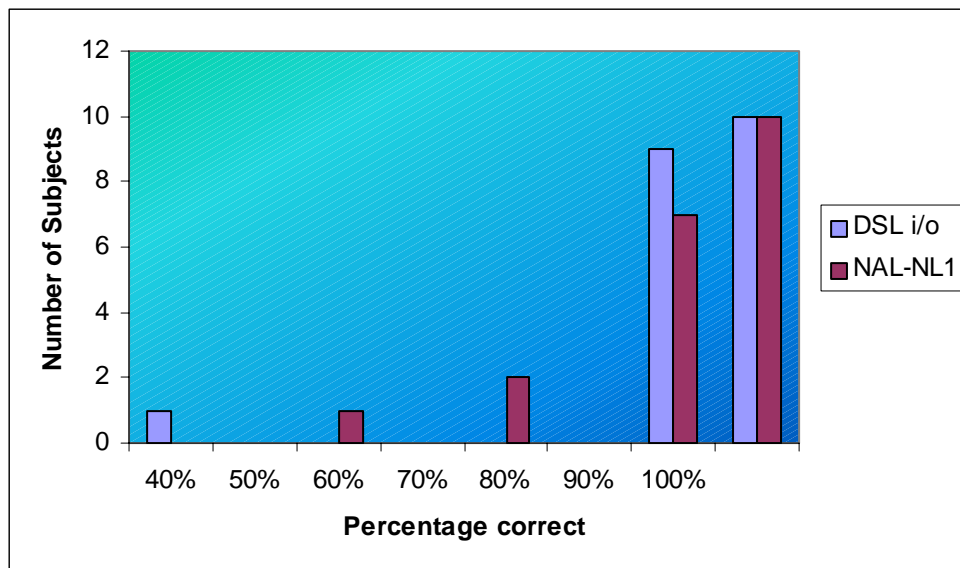
### **3.1.2 Data obtained through Speech Recognition Measures**

A closed set of familiar words was used to determine the extent to which each prescriptive method contributes to the recognition of speech.

Figure 2 illustrates the individual performances obtained by the participants in relation to the group.

Measurements with DSL (i/o) resulted in one participant obtaining a score of 40% words correct, and nine participants obtaining a score of 100% words correct. With NAL-NL1 as the prescriptive method, one participant obtained a score of 60% correct, two participants obtained 80% words correct, and seven participants obtained scores of 100% correct.

To determine the statistical significance of the scores obtained during speech recognition testing, a t-test of paired variables was performed. A t-value of 0.56 and an exceedence probability value of 0.5911 were obtained, indicating that no significant difference exists ( $p > 0.05$ ) between the scores obtained for DSL (i/o) and NAL-NL1. One could assume that a significant difference is present if the exceedence probability value ( $p$ ) is smaller than 0.05. The relatively large value of 0.5911 hence indicates that no significant statistical difference exists.



**Figure 2: Results of speech recognition measurement.**

The results obtained consequently indicate that no significant statistical difference in performance with the speech recognition test was noted, in comparing results obtained with DSL (i/o) and NAL-NL1.

Ching, Dillon and Katsch (2001) accentuates the fact that restoring speech understanding over the entire range of speech frequencies is undoubtedly one of the major goals of providing amplification to young children. The speech recognition result obtained in this study is certainly thought provoking, since one would not expect that the two methods, with vastly different amplification strategies as described by Byrne, Dillon, Ching, Katsch & Keidser (2001) could result in achieving the same amplification goal, which is to provide optimum speech intelligibility. It seems to reflect the current dispute within the research fraternity, whether increased amplification of high frequencies (mostly obtained with DSL i/o prescriptions) improves speech perception in young children or not (Hogan & Turner, 1998; Amos & Humes, 2000; Byrne, Dillon, Ching, Katsch & Keidser, 2001; Stelmachowicz, 2001).



### 3.2 The effect of DSL (i/o) and NAL-NL1 on loudness perception.

#### 3.2.1 Functional gain test results

A functional gain test at four important speech frequencies (500 Hz to 4 kHz) was used to demonstrate the softest sound audible to the participant in an acoustic environment.

##### 3.2.1.1 Participant response at 500 Hz

Figure 3 represents the response of participants at 500 Hz. It illustrates the intensity at which participants responded as a function of the number of participants responding at that particular frequency.

It is clear from Figure 3 that the softest audible sound at 500 Hz for the majority of respondents was from 25 to 30 dB. This is true for both DSL (i/o) where 60% of participants responded (n=6) and NAL-NL1 with a response rate of 50% (n=5). Ten percent of participants (n=1) responded at an intensity level higher than 30 dB for DSL (i/o). In contrast, thirty percent (n=3) responded at levels higher than 30 dB for NAL-NL1.

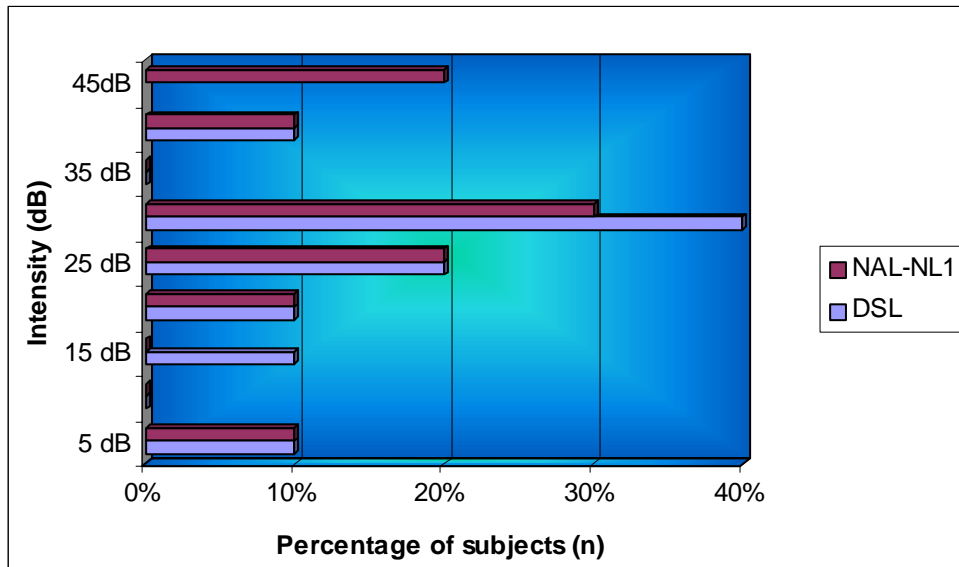


Figure 3: Participant responses at 500 Hz.

### 3.2.1.2 Participant response at 1 kHz

The response of participants at 1 kHz is represented in Figure 4. The intensities at which participants responded are illustrated as a function of the number of participants responding at the particular intensity.

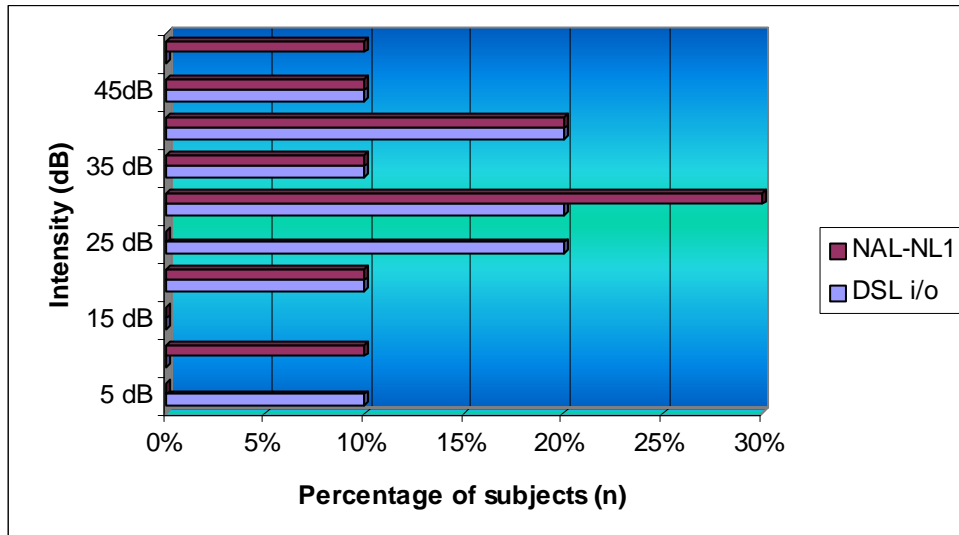


Figure 4: Participant responses at 1 kHz.

Most participants (30%) responded at 30dB with NAL-NL1. With DSL (i/o) an equal number of responses (20%) were recorded at 25 dB, 30 dB and 40 dB. For discussion purposes, the responses were classified into categories of responses higher than 30 dB and responses lower than 30 dB. It revealed that fifty percent of participants (n=5) responded at levels lower than 30 dB for NAL-NL1, and an equal number at levels higher than 30 dB. The highest response was recorded at 50 dB.

With DSL (i/o) prescriptions sixty percent of participants (n=6) responded at levels lower than 30 dB for DSL. The highest response was recorded at 45 dB.

### 3.2.1.3 Participant response at 2 kHz

In Figure 5 the intensities at which participants responded is again illustrated as a function of the number of participants responding at 2kHz.

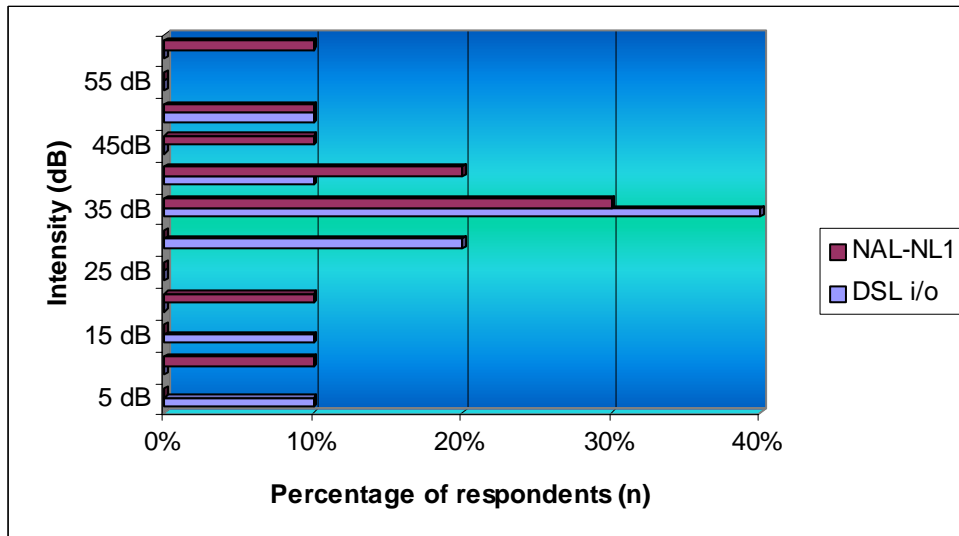


Figure 5: Participant response at 2 kHz.

At 2 kHz, the highest number of responses for NAL-NL1 (30%) and DSL (i/o) (40%) was recorded at 35 dB. With NAL-NL1, forty percent (n=4) of participants responded at intensity levels higher than 35 dB, with the highest intensity level recorded at 60 dB. Only 20% of participants responded at levels higher than 35 dB with DSL (i/o).

#### 3.2.1.4 Participant responses at 4 kHz

Figure 6 represents the responses of participants at 4000 Hz. The intensity at which participants responded is once again illustrated as a function of the number of participants responding at the respective intensity levels.

At 4 kHz, the highest number of participants (30%) responded at 40 dB with DSL (i/o), and at 60 dB with NAL-NL1. Only 20% of participants (n=2) responded at levels higher than 40 dB with DSL (i/o), as opposed to 70% of participants (n=7) with NAL-NL1.

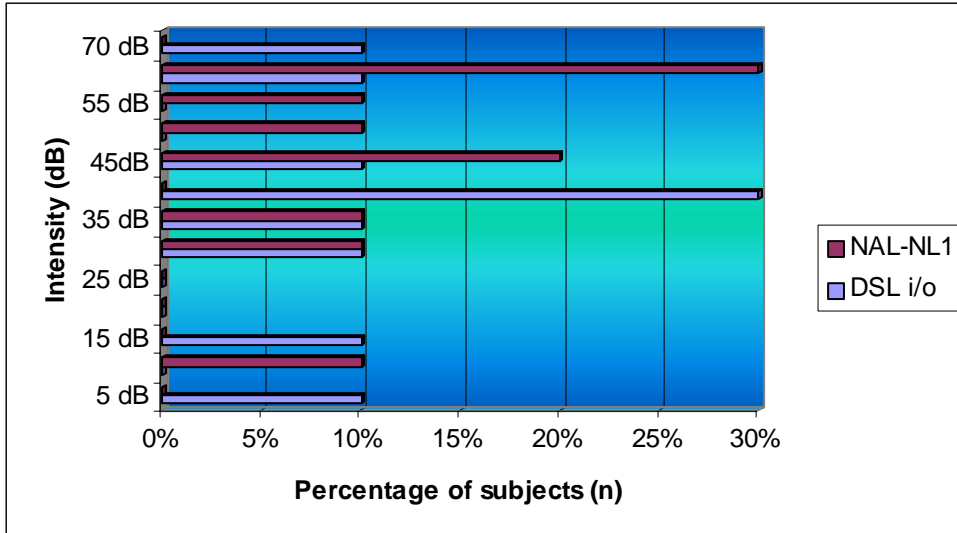


Figure 6: Participant responses at 4 kHz.

The highest intensity level recorded with DSL (i/o) was one participant (10%) at 70 dB. Three participants (30%) responded at 60 dB with NAL-NL1.

### 3.2.1.5 Analysis of differences

A t-test of paired variables was used to investigate whether significant statistical differences exist between results obtained with DSL (i/o) and NAL-NL1 at the four individual frequencies.

The results obtained from the t-test performed are tabulated as follows in Table 4.

Based on the exceedence probabilities and mean values depicted in table 4, the following conclusions can be drawn. Firstly, no significant statistical difference of loudness perception exists between the respective methods at 500 Hz. Conversely, the softest sound audible to participants at 500 Hz was very similar with both prescriptive methods. In sharp contrast to results obtained at 500Hz, significant statistical differences were noted at 1 kHz, 2 kHz and 4 kHz. Thus, clear differences in the perception of soft sounds for the two methods were noted at these frequencies. The negative mean value obtained furthermore indicates results in favour of the DSL (i/o) method. The results consequently indicate that

lower functional gain thresholds were obtained for DSL (i/o) than for NAL-NL1 at these frequencies.

**Table 4: Analysis of differences between DSL (i/o) and NAL-NL1 with respect to functional gain.**

| <b>Variable</b>                            | <b>Mean value</b> | <b>Standard deviation</b> | <b>Exceedence Probability (Pr)</b> |
|--|-------------------|---------------------------|------------------------------------|
| <i>Functional gain threshold at 500 Hz</i> | -4.5              | 6.4334                    | 0.0543                             |
| <i>Functional gain threshold at 1 kHz</i>  | -3.5              | 4.7434                    | 0.445                              |
| <i>Functional gain threshold at 2 kHz</i>  | -6                | 6.5828                    | 0.181                              |
| <i>Functional gain threshold at 4 kHz</i>  | -7                | 9.7753                    | 0.0498                             |

In light of the described results, one can therefore assume that participants were able to perceive sounds at lower intensity levels with DSL (i/o) prescriptions than with NAL-NL1 in the mid to high frequency range. Soft sounds in the low frequency area (500Hz) were not perceived to be different for the two prescriptive methods.

Despite the limitations of functional gain measurements reviewed in current literature (Stelmachowicz, Hoover, Lewis & Brennan, 2002) it was decided to use functional gain thresholds to determine and compare the softest sound audible to the participants in an acoustic environment. Similarly to the AI results, the functional gain results obtained can once again be attributed to the opposing amplification strategies of DSL (i/o) and NAL-NL1 (Byrne, Dillon, Ching, Katsch & Keidser, 2001) where DSL (i/o) prescribes more high frequency amplification. It is obvious that with DSL (i/o)'s increased sensation levels in the high frequency area, participants were able to respond at much lower intensity levels than with NAL-NL1 prescriptions.

At this point, it is important to remember that a limitation of functional gain measurements is its inability to accurately indicate gain for typical speech inputs in non-linear instruments (Stelmachowicz & Lewis, 1988). The results obtained should as a consequence be carefully interpreted, especially when pertaining to speech recognition. Thus, in support of the lower thresholds obtained with NAL-NL1 prescriptions, the actual contribution of increased high frequency sensation levels towards improved speech recognition, has not yet been resolved by current research (Hogan & Turner, 1998; Amos & Humes, 2000; Byrne, Dillon, Ching, Katsch & Keidser, 2001; Stelmachowicz, 2001). However, some studies on the comparison of prescription targets to the preferred listening levels of children (Scollie, Seewald, Moodie & DeKok, 2000) seem to indicate that DSL (i/o) seems to underestimate the gain preferred by participants less so than with NAL-NL1 prescriptions.

This raises the question of whether the increased sensation levels obtained with DSL (i/o) prescriptions, and possibly preferred by participants, actually contribute more towards speech recognition than NAL-NL1 prescriptions. In light of the conflicting ideas of current research cited, this question remains difficult to answer.

### **3.2.2 Loudness Rating Measures**

Non-linear prescriptive methods aim to restore the abnormal loudness growth often associated with sensorineural hearing loss. It was consequently the aim of this study to determine and describe the loudness perception of the participants with both prescriptive methods.

Loudness ratings were obtained at three intensities (45 dB, 65 dB and 90 dB), and three loudness judgement categories were provided for selection (soft, average and loud). An additional category was created for participants not responding appropriately (NR = no response).

The results obtained with DSL (i/o) and NAL-NL1 prescriptions during the loudness rating measurements, will be described in accordance with the results obtained at the loudness categories for soft sounds (45 dB), average sounds (65dB) and loud sounds (90dB).

### 3.2.2.1 Loudness rating at 45 dB

Figure 7 illustrates the participants rating of a 45 dB warble tone for both prescriptive methods.

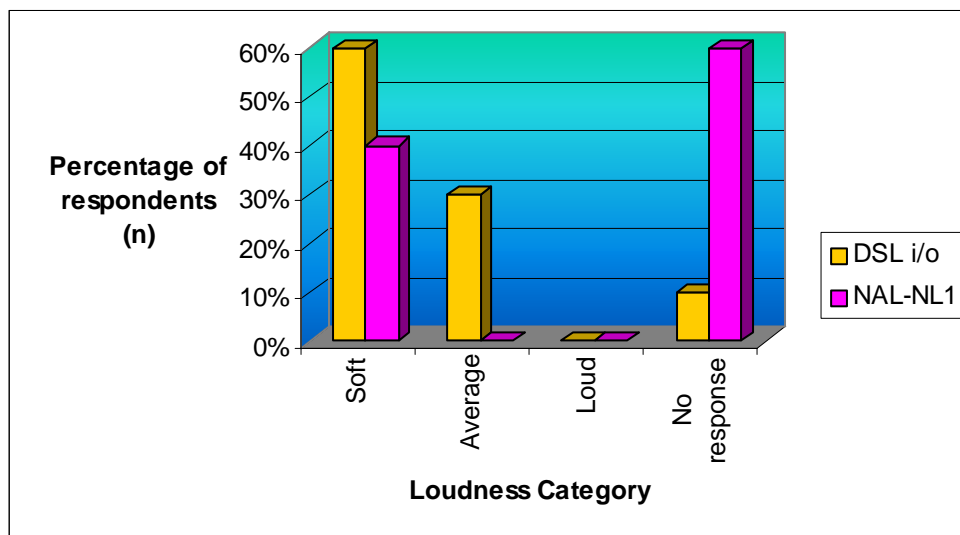


Figure 7: Results of loudness rating at 45 dB.

Sixty percent of participants (n=6) described a 45 dB warble tone as soft with DSL (i/o) prescriptions. Thirty percent of participants (n=3) rated it as average. One participant did not respond at all.

With NAL-NL1 as the prescriptive method, 40% of the participants (n=4) described the 45 dB warble tone as soft. The majority of participants (n=6) did not respond.

### 3.2.2.2 Loudness rating at 65 dB

A summary of participants' responses at 65 dB is provided in Figure 8.

Loudness judgements obtained with DSL (i/o) indicated that the majority (50%) of participants (n=5) rated the 65 dB signal as average. Ten percent of participants (n=1) rated it soft, and twenty percent of participants (n=2) as loud. Two participants did not respond.

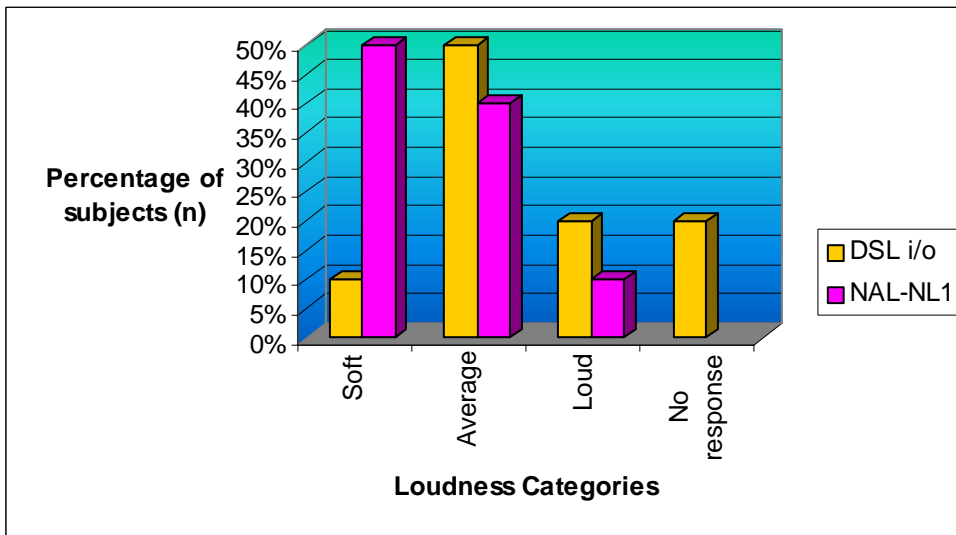


Figure 8: Results of loudness rating at 65 dB.

Most participants (50%) described the 65 dB signal as soft and average (40%) with NAL-NL1 prescriptions. One participant (n=1) rated the signal as loud.

### 3.2.2.3 Loudness rating at 90 dB

Participants' responses to the 90 dB signal are illustrated in Figure 9.

Most of the participants (70%, n=7) described the 90 dB signal as loud with DSL (i/o) prescriptions. Thirty percent of the participants (n=3) rated the signal as average.

Results obtained with NAL-NL1 prescriptions indicated that 50% of the participants (n=5) rated the 90 dB signal as average and 50% (n=5) as loud.

All participants responded to the 90 dB signal.



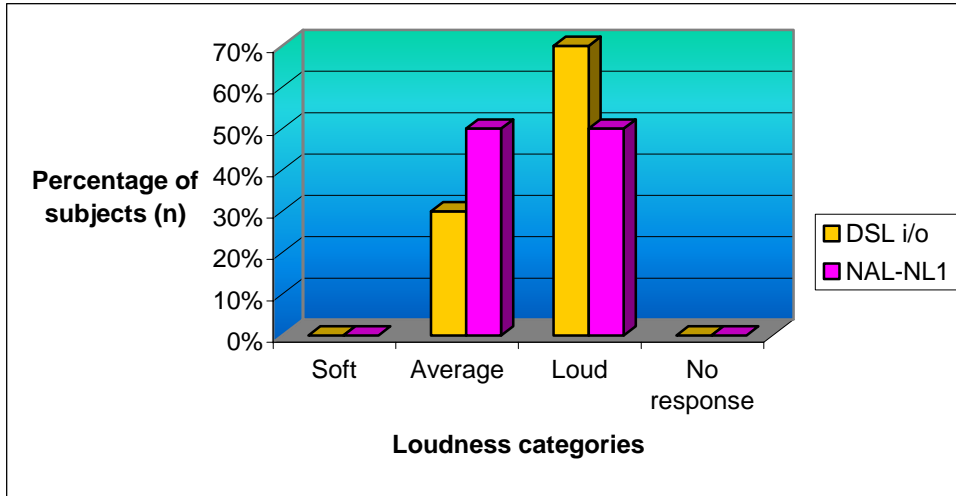


Figure 9: Results of loudness rating at 90 dB.

The results obtained at the respective frequencies clearly indicate that DSL (i/o) prescriptions result in a more accurate loudness rating of non-speech stimuli over a range of input levels than NAL-NL1 prescriptions. It is also interesting to note that NAL-NL1 prescriptions were almost consistently rated one loudness category “softer” than the required response. That is, soft input levels were in most cases not responded to, average inputs were generally rated as soft, and half of the participants rated loud input levels as average.

It is assumed that the difference in amplification targets for both methods as described by Byrne, Dillon, Ching, Katsch & Keidser (2001) may contribute to the results as DSL (i/o) recommends a higher overall listening level (Scollie, Seewald, Moodie & Dekok, 2000). Other investigations of DSL (i/o) targets by Jenstadt et al. (1999, 2000) concluded that for speech across a wide range of input levels, DSL (i/o) provided acceptable and normalised loudness ratings. Similarly, studies also indicated that NAL-RP (the basis of the NAL-NL1 formulation) closely agreed with children’s preferred gain (Snik & Stollman, 1995; Ching, Newall & Whitney, 1997). This preferred gain or preferred listening level (PLL) may be of significant use in the comparison of prescription methods as studies have indicated its relation to both listening comfort and speech intelligibility (Scollie, Seewald, Moodie & Dekok, 2000).

Despite the inconclusive reports from researchers, it is clear from the results of this study that DSL (i/o) approximates the loudness growth function more effectively than NAL-NL1. Conversely, participants were more able to correctly rate the loudness category of varied inputs. Whether this may be attributed to the higher input levels prescribed by DSL (i/o) is speculated however.

## 4. SUMMARY AND CONCLUSION

### 4.1 The Effect of DSL (i/o) and NAL-NL1 Prescriptions on Speech Recognition and Loudness Perception

The research question posed by this study was to describe the differences in speech recognition and loudness perception obtained with hearing aid fittings in young children when using the two non-linear prescriptive methods, DSL (i/o) and NAL-NL1.

The results obtained indicated that a significant statistical difference was obtained in articulation index (AI) results between unaided and aided prescriptions of DSL (i/o) and NAL-NL1. However, AI predictions were in favour of DSL (i/o) prescriptions. Despite the differences in AI predictions of speech intelligibility, no significant statistical differences were noted in speech recognition measures. Functional gain measures revealed significant statistical differences favouring DSL (i/o) prescriptions at 1kHz, 2kHz and 4kHz. Finally, loudness rating measurements were mostly in favour of DSL (i/o) with sixty percent of participants accurately describing a 45dB signal as soft, fifty percent describing a 65dB signal as average and seventy percent a 90dB signal as loud.

The findings obtained and described in this study provide the opportunity to draw the following conclusions:

1. Although speech intelligibility predictions (for example articulation index calculations) favoured DSL (i/o) prescriptions, no significant statistical difference was noted when comparing the actual **speech recognition** measurements obtained with both prescriptive methods.
2. The DSL (i/o) prescription resulted in lower high frequency functional gain thresholds and more accurate loudness ratings of non-speech stimuli at various input levels. The amplification strategy of the two methods is proposed as the cause of the differences noted in **loudness perception**, as NAL-NL1 consistently resulted in lower sensation levels.

*It is interesting to note that the significant statistical difference observed in the sensation levels did not result in a difference in speech recognition.* This seems to be consistent with some debates in current research (Stelmachowicz, 2001; Ching, Dillon & Katsch, 2001) on amplification requirements for young children. These conflicts depict the two schools of thought that are predominant in the current issues in paediatric hearing aid fitting: whether high frequency amplification indeed contributes to better audibility or not. The developers of prescriptive methods evidently also dispute this issue (Cornelisse, Seewald & Jamieson, 1994; Byrne, Dillon, Ching, Katsch & Keidser, 2001). From the previously described comparison of DSL (i/o) and NAL-NL1, it is clear that DSL (i/o) generally prescribes more high frequency gain than NAL-NL1. The question still remains, however, whether the increased amplification of high frequencies improves speech recognition in young children.

In studies with adults, Hogan and Turner (1998) found that very little benefit was received from adding audible speech when the hearing loss was 60dB or worse in the 4000Hz region. In a similar study Ching, Dillon and Byrne (1998) claimed that severely impaired listeners were less proficient in using speech information contained in the audible signal. The authors concluded that amplifying high frequencies to high sensation levels could, in fact, be detrimental to speech intelligibility. It was also reported that, although speech scores improved with increases in sensation level and bandwidth extensions, reduced performance was noted with the broadest bandwidth (beyond 5600Hz) and highest sensation level. Their finding seemed to be in agreement with results reported by Amos and Humes (2000), which supports the probability that when hearing loss is extreme at the high frequencies, it may not be beneficial to provide audible signal at those frequencies.

From these studies with adults, two questions come to mind. Firstly, can we provide children with audibility similar to that of adults? Secondly, what is the importance of high-frequency amplification, specifically for young children?

Some past and present research indicated that age has an influence on several auditory perceptual tasks (Ching, Dillon & Katsch, 2001), and that normal hearing children required more audibility than adults, in order to achieve similar performance. However, some

authors cautioned that developmental changes in speech perception appear to be related to phonological and linguistic development, rather than sensory capacity (Hnath-Chisolm, Laipply & Boothroyd, 1998). As a consequence, the authors state that a conclusion can still not be made that young children require more high frequency amplification. Studies by Byrne, Parkinson & Newall (1991) and Ching, Hill, Birtles & Beecham (1999) continued to demonstrate that in children with a profound hearing loss, less high frequency gain is preferred. In opposition to the findings of the mentioned studies, several researchers support the importance of high frequency amplification in order to achieve improved speech recognition in young children. Stelmachowicz (2001) motivates the provision of high frequency amplification to young children, as hearing loss often results in delayed vocabulary development, verbal abilities, reasoning skills, and the delayed development and/or acquisition of language rules (for example plurality).

Although the importance of high frequency amplification can therefore not be denied, it is important to interpret the results of these past studies with caution. Not only have most of the studies been performed on adults only, but aspects like high inter-participant variability and disagreement regarding the degree and/or configuration of hearing loss limits the interpretation of the results (Stelmachowicz, 2001). In addition, the research methodology and test stimuli used in the studies often vary. This study attempted to take into account the described pitfalls in research methodology, in an attempt to resolve the issue of whether increased high frequency amplification (used in DSL i/o prescriptions) leads to greater audibility.

Ching, Dillon & Katsch (2001) attempt to answer this question by differentiating desensitisation of the cochlea from deprivation of auditory stimuli. Desensitisation is described as cochlea damage leading to a deterioration of frequency and temporal resolution ability in the high frequencies. This degraded ability to extract information in the high frequency area is not usually overcome by providing substantially more high frequency emphasis. Stelmachowicz (2001) on the other hand, refers to research from Moore, Huss, Vickers, Glasberg & Alcantarra (2000) that indicated the presence of possible dead regions in the cochlea. The author feels that listeners with these presumed

dead regions in the high frequency area would not be expected to benefit from high frequency amplification anyway.

Although the questions to the provision of high frequency amplification through prescriptive methods are clear, the answers are not. This study indicated that the increased amplification of the high frequencies through DSL (i/o) prescriptions resulted in increased sensation levels and accurate loudness judgements. However, it did not indicate improved speech recognition. It therefore merely suggests that the increased gain provided by DSL (i/o) prescriptions allowed for lower sensation levels. Whether the increased high frequency gain contributed to speech recognition remains uncertain. Especially if one considers that the same speech recognition results were obtained with NAL-NL1 prescriptions, despite the perception that NAL-NL1 slightly underestimated the gain required by the participants for accurate loudness judgements. Perhaps with a collaborative research effort, all the contributing factors affecting high frequency amplification, such as the effect of possible dead regions (Stelmachowicz, 2001) or desensitisation (Ching, Dillon & Katsch, 2001) of the cochlea, can be investigated more extensively.

Despite the current uncertainty as to which argument to support, the importance of selecting the appropriate prescriptive procedure cannot be underestimated (Dillon, 2000), and it remains the task of the dispenser to select the most suitable prescriptive method. Yet, the task of selecting amplification characteristics for children seems challenging at best. Especially if one considers the well-documented contributing factors that have to be considered during the intricate rehabilitation process (Stach, 1998; Seewald, Ross & Spiro, 1985). In spite of the challenges, the dispensing audiologist is acutely aware of the importance of timeously providing efficient amplification for linguistic and psychosocial development, as it was described comprehensively in past and present literature (Martin & Clark, 2000; Stelmachowicz, 2000; Alpiner & McCarthy, 1993; Northern & Downs, 1991). This is especially true for young children, as they will have to live with the prescribed fitting on which their audiologist decides. The implicated long-term effect of this decision on a child's speech and language development is quite obvious.

When determining amplification targets for children, a prescriptive method is a good starting point, as it uses threshold data to set targets for gain, output and compression. Most generic prescriptive methods today are also available in the programming software of hearing instrument manufacturers. This critical decision as to which prescriptive method to use should consequently be based on the most recent literature and research available to the dispenser. It is important to keep in mind that, even when a prescription method is used, it should only be regarded as a general statistical rule. As they are developed for the average listener, it is unlikely to be perfect for all situations and individuals.

*It therefore continues to remain the responsibility of the dispenser to select the most appropriate method, and to use this as a base from which to make individual adjustments. The results of the fitting should then be assessed through current verification and validation protocols.*

#### **4.2 Evaluation of Research Methodology**

A critical review of the study is required in order to determine the value of the results obtained.

The difficulties often cited with paediatric research, such as limited subject participation, presented in this study as well. In order to obtain valuable and consistent results, the participant criteria were limited to an age group where participation was likely. As Van Vliet (2002) describes, working with hearing-impaired children requires skill, flexibility and patience. Individual differences in responses were allowed for, and rest periods were scheduled to maximise performance. Despite these attempts to accommodate such a young population, the complexity of test material had to be limited, resulting in a lack of generalisation to other studies.

Neuman (1997) recommends a large sample, as it allows for reliable generalizations from a broader range of perspectives. This was difficult to achieve with the present study, as participants were selected with the same degree of hearing loss, and with no prior exposure to any of the evaluated prescriptive methods.

It was furthermore essential to use test materials that would elicit legitimate responses. Due to the multi-cultural characteristics of the participants and the anticipated language delays often associated with hearing-impaired children, the test material was carefully selected. A closed test of speech recognition was used to limit the options available to participants, thus simplifying the task. It was also a prerequisite of the study that audiometric thresholds should be available. Obtaining functional gain thresholds was consequently possible. Only the loudness judgement task required some conditioning prior to the task. Despite the training provided, some participants continued to find it difficult. Unreliable responses in sensation areas where the researcher expected appropriate responses, were indicated with the no-response category. A disadvantage of the test materials used, is that, although appropriate for this study, these materials cannot be generalised to other studies. It is clear from past research (Byrne, Dillon, Ching, Katsch & Keidser, 2001) that the research methodology often differs, which does not allow the results to be accurately compared.

In spite of the limitation mentioned, the value of the study lies in the fact that it addresses a specific need identified in current research (Scollie, Seewald, Moodie & Dekok , 2000; Stelmachowicz, 2001; Byrne, Dillon, Ching, Katsch & Keidser, 2001) and is consequently a very relevant issue in the field of paediatric hearing aid fitting.

Special care was taken to apply strict selection criteria, in an attempt to obtain the most homogeneous participant group possible.

### **4.3 Research Implications**

Paediatric hearing aid requirements is clearly an unresolved topic, with several authors expressing the necessity for research on prescriptive methods and their application in the hearing aid fitting of young children:

- Scollie, Seewald, Moodie & Dekok (2000) reported that the relative success of alternative amplification strategies for young children with a hearing loss is a key issue, deserving of further study.



- Stelmachowicz (2000, 2001) expresses concern as various advanced hearing instrument technologies were developed using information from adults with a hearing loss. She continues that an urgent need exists for a well-defined, scientifically-based approach for the selection and fitting of amplification in children.
- Byrne, Dillon, Ching, Katsch & Keidser (2001) cite the complexities of determining optimum amplification, and the consequent validation of prescriptive methods. Conversely, validation research is encouraged.

The answers to many questions posed by current research pertaining to hearing aid fitting in young children are not clear. Consequently, this study has specifically attempted to provide some insight into the use of prescriptive methods in young children with a hearing loss, by drawing conclusions from the results obtained. More importantly, and in agreement with other researchers, it aims to provoke the thoughts of colleagues in the profession and to draw them into the challenge of finding answers through research and discussions. It is the opinion of the author that, only through a collective research effort can we ever hope to find answers pertaining to effective amplification methods and evaluative procedures.

Although the results obtained in the study favoured DSL (*i/o*) prescriptions in terms of loudness judgements, no statistical difference in speech recognition was obtained between NAL-NL1 and DSL (*i/o*) prescriptions. For this reason, it is important for future studies to explore these uncertainties by using similar research methodologies and test materials, in an attempt to provide results that may be generalised to the entire population. Studies with specifically young children are furthermore encouraged, despite the known limitations, as we cannot always generalise data obtained with adults (Stelmachowicz, 2000).

This study involved participants with varied backgrounds and developmental levels. Future studies with participants from a similar cultural background and level of language development is suggested, as it may provide the opportunity to investigate speech recognition with more sophisticated test materials. In turn, it may allow the researcher to draw more extensive conclusions pertaining to the recognition of not only a closed set of

familiar words, but also the recognition of phonemes, phonetically balanced words, and sentences.

This study furthermore agrees with the concerns expressed by authors such as Scollie, Seewald, Moodie & Dekok (2000), Stelmachowicz (2000, 2001) and Byrne, Dillon, Ching, Katsch & Keidser (2001). Amplification strategies for young children are a key issue, and a well-defined approach is required to provide answers to the complexities associated with the validation of prescriptive methods.

“Although the issues surrounding amplification for the hearing-impaired child are relatively straightforward, the answers are not.

As we search for a better understanding of what constitutes optimal gain/output, optimal speech spectrum characteristics, and an understanding of the extent that one can generalise adult data to infants and children, we should continue to question ourselves.

Just as the diagnostic and rehabilitative processes need to be ongoing, our critical evaluation of the proposed solutions needs to be ongoing.

Although we cannot make up for those early years of a child’s life, We should feel confident that we never stopped looking for the answers.”

(Alpiner & McCarthy, 1993, pp. 97)

5. REFERENCES

Alpiner, J. G. & McCarthy, P.A. (1993). *Rehabilitative Audiology: Children and Adults*, Williams & Wilkins, Baltimore.

American Speech and Hearing Association. (1978). *Guidelines for manual pure-tone threshold audiometry*, Author, Washington D.C.

Amos, N.E. & Humes, L.E. (2001). The contribution of high frequencies to speech recognition in sensorineural hearing loss. In D.J. Breebaart et al. (eds.), *Physiological and psychophysical bases of auditory function*, Shaker BV, Maastricht.

Bench, R.J. (1992). *Communication Skills in Hearing-impaired Children*, Whurr, London.

Berger, K.W., Hagberg, E.H. & Rane, E.K. (1984). *Prescription of Hearing Aids: Rationale, procedures and results*, Herald, Ontario.

Bernstein, R.S. & Kruger, B. (1986). "The external ear sound pressure level transformation in infants", *Journal of the Acoustical Society of America*, vol. 79:S33(A).

Bess, F.H. & Paradise, J.L. (1994). "Universal screening for infant hearing impairment: A reply", *Pediatrics*, vol. 94, no. 6, pp. 959-963.

Byrne, D., Dillon, H., Ching, T., Katsch, R. & Keidser, G. (2001). "NAL-NL1 Procedure for fitting nonlinear hearing aids: Characteristics and Comparisons with other procedures", *Journal of the American Academy of Audiology*, vol. 12, pp. 37-51.

Byrne, D., Parkinson, A. & Newall, P. (1991). "Modified hearing aid selection procedures for severe to profound hearing losses", *Ear & Hearing*, vol. 11, pp. 40-49.

- Ching, T. (2002). "Effective amplification for hearing-impaired children", *Hearing Journal*, vol. 55, pp. 10-18.
- Ching, T.Y.C., Dillon, H. & Byrne, D. (1998). "Speech recognition of hearing-impaired listeners: Predictions from audibility and the limited role of high frequency amplification", *Journal of the Acoustical Society of America*, vol. 103, pp. 1128-1140.
- Ching, T.Y.C., Dillon, H. & Katsch, R. (2001). Do children require more gain than adults with similar hearing losses? In R.C. Seewald & J.S. Gravel (Eds.), *A Sound Foundation through Early Amplification 2000. Proceedings of the Second International Conference*, Phonak, Chicago, Illinois.
- Ching, T.Y.C., Hill, M., Birtles, G. & Beecham, L. (1999). "Clinical use of paired comparisons to evaluate hearing aid fitting of severely/profoundly hearing-impaired children". *Australian and New Zealand Journal of Audiology*, vol. 21, pp. 51-63.
- Ching, T.Y.C., Newall, P. & Witney, D. (1997). "Comparison of severely and profoundly hearing-impaired children's amplification preferences with the NAL-RP and DSL 3.0 prescriptions", *Scandinavian Audiology*, vol. 26, pp. 219-222.
- Clark, J.G. (1996). "Guidelines for the Classroom Teacher: Appendix 9". In F.N. Martin & J.G. Clark (Eds.), *Hearing care for children*, Allyn & Bacon, Boston.
- Cornelisse, L., Seewald, R.C. & Jamieson, D.G. (1994). "Fitting wide dynamic range compression hearing aids: The DSL (i/o) approach", *Hearing Journal*, vol. 47, pp. 23-26.
- Cornelisse, L., Seewald, R.C. & Jamieson, D.G. (1995). "The input/output formula: a theoretical approach to the fitting of personal amplification", *Journal of the Acoustical Society of America*, vol. 93, pp. 1854-1864.
- Dillon, H. (2000). *Hearing Aids*, Thieme, New York

Feigin, J.A., Kopun, J.G., Stelmachowicz, P. & Gorga, M.P. (1989). "Probe-tube microphone measures of ear canal sound pressure levels in infants and children", *Ear and Hearing*, vol. 10, pp. 254-258.

Gillham, B. (1979). *The First Words Language Programme*, George, Allen & Unwin, London.

Hedley-Williams, A., Tharpe, A.M. & Bess, F.H. (1996). "Fitting hearing aids in children: A survey of practice procedures". In F.H. Bess, J.S. Gravel & A.M. Tharpe (eds.), *Amplification for children with auditory deficits*, TN Bill Wilkerson Centre Press, Nashville.

Hnath-Chisolm, T.E., Laipply, E. & Boothroyd, A. (1998). "Age-related changes on children's test of sensory level speech perception capacity", *Journal of Speech, Language and Hearing Research*, vol. 91, pp. 94-106.

Hogan, C.A. & Turner, C.W. (1998). "High frequency audibility: Benefits for hearing-impaired listeners", *Journal of the Acoustical Society of America*, vol. 104, pp. 432-441.

<http://www.dslio.com>

Desired Sensation Level Method. "*Hearing Aid Selection*",  
(retrieved 3 August 2002)

<http://www.nal.gov.au>

National Acoustic Laboratories homepage  
(retrieved 5 August 2002)

Jenstadt, L.M., Pumford, J., Seewald, R.C. & Cornelisse, L.E. (2000). "Comparison of linear gain and wide dynamic range compression hearing aid circuits II: Aided loudness measures", *Ear and Hearing*, vol. 21, pp. 32-44.

- Jenstadt, L.M., Seewald, R.C., Cornelisse, L.E. & Shantz, J. (1999). "Comparison of linear gain and wide dynamic range compression hearing aids circuits: Aided speech perception measures", *Ear and Hearing*, vol. 20, pp. 117-126.
- Katz, J. (1994). *Handbook of Clinical Audiology: Fourth Edition*, Williams & Wilkins, Baltimore.
- Kawell, M.E., Kopun, J.G. & Stelmachowicz, P. (1988). "Loudness discomfort levels in children", *Ear and Hearing*, vol. 9, no 33, pp. 133-136.
- Killion, M.C., Mueller, H.G., Pavlovic, C.V. & Humes, L.E. (1983). "A is for audibility", *The Hearing Journal*, vol. 46, no. 4, p. 9.
- Leedy, P.D. (1997). *Practical Research. Planning and Design*. Sixth Edition, Prentice Hall, New Jersey.
- Leedy, P.D. & Omrod, J.E. (2001). *Practical Research. Planning and Design*, Merrill, Upper Saddle River, NJ.
- Lutermann, D.M. (1999). *The Young Deaf Child*, York Press, Timonium Maryland.
- Macrae, J. (1982). "Invalid aided thresholds", *Hearing Instruments*, vol. 33, pp. 20-22.
- MacPherson, B.J., Efenbein, J.L., Schum, R.L. & Bentler, R. (1991). "Thresholds of discomfort in young children", *Ear and Hearing*, vol. 12, no. 3, pp. 184-190.
- Macrae, J. & Frasier, G. (1980). "An investigation of variables affecting aided thresholds", *Australian Journal of Audiology*, vol. 2, pp. 56-62.
- Martin, F.N. & Clark, J.G. (2000). *Introduction to Audiology – Seventh Edition*, Pearson Education, Needham Heights.

- Moodie, K.S., Seewald, R.C. & Sinclair, S.T. (1994). "Procedure for predicting real-ear hearing aid performance in young children", *American Journal of Audiology*, vol. 3, pp. 23-31.
- Moore, B.C., Huss, M., Vickers, D.A., Glassberg, B.R. & Alcantara, J.I. (2000). "A test for the diagnosis of dead regions in the cochlea", *British Journal of Audiology*, vol. 34, pp. 205-224.
- Mueller, H.G. & Hawkins, D.B. (1990). "Three important considerations in hearing aid selection". In Sandlin R.E. (ed.), *Handbook of Hearing Aid Amplification*, College-Hill, Boston.
- Mueller, H.G. & Killion, M.C. (1990). "An easy method for calculating the articulation index", *Hearing Journal*, vol. 43, pp. 14-17.
- Nelson, K. (1973). "Structure and strategy in learning to talk", *Monographs for the Society for Research in Child Development*, vol. 38, pp.1-2.
- Nelson-Barlow, N.L., Auslander, M.C., Rines, D. & Stelmachowicz, P.G. (1988). "Probe tube microphone measures in hearing-impaired children", *Ear and Hearing*, vol. 9, pp. 243-247.
- Neuman, W.L. (1997). *Social Research Methods: Qualitative and Quantitative Approaches*, Allyn & Bacon, Boston.
- Northern, J.L. & Downs, M.P. (1991). *Hearing In Children – Fourth Edition*, Williams & Wilkins, Baltimore.
- Pavlovic, C.V. (1989). "Speech spectrum considerations and speech intelligibility predictions in hearing aid evaluations", *Journal of Speech and Hearing Disorders*, vol. 54, pp. 3-8.



- Scollie, S.D., Seewald, R.C., Moodie, K.S. & Dekok, K. (2000). "Preferred listening levels of children who use hearing aids: comparison to prescriptive targets", *Journal of the American Academy of Audiology*, vol. 11, pp. 230-238.
- Seewald, R.C. (1994). "Fitting Children with the DSL method", *The Hearing Journal*, vol. 47, no. 9, p. 10.
- Seewald, R.C., Hudson, S.P., Gagne, J.P. & Zelisko, D.L. (1992). "Comparison of two methods estimating the sensation level of amplified speech", *Ear and Hearing*, vol. 13, no. 3, pp. 142-149.
- Seewald, R.C., Ross, M. & Spiro, M.K. (1985). "Selecting Amplification Characteristics for Young Hearing-impaired Children", *Ear and Hearing*, vol. 6, no. 1, pp. 48-53.
- Seewald, R.C., Ross, M. & Stelmachowicz, P.G. (1987). "Selecting and verifying hearing aid performance characteristics for young children", *Journal of the Academy of Rehabilitative Audiology*, vol. 20, pp. 25-37.
- Smit, G.J. (1985). *Research Guidelines for Planning and Documentation*, HAUM, Pretoria.
- Snik, A.F. & Homberger, G.C. (1993). "Hearing aid fitting of preschool and primary school children - An evaluation using the insertion gain measurement", *Scandinavian Audiology*, vol. 22, pp.245-250.
- Snik, A.F.M., & Stollman, M.H.P. (1995). "Measured and calculated insertion gains in young children", *British Journal of Audiology*, vol. 29, pp. 7-11.
- Staab, B.M., & Lybarger, S.F. (1994). "Characteristics and use of hearing aids", In *Handbook of Clinical Audiology*, Williams & Wilkins, Baltimore.
- Stach, B.A. (1998). *Clinical Audiology: An Introduction*, Singular Publishing Group, San Diego.

- Stein, L.K. (1995). "On the real age of identification of congenital hearing loss", *Audiology Today*, vol. 7, no. 1, pp. 10-11.
- Stelmachowicz, P.G. (2000). "Amplification for Infants", *Seminars in Hearing*, vol. 21, no. 4, pp. 409-422.
- Stelmachowicz, 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 2000. Proceedings of the Second International Conference*, Phonak, Chicago.
- Stelmachowicz, P.G., Dalzell, S., Peterson, D., Kopun, J., Lewis, D.L. & Hoover, B.M. (1998). "A comparison of threshold-based fitting strategies for non-linear hearing aids", *Ear and Hearing*, vol. 19, pp. 131-138.
- Stelmachowicz, P., Hoover, B., Lewis, DE., & Brennan, M. (2002). "Is functional gain really functional?", *The Hearing Journal*, vol.55, no. 11, pp. 38-42.
- Stelmachowicz, P.G. & Lewis, DE. (1988). "Some theoretical considerations concerning the relation between functional gain and insertion gain", *Journal of Speech and Hearing Research*, vol.33, pp. 491-496.
- Steyn, A.G.W., Smit, C.F., Du Toit, S.H.C., & Strasheim, C. (1994). *Modern Statistics in Practice*, J.L. Van Schaik, Pretoria.
- The DSL Report* (2001). Ontario Rehabilitation Technology Consortium: Ontario.
- Trochim, W.M.K. (2002). *Research Methods Knowledge Base*. [Online]. Available: <http://trochim.human.cornell.edu/kb/design.htm>
- Van Vliet, D. (2002). "With two-year old patients, patience is key", *The Hearing Journal*, vol. 55, no. 11, p. 90.

Volanthen, A. (2000). *Hearing instrument technology for the hearing healthcare practitioner*.  
Second Edition, Singular, Switzerland.

APPENDIX A

ETHICAL CLEARANCE FORM



## **1. OBJECTIVES OF THE RESEARCH**

Please list:

The main aim of this study is to determine and compare the effect of two non-linear prescriptive methods, for fitting digital hearing instruments in children, on aided verification and validation measures.

The following sub-aims are formulated in order to provide data in which the main aim can be realized:

1. To determine and compare the effect of two non-linear prescriptive methods on speech recognition skills. More specifically,

1.1 To determine and compare the effect of DSL i/o and NAL-NL1 on predicted speech intelligibility

1.2 To determine and compare the effect of DSL i/o and NAL-NL1 on actual speech recognition measures

2. To determine and compare the effect of two non-linear prescriptive methods on loudness perception. This aim will be realized in the following way:

2.1 To determine and compare the effect of DSL i/o and NAL-NL1 on functional gain measurements

2.2 To determine and compare the effect of DSL i/o and NAL-NL1 on loudness rating measurements

## **2. SUMMARY OF THE RESEARCH**

Please provide a brief summary of the research (maximum 250 - 300 words)

Despite remarkable developments in hearing instrument technology, there are often doubts that especially young children are fitted appropriately. Furthermore, the availability of advanced digital technology does not necessarily imply optimum benefit to the young child. The task of selecting hearing instruments for young children is therefore quite challenging, especially if one considers that children are often not active participants in the fitting process. Audiologists are currently faced with many decisions during the instrument fitting in order to provide optimum speech understanding while avoiding discomfort sound levels. Consequently, prescriptive methods for hearing instruments were developed in an attempt to achieve these goals of amplification. This approach prescribes the amplification of the hearing instrument by using a statistically calculated formula to link the audiological characteristics of the individual with the amplification characteristics of the instrument. Specifically, the recent popularity of non-linear hearing instrument technology led to the subsequent development of non-linear prescriptive methods. This study will focus on two non-linear prescriptive methods used with digital hearing instrument fittings. Although the formulation of both methods is well

supported by research, very little experimental evaluations are available to ascertain how well each of the methods work in practice. As young children will use their amplification to acquire linguistic skills, the selection of the most appropriate prescriptive method is an essential prerequisite to the rehabilitation process. It is therefore the purpose of this study to apply the Desired Sensation Level (input/output) method and the National Acoustics Laboratory Non-Linear 1 method to digital hearing aid fittings with a group of children with similar hearing losses. This is done in an attempt to provide the dispensing audiologist with more objective information on the effect of these nonlinear prescriptive methods on their hearing instruments fittings with specifically young children. Consequently, a more informed decision could be made by the audiologist as to which prescriptive method to use.

### 3. SUBJECTS' PARTICIPATION

#### 3.1 Where and how are subjects to be selected?

Subjects will be selected from the clinical caseload of the Department of Communication Pathology on a non-probability convenience sampling approach.

#### 3.2 If subjects are asked to volunteer, who is to be asked to volunteer how are they to be selected?

Not applicable in this study.

#### 3.3 If subjects are to be recruited, what inducement is to be offered?

Subjects are bilaterally fitted with digital hearing instruments sponsored by Siemens Hearing Solutions.

#### 3.4 If subjects' records are to be used, specify the nature of these records and indicate how they will be selected.

The audiogram data obtained during initial hearing assessments, as well as the case history information (revealing age and language proficiency) will be used in determining the candidacy of the subject for the study.

#### 3.5 Has permission been obtained to study and report on these records?

Yes  No  Not applicable

*If Yes, attach letters.*

#### 3.6 Salient characteristics of subjects:

Number : 10  
Gender : Female X Male X  
Age :... Five to twelve years of age

3.7 **Describe if permission of relevant authorities (e.g. school, hospital, clinic) has been obtained?**

Yes  No  Not applicable

*If Yes, attach letters.*

3.8 **List proposed procedures to be carried out with subjects to obtain data required by marking the applicable box(es):**

- Record review
- Interview (*Attach*)
- Questionnaire (*Attach, if available. If not, submit at a later stage, together with initial approval of Ethics Committee*)
- Clinical assessment
- Procedures (e.g. therapy). Please describe:
- Other. Please describe.

3.9 **If specific evaluation/assessment and treatment procedures are to be used, is the researcher registered to carry out such procedures?**

Researcher is registered with the Health Professions Council of South Africa as a Speech-Language Therapist and Audiologist.

3.10 **If the researcher will not personally carry out the procedure, state name and position of person who will.**

Researcher will be assisted by Mrs. Carin Cilliers and Mrs. Leone Nauta from the Department Communication Pathology.

#### **4. INFORMED CONSENT**

4.1 ***Attach copy of consent form***

Please refer to the attached consent form.

4.2 **If subjects are**  
- **under 18, mentally incompetent, legally incompetent to consent to participation, how is their assent obtained and from whom is proxy consent obtained?**



*Please describe.*

Consent is obtained from the parents by means of a letter of consent.

- If subjects are**  
- **under 18, mentally incompetent, legally incompetent, how will it be made clear to the subjects that they may withdraw from the study at any time?**

*Please describe.*

Subjects will be closely monitored for any sign of discomfort or fatigue by the researcher, assistants and the parents. Parents will be asked to provide guidance as to the withdrawal of the subject at such time. Parents will furthermore be reminded in the letter of consent that their participation in the study is completely voluntary.

- 4.3 **If the researcher is not competent in the mother tongue of the subjects, how will he/she ensure that subjects fully understand the content of the consent form?**

*Please describe.*

The assistance of an interpreter will be used in instances that necessitate the need.

## **5. RISKS AND DISADVANTAGES TO THE SUBJECTS**

- 5.1 **Do subjects risk any potential harm (e.g: physical, psychological, legal, social) by participating in the research?**

No  Yes

*If Yes, answer 5.2:*

- 5.2 **What safeguards will be taken to minimize the risks?**

*Please describe.*

Not applicable.

- 5.3 **Will participation or non-participation disadvantage the subjects in any way?**

No Yes  If Yes, explain in which way?

As all participants will receive new technology hearing aids, the non-participants will forego the use of these new instruments.

**6. DECEPTION OF SUBJECTS**

**6.1 Are there any aspects of the research about which the subjects are not to be informed?**

No  Yes

If *Yes*, describe the nature thereof.

**7. BENEFITS TO THE SUBJECTS:**

**7.1 Will participation benefit the subjects?** No  Yes

If *Yes*, please describe.

Participants will receive a sponsorship of two digital hearing instruments from Siemens Hearing Solutions.

**8. CONFIDENTIALITY**

**8.1 How are confidentiality and/or anonymity to be assured?**

Please describe.

All records of the evaluation results will be held strictly confidential. Individual scores will not be identified and reported within the final written study. All raw data will be held by the principal investigator, and not be distributed to any unauthorized individual.

**9. DISSEMINATION OF RESEARCH**

**9.1 To whom will results be made available?**

Results will be made available to authorized personnel from the Department Communication Pathology, as well as by means of scientific reporting.

**9.2 In which format do you expect results to be made available?**

Please mark those applicable:

book  scientific article  lay article  TV  radio

conference papers  other, please describe:

**10. STORAGE OF RESEARCH DATA**

**10.1 Will research data be destroyed at the end of the study?**

Yes  No

**10.2 If No, where, and in what format and for how long will data be stored?**

Data will be stored in the form of the clinical records for as long as the subject remains a client at the Department Communication Pathology.

**10.3 For what uses will data be stored?**

Please mark those applicable:

- research
- demonstration
- public performance
- archiving

**10.4 How will subjects' permission for further use of their data be obtained?**

- Informed consent form
- Other. Please describe.

**11. OTHER INFORMATION**

Any other information which may be of value to the committee should be provided here:

**APPLICANT'S SIGNATURE :** M. Reyneke (signed) **DATE:**2002/06/12

**SUPERVISOR'S SIGNATURE:** **DATE:**

**CHAIR : DEPARTMENTAL  
RESCOM: SIGNATURE:** **DATE:**

**CHAIR : FACULTY ETHICS  
COMMITTEE:** **DATE:**

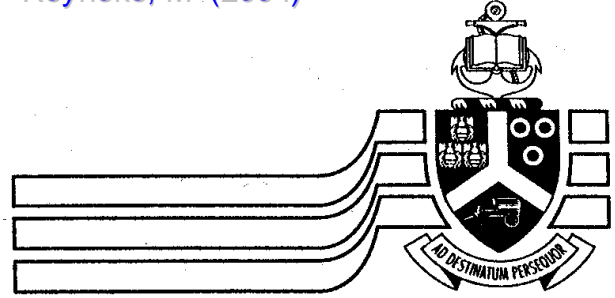
**ATTACHMENTS:**

- |   |  |
|---|--|
| <input type="checkbox"/> Other authorities' approval            | <input checked="" type="checkbox"/> Informed consent |
| <input type="checkbox"/> Questionnaires, interviews, assessment | <input type="checkbox"/> Subject instructions        |
| <input type="checkbox"/> Other                                  |  |

\* *With acknowledgement to Harvard University 1999-2000, and the University of the Witwatersrand 1992*

APPENDIX B

LETTER OF CONSENT



## University of Pretoria

### Department of Communication Pathology Speech, Voice and Hearing Clinic

Tel : +27 12 420 2302

Fax : +27 12 420 3517

E-mail : cavenant@postino.up.ac.za

11 April 2003

Dear Parent

Thank you for your decision to partake in this study. Your participation in this study is completely voluntary.

This research project involves the study of hearing aid fitting methods in specifically young children. Your child will be provided with advanced digital hearing instruments sponsored by Siemens Hearing Solutions.

After the initial fitting of the instruments, we will conduct a series of evaluations. These tests are essential in providing us with the information to ensure that the instruments are accurately set. Furthermore, the information obtained during the evaluations will be used for research purposes.

All records of the evaluation results will be held strictly confidential. Individual scores will not be identified and reported within the final written study. All raw data will be held by the principal investigator, and not be distributed to any unauthorized individual.

Any further information on the research may be obtained from the principal investigator, Michelle Reyneke, Tel (011) 886 6734.

\_\_\_\_\_  
SIGNED: PARENT

\_\_\_\_\_  
SIGNED: INVESTIGATOR

\_\_\_\_\_  
DATE

\_\_\_\_\_  
DATE

\_\_\_\_\_  
Signed: Carina Avenant (Study Leader)

FOR: Prof. S.R. Hugo

HEAD: Department of Communication Pathology

APPENDIX C

SCORE SHEET

|              |                       |                      |
|--------------|-----------------------|----------------------|
| <b>NAME:</b> | <b>DATE OF BIRTH:</b> | <b>DATE OF TEST:</b> |
|--------------|-----------------------|----------------------|

**1. ARTICULATION INDEX**

**UNAIDED**

|                                  | 500 Hz | 1000 Hz | 2000 Hz | 4000 Hz |
|----------------------------------|--------|---------|---------|---------|
| <b>Threshold</b>                 |        |         |         |         |
| <b>Speech minima</b>             | 20     | 20      | 20      | 20      |
| <b>Speech peak</b>               | 50     | 50      | 50      | 50      |
| <b>Insertion gain</b>            | -      | -       | -       | -       |
| <b>Difference:<br/>D=p – m/t</b> |        |         |         |         |

Sum of positive difference: \_\_\_\_\_  
 Divided by 120: \_\_\_\_\_

**AIDED DSLi/o**

|                                  | 500 Hz  | 1000 Hz | 2000 Hz | 4000 Hz |
|----------------------------------|---------|---------|---------|---------|
| <b>Threshold</b>                 |         |         |         |         |
| <b>Speech minima</b>             | 20 + IG | 20 + IG | 20 + IG | 20 + IG |
| <b>Speech peak</b>               | 50 + IG | 50 + IG | 50 + IG | 50 + IG |
| <b>Insertion gain</b>            |         |         |         |         |
| <b>Difference:<br/>D=p – m/t</b> |         |         |         |         |

Sum of positive difference: \_\_\_\_\_  
 Divided by 120: \_\_\_\_\_

**AIDED NAL-NL1**

|                                  | 500 Hz  | 1000 Hz | 2000 Hz | 4000 Hz |
|----------------------------------|---------|---------|---------|---------|
| <b>Threshold</b>                 |         |         |         |         |
| <b>Speech minima</b>             | 20 + IG | 20 + IG | 20 + IG | 20 + IG |
| <b>Speech peak</b>               | 50 + IG | 50 + IG | 50 + IG | 50 + IG |
| <b>Insertion gain</b>            |         |         |         |         |
| <b>Difference:<br/>D=p – m/t</b> |         |         |         |         |

Sum of positive difference: \_\_\_\_\_  
 Divided by 120: \_\_\_\_\_



**2. SPEECH RECOGNITION AT 65DB**

Tick correct/incorrect responses in box.

| WORD                       | DSL I/O | NAL-NL1 |
|----------------------------|---------|---------|
| 1.mom                      |         |         |
| 2.shoe                     |         |         |
| 3.bird                     |         |         |
| 4.dad                      |         |         |
| 5.cake                     |         |         |
| 6.spoon                    |         |         |
| 7.cat                      |         |         |
| 8.sock                     |         |         |
| 9.baby                     |         |         |
| 10.car                     |         |         |
| <b>Percentage Correct:</b> |         |         |

**3. LOUDNESS JUDGMENT: WARBLE TONE AT 1KHZ**

Circle appropriate response.

| Rating at: | 45dB                  | 65dB                  | 90dB                  |
|------------|-----------------------|-----------------------|-----------------------|
| DSL (i/o)  | Soft / Average / Loud | Soft / Average / Loud | Soft / Average / Loud |
| NAL-NL1    | Soft / Average / Loud | Soft / Average / Loud | Soft / Average / Loud |

**4. SOUNDFIELD AUDIOGRAM**

Determine response in dB at 500HZ, 1kHz, 2kHz and 4kHz.

Key: F Unaided freefield  
 D Aided freefield DSL (i/o)  
 N Aided freefield NAL-NL1

| Frequency | F | D | N |
|-----------|---|---|---|
| 500 Hz    |   |   |   |
| 1 kHz     |   |   |   |
| 2 kHz     |   |   |   |
| 4 kHz     |   |   |   |