

Evaluation of Hearing Aid Performance in School-Aged Children with Moderately Severe to Profound Hearing Loss Fitted According to the NAL-NL1 and DSL v5 Prescriptive Procedures

Quar Tian Kar

Department of Linguistics
Macquarie University

&

National Acoustic Laboratories
Sydney

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Statement of Candidate

I certify that the work in this thesis is original and has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree to any university or institution other than Macquarie University.

All references have been cited in this thesis and every individual involved in the research work has been acknowledged.

Quar Tian Kar

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Between the years of 2006 and 2007, Emeritus Professor Philip Newall of Macquarie University was invited as a visiting lecturer by the Universiti Kebangsaan Malaysia (UKM) where I worked. It was his visit that sparked my motivation to pursue my PhD plan which had been abandoned due to job and family commitments, as well as personal hesitations. My deepest and most sincere gratitude goes to him for providing me the confidence, for his encouragement, his patience to guide and his constant efforts to explain things clearly and simply which make every discussion and conversation with him meaningful and relaxing. My course mates and I deeply admire his kindness, his support, his humor and his great sense of respect for people from different cultures. Emeritus Professor Philip Newall was also one of the key persons in initiating the audiology program in UKM. We could never thank him enough for his contributions.

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Abstract

The National Acoustic Laboratories (NAL) and the Desired Sensation Level (DSL) prescriptive procedures are often cited as the most sustainable, validated procedures and the most common methods used for hearing aid fitting in adults and in children. The overall aim of the present study is to evaluate the relative performance of the two procedures in children. The study focuses on children because they are most likely to rely on hearing aids fitted with techniques based solely on prescriptive approach.

Sixteen Malaysian children with moderately severe to profound hearing loss were involved in the study. The children were fitted with the Phonak Naida V SP hearing aids based on the NAL-NL1 and DSL v5 prescriptive procedures. The NAL-NL1 and DSL v5 were the latest versions of the respective prescriptive formulae available at the time when this study was carried out. After hearing aid fitting, an extended period of hearing aid trial was given to each child. The relative performance of the two procedures was assessed using speech tests, paired-comparison judgments of speech intelligibility tests and questionnaires completed by the parents, teachers and the children themselves. The questionnaires used in the study were the Parents' Evaluation of Aural/Oral Performance of Children (PEACH), the Teachers' Evaluation of Aural/Oral Performance of Children (TEACH) and the Self Evaluation of Listening Function (SELF). The questionnaires were adapted into the Malay language. Each child also completed a short diary for them to compare the performance of the two procedures in different listening environments.

The results showed a significant difference of performance between the NAL-NL1 and DSL v5 procedures for sentence test in quiet and for the subjective measures using questionnaires completed by the parents, teachers and children. The study concluded that the required hearing aid gain for children with moderately severe to profound hearing loss would seem to approximate the DSL v5 prescription, at least in quiet listening environments. The findings have important clinical implications for country like Malaysia where many children with severe to profound hearing loss still rely on hearing aids as their primary amplification devices.

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CHAPTER 1

Introduction

1.1 Overview of study

“Theoretical procedures for hearing aid selection are based on established or hypothesized relationships between, on the one hand, the characteristics of hearing impaired individuals and, on the other, the amplification characteristics which they require for optimal auditory function.” (Byrne, 1983)

A more common term used today for “*theoretical*” is “*prescriptive*”. Byrne further explained that hearing aid selection procedure requires the use of theoretical procedure/s to reduce the limitless number of amplification options to one or a few which are suitable for the client. In hearing aid fitting, this stage is the most complex conceptually and is the most critical since everything that follows depends upon it (Byrne, 1983).

According to Seewald et al (1985), selection of amplification characteristics for hearing-impaired children is one of the most challenging clinical tasks. This is because children are usually neither reliable in clinical tests, nor can they provide feedback which will assist clinicians to evaluate the benefits of the hearing aids fitted to them. With the widespread implementation of newborn hearing screening program, hearing loss can be identified in infants by as early as three months of age (King, 2010; Bagatto et al., 2010). Until hearing aid assessment can be carried out, infants and young children especially are often left with the amplification characteristics prescribed for them without later modification common in adults. Hence, studies that examine the appropriateness of hearing aid prescriptive procedures in children would seem to be important, as reported by Seewald et al (2005).

Numerous prescriptive procedures have been developed for fitting hearing aids to individuals with hearing impairment. Mueller (2005) reported there are perhaps 20-30 prescriptive procedures which have been developed over the years. Many of these procedures, especially those designed for linear amplification are not in current use for hearing aid fitting. Two hearing aid prescriptive procedures, however, have remained widely used by clinicians since they were developed. These procedures are referred as the National Acoustic Laboratories (NAL) and the Desired Sensation Level (DSL) procedures. According to a survey conducted by Mueller and Picou (2010), about 30% of audiologists reported using the real-ear probe

microphone equipment for matching real-ear gain to gain prescribed by either the NAL or DSL procedures. About 10% of the audiologists used the manufacturer software targets for hearing aid verification purposes. The findings suggested that many clinicians still rely on generic prescriptive methods such as the NAL and DSL procedures to fit hearing aids. For this reason, studies on the effectiveness of the NAL and DSL procedures would seem to be clinically very important (Seewald et al., 2005; Ching et al., 2010a).

Previous studies showed that the optimum amplification characteristics defined by the NAL and DSL procedures are substantially different (Byrne, 1996; Byrne & Ching, 1997; Byrne et al., 2001; Keidser et al., 2003; Seewald et al., 2005; Ching et al., 2010a; Johnson & Dillon, 2011). Several studies have been carried out in the past to examine if differences in the amplification characteristics prescribed by the NAL and DSL procedures lead to differences in performance between the two procedures (e.g. Snik & Stollman, 1995; Snik et al., 1995; Ching et al., 1997; Ching et al., 1999; Scollie et al., 2000; Mueller, 2005; Jenstad et al., 2007; Johnson & Dillon, 2011). Many of these studies that compared either directly or indirectly, the performance of the two procedures, involved adult subjects (see Mueller, 2005 for summary of previous studies in adults). While previous studies have begun to shed some light on the relative effectiveness of the NAL and DSL procedures in adults (Mueller, 2005; Jenstad et al., 2007), much is still required to be done to investigate the relative effectiveness of the two procedures in pediatric population .

In recent years, the National Acoustic Laboratories (NAL) has collaborated with the University of Western Ontario (UWO) to conduct a study that compared the relative performance of the NAL-NL1 and DSL v4.1 procedures in children with mild to moderately severe hearing loss (Ching et al., 2010a). Even though the study has provided useful information with regard to the benefits offered by the NAL-NL1 and DSL v4 procedures to the children, question remain as whether the research findings can be applied to children with severe to profound hearing loss. There were other studies that investigated the relative performance of the NAL and DSL procedures in children with severe to profound hearing loss (Snik & Stollman, 1995; Snik et al., 1995; Ching et al., 1997; Ching et al., 1999; Scollie et al., 2000). Most of these studies however, compared the performance of the earlier versions of the NAL and DSL procedures (i.e. NAL-R or NAL-RP versus DSL v3 or DSL v4). Both the NAL and DSL procedures have been revised several times with the NAL-NL2 and the DSL v5 procedures being the latest versions of the respective procedure. Whenever a prescriptive procedure is revised or whenever changes are implemented on the original procedure, it is

necessary to conduct research to validate or to evaluate the revised procedure (Byrne & Ching, 1997; Byrne et al., 2001; Seewald et al., 2005).

It is possible that the recent study carried out by the NAL and UWO did not include severe to profound hearing loss is because more children with severe to profound hearing loss receive cochlear implants and therefore less children in this category were available for the study. In developing countries like the Malaysia, most children with severe to profound hearing loss still rely on hearing aids despite the documented benefits of cochlear implants for individuals with severe to profound hearing loss. Financial restraint, cost effectiveness, public awareness and availability of intervention centers are among the factors that limit the availability of cochlear implants or even other amplification devices in Malaysia and most likely in many other developing countries as well (McPherson & Brouillette, 2008). Even for the developed countries, studies have shown that children who could benefit from the cochlear implants were not referred consistently for candidacy assessment and studies also found a disparity in rate of cochlear implantation based on race and socioeconomic status (Stern et al., 2005; Bradham & Jones, 2008; Wiley & Meinzen-Derr, 2009). For these reasons, it remains important to investigate the optimum hearing aid characteristics for children with hearing losses that fall in the severe to profound category, at least in Malaysian scenario.

1.2 Purpose of study

The overall aim of the present study is to compare the performance of the NAL-NL1 and DSL v5 prescriptive procedures and to find out which one is more appropriate or beneficial for children with moderately severe to profound hearing loss. The specific aims of the study are :

- i) To compare the gain and frequency response slopes prescribed by the NAL-NL1 and the DSL v5 procedures.
- ii) To compare the speech performance of children fitted with hearing aids according to the NAL-NL1 and DSL v5 procedures.
- iii) To determine the children's preferred prescriptive procedure using paired-comparison judgments of speech intelligibility test.
- iv) To compare the functional hearing of children using hearing aids fitted according to the NAL-NL1 and DSL v5 procedures, based on parents, teacher and children self-report assessment and subjective ratings.

- v) To adapt the parental self-report questionnaire into Malay language and to establish normative data for the adapted questionnaire.
- vi) To use the hearing aid data logging feature for comparing the duration and frequency of use of the NAL-NL1 and DSL v5 fittings among the children.
- vii) To determine the children's preferred prescriptive procedure at the end of the study.

1.3 Research hypothesis

The research hypothesis is constructed based on previous studies which found differences in amplification characteristics and performance between the NAL and DSL procedures. For the present study, it is hypothesized that the performance of children using hearing aids fitted based on the NAL-NL1 and DSL v5 procedures are significantly different.

1.4 Location of study

The study was conducted at the Audiology and Speech Sciences Clinic, Universiti Kebangsaan Malaysia (UKM) of Kuala Lumpur, Malaysia. A brief description of the clinic is provided in this section to the reader. The Audiology and Speech Sciences Clinic in UKM was established in 1994. The clinic was the first of its kind set up in Malaysia and has become the main center of referral for the country. The main objective of the clinic is to provide clinical training for the university's undergraduate students as well as to provide clinical services to clients with hearing and communication disorders. The audiology clinic offers services that include hearing assessment, hearing aid fitting and evaluation, auditory evoked potential tests and counseling. The clinic is also a part of the cochlear implant program which was initiated by the university in 1995. Photos of the UKM clinic are shown in Appendix 1.

1.5 Organization of the thesis

The thesis is divided into three major sections comprising of literature review, research studies and research conclusions. Each section covers the following chapters :

(I) First Section : Literature review

The first section includes explanations about the purpose and the significance of the study, definitions of concepts related to the study, findings from past studies and current hearing aid fitting protocols for children. The section covers Chapter 1 to Chapter 5 :

- i) **Chapter 1 (Introduction)** : Overview and purpose of the study.
- ii) **Chapter 2 (National Acoustic Laboratories Procedure)** : This chapter explains the development of the NAL procedure, its rationales, formulae and the validation of the procedure.
- iii) **Chapter 3 (Desired Sensation Level)** : This chapter focuses on the development of the DSL method, the rationales, formulae and validation of the procedure.
- iv) **Chapter 4 (Comparison of the NAL and DSL Procedures)** : This chapter summarizes the difference in rationale between the NAL and the DSL procedures and discusses about the different target gain prescribed by the two procedures. It also includes a comparison of the performance of the two procedures based on past studies. The significance of the present study is also explained.
- v) **Chapter 5 (Hearing Aid Fitting in Children)** : This chapter provides some information regarding current hearing aid fitting protocol for infants and young children. The chapter also describes the hearing aid selection, fitting and validation procedures adopted in the present study.

(II) Second Section : Research studies

The second section describes about the aims, the methodology and the findings of the overall study. There are three studies reported in this section. Each of the study is explained in Chapter 6, 7 and 8 respectively :

- i) **Chapter 6 (Study I)** : Parents' Evaluation of Aural/Oral Performance of Children (PEACH) Scale in the Malay language. The PEACH scale in Malay language was used as one of the assessment tool to compare the performance of NAL-NL1 and DSL v5 procedures. This study describes about the process of adapting and developing normative data for the PEACH scale

in Malay language. This paper has published been submitted to the *International Journal of Audiology* on 10th May 2011 and has been accepted for publication on 28th October 2011

ii) **Chapter 7 (Study II)** : Prescribed and achieved gain of hearing aids fitted according to the NAL-NL1 and DSL v5 procedures in children with moderately severe to profound hearing losses. The main objective of this study was to compare the hearing aid gain and frequency response prescribed by the NAL-NL1 and DSL v5 procedures and to determine the actual gain achieved in the hearing aids.

ii) **Chapter 8 (Study III)** : Evaluation of real-world preferences and performance of hearing aid in children with moderately severe to profound hearing loss fitted according to the NAL-NL1 and DSL v5 procedures.

Author's contribution

The author was responsible in implementing the research procedures, analyzing the research data and writing the research paper. The author was assisted by two research assistants for Study I - Parents' Evaluation of Aural/Oral Performance of Children (PEACH) Scale in the Malay language : Data of normal hearing children

Co-authors contributions

The co-authors of the paper were responsible for providing advice with regard to the research methodology, statistical analyses and in editing the research papers.

(III) Third Section : Research Conclusions

i) **Chapter 9 (Summary and Conclusions)** : The third section covers the final chapter of the thesis. This section or chapter summarizes the research findings, explains the limitations of the study and suggests future studies.

Appendix

The Appendix section includes photographs of the test site, the Macquarie University ethics approval letter, the subject informational and consent forms, hearing aid manufacturer specification, speech materials and auditory inventory scales used in the study.

CHAPTER 2

The National Acoustic Laboratories (NAL) Prescriptive Procedure

This chapter provides an overview of the National Acoustic Laboratories (NAL) prescriptive procedure. The early NAL procedure (i.e the Byrne and Tonisson method), the revised NAL procedures (NAL-R and NAL-RP) and the NAL procedures for non linear hearing aids (NAL-NL1 and NAL-NL2) will be described. The explanations will focus on their aims, rationales, prescriptive formulae, applications, the differences between these procedures and the validations of the NAL procedure.

2.1 The Early NAL Procedure / Byrne and Tonisson Procedure

2.1.1 The Aim of the Byrne and Tonisson Procedure

The original NAL prescriptive procedure was proposed by Byrne and Tonisson in 1976. After this, the prescriptive method was used by all the hearing centers in Australia until 1985/86, where the revised Byrne and Tonisson procedure was introduced. The aim of the procedure is to determine gain and frequency response so that, for a speech signal, the hearing aid users receive the maximum amount of signal averaged over a wide frequency range at the most comfortable listening level (MCL) and this is to be achieved by amplifying all frequency bands of speech to equal loudness (Byrne & Tonisson, 1976).

2.1.2 The Byrne and Tonisson's Preferred Gain

According to the procedure, gain and frequency response of hearing aids are selected based on the hearing threshold level (HTL) at each audiometric frequency. The HTL measure was reported as a more reliable, practical and faster method to prescribe hearing aid gain than the supra-threshold measures based on loudness scaling or loudness discomfort level (LDL) (Byrne & Murray, 1985; Lindley & Palmer, 1997; Dillon, 2001 pg. 259). To determine the required hearing aid gain, Byrne and Fifield (1974) conducted a study on 182 hearing impaired children of seven years of age or above. The major aim of their study was to find out how the hearing level correlates with the preferred sensation level (preferred gain) of subjects using a properly selected and fitted hearing aid. To derive the preferred sensation level, aided

thresholds were measured at 500, 1000 and 2000 Hz, with the volume control of the hearing aid on the setting normally used by the children. The values obtained were then subtracted from the corresponding frequency bands of speech with an overall SPL of 70 dB, to determine the preferred sensation level. It was found from their results that the preferred gain increased at 0.46 times the rate of increase in HTL. This means that individuals with sensorineural hearing loss would prefer hearing aid gain which is approximately half of his/her hearing loss. This agreed with the well known 'half gain rule' first proposed by Lybarger in 1944 which became well established after many other early studies also supported the rule (Brooks, 1973; Martin, 1973; Boorsma & Courtoy, 1974). This relationship of gain and HTL was then used by Byrne and Tonisson as the basis for their hearing aid gain selection procedure.

In order to determine the required gain at different audiometric frequencies, it was necessary to adjust the preferred gain/HTL function to take into account two factors : (i) adjustment allows for the intensity differences that exist between the frequency components of the long term root mean square (rms) of the average speech spectrum. The correction figures were obtained from a real-time analysis of samples of Australian speech and (ii) adjustment compensates for the differences in loudness at various frequencies shown by the 60 phon equal loudness contour. The rationale for these adjustments is that all frequency components of speech will be presented with approximately equal loudness so as to maximize the amount of signal received by the hearing aid user at the most comfortable level (Byrne & Tonisson, 1976).

2.1.3 The Byrne and Tonisson Formula

The Byrne and Tonission formula involved a calculation of the required gain for a given HTL at a particular frequency. This formula was derived based on the experimental findings, theoretical considerations and adjustments described above and is shown as follow :

$$G(f) = 0.46 \text{ HTL}(f) + C(f)$$

$G(f)$ = required insertion gain

$\text{HTL}(f)$ = air conduction hearing threshold level

$C(f)$ = additive constant [this constant act as compensation for the two sets of adjustment explained above]

(f) = frequency

Alternatively, the required gain for different HTLs and frequencies can be read from a graph or table. In addition to required real ear gain, required 2cc coupler gain and required aided thresholds are also provided by the formula for different types of hearing aids i.e. in-the-ear, behind-the-ear and body worn hearing aids. The required 2cc coupler gain was derived after taking into account the 15 dB reserve hearing aid gain measured in the coupler and the average differences between the real ear and coupler gain.

2.1.4 Applying the Byrne and Tonisson Procedure

Byrne and Tonisson (1976) recommended the use of the required coupler gain to pre-select the hearing aid that will most likely provide the desired real ear gain and to minimize the subsequent adjustments to the hearing aid. Real ear or insertion gain measurements are then carried out to determine if adjustments to the hearing aid setting or ear mould are required to achieve a close match with the target insertion gain. Another method used to obtain the real ear gain is to measure the aided and unaided hearing thresholds in a sound field. The difference between the two measurements is the real ear or functional gain. Functional gain however, is less reliable as compared to insertion gain. Higher variability of responses has been reported in functional gain as opposed to insertion gain (Humes & Kirn, 1990). When the unaided sound field hearing thresholds cannot be measured, such as in cases of severe and profound hearing loss, the prescribed aided threshold values can be used as guide to fit the hearing aid.

2.1.5 Validation of the Byrne and Tonisson Procedure

The Byrne and Tonisson procedure was developed based on the study conducted by Byrne and Fifield (1974). The aims of the Byrne and Fifield (1974) study were (i) to determine the correlations between subjects' HTLs and preferred gains and also, (ii) to validate the correlations obtained. The validation was carried out by examining the relationship between the subjects' preferred gain and the degree of benefit received by them when using the hearing aids. The study involved parents of 182 hearing impaired children. Thirty four parents took part in the study by filling in questionnaires with regard to how well their child could hear with their hearing aids. The results showed a large range of scores reported by the parents and thus the relationship between the reported benefits and the preferred gain was considered poor. One of the major reasons reported was the poor reliability of ratings given by the parents and therefore very little evidence could be used to validate the procedure. It was

suggested that the parents might have had difficulty rating their children objectively or felt obliged to give favorable rating. Even though the authors cautioned against the reliance of parental reports, many established questionnaires today have been shown to be reliable for assessing auditory performance in children (Bagatto et al., 2011)

Some evidence was found in Brooks and Chetty (1985) study that reported the Byrne and Tonisson was a clinically practicable and satisfactory method for determining the amplification characteristics. Thirty adults with degree of hearing loss ranging from mild to severe took part in their study. Assessments of the procedure were carried out by using the listening comfort measurement and interviews with subjects. The study reported that on average, good correlations (± 2 dB) could be observed between the theoretical derived gain and the subjects' listening comfort levels. Within the groups of subjects, moderately high variations were found for the correlations between the theoretical derived gain and the subjects' listening comfort levels.

A study conducted by Leijon et al (1984) however, showed the Byrne and Tonisson procedure overestimated preferred gain by about 10 dB for a group of 12 adults with mild to moderate hearing loss. The preferred gain was determined using laboratory tests and hearing aid trial in everyday situations. According to the authors, the laboratory tests were carried out with the presence of noise and it is possible that this factor had caused the subjects to prefer a lower volume setting for listening comfort.

The Byrne and Tonisson procedure, like other hearing aid procedures in the early 1980's, was considered lacking in terms of rigorous evaluation (May, 1988). According to May (1988), another concern was that it assumes the gain required at each frequency is independent of the gain required at all other frequencies. If this assumption is not true, then it is possible that the procedure's aim to amplify all frequency bands of speech to equal loudness is actually not achieved. To justify the continued use of the Byrne and Tonisson procedure, two studies (Byrne & Dillon, 1986; Byrne & Murray, 1986) were carried out.

The first study (Byrne & Dillon, 1986) was carried out on 11 hearing impaired adults (14 test ears) with various configuration of audiogram. The aim of the study was to verify whether the original NAL procedure amplifies all frequency bands of speech so that they are equally loud and comfortable for the subjects. The experiment involved measuring subjects' most comfortable levels (MCLs) for speech bands of three different frequency regions (a low region centered at 0.4 kHz, a mid region centered at 1.25 kHz and a high region centered at 3.15 kHz). At first, the three speech bands were prescribed the relative amounts of gain

according to the NAL procedure for the ear being tested. Next, subjects' MCLs for the three speech bands were measured using a Bekesy tracking procedure. It was reasoned that if the early NAL procedure was achieving its aim, then all three speech bands would require the same amount of additional or reduced gain to reach the subjects' MCLs, except for some differences to be expected because the speech band stimuli were not equal in bandwidth, when expressed in normal critical bands (Byrne & Murray, 1986). The results showed that with the Byrne and Tonisson procedure, the MCLs could not be reached by the same amount of additional or reduced gain for the three frequency bands. In other words, the experiment showed that the procedure did not exactly achieve the loudness equalization aim and it was necessary to alter the prescribed gain so that all frequencies could be amplified to MCLs with equal loudness. It was also found that the gain prescribed for the low frequency band was insufficient (by 5-10 dB) compared to the gain prescribed for the mid frequency band, in order to reach the comfortable listening level with same overall gain setting. The procedure also prescribed too much variation in frequency response slopes for variations in audiogram slopes. For example, there were four ears with steeply sloping hearing losses and for these ears, the gain prescribed for the high frequencies was far too much relative to the prescribed mid frequency gain.

The second study (Byrne & Murray, 1986) which involved the same 11 subjects from the first study, compared the Byrne and Tonisson procedure to several alternatives. Comparison were made between the performance of hearing aid's frequency responses derived from HTLs (using the Byrne and Tonisson formula), pure tone most comfortable levels (MCLs), pure tone loudness discomfort levels (LDLs) and three speech band MCLs (1/3-octave speech bands, 1 octave speech bands and 1 2/3-octave speech bands). The effectiveness of each method was assessed using speech discrimination test plus paired-comparison tests on the intelligibility and pleasantness of running speech in quiet and noise. Results revealed that overall, the subjects performed better with the frequency response derived from the speech band MCLs measurement. Thus, this study strongly supported the rationale of amplifying all frequency bands of speech to MCL. However, as the first study showed that the Byrne and Tonisson failed to achieve this aim consistently, a more effective procedure was needed to meet its original aim. The Byrne and Tonisson procedure was then revised. The following section will discuss the NAL revised procedure (NAL-R).

2.2 The NAL revised procedure (NAL-R)

The NAL revised procedure (NAL-R), was developed by Byrne and Dillon (1986) to replace the Byrne and Tonisson procedure.

2.2.1 Aim of NAL-R

Like the early NAL procedure, the Byrne and Dillon procedure aimed to amplify all frequency bands of speech to equal loudness so that the hearing aid user may receive the maximum amount of signal averaged over a wide frequency range at the most comfortable listening level (Byrne & Dillon, 1986). According to Byrne and Dillon (1986), this frequency response selection rationale has been maintained since it is the most widely acceptable principle and furthermore it has been proven to be effective by Byrne & Murray (1986) study, as explained earlier.

2.2.2 The NAL-R Required Frequency Response

The required frequency response prescribed by the NAL-R procedure was developed based on the studies conducted by Byrne and Dillon (1986) and Byrne and Murray (1986).

Optimal or required frequency response characteristics for different shape of audiogram were estimated from the two studies. The optimal frequency responses were derived from the MCLs measurements with speech bands representing low, mid and high frequency regions. Optimal frequency response characteristics were defined by the relative amounts of gain required to amplify all the three frequency bands to MCL. The speech band MCLs measurement was selected to derive the required frequency response characteristics, after finding such responses were superior to the ones derived from other procedures (i.e. pure tone MCLs and pure tone LDLs) (Byrne & Murray, 1986).

After finding out the optimal frequency responses for all the subjects, Byrne and Dillon (1986) looked at how well these frequency responses could be predicted from the audiogram. To do this, the required frequency response slopes were compared to the audiogram slopes. These slopes were divided into three regions described as total slopes [0.4 (or 0.5) to 3 kHz], low-frequency slopes [0.4 (or 0.5) to 1.25 kHz] and high-frequency slopes (1.25 to 3 kHz). It was found that a moderately strong relationship (average correlation = 0.6) was observed between the audiogram slopes and optimal or required frequency response slopes and that a

formula could be derived from the regression equations for prescribing optimal frequency response from the audiogram, without many substantial errors (i.e exceeding 5 dB/octave).

2.2.3 The NAL-R Formula

The regression equations reported in Byrne and Dillon (1986) study were used to calculate the NAL-R formula. To derive the formula, the following steps were followed:

- (i) calculation of the frequency response required for a flat audiogram
- (ii) calculation of how the required slope should vary for different audiograms
- (iii) calculation of absolute gain at each frequency

The NAL-R formula for calculating the required real ear gain at a particular frequency for sensorineural hearing losses is shown below. The “X” factor represents the three frequency average gain (3FA) where the multiplicative factor, 0.05 was derived based on the Byrne and Tonisson and the NAL-R frequency slope coefficients for each of the three frequency (0.46 – 0.31/3). The additive constant “K” is frequency dependent constant. It shows the required slope for a flat audiogram, is different in each frequency range. The multiplication of HTL by 0.31 shows the rate of variation in response slope required for variation in audiogram slope (Byrne & Dillon, 1986).

$$G(f) = X + 0.31 \text{ HTL}(f) + K(f)$$

Where $G(f)$ = required real ear insertion gain

$\text{HTL}(f)$ = air conduction hearing threshold level

$K(f)$ = additive constant

$$X = 0.05 [\text{HTL}(500\text{Hz}) + \text{HTL}(1000\text{Hz}) + \text{HTL}(2000\text{Hz})]$$

Formulae for calculating the required coupler gain, required ear simulator gain and required aided thresholds were developed from the initial basic formula. Separate formulae have been calculated for behind-the-ear (BTE), in-the-ear (ITE) and body-worn aids. The required frequency response can be obtained directly from the formula table, by using the slide rule and by using the computer or programmable calculator.

2.2.4 Applying the NAL-R Formula

The guide recommended by the NAL-R procedure in selecting hearing aid is the same as in the Byrne and Tonisson procedure. It follows the following steps :

- (i) Calculate the required coupler and insertion gain based on the HTL
- (ii) Select an aid which, taking the earmold requirements into consideration most closely matches the required coupler gain
- (iii) Conduct real ear measurement and adjust the aid if necessary to achieve the required real ear gain at each frequency
- (iv) The procedure should be supplemented with other forms of evaluation (e.g. paired-comparison tests) to ensure optimal fitting is achieved.

2.2.5 Comparison of the Original and Revised NAL Procedure

May (1988) summarized the differences and similarities between the NAL-R and the Byrne and Tonisson procedure as follow:

- (i) Both procedures aim to amplify all frequency bands of speech signal to equal loudness so that the hearing aid user may receive the maximum amount of signal averaged over a wide frequency range at the most comfortable listening level.
- (ii) The 'half gain rule' is maintained in the NAL-R procedure. Like the Byrne and Tonisson procedure, the overall gain prescribed by the NAL-R procedure increases at 0.46 times the increase in HTL. Research findings as well as many years of experience in hearing aid fitting had made this rule acceptable. Furthermore as Byrne and Dillon (1986) had pointed out, there is no need for great precision in gain prescriptions as most hearing aid volume controls offer a large range of adjustment and do not affect the shape of the frequency response.
- (iii) Unlike the Byrne and Tonisson procedure, the required gain at each frequency is dependent on the gain at other frequencies (500, 1000 and 2000Hz).
- (iv) The Byrne and Tonisson formula prescribes the frequency response by using the half-slope rule. This was altered to a one-third slope rule in the NAL-R formula (i.e., variations in audiogram slope are compensated for by about one-third as much variation in the frequency response slope). The NAL-R provides less variation in frequency response slopes for difference in audiogram slopes

- (v) The NAL-R formula prescribes more gain around 500 Hz relative to gain at other frequencies.
- (vi) As already explained, in Byrne and Tonisson procedure, two sets of corrections were used for calculating the required gain at different audiometric frequencies. One adjustment allows for the intensity differences that exist between the frequency components of the long term rms of the average speech spectrum and the second adjustment compensates for the differences in loudness at various frequencies shown by the 60 phon equal loudness contour. The rationale for these adjustments is that all frequency components of speech will be presented with approximately equal loudness. For the NAL-R procedure, an updated version of the average long term speech spectrum makes a small contribution while the phon curves do not play a role in determining the required gain at each frequency. Optimal frequency responses are derived from the measurement of speech band MCLs.

2.2.6 Validation of the NAL-R formula

An experiment was carried out by Byrne and Cotton (1988) to verify the NAL-R formula for prescribing the gain and frequency response of hearing aid. Forty four adult subjects with mild to moderate hearing loss were fitted with hearing aids according to the NAL-R procedure. Two to three weeks post fitting, paired-comparison judgments of speech intelligibility in quiet and speech pleasantness in noise were conducted on the subjects. In the paired-comparison test, the NAL-R procedure was compared with four alternative responses (i.e. low cut, low boost, high cut and high boost). The purpose of the experiment was to determine whether subjects would perceive speech to be more intelligible and pleasant with a frequency response that was different from the one prescribed by the NAL-R procedure. From the total of 67 test ears, 4 ears (6%) judged one of the comparison responses as more intelligible than the NAL-R response while 16 ears (24%) judged a comparison response as more pleasant. Overall there was a significantly greater number of preferences for the NAL-R response over the comparison response for both intelligibility and pleasantness. The three frequency average (500, 1000 and 2000 Hz) used gain were in close agreement with the prescribed gain (ranged from -0.5 to 1.5 dB) regardless of the audiogram configuration, experience in hearing aid usage and type of hearing aid limiting. It was concluded in this study that the NAL-R was found to be highly effective even though for some individuals, a change in hearing aid prescription was indicated.

Another study conducted by Leijon et al (1990) that looked at the insertion gain preferred by a group of 26 mild to moderately hearing impaired, elderly hearing aid users. The subjects were monaurally fitted with hearing aids based on the NAL-R procedure. If necessary, fine tuning on follow-up appointments were performed until the subjects were satisfied with the sound quality of their hearing aids. Subsequently, subjects were allowed to adjust the hearing aid volume in order to determine the preferred settings for daily listening environments. The results showed most subjects preferred average gain at 1000 to 2000 Hz that was 5 to 10 dB lower than prescribed by the NAL-R procedure.

In a longitudinal study conducted by Bentler et al (1993), objective measures were carried out on 65 adults with mild to moderate hearing loss, for 12 months post-hearing aid fitting. The purpose of the study was to investigate if speech performance and gain preference would change over time after the initial hearing aid fitting. Insertion gain was carried out to match the hearing aid gain as close as possible to the gain prescribed by the NAL-R procedure. Subsequent to the initial fitting, subjects were allowed to adjust the hearing aid volume control to their preferred levels. Subjects' used or preferred gains were measured at 6 and 12 months post-fitting. The results revealed most of the subjects used or preferred gains that were close to the NAL-R prescribed gain except for subjects with steeply sloping hearing loss who used significantly less gain than prescribed for 1000 and 2000 Hz at 12 months. No change of speech performance was observed for the 12 months post-fitting evaluation.

Kuk and Pape (1993), compared subject's satisfaction with hearing aid frequency responses fitted according to a Simplex procedure and those fitted according to the NAL-R procedure. The Simplex procedure required the subjects to compare one hearing aid frequency response with other frequency responses. The purpose of the procedure was to determine the frequency response that was preferred by the subjects for a specific listening condition. The hearing aid frequency responses fitted based on the Simplex procedure and the NAL-R procedure were stored in the hearing aid multimemory program. Subjects were required to try out the hearing aid with the NAL-R program for two weeks followed by another two weeks with the frequency responses fitted based on the Simplex procedure. Nineteen elderly subjects with moderate to severe sensorineural hearing losses were involved in the study. The results showed there was no difference in everyday satisfaction among the fitted frequency responses, including that prescribed by the NAL-R procedure. However, for subjects with a flat hearing loss showed a slight, but consistent, preference for frequency responses fitted based on the Simplex procedure.

Convery et al (2005) analyzed data from three studies (Cox & Alexander, 1992; Horwitz & Turner, 1997; Humes et al., 2002) to compare the hearing aid gain preferred by new and experienced hearing aid users. A total of 98 new and 77 experienced hearing aid users were subjected to the analysis. To eliminate the effect of audiogram configurations on the analysis, the actual preferred gain was referenced to the NAL-R targets. The NAL 2cc coupler targets were calculated and compared with the used or preferred gain of the subjects. The results showed both new and experienced hearing aid users preferred gain levels that were, on average, 5.5 dB below the NAL-R target.

Overall, previous studies (Byrne & Cotton, 1988; Bentler et al., 1993; Kuk & Pape, 1993) support the appropriateness of NAL-R procedure, at least for adults with mild to moderately severe degree of hearing loss. There were several studies (Leijon et al., 1990; Bentler et al., 1993; Convery et al., 2005) however, showed significant deviations of subjects' preferred gain from the gain prescribed by the NAL-R procedure. In this case, the studies found the NAL-R procedure tend to provide higher gain than required.

2.2.7 The NAL Revised Profound (NAL-RP) Procedure

When using the new NAL-R formula, Byrne & Dillon (1986) reported that it might not be applicable to severe and profound hearing losses since the data was derived from mildly to moderately hearing impaired subjects. To investigate the hearing aid frequency response and gain required by the severely and profoundly hearing impaired people, a group of 46 adult subjects with three frequency average HTLs ranged from 73 to 113 dB were selected (Byrne et al., 1990). The optimal frequency response slope, from the low frequencies (250 or 500 Hz) to 2000 Hz, was derived from paired-comparison judgments of filtered speech, home trials, quality ratings and speech recognition tests. The study concluded most of the severely and profoundly hearing impaired require more gain than would be prescribed by the NAL-R procedure. Clients with little hearing at high frequencies preferred more gain for the low frequencies. By using this data, the NAL-R procedure was further modified. The NAL-RP (revised profound) prescribes gain that increases at two-thirds of the rate that HTL increases for hearing levels that exceed 60 dB and prescribes less high frequency gain when HTL at 2000 Hz exceeds 95 dB (Byrne et al., 1990).

2.3 The NAL-NL1 Procedure

In the 1990s, many of the hearing aids manufactured were non-linear hearing aids. Dillon (1996) in his review, has outlined the advantages and benefits of non-linear amplification over linear amplification. With the introduction of non-linear hearing aids, new prescriptive procedure was required to fit the hearing aids (Byrne, 1996). The NAL-NL1 is the first prescriptive procedure developed by the National Acoustic Laboratories to select optimal frequency response for non-linear hearing aids.

2.3.1 The Aim of NAL-NL1

Unlike the NAL-R procedure, NAL-NL1 is not designed to equalize loudness across frequency even though it does tend to do so as a consequence of optimizing the predicted speech intelligibility for a specific loudness (Byrne et al., 2001). The underlying principle of NAL-NL1 is to maximize speech intelligibility and to apply loudness normalization to the total or overall loudness and not the loudness at each frequency as in other non-linear formulae. The aim of the NAL-NL1 is thus to provide the gain-frequency response that maximizes speech intelligibility while keeping overall loudness at a level no greater than that perceived by a normal-hearing person listening to the same sound (Dillon, 1999).

2.3.2 Development of the NAL-NL1 Procedure

The procedure was developed based on two theoretical models i.e. the loudness model (Moore & Glasberg, 1997) and a modified Speech Intelligibility Index (SII) (Ching et al., 2001). The Speech Intelligibility Index (SII), which is a modification of the Articulation Index (AI) is one of the methods used to predict speech intelligibility from a specified loudness level or degree of audibility. The original AI relies mostly on two factors, (a) the audible signal above one's hearing threshold and (b) the contribution provided by each frequency region to speech intelligibility. It assumes that speech intelligibility or speech performance will increase with increasing audibility. By simply providing enough gain at each frequency to make speech highly audible, the AI will be increased and thus the speech performance will be increased (Dillon, 2001 pg. 28). According to Ching et al (2001) and other studies (Ching et al., 1998; Hogan & Turner, 1998; Turner & Cummings, 1999) however, maximizing audibility will not necessarily maximize the ability to understand speech.

Ching et al (1998 & 2001) explained in relating audibility with speech performance, one must consider two crucial factors – the level distortion factor (LDF) and the hearing loss desensitization (HLD). Ching et al (2001) explained that the LDF is associated with the deterioration of the speech performance as a result of the high sound pressure levels received by the ear. This is due to the inability of the cochlea to analyze the signal when it is presented at a level such that even a normal cochlea cannot function optimally. The HLD refers to the decreased ability of the damaged cochlea to extract information even when it is audible. By taking into account of these two factors, a modified SII was produced which stresses on the importance of looking at the “effective audibility” rather than the “raw audibility” in predicting speech intelligibility (Ching et al., 2001).

To assess the modified SII, Ching et al (2001) conducted a speech test on 14 normal-hearing and 40 hearing-impaired listeners with a wide range of hearing losses. The 54 subjects listened to broadband speech low-pass filtered at 5600 Hz. Sentences were presented at six sensation levels, and performance was scored in terms of number of words correctly repeated. The mean observed speech scores were compared with the calculated original Articulation Index (AI), the SII with LDF correction and the modified SII with both LDF and HLD corrections. In conclusion, the results showed that the modified SII could provide better predictions of speech performance from a wide range of hearing threshold levels. Overall, the results revealed that the effectiveness of audibility decreased with hearing loss, and the decrement was greater at high frequencies than the lower frequencies.

The implication of the Ching et al (2001) study on NAL-NL1 procedure is that the amplification goal should aim to provide the sensation level or gain that will maximize effective audibility. In addition to this aim, overall loudness should also be taken into account. As explained earlier, NAL-NL1 aims to provide the gain-frequency response that maximizes speech intelligibility while keeping **overall loudness** at a level no greater than that perceived by a normal-hearing person listening to the same sound. According to Ching et al (2001) and Dillon (1999), optimizing hearing aid gain will mean balancing or juggling between effective audibility and total loudness. When more gain is provided to one frequency, the loudness will also increase. The balancing process will therefore involves considering which frequencies have less contribution to speech intelligibility and thus can be sacrificed, so that the extra gain can be given to other frequencies (Ching et al., 2001).

2.3.3 Derivation of the NAL-NL1 Formula

Dillon (1999) had briefly explained in an article about the process of deriving the NAL-NL1 formula from the set of theoretical models reported by Ching et al (2001). In the process of doing this, 52 audiograms that covered the common range of configurations and severity were entered into a computer program. For each audiogram, the program manipulated the gains in each 1/3-octave band until the SII was maximized whilst keeping the overall loudness at a level equal to or no greater than that perceived by the normal-hearing person. This process of deriving the optimum gains for each audiogram was carried out for different overall speech input levels. For instance, an audiogram and a speech level of 40 dB SPL is selected and entered into the program. Next, the computer will keep altering the gain at each 1/3-octave frequency until the gain that maximized the calculated SII without exceeding the normal overall loudness for 40 dB SPL speech. This was then repeated for five more input levels from 50 to 90 dB SPL.

2.3.4 The NAL-NL1 Formula

The process of calculating the optimum gain for each frequency described by Dillon (1999) is a long process. For one audiogram and a selected input level, the computer took about an hour or more to carry out the task, according to Dillon (1999). The procedure was therefore considered not practical for clinical use. To overcome this practical barrier, the end results of each calculation were used to form a prescription formula. The formula produced is too complex to be used manually and hence it is not intended for public use. Instead it was implemented in computer software that is easy to use by clinicians (Byrne et al, 2001).

The NAL-NL1 prescription software calculates required gain at each standard 1/3 octave gain frequency from 125 to 8000 Hz. At each frequency, the gain prescribed is dependent on the following four pieces of information (Dillon, 2001 pg. 255) :

- i) Hearing threshold at that frequency
- ii) Three-frequency average hearing threshold (500, 1000 and 2000 Hz)
- iii) Audiogram slope (from 500 to 2000 Hz)
- iv) Overall level of the speech input signal

The software generates targets for insertion gain, real ear aided gain, 2-cc coupler gain or ear simulator gain. It calculates different target gains for different input levels and for different types of signals. The targets can be displayed either in the form of gain versus frequency graphs or input-output curves. The target gain prescribed is also influenced by the number of channels available for one hearing aid and whether it is a bilateral or unilateral fitting. For a multichannel hearing aid for example, a lower gain will be applied when pure tone input signal is used as compared to when a broadband signal is used. This is because when a pure tone signal is used, all of its power falls into a single channel at any one time and consequently this channel will go into compression which results in gain reduction. As for bilateral or unilateral fitting, the formula prescribes less gain for a bilateral fitting after taking loudness summation effects into account (Byrne et al., 2001).

Other parameters prescribed by the NAL-NL1 formula include maximum power output, cross-over frequencies, compression ratios and compression thresholds, as explained briefly by Dillon (1999). The maximum power output is calculated based on the same principles and data as the NAL linear procedure (Dillon & Storey, 1998). However, because most of the hearing aids now are multichannel, the NAL-NL1 formula prescribes the maximum power output at each frequency rather than the three frequency average maximum output. The prescriptions also take into account the number of channels and its effect on loudness summation. As for the compression threshold, the default setting in the formula software ensures that all compression channels will go into compression when the overall level of speech signal is 52 dB SPL. This value was chosen based on two studies which showed that for a single channel hearing aid with fast acting compressor, the majority of the subjects tested prefer a compression threshold that is higher (above 60 dB SPL) (Dillon et al., 1998; Barker & Dillon, 1999). The compression ratio is derived by fitting a straight line to the input-output curve above the compression threshold. The cross-over frequencies are selected based on the shape of the audiogram. It is defined as the frequency at which the dividing hearing aid channels 'meet' (Venema, 2006, pg. 140).

2.3.5 Comparison of the NAL-NL1 and the NAL-RP prescriptions

Byrne et al (2001) looked at the differences between insertion gain prescribed by the NAL-NL1 and NAL-RP procedures derived from five sample audiograms. The comparison was made for an average input level of 65 dB SPL at six frequencies (250, 500, 1000, 2000, 4000 and 6000 Hz). It was found that for an average speech input level,

the NAL-NL1 prescriptions agree closely with the NAL-RP prescriptions (differences are not more than 5 dB across all the frequencies).

2.3.6 Validation of the NAL-NL1 Procedure

Byrne et al (2001) reported that the gains prescribed by the NAL-NL1 procedure are very similar to those prescribed by the NAL-RP for a mid level input or for an average speech input. As the NAL-RP procedure is supported by empirical research, the NAL-NL1 procedure was thus regarded by Byrne et al (2001) as partly validated (for mid input level) even before any direct validations were attempted.

The NAL-NL1 procedure was assessed in a study conducted by Keidser and Grant (2001) that compared the performance of the procedure to the Independent Hearing Aid Fitting Forum (IHAF) procedure. Twenty four adults with hearing losses that ranged from mild to severe and of different configurations, participated in the study. Subjects were fitted with a 2-channel compression hearing aid set according to the two prescriptive methods. Laboratory tests (paired-comparison judgments of speech intelligibility using four stimuli under quiet and noisy listening conditions and sentences tests) and field test (4 weeks of home trial with both fittings) were carried out to compare their performance. Results showed the IHAF prescribed relatively more low frequency gain for a flat hearing loss and more high frequency gain for a steeply sloping hearing loss. The sentence tests revealed subjects performed significantly better with NAL-NL1 than IHAF in a low-frequency weighted background noise. The paired-comparison tests and field tests showed a significant correlation between the difference in gain achieved from both fittings and subject's preference. As the achieved difference between the two fittings increased, subjects tend to prefer the NAL-NL1 fitting more.

Other studies (Smeds, 2004; Smeds et al., 2006a; Smeds et al., 2006b) assessed the NAL-NL1 procedure by comparing the preferred overall loudness of the hearing impaired subjects to the overall loudness provided by the NAL-NL1 prescriptions. Smeds (2004) selected 21 adults with no previous hearing aid experience and with mild to moderate sensorineural hearing loss to take part in a study. All subjects were fitted with wide dynamic compression (WDRC) hearing aids based on two prescriptive methods; the NormLoudn and the LessLoudn method. The NormLoudn method aims to prescribe gain so that the overall loudness is restored to normal. The LessLoudn method on the other hand aims to provide overall loudness that is less than normal. Subjects' preferences were

investigated using the field tests (interview, questionnaire and diary) and laboratory tests (paired-comparison judgments of preference and loudness and speech recognition test). The results indicated that the NormLoudn fittings provided higher overall gain and had calculated overall loudness that was close to normal. Despite that, the NormLoudn fittings did not provide significant improvement in speech recognition test. The field and laboratory tests revealed most of the subjects preferred the LessLoudn over the NormLoudn fitting. The study reported that the target gain prescribed by NAL-NL1 was similar to the gain prescribed by the NormLoudn procedure. Therefore, the study questioned whether the NAL-NL1 like the NormLoudn procedure, (and also other prescriptive methods such as DSL[i/o]) might be prescribing gain which is higher than is necessary for the new hearing aid users.

Whether the NAL-NL1 procedure provides gain which is higher than required, was further investigated in two studies conducted by Smeds et al (2006a,b). The actual aim of the studies was to determine the preferred overall loudness by hearing aid users with mild to moderate hearing loss and to compare their results with normal loudness. In the laboratory test, subjects were asked to listen to 11 listening situations presented to them in free field and to rate the loudness for each of the listening conditions. The subjects first performed the task with the original NAL-NL1 amplification. There were then allowed to adjust the volume control of the amplification devices fitted to them until the preferred loudness for each listening situation was achieved. For the field study, the hearing aid logged the preferred volume control setting and the calculated loudness at that setting. Overall loudness was calculated based on the Moore and Glasberg (1997) loudness model. The results revealed that the subjects preferred less than normal calculated loudness. When compared with subjects with normal hearing, hearing impaired subjects rated loudness as higher especially for the medium and high presentations levels. The studies indicated that current prescriptive methods like NAL-NL1, Cambridge procedure for loudness restoration (CAMREST) and DSL[i/o] in particular which aim to restore normal loudness (or less), might be prescribing too much overall gain for the mild to moderate degrees of hearing impairment.

A study conducted by Zakis et al (2007) on a trainable hearing aid has also provided some information regarding the effectiveness of the NAL-NL1 formula. A trainable hearing aid allows the wearer to teach or to train the instrument how it should be adjusted. The wearer does so by using the aid in situations in which he or she would like assistance with hearing. Therefore, the process takes place after the client leaves the clinic (Dillon et al.,

2006). In the Zakis et al (2007) study, adult subjects with symmetrical mild to moderate sensorineural hearing loss were fitted with a prototype trainable hearing aid. Basically, the aid was first fitted to the subjects with an untrained setting based on the NAL-NL1 prescription. The subjects then took the aid home and trained the aid's amplification settings to their preference in everyday situations. The subjects were then required to compare their trained settings to untrained settings and voted for their preferred settings in everyday situations. The study revealed that the subjects were able to train the aid to provide amplification parameters that, in such situations, they preferred significantly more often than the untrained parameters prescribed and adjusted in a clinic. Part of the research outcome indicated that on average, the subjects trained the aid to apply higher compression ratios than were prescribed by NAL-NL1 and less gain at typical speech levels. Also, it was found that during the process of fitting using the NAL-NL1 prescriptions, the gain was often reduced from the prescribed value at some frequencies in accordance with individual preferences. This was necessary usually to reduce the effects of occlusion and feedback.

The NAL-NL1 formula was also evaluated in the Keidser et al study (2008) that compared the gain preferences for average input level in real life, between experienced and new hearing aid users. Fifty new and 26 experienced hearing aid users with mild to moderate hearing loss took part in the study. The participants were fitted with the same model of hearing aid that had three listening programs; the NAL-NL1 program and the NAL-NL1 program with low- and high-frequency cuts. The participants were requested to use the fitted programs and were allowed to use the hearing aid volume control in everyday listening environments. On average, experienced hearing aid users preferred 2.6 dB less gain than prescribed by the NAL-NL1 formula. Mean results showed the new hearing aid users preferred 2.7 dB less gain, relative to the NAL-NL1 target, than did experienced users. The overall difference of preferred gain between the two groups however was not significant and dependent on the degree of hearing loss. For mild hearing loss, the new users preferred the same gain derivation from the NAL-NL1 target as did the experienced users (approximately -3.9 dB). As the hearing loss increased, new users preferred, on average, 6 dB less gain than did experienced users and this difference of preferred gain was found significant. The study also found about half of both new and experienced users preferred the high-frequency cut fitting.

In conclusion, the studies described above have consistently showed that the NAL-NL1 procedure provides gain which is higher than what is actually preferred at least, by adults

with mild to moderate sensorineural hearing loss. According to the Smeds et al studies (2006 a,b), it was suspected that the Moore and Glasberg (1997) loudness model used to derive the NAL-NL1 formula might slightly underestimate overall loudness for people with hearing loss. Hence the formula predicts more room to fit in more gain before the overall loudness exceeds normal overall loudness. The degree of over-prescription by the NAL-NL1 however was considered to be small (4 dB for mid-input levels and slightly higher for high input levels) as pointed out by Dillon (2006). These gain corrections has been incorporated into the latest version of the NAL non linear procedure at which is called the NAL-NL2.

2.4 The NAL-NL2 Procedure

The NAL-NL2 procedure is the revised version of the NAL-NL1 procedure. Like the NAL-NL1 procedure, the NAL-NL2 procedure aims to maximize speech intelligibility whilst keeping overall loudness no greater than that perceived by a normal hearing person listening to the same sound (Dillon et al., 2011). Briefly, the differences between the NAL-NL1 and NAL-NL2 prescriptions are reported by Dillon et al (2011) as follow :

- i) Relative to the NAL-NL1 prescription, the NAL-NL2 procedure prescribes more gain at the low and high frequencies than at the mid frequencies.
- ii) The NAL-NL2 procedure prescribes more gain at the low frequencies and less gain at the high frequencies for tonal languages.
- iii) The NAL-NL2 prescribes age dependent gain. It prescribes a few dB more gain than that prescribed by the NAL-NL1 procedure for children. The gain difference is greatest for soft input levels.
- iv) The NAL-NL2 procedure prescribes slightly higher gain for males than females.
- v) The NAL-NL2 procedure prescribes higher gain for experienced hearing user than for new hearing aid user.
- vi) The gain difference between bilateral and unilateral fittings is relatively smaller for the NAL-NL2 prescription than the NAL-NL1 prescription.

Using a model-based study, Johnson and Dillon (2011) compared the insertion gain and compression ratio prescribed by the NAL-NL1, NAL-NL2, Cambridge Method for Loudness Equalization 2—High-Frequency (CAMEQ2-HF) and DSL v5 procedures. The

prescriptions were based on seven hypothetical audiograms and for adults at conversational level. The results showed different compression ratio and insertion gain prescribed by the different prescriptive procedures. The respective prescriptions were then used to predict the overall loudness and speech intelligibility in quiet and in noise. It was found that the NAL-NL2 and DSL v5 procedures provided the least average loudness while the NAL-NL1 procedure provided the most average loudness. The differences in the predicted loudness however, did not produce different predicted speech intelligibility among the procedures.

2.5 Conclusions

The original NAL procedure was revised several times based on empirical studies. For each revision made, studies were carried out to validate or to evaluate the effectiveness of the procedure. Byrne and Ching (1997) reported the NAL procedure is probably the most experimentally verified procedure. This is perhaps true for adult population since many of the studies that verified the procedure, involved adult subjects. Previous studies that examined the effectiveness of NAL procedure in pediatric population are considered limited and are still lacking in terms of extensive evaluation (Ching et al., 2010a). The studies that examined the effectiveness of the NAL procedure in children (Snik et al, 1995; Snik & Stollman, 1995; Ching et al, 1997; Ching et al, 1999; Scollie et al, 2000; Ching et al, 2010a) are not discussed in this chapter but will be discussed in Chapter 4. In addition, many of the previous studies that evaluated the effectiveness of the NAL procedure were focused on mild to moderate degree of hearing loss. As the NAL-NL1 and NAL-NL2 procedures emphasize on effective audibility or effective amplification, this might limit the gains prescribed for hearing losses that falls in the severe to profound category (Scollie, 2006; Johnson & Dillon, 2011). Thus, it is important to investigate the effectiveness of the NAL non-linear procedures on individuals with severe to profound hearing loss.

CHAPTER 3

The Desired Sensation Level (DSL) Procedure

The Desired Sensation Level or DSL prescriptive procedure was introduced by Seewald in the mid 1980s. It is a method designed for prescribing hearing aid characteristics especially for the pediatric population. The birth of the DSL method can be linked to a rubella outbreak in 1973-1974 at the Children's Hospital in Halifax, Nova Scotia, Canada. With the increase number of infants born deaf, the alarm was switched on to pay serious attention in improving methods to assess and to select appropriate amplification for children. Hence, Dr Richard Seewald who was then working as an audiologist in the hospital began his work to develop the DSL method (Seewald et al., 2005).

This chapter will describe the early versions of the DSL method, the development of the DSL approach for non-linear hearing aid (i.e DSL input/output formula (DSL [i/o] or DSL v4) and the currently used DSL method which is called the DSL multi stage input/output (DSL m[i/o] or DSL v5).

3.1 The earlier versions of DSL

The primary goal of the DSL method is to provide appropriate amplification characteristics to children that will optimize their auditory perception of speech. With the primary focus on the amplification of speech signals, the DSL method was developed based on studies that looked at the long term average speech spectrum characteristics. Hence it is a method known also as a speech spectrum based procedure (Seewald & Ross, 1988). The aim of DSL on the early days was to select hearing aid characteristics that will place the long term average speech spectrum at levels which are audible, comfortable and undistorted across the broadest relevant frequency range possible (Seewald et al., 1987).

The DSL procedure agreed with Byrne (1983) that the initial selection of amplification characteristics should be based on the theoretical or prescriptive approach (Seewald et al., 1985). The DSL formula is described as a two-thirds slope rule as well as a two-thirds gain rule. This means individual with sensorineural hearing loss would prefer hearing aid gain which approximates two-thirds of his/her hearing loss. The DSL formula prescribes the sensation level targets for amplified speech as a function of frequency and hearing levels. The sensation

level target is referred as the level above hearing threshold that the average speech spectrum should be delivered. The sensation level targets were derived based on studies that estimated the most comfortable listening levels (MCLs) (Gengel et al., 1971; Kamm et al., 1978) and the optimal levels for listening to speech (Erber & Witt, 1977). Clinicians who used the DSL method on children in its early versions, would refer to the look-up tables which provide the sensation level targets for amplified speech (DSLs) as a function of frequency and hearing levels. Once the sensation level targets are determined, the target real-ear gain can be calculated. Table 3.1 illustrates how the target real-ear gain at different frequencies can be calculated (Seewald et al., 1987). First, the desired sensation levels are added to the hearing thresholds (in dB SPL at the eardrum) and this will result in the targets levels for the amplified speech spectrum. The target real-ear gain is the difference between the targets levels for amplified speech and the unamplified long-term average speech spectrum.

Table 3.1 : Illustration of how desired real-ear gain is calculated based on the DSL procedure

		Frequency (kHz)								
		.25	.5	.75	1	1.5	2	3	4	6
Thresholds (dB HL)		45	55	65	70	75	80	85	85	75
Desired Sensation Levels (dB)		16	22	19	15	18	19	16	14	13
Thresholds (dB SPL)	(+)	65	63	69	74	78	84	82	80	79
Amplified Speech Targets (dB SPL)		81	85	88	89	96	103	98	94	92
Speech Spectrum (dB SPL)	(-)	60	66	62	55	57	57	51	49	47
Desired Real-Ear Gain (dB)		21	19	26	34	39	46	47	45	45

In 1985 Seewald et al reported on a preliminary version of a computer assisted method to facilitate clinicians in selecting hearing aid gain/frequency response for children. In 1991, software program that incorporated the DSL procedure (DSL v3) was published (Seewald et al., 1991) and made available for clinical use. One unique feature of this computer assisted approach is that all audiometric and electroacoustic variables are converted to a common reference level which is the ear canal sound pressure level (SPL) and to be displayed on a single graph which is known as the SPLogram. Figure 3.1 shows an unaided SPLogram from the early versions of the DSL method (versions up to and including v3.1). Converting the audiometric data, the hearing aid characteristics and as well as the acoustics of speech into the same SPL reference level was initially proposed by Erber, (1973). According to Seewald et al

(1985), this approach allows one to visualize the inter-relationships of the hearing threshold, unaided and aided speech spectrum as well as the output limiting of the hearing aid and thus can serve as a very useful counseling tool for the parents of hearing impaired children.

The DSL v3 software automatic calculates the frequency-specific target values for hearing aid gain and also targets for hearing aid output-limiting. To obtain the target values, clinicians need to enter audiometric data (measured using insert phones, TDH headphones, or sound field), child's age and probe microphone measurement results, if any. The software will convert the thresholds into ear canal SPL threshold values using average transform values or individual values. Based on these threshold values, a set of ear canal SPL target values will be generated. The target values can be converted to 2 cc coupler equivalent to allow coupler-based fitting (Seewald et al., 1991).

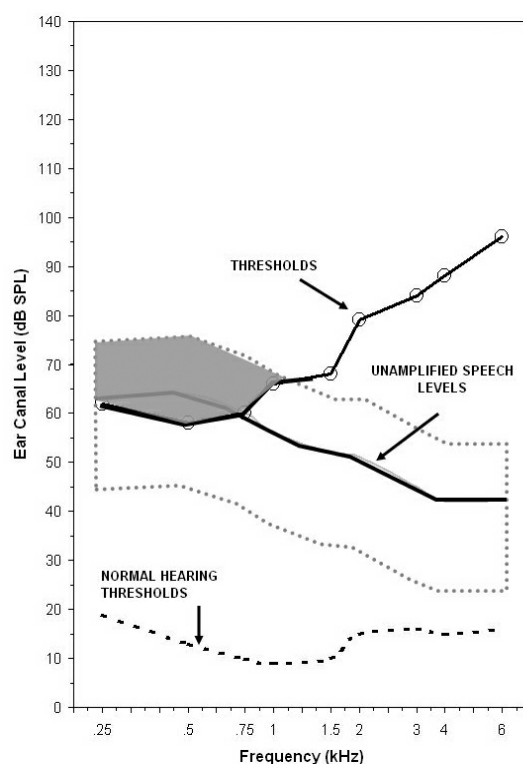


Figure 3.1 : Pure tone air conduction thresholds plotted in dB SPL (ear canal level) as a function of frequency. All other variables, including average normal hearing sensitivity and the average unamplified long term average speech spectrum level with its associated range of approximately 30 dB, have also been plotted. The portion of the unamplified speech spectrum that would be audible for this child has been shaded (Seewald et al, 2005, pg 148. Reprinted with authors' permission)

3.1.1 Validation of DSL v3

The validation of the DSL v3 procedure in children has been attempted by few studies. Snik et al (1995) conducted a study to compare the hearing aid gain used by 16 profoundly hearing-impaired children to that prescribed by the POGO II, NAL-RP and DSL v3 procedures. The children were considered as successful hearing aid users.

Insertion gain was measured on the children and the results were used to compare with the target insertion gains. The results showed that the measured insertion gains corresponded with both the NAL-RP and DSL v3 prescribed gains at most of the frequencies (within ± 5 dB).

In a separate study by Snik and Stollman (1995), insertion gain was measured from 34 children who had been fitted successfully with hearing aids. The children aged between 1.8 to 6.5 years old and had degree of hearing loss that ranged from mild to profound. Consistent with the previous study, the average used gain was within ± 5 dB of the average gain prescribed by the NAL-RP and DSL v3 procedures.

Like the early version of the NAL procedure, the DSL v3 procedure were lacking in terms of studies to validate its benefits to hearing aid users.

3.2 The DSL[i/o] or DSL v4 Procedure

The DSL input-output (DSL[i/o]) or DSL v4 formula was presented in a paper by Cornelisse, (1995), as a series of mathematical equations that define the relationship between the input level of a signal delivered to a hearing aid and the output level produced by the hearing aid. It is a device-independent prescriptive formula and can be used to fit either linear or wide dynamic range compression (WDRC) hearing instruments. The main goal of the formula was to place a wide range of input levels which correspond with the normal auditory dynamic range into the auditory dynamic range of individuals with hearing impairment so that all or almost all the input levels are audible to the individuals. The procedure divides the frequency-specific input-output (I/O) function into three stages : (i) linear region, (ii) compression region, and (iii) output limiting region.

The DSL[i/o] procedure can be divided into two different methods for defining the required amplification characteristics. The first one is called the DSL[i/o] linear compression while the second one is called the DSL[i/o] curvilinear compression. With the DSL[i/o] linear compression, the compression ratio is constant within the compression region while the curvilinear compression provides compression ratio that varies as a function of input level. The curvilinear compression is designed to normalize loudness perception (Cornelisse, 1995). The curvilinear and linear compression

input/output functions are illustrated in Figure 3.2. The linear compression uses extended input dynamic range and as a result it covers a larger input dynamic range than the I/O curvilinear compression function.

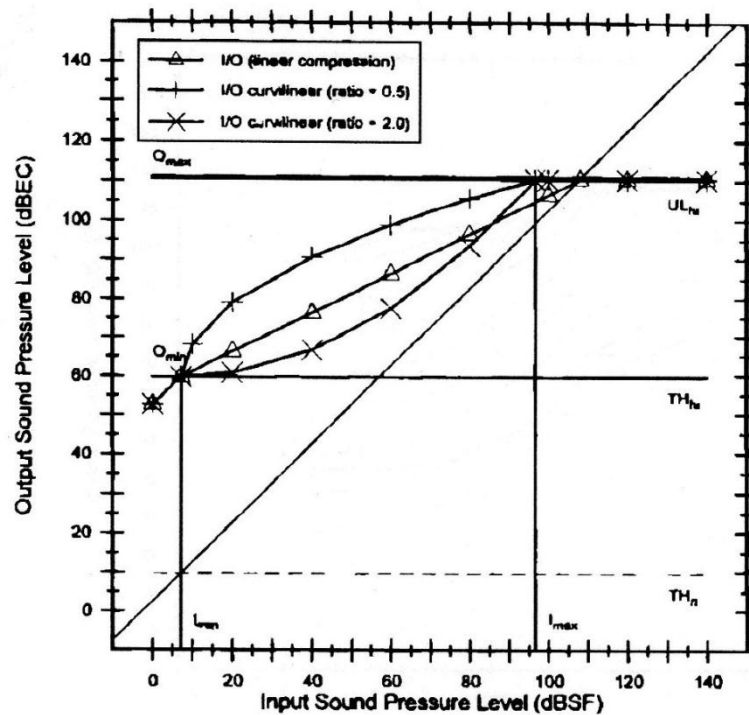


Figure 3.2 : The I/O curvilinear compression input/output for loudness exponent ratios of 0.5 and 2.0. The I/O linear compression input/output function is plotted for comparison. Data are for 50-dB hearing loss at 1000 Hz (Cornelisse et al, 1995, pg 1861. Reprinted with authors' permission)

Other than generating the desired gain like the earlier version of DSL procedure, the DSL[i/o] also consists of a set of recommended clinical protocols for hearing aid fitting in children. The clinical protocols to fit hearing aid based on the DSL[i/o] procedure are similar to that used in the DSL v3 procedure. Both procedures specific audiometric characteristics in SPL at the ear canal and incorporated real-ear-to-coupler difference (RECD) measurement for coupler based fitting in infants and young children (Seewald, 2000). The primary difference between the DSL v3 and DSL[i/o] is that the DSL[i/o] formula generates targets for input levels ranging from 50 dB SPL to 90 dB SPL, whereas the DSL v3 provides only a single target.

3.2.1 Validation of DSL[i/o] on children and adolescents

The appropriateness of DSL[i/o] targets for 12 adolescents and young adults with moderate to severe hearing loss had been evaluated by Jenstad et al (1999). Each subject was fitted with a single-channel hearing aid based on the DSL[i/o] procedure for both linear and WDRC processing. Speech perception was measured in unaided, linear gain and WDRC conditions. The speech items were digitally filtered to represent five different speech spectra. The results showed both the linear and WDRC fittings resulted in improved speech perception relative to the unaided condition. With the WDRC fitting however, subjects consistently showed good speech perception ability across the five speech spectra. With the linear fitting, reduced speech perception ability was observed for soft and shout speech relative to speech performance measured at average speech level. It was concluded that WDRC hearing aids fitted based on the DSL[i/o] procedure is capable of providing audible and comfortable signal across a wide range of listening conditions in quiet.

Jenstad et al (2000) also evaluated loudness perception in subjects who were fitted with the WDRC hearing aids based on the DSL[i/o] procedure. Ten participants from the study by Jenstad et al (1999) were fitted monaurally with the single-channel WDRC hearing aids. The hearing aids were fitted for both linear and WDRC processing based on the DSL[i/o] procedure. Threshold, upper limit of comfort and loudness growth perception from each participant were measured using warble tones, environmental sounds and speech, in three test conditions : unaided, linear gain and WDRC processing conditions. Twelve normally hearing adults were also tested monaurally in unaided conditions for comparison purposes. Results showed the WDRC processing provided the greatest input dynamic range and was the most effective in normalizing loudness.

The benefits offered by WDRC hearing instrument fitted according to DSL[i/o] have also been assessed on children. Fifteen children with severe to profound hearing loss from the Marriage et al study (2005) were fitted with high-power, multichannel compression hearing aids. Speech tests were conducted to compare the performance of the hearing aids fitted according to DSL[i/o] for linear, linear with compression limiting and WDRC processing. Closed-set speech test revealed children in the profound group did significantly better with the WDRC fitting. The study suggested that the use of well-designed WDRC in hearing aids for children with severe to profound hearing loss is unlikely to lead to poorer performance and is likely to lead to improved performance.

Scollie et al (2005) reported on a study that compared adults and children preferred listening levels to that prescribed by the DSL[i/o] procedure. Research participants were divided into three groups : i) children, ii) experienced adult hearing aid users and iii) inexperienced adult hearing aid users. There were 24 subjects in each group and most of the subjects had moderate to severe hearing losses. Subjects' preferred listening levels were measured and compared with the recommended level by DSL[i/o] procedure. The study concluded that the recommended volume control settings from the DSL[i/o] procedure closely approximated the children's preferred listening level (2 dB) for a 60 dBA speech input. The adults, especially the inexperienced hearing aid users however, preferred the volume control settings to be lower (11 dB) than what was prescribed by the procedure. The finding suggests that children's preferred listening levels are very likely to differ from those of adults and that a hearing aid prescriptive formula should at least consider these differences.

The performance of the DSL formula for children has also been compared to the NAL procedure in other studies. This will be discussed separately in Chapter 4 that compares the DSL and NAL performance in children.

3.2.2 Validation of DSL[i/o] on adults

The benefits of threshold-based fitting strategy based on DSL[i/o] versus a loudness-based hearing aid fitting strategy was assessed by Wesselkamp et al (2001). Twenty one adults with mild-to-moderate hearing loss were fitted with the same hearing aids according to the two fitting strategies. The performance of both fittings strategies were assessed using laboratory and field tests. Speech tests did not showed significant differences between the two fitting strategies. Sound quality ratings and self-report hearing aid benefits revealed the DSL[i/o] fittings were more preferred by the subjects. Other studies however, found the DSL[i/o] method did not prescribe gains that were preferred by many of the adult listeners (Stelmachowicz et al., 1998; Moore et al., 2001; Alcantara et al., 2004; Mackersie et al., 2004; Marriage et al., 2004).

Stelmachowicz et al (1998) compared for 49 mild to severely hearing impaired adults, the hearing aid used/preferred gain to that prescribed by the DSL[i/o] and FIG6 procedures. The study found in general, both the DSL[i/o] and FiG6 prescribed more gain (10 and even up to 20 dB) than actually used by the subjects. However, the study cautioned that the lower gain settings preferred by their adult subjects might not be

suitable for children. This is because when the adult subjects' used settings were used to calculate the Aided Audibility Index (AAI), it suggested that the used gain could not provide adequate audibility for low-context speech materials and thus may not be appropriate for prelingually hearing impaired children.

Moore et al (2001) compared the performance of DSL[i/o] with other two prescriptive procedures; the Cambridge procedure for loudness equalization (CAMEQ) and the Cambridge procedure for loudness restoration (CAMREST). Participants were 10 adults with moderate hearing loss, fitted bilaterally with multi-band compression hearing aids. The effectiveness of the three fitting procedures was judged based on the amount of gain adjustment required to achieve the satisfactory fittings, speech test and self-report benefits. The speech test and self-report measures were carried out after the gain adjustment and after a three weeks home trial. The results revealed that on average, the CAMEQ fitting required the least adjustment to achieve acceptable fitting and the DSL[i/o] fitting required the most gain adjustment. Most of the participants preferred lower gains than what were prescribed by the DSL[i/o] procedure, especially for high frequencies. The speech test and self-report measures did not reveal any significant differences between the three fitting strategies.

A similar study was conducted by Alcantara et al (2004) to compare the performance of the same three fitting strategies but on adults fitted unilaterally. Data gathered from 10 adults showed similar findings with those obtained from the Moore et al (2001) study. Both of the studies agreed that the DSL[i/o] procedure provided less appropriate initial fitting for adults when compared with the CAMEQ and CAMREST procedures. The three fitting procedures were also compared among inexperienced versus experienced hearing aid users (Marriage et al., 2004). The study was conducted on 20 experienced hearing aid users and 20 new users with mild to severe sensorineural hearing loss. The results were consistent with the Moore et al (2001) and Alcantara et al (2004) studies. On average, the DSL[i/o] method overestimated the gain preferred by both the experienced and non-experienced hearing aid users and the degree of overestimation was greater for the non-experienced group.

It has been documented that providing high-frequency amplifications to patients suspected with cochlear dead regions will not increase the ability of speech understanding (Vickers et al., 2001; Baer et al., 2002). In a study conducted by Mackersie et al (2004), 14 adults with steeply sloping high-frequency hearing loss were

fitted with hearing aids based on the DSL[i/o] procedure. The DSL procedure was selected in order to maximize high-frequency gain. Participants were tested with unfiltered and filtered speech stimulus at different cutoff frequencies. Contradictory with the findings from previous studies (Vickers et al., 2001; Baer et al., 2002), the results showed that in quiet and in low levels of noise, listeners with and without suspected dead regions benefited equally from wide-band amplification. It was concluded that high-frequency amplification should not necessarily be limited for patients with suspected cochlear dead regions.

In conclusions, most of the past year studies presented above, found the DSL[i/o] procedure was appropriate for children but for adults, there was a tendency for the procedure to overestimate the gain requirement.

3.3 The DSL m[i/o] or DSL v5 Procedure

The report about DSL v5 hearing aid prescriptive approach was published in a single issue of the *Trends in Amplification Vol 9(4)* in 2005. The single issue contains three separate chapters that, describe the historical perspective of the DSL approach (Seewald et al, 2005), the DSL v5 algorithm (Scollie et al, 2005) and the clinical protocols for fitting hearing instrument using the DSL approach (Bagatto et al., 2005). DSL v5 was first made available in one manufacturer's fitting software in 2006 (Scollie, 2006) and by 2008, the DSL v5 was made available in seven other manufacturers fitting software (www.dslio.com).

Seewald et al (2005) reported that the DSL v4 need to be revised and replaced by a newer version of the fitting approach due to several reasons. First, with the newborn hearing screening programs, more and more children with hearing loss are being identified and thus being fitted with amplification at a younger age. Young children or infants are normally 'forced' to use the hearing aids set by their clinicians for at least few years. Thus, a more evidence-based procedure is consider necessary with the hope that these children will receive the best amplification if possible, during the time period where speech and language acquisitions is very critical to them. Secondly, a new version of DSL was required to accommodate the changes and development in electrophysiology test and hearing instrument technologies. Thirdly, research studies, as well as reports from clinicians suggested that the DSL v4 procedure needed some modifications. Finally, according to Seewald et al (2005) many clinicians still choose to

rely on generic prescriptive algorithms such as the DSL procedure for children and this makes improvement to the DSL procedure even more necessary.

3.3.1 The DSLm[i/o] or DSL v5 Algorithm

The DSLm[i/o] stands for DSL multistage input-output. The term multistage refers to the four stages of processing which includes expansion, linear gain, compression and output limiting (Scollie et al., 2005, Scollie, 2006). The four stages of processing are briefly explained below.

For hearing aids that offer an expansion feature, the DSL v5 provides the expansion threshold (ET) which is defaulted to be approximately 10 dB below the level of soft speech. Input signals below the ET are considered as unwanted background noise and hence no gain or negative gain will be prescribed for this region. If this ET is applied, the linear region will cover the input range between the ET and the compression threshold (Scollie et al, 2005).

The maximum output level or output limiting stage can be defined in two different ways according to the DSL v5; (a) output limiting levels defined with narrowband inputs and (b) output limiting levels defined with broadband inputs. For the output limiting defined with narrowband inputs, DSL v5 provides narrowband predictions of individual's upper limit of comfort (ULC). These predicted ULCs are limited to a maximum of 140 dB SPL in the ear canal. The hearing instrument output when measured using the narrowband signals (pure tones, warbled tones or speech peaks), should not exceed these predicted ULCs. The predicted ULCs can be replaced by measured ULCs, if available. Alternatively, clinician can refer to the narrowband targets for 90 dB SPL generated by the DSL v5. Output limiting defined with broadband inputs (BOLT), prescribes a limiting stage for the one-third octave band levels of speech signals. The BOLT level is fixed at a certain level below the ULC. The BOLT is an addition to the narrowband output limiting targets that aims at providing appropriate output limiting for speech signals (Scollie et al., 2005).

The compression region corresponds with the input range that begins at the compression threshold and ends at the BOLT level. The input range where the compression operates for DSL v5 is smaller compared to the DSL v4 (approximately 30 to 70 dB SPL) (Scollie et al., 2005). Figure 3.3 shows the DSL v5 target input/output functions as

compared to the one generated by the DSL v4 formula. Figure 3.4 shows an example of the SPLogram generated from the DSL v5 algorithm.

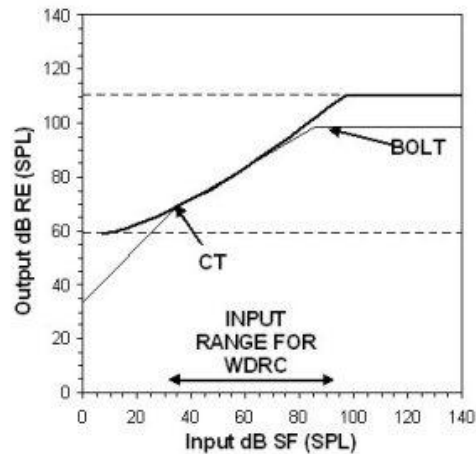


Figure 3.3 : Comparison of DSLv4 and DSL v5 target input/output functions, shown as thick and thin lines respectively. The dashed lines mark the detection thresholds and upper limits of comfort (Scollie et al., 2005, pg 183. Reprinted with authors' permission)

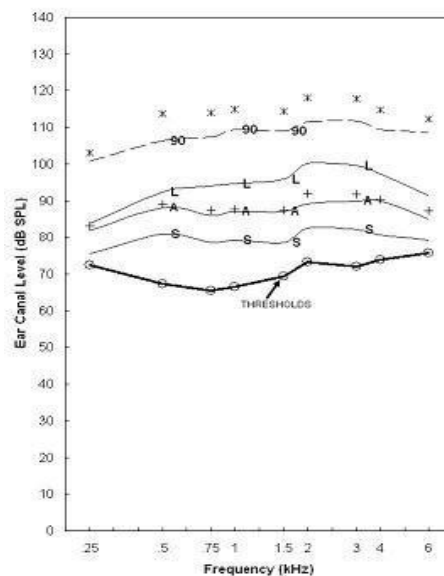


Figure 3.4 : Sample of SPLogram for a child with a moderate hearing loss from .25 to 6 kHz. Unaided hearing thresholds and predicted thresholds of discomfort define the residual auditory area in a dB SPL reference level. Targets for maximum power output of a hearing aid and for aided conversation-level speech are also plotted. Measured aided responses for soft, average and loud conversational speech inputs are shown (www.dslio.com. Reprinted with authors' permission)

3.3.2 Differences between DSL v5 and DSL v4

Details on the differences between the DSL v5 and DSL v4 prescriptive algorithm and why modifications were implemented on the DSL v4 can be found in Scollie et al (2005) and also in the www.dslio.com website. Different audiometric calibration standards and new transfer functions to estimate the hearing threshold levels from electrophysiologic thresholds are used to derive prescriptive targets in DSL v5. Other differences between the DSL v5 and DSL v4 are summarized below (see Scollie et al., (2005) for full report) :

i) The Speech Spectrum

A revised speech spectra is used in DSL v5 to derive targets for different speech input levels. In the former version of DSL procedure, 82 dB SPL was used as an estimate of loud speech. This level was actually derived from the “shout” vocal effect which is rarely encountered by people during communication. In the new DSL procedure, 74 dB SPL is found more representative of loud speech and is used to replace the 82 dB SPL. Hence, the new procedure focuses on generating targets for input level that range from 52 (soft) to 74 (loud) dB SPL. To derive targets for conversational speech level, the older version of DSL used the “UWO Child” speech spectrum which was derived by averaging out the spectrum of the talkers’ speech level as well as the child’s own speech level and the resulted spectrum was adjusted to have an overall level of 70 dB SPL. With the compression features which allow most of the current hearing aids to ‘adapt’ to changes of the input levels, the new DSL v5 procedure recommends a lower input level, i.e 60 dB SPL to be used instead of 70 dB SPL as a reference to derive the target for the average speech level. Unlike the “UWO Child” spectrum, this newly derived average speech spectrum does not reflect components of the child’s own speech level.

ii) Compression

The DSL v4 procedure aimed to achieve loudness normalization as a function of frequency by placing a wide range of input levels which correspond with the normal auditory dynamic range into the auditory dynamic range of individuals with hearing impairment. In DSL v5 however, loudness normalization is not considered to be a necessary requirement due to several reasons such as the appropriateness of applying

the loudness models on children, the unnecessary amplification of low-level background sounds, the limits of current hearing aid devices and the limited dynamic range of individuals. Thus, instead of making all the input range of sounds audible and of normal loudness, the DSL v5 procedure focuses on the input range that is considered important for speech perception.

Since the DSL v4 was originally designed for WDRC hearing instruments, the formula did not specify the required compression threshold. With the DSL v5, a new concept is implemented in which compression thresholds are prescribed according to the hearing levels. In general the DSL v5 prescribes higher CT as the hearing loss increases (Figure 3.5).

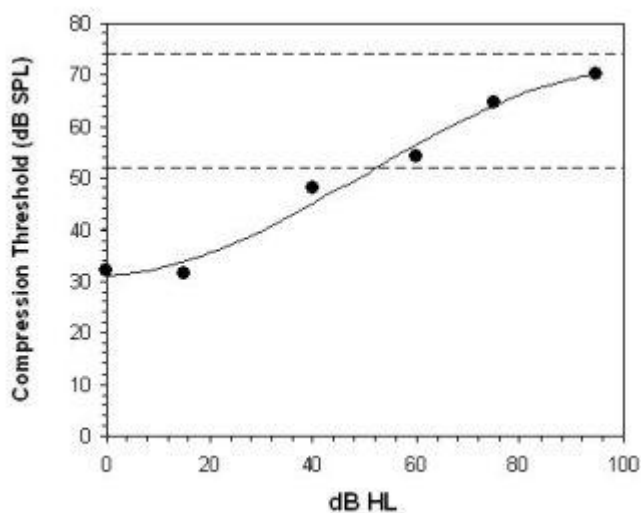


Figure 3.5 : Relation between hearing threshold levels (dB HL) and proposed input levels (dB SPL in the sound field) for the wide-dynamic-range compression (WDRC) threshold. The solid line is a third-order polynomial fit to a set of hypothesized compression threshold values. Dashed lines indicate the range of speech inputs considered by DSL 5 (i.e., 52 and 74 dB SPL), for reference (Scollie et al., 2005, pp 185. Reprinted with authors' permission)

iii) Multichannel Compression

Unlike the older version of DSL procedure, which prescribed compression ratios per audiometric frequency, DSL v5 offers target compression ratios according to the number of channels in the hearing aid.

iv) Binaural Correction

In DSL v5, prescribed targets for speech are reduced by 3 dB across input levels for binaural fittings. The reduction of 3 dB is a conservative estimate to preserve audibility,

particularly for pediatric fittings. The advantage of applying the binaural corrections on children is however, still questionable (Scollie et al., 2005).

v) Adult Fittings

The DSL v5 supports the studies that showed adults with acquired hearing loss had lower preferred listening levels (approximately 7 dB) than children (Stelmachowicz et al, 1998; Moore, 2001; Alcantara, 2004) and thus a different algorithm is created for the adult hearing aid users in the DSL v5 procedure. The differences between the gains prescribed for adult and children are more prominent for mild to moderate hearing loss and smaller for severe to profound hearing loss.

vi) Prescriptions for Noisy Situations

Different sets of targets are available for use in noisy environments for both adult and children in the DSL v5 procedure. Generally, this algorithm generates lower gains than the gains used for quiet environment and aims to increase listening comfort in noise without affecting significantly, the speech cues.

vii) Prescriptions for Conductive Hearing Loss

The DSL v5 includes gain prescriptions for people with pure conductive and mixed hearing loss. The strategy applied is to increase the predicted upper limits of comfort (ULC), causing the input/output function to steepen so that it is more linear and hence more gain is produced. The predicted ULCs are increased by 25% of the average air-bone gap at 500, 1000, 2000 and 4000 Hz and the targets generated should not exceed 140 dB SPL in the ear canal. The correction for conductive hearing loss decreases as the hearing level increases.

viii) Prescribed Gains

In the last section of Scollie et al (2005)'s report, comparisons were made between the gains prescribed by DSL v4 versus those prescribed by DSL v5. In summary, DSL v5 generates similar targets (within 3dB) to DSL v4 when a child and a 'quiet' prescription is selected. However, for severe to profound and/or steeply sloping hearing losses, the

gains prescribed by DSL v5 are lower (i.e. approximately 5 dB lower for 70 dB SPL speech input level). The reduction of gain is necessary due to the lower target limits for speech signals being prescribed by the DSL v5.

3.3.3 Validation of DSL v5 procedure

Two studies were carried out to validate the DSL v5 adult algorithm. The first study was conducted on 30 adults with hearing loss ranging from mild to severe (Polonenko et al., 2010). The subjects were fitted with hearing aids based on the DSL v5 adult algorithm. Hearing aid fine tuning was carried out if necessary, to ensure subjects would use their hearing aids in a field trial that lasted for approximately 90 days. Subjects' preferred listening levels (PLLs) were measured and compared to the DSL v5 targets at different frequencies. The Client Oriented Scale of Improvement (COSI) was used to evaluate the hearing aid outcomes. The results showed significant correlations between the subjects PLLs and the DSL v5 targets. On average, the PLLs were close to the DSL v5 targets (within 2.6 dB). The COSI showed improvements of outcomes with hearing aids fitted based on the DSL v5 procedure. The study however, has several limitations. The PLL for instance, was measured only at conversational level and in quiet. In the field trial, subjects had access to multi memory programs, volume control and noise reduction feature. It was possible that these factors (other than the DSL v5 prescription) had resulted in the improvement of hearing aid outcomes reported by the subjects. In addition, the study did not report how many of the subjects required their hearing aids to be fine tuned, how the hearing aid tuning affects the final gain and it's effect on the validity of the study.

Johnson and Dillon (2011) compared the insertion gain and compression ratio prescribed by the DSL v5, NAL-NL1, NAL-NL2, and Cambridge Method for Loudness Equalization 2—High-Frequency (CAMEQ2-HF) procedures. The prescriptions were generated based on seven hypothetical audiograms. Adult fittings were assumed and prescriptions were produced for conversational level. The respective prescriptions were used to predict the overall loudness and speech intelligibility in quiet and in noise. It was found that the DSL v5 and NAL-NL2 procedures provided the least average loudness. Even though the CAMEQ2-HF and NAL-NL1 procedures provided greater average loudness, this did not result in better predicted speech intelligibility. The study

is a model-based study and thus the predicted speech intelligibility could not be applied to all individuals.

3.4 Conclusions

This chapter describes the older and the current version of the DSL procedure. For each revision made, the primary goal of the DSL procedure is to select optimum amplification characteristics and to provide a set of clinical protocols for fitting hearing aid in pediatric population. Previous studies discussed in this chapter, showed the earlier versions of the DSL procedure (i.e DSL v3, and v4) were appropriate for children but consistently prescribed too much gain for adult populations. Despite previous studies that supported the use of the DSL procedure in children, Ching et al (2010a) cautioned that research data on the appropriateness of the DSL procedure and also the NAL procedure in children are still considered limited. Furthermore, previous studies that assessed the effectiveness of the DSL and the NAL procedures in children could be biased by the test site or the children's previous amplification history (Ching et al., 2010a; Scollie et al., 2010e). In other words, studies conducted on children in Canada for instance, will likely support the DSL procedure since the children are more accustomed to the DSL fitting. In addition, previous studies discussed in this chapter are limited to laboratory based evaluations and hence not much is understood about the children's use of amplifications in real world setting. The new DSL procedure, DSL v5 has introduced several prescriptions which were not present in its predecessors. This includes different prescriptions for quiet and noisy listening situations and a set of modified prescriptions for severe to profound hearing loss. Few studies had been conducted to validate the DSL v5 procedure on adults (Jenstad et al., 2007; Polonenko et al., 2010; Johnson & Dillon, 2011). Up to date, there were no published studies that look at the validation of the DSL v5 procedure on children.

CHAPTER 4

Comparison of the NAL and DSL procedures

4.1 NAL and DSL fitting rationales

Chapter 2 and 3 of this thesis have presented in detailed about the NAL and DSL procedure respectively. To recap, both the original NAL and DSL procedures were derived from principles based on similar objective, that is, to amplify speech sounds to the most comfortable listening level (MCL). The DSL procedure specifies audiometric and electroacoustic measurements in dB SPL at the eardrum. It prescribed real-ear aided gain (REAG) instead of real-ear insertion gain (REIG) as provided by the early versions of the NAL procedure initially. The NAL procedure at the beginning was based on a half-gain rule and half-slope rule. The DSL procedure on the other hand was based on a two-third gain rule and two-third slope rule. To achieve the aim of loudness equalization, the NAL procedure was revised (NAL-R) and the original half-slope rule was changed to one-third slope rule. As the NAL-R was not providing sufficient audibility for severe losses, it was further revised (NAL-RP) where the half-gain rule was changed to a two-third gain rule. For profound loss at high frequencies, amplification is concentrated on the lower frequency region.

With the existence of non-linear hearing aids, the NAL and DSL procedures developed their respective fitting algorithms for this type of hearing aid circuit. Unlike the NAL-RP procedure which aims to equalize loudness across frequency, the NAL non-linear procedure (NAL-NL1) aims to amplify overall loudness at a level equal or no greater than that perceived by a normal-hearing person listening to the same sounds. The NAL-NL1 prescriptive formula was derived using the Speech Intelligibility Index (SII) which takes into account level distortion and hearing loss desensitization. The gain prescribed by the procedure is dependent on the ability of the frequency region to extract speech information. The frequency region that has reduced ability to understand amplified speech will receive less gain than the frequency region that provides a better contribution to speech understanding.

The DSL[i/o] or DSL v4 procedure is designed for fitting wide dynamic range compression (WDRC) hearing aids, although it can also be applied to linear hearing aids. It aims to amplify sounds at each frequency to a level perceived as equally loud by

people with normal hearing. This principle, referred as loudness normalization, is also used in the NAL-NL1 procedure, but for overall loudness and not at each individual frequency. In the DSL v4 procedure, a wide range of input levels are amplified so they are audible and comfortable to the listeners. Its main goal is to fit the extended normal auditory dynamic range into the residual auditory dynamic range of hearing impaired individuals. The DSL v4 procedure has been modified and is now referred as the *DSL_m[i/o]* or DSL v5. The DSL v5 procedure involves four stages which are : expansion, linear, compression and output limiting. Unlike the DSL v4 procedure which tries to fit a wide range of input level into the auditory dynamic range, the newer version focuses on an input range that is considered important for speech understanding. Other differences between the DSL v5 and the DSL v4 are that, the DSL v5 procedure includes prescriptions for different listening situations, monaural versus binaural fitting, a correction for conductive hearing losses and generation of different targets for children and adults.

The remaining of this chapter will involve a comparison of the hearing aid gain and frequency response prescribed by the NAL and DSL procedures. The relative performance of the NAL and DSL procedures based on past studies will also be discussed and finally the significance of the present study will be explained.

4.2 NAL and DSL prescriptions

According to Byrne (1996), hearing aid fitting procedures based on different rationales or even the same rationale can result in substantially different prescriptions. The aim of the NAL and DSL procedures is to select amplification characteristics that will provide speech signals at an audible and at a comfortable level to hearing aid users. To achieve this aim however, these procedures use different formula and hence result in different gain prescriptions (Byrne, 1996). For a person with a moderate, gently sloping audiogram for instance, the DSL procedure tends to prescribe higher gain than the NAL-RP procedure at 250 Hz and also for frequencies above 1000 Hz. For steeply high-frequency audiograms, DSL will prescribe far more high-frequency emphasis than NAL-RP. This is because the DSL procedure is dependent on two-thirds-slope rule whereas the NAL-RP is based on the one-third-slope rule (Byrne, 1996). For individuals with flat audiograms, Byrne and Ching (1997) explained both NAL-RP and DSL tend to prescribe a similar frequency response, but DSL will prescribe higher overall gain.

Based on five different audiograms, Byrne et al (2001) investigated the differences of gains prescribed by the NAL-NL1, DSL[i/o], Independent Hearing Aid Fitting Forum (IHAF) and Figure 6 (FIG6) procedures. The differences between NAL-NL1 and DSL[i/o] prescriptions for non-linear amplification has been summarized by Byrne et al (2001) as follow and is also shown in Table 4.1:

- i) For a flat 60 dB HTL, DSL[i/o] prescribed more low-frequency gain than NAL-NL1 for soft, medium and high input levels.
- ii) For a reverse slope audiogram, DSL[i/o] prescribes considerable higher gain at the low frequencies but a little less than NAL-NL1 at the high frequencies. For DSL[i/o], the gain for low and medium levels is the same for frequencies above 1000 Hz, suggesting linear amplification for all below-average inputs.
- iii) For a moderately sloping high-frequency hearing loss, the NAL-NL1 procedure prescribes less gain and compression at low frequencies. Both NAL-NL1 and DSL[i/o] prescribe similar gain at mid frequencies (1000 – 2000 Hz). At frequencies at and above 4000 Hz, the DSL[i/o] procedure prescribes more gain than NAL-NL1.
- iv) For a steeply sloping high-frequency hearing loss with normal or near-normal hearing at the low frequencies, the DSL[i/o] procedure prescribes more high-frequency emphasis. The difference of high-frequency slopes prescribed by the two procedures was large (19 dB for NAL-NL1 and 44 dB for DSL[i/o] at medium input level).

Table 4.1 : The insertion gains prescribed by the NAL-NL1 procedure in relative to the gains prescribed by the DSL[i/o] procedures for different audiograms, at 65 input level

Audiogram	Low frequencies (250 – 500 Hz)	Mid Frequencies (1000 – 2000 Hz)	High Frequencies (at 4000 Hz and above)
Flat 60 dB HTL	less	similar	less
Reverse slope	less	similar	slightly more
Moderate sloping high-frequency loss	less	similar	less
Steeply sloping high-frequency loss (near-normal hearing at low frequencies)	less	similar	less

Using five diverse audiogram configurations, Keidser et al (2003) examined insertion targets prescribed by four proprietary fitting algorithms and two generic prescription algorithms (NAL-NL1 and DSL[i/o]). To compare overall gain prescribed by the different fitting algorithms, the insertion gain was averaged across frequencies (500, 1000, 2000 and 4000 Hz), input levels and hearing loss. The results showed that DSL[i/o] prescribed higher overall gain (21.4 dB) than NAL-NL1 formula (17.8 dB) and the other fitting algorithms. To compare the frequency slopes prescribed by each of the fitting algorithms, the insertion gain curves were normalized to the same gain level at 1000 Hz and comparisons between the prescribed slopes were made only for a medium input level. For flat and reverse sloping loss, DSL[i/o] prescribed relatively flat low-frequency response slopes while the NAL-NL1 procedure prescribed steeper low-frequency slopes. For high-frequency slopes, both procedures prescribed similar shapes. These findings were consistent with that reported by Byrne et al (2001) when similar configurations of audiogram were examined. For gently sloping high-frequency hearing loss, Keidser et al found both NAL-NL1 and DSL[i/o] prescribe a similar frequency slope from 500 to 2000 Hz. Outside this range DSL[i/o] prescribes relatively more gain than NAL-NL1. For steeply sloping losses, the NAL-NL1 procedure prescribes a shallower high-frequency slope than the DSL[i/o], with NAL-NL1 target rolling off at 3000 Hz while the DSL[i/o] continues to rise steeply. Variations of gain between targets were greater if there was a mild low-frequency hearing loss (DSL prescribes more gain) as compared to normal low-frequency hearing loss which is consistent with Byrne et al (2001) findings.

In conclusions, both the Byrne et al (2001) and Keidser et al (2003) studies agreed that the NAL-NL1 and DSL[i/o] procedures prescribe very different frequency gain and slope. The extent of the difference between the prescriptions is dependent on the degree and configuration of the hearing loss. The DSL[i/o] procedure will usually prescribe higher overall gain with higher gain, especially for the higher-frequency region.

A different approach was used by Seewald et al (2005) to generate targets based on three different prescriptive procedures; the DSL[i/o], CAMFIT (v1) Restoration and NAL-NL1 procedures. The CAMFIT is a hearing aid fitting procedure that is based on two theoretical rationales : i) the Cambridge method for loudness equalization (CAMEQ) and ii) the Cambridge method for loudness restoration (CAMREST). Briefly, the CAMEQ procedure aims to provide a flat specific loudness pattern over the frequency range important for speech (Moore & Glasberg, 1997; Moore et al., 1999)

while the CAMREST procedure aims to normalize specific loudness patterns for speech-shaped noise (Moore, 2000). Using 61 theoretical audiograms with varying degree and configurations, hearing aid targets were generated in the Seewald et al (2005) study. In order to have a true target-to-target comparisons, Seewald et al (2005) suggested the use of real-ear aided gain (REAG) instead of real-ear insertion gain (REIG) as the reference to generate the targets. This is because the REIG format normally uses average adult real-ear unaided gain (REUG) values to derive targets, which is inappropriate for children. Also, it is suggested that hearing aid parameters for each prescriptive procedure were matched as closely as possible when comparing the targets. Figure 4.1 shows an illustration of REAGs derived from the DSL v4, NAL-NL1 and CAMFIT procedures.

To conclude the study, Seewald et al (2005) reported that :

- i) the targets were similar in shape for most of the audiometric configurations
- ii) the DSL[i/o] procedure did not always generate the maximum target, with regard to gain.
- iii) the DSL[i/o] procedure prescribed maximum gain for high frequencies, most of the time
- iv) NAL-NL1 did not generate targets for all frequencies, especially for more severe-to-profound hearing losses. This finding agreed with Dillon (2006)

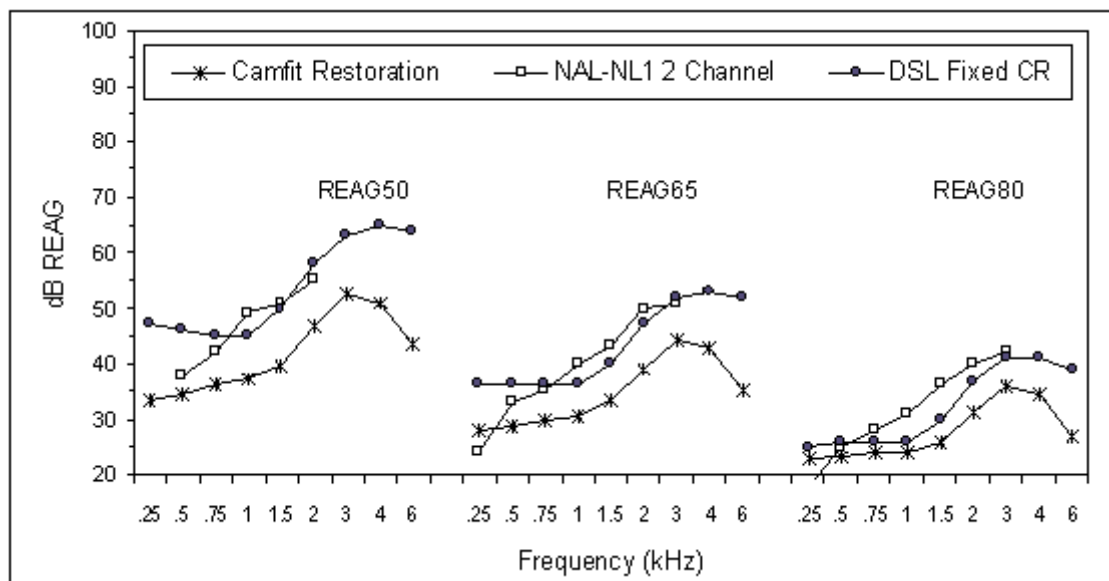


Figure 4.1 : Measured REAG as a function of frequency for a gently sloping severe to profound hearing loss derived using the CAMFIT Restoration, DSL v4.1 fixed and NAL-NL1 software (Seewald et al., 2005, pg 155. Reprinted with authors' permission)

In a study conducted by Ching et al (2010b), real-ear-to-coupler difference (RECD) of 48 children with mild to moderately severe hearing loss were measured and used to derive coupler gain targets based on the NAL-NL1 and DSL v4 procedures. For medium input levels, the study found that the DSL v4 procedure prescribed higher overall gain (averaged across 500 to 4000 Hz) than NAL-NL1 procedure for all the subjects and the difference in gain ranged from 2.9 to 16.4 dB. The frequency slopes prescribed by DSL v4 and NAL-NL1 were found to be different at low frequencies (250 – 1000 Hz) and high frequencies (1000 – 4000 Hz). The prescribed slope difference was greater at low frequencies (up to 13 dB/octave) than at high frequencies (up to 10 dB/octave). Table 4.2 shows the mean and range of gain differences between the NAL-NL1 and DSL v4 (DSL – NAL) target values, at different frequency regions and input levels.

Table 4.2 : Mean and range of gain differences between the NAL-NL1 and DSL v4 (DSL – NAL) prescriptions for low, high frequencies and different input levels (presented with authors' permission as part of data found in the Ching et al (2010b) study).

Level		Gain differences (DSL – NAL)	
		Low frequency (250–1000 Hz)	High frequency (2000–4000 Hz)
55	Mean	9.5	6.3
	Range	0.0 – 18.8	-3.7 – 19.5
70	Mean	10.8	10.0
	Range	0.0 – 19.9	3.2 – 16.4
80	Mean	8.7	4.2
	Range	0.0 – 19.0	-0.8 – 14.1

In a more recent study, Johnson & Dillon (2011) conducted a study to compare the insertion gain at medium input level and compression ratio as prescribed by different prescriptive methods for adults. The prescriptive methods were the NAL-NL1, the NAL-NL2, DSL v5 and Cambridge Method for Loudness Equalization 2--High-Frequency (CAMEQ2-HF) procedures. Targets were generated based on the same five audiograms in the Byrne et al (2001) study with addition of two audiograms; i.e. mixed and conductive hearing loss. The results showed that for adults with sensorineural hearing loss, the DSL v5 procedure tend to prescribed more gain for low and high frequencies while the NAL-NL1 and NAL-NL2 procedures tend to prescribe more gain

for mid frequency. For conductive hearing loss, the DSL v5 generated the least insertion gains relative to other procedures across the tested frequencies. The authors added that the differences of prescriptions observed among the prescriptive methods are likely to be greater for severe and profound sensorineural hearing losses. Despite the variation in gains prescribed by the different procedures, the study found comparable predicted speech intelligibility at normal conversational levels, between the NAL and DSL procedures.

In general, previous studies agree that the NAL and DSL prescribe different overall gain and frequency response and the differences between prescriptions can be large, depending on the degree and configuration of hearing loss. Whether the differences of gain and frequency response prescribed will result in the difference of hearing aid performance fitted according to the two procedures has been investigated by several studies in the past. The following section discusses about listening requirements in children and adults. The effect of listening requirements on listening preferences will then be discussed and finally comparison between the relative performance or the effectiveness of hearing aid fitted according to the NAL and DSL procedures will be presented.

4.3 Children versus adults' listening requirements

Many studies have been carried out in the past to compare the intensity levels required by children to discriminate speech as compared to adults. A brief description for some these studies are presented below.

Nozza and colleagues (1987, 1988, 1990) have conducted several experiments on infant speech-sound discrimination ability. Using the operant head-turn procedure, Nozza (1987) examined the ability of 10 infants to discriminate the speech sound (/ba/ vs /da/) presented at 50, 60 and 70 dB SPL. The experiment showed infants could not perform well when the speech sound was presented at 50 dB SPL but at this level, adults are able to perform optimally. The effect of noise on infant speech-sound discrimination has also been studied. Nozza et al (1988) measured binaural masked thresholds using speech sound /ba/ on infants, preschoolers and adults. The study found infants required higher signal-to-noise ratio (SNR) than adults and preschoolers to reach masked thresholds and the difference increased when there was an interaural phase difference for the speech sound. In another study, Nozza et al (1990) measured speech-sound discrimination (/ba/

vs /ga/) on 37 infants aged between 7 to 11 months old and compared their performances with 16 adult subjects. Both groups were tested using an adaptive threshold procedure. The study reported that an average difference of 5.8 dB SNR was observed between the two groups. As with the previous study, infants would seem to have poorer speech discrimination ability than adults when listening in noisy conditions.

As for younger children, Elliot et al (1979) conducted a study that measured the lowest intensity at which children from 5 to 10 years old could identify monosyllabic words. The study showed for speech stimuli presented in quiet, there was an improvement of performance between the ages of 5 and 10 years old and by the age of 10 years, performance was close to the adult results. For speech presented in noise, no age-related performance changes were observed. The study also found children with learning problems generally displayed poorer performance than children without learning problems. Nabelek and Robinson (1982) found children as well as elderly individuals performed poorer than young adults. Subjects from different age groups (10 to 72 years old) were presented with the Modified Rhyme Test (MRT). The results showed children and elderly required from 10 to 20 dB higher sound pressure levels than young adults to obtain maximum scores in quiet.

Another study by Nittrouer and Boothroyd (1990) showed that both children (aged between 4 to 6 years old) and older adults demonstrated poorer performance than young adults for word and sentence materials presented in noise. The study also found that children, young adults and older adults relied on similar but also different contextual cues to recognize speech. Children's use of contextual cues has also been studied by Fallon et al (2002). Children aged 5 and 9 years old and adults were required to identify the final words of low- and high-context sentences presented in noise. The results showed children required higher SNRs than adults to reach comparable scores and the performance of 5 year old children was poorer than that of 9 year old children.

A more recent study has been conducted by Neuman et al (2010) to examine the difference in listening ability between children and adults. The study determined how the combinations of noise levels and reverberation time affect the speech recognition ability of a group of normally hearing children (aged between 6 – 12 years old) and adults. Speech recognition performance was measured using the Bamford-Kowal-Bench Speech in Noise test (Bench et al., 1979). Participants were assessed using a virtual test paradigm represented the signal reaching a student seated in the back of classrooms

with reverberation times of 0.3, 0.6, and 0.8 sec. The SNRs required for 50% performance and for 95% performance were measured. Results showed that higher SNRs were required to reach the 50% performance as the reverberation time increased and as the age decreased. The author concluded the younger the child, the higher the SNR is required for speech understanding and that this SNR will increase with increased reverberation time.

Studies comparing the auditory performance of children versus adults have also been carried out on individuals with hearing impairment. Gravel et al (1999) looked at the relations of children's age and their ability to discriminate speech. Twenty children (aged 4 to 11 years old) with mild to severe hearing loss were included in the study. An adaptive procedure was used to measure the SNR required by the children to score 50% for words and sentences presented in noise. The study found that younger children required a higher SNR to achieve comparable performance with the older children. Stelmachowicz et al (2001) investigated the effect of stimulus bandwidth on the perception of three fricative sounds in normal and hearing-impaired children and adults. Eighty subjects, with 20 in each group, participated in the study. The stimulus produced by a male, a female and a child speaker, were low-pass filtered at five frequencies from 2000 to 9000 Hz. The results showed for all speakers, both groups of children performed more poorly than their adult counterparts at similar bandwidths. For a male speaker, maximum performance was reached at a higher bandwidth (5000 Hz) for the children and also the hearing-impaired adults, but not for the normal-hearing adults. The study suggested the importance of high-frequency audibility in the development of speech by children.

In conclusions, much research from the past has demonstrated that children required higher intensity level or SNR to achieve speech scores which are similar to their adult counterparts. In addition, past studies showed that children at different chronological age demonstrate different ability of speech discrimination. There are also studies that found a decline of performance in speech recognition for the elderly group. According to Blamey et al (2001), the difference in ability to recognize speech between children and adults is due to the development of auditory and phonologic systems that continue to mature throughout the early school years.

4.4 Children versus adults' listening preferences

To examine if the listening requirement is related to listening preference, Scollie et al (2005) reported on a study that compared adults and children preferred listening levels to that prescribed by the DSL v4.1 procedure. Children, experienced adult hearing aid users and inexperienced adult hearing aid users with mostly moderate to severe hearing losses, were recruited for the study. Subjects' preferred listening levels were measured and compared with the recommended level by DSL v4.1 procedure. The study concluded that the recommended volume control settings from the DSL v4.1 procedure closely approximated the children's preferred listening level (2 dB) for a 60 dBA speech input. The adults, especially the inexperienced hearing aid users however, preferred the volume control settings to be lower (11 dB) than what was prescribed by the procedure.

The finding suggested the DSL v4.1 procedure overestimated the preferred gain for adults and this is consistent with results from the earlier study by Snik and Hombergen (1993). Forty adults and 95 children aged from 2 to 12 years old were selected in the Snik and Hombergen study. The participants' hearing aids were fitted or optimized based on clinical evaluations, hearing aid trials and professionals' observations. The results showed that the average insertion gain for children was about 7 dB higher than the insertion gain measured from adults, suggesting the appropriate or required gain for children and adults are different.

A review article by Ching et al (2001) explained that children's amplification requirements and preferences are not necessarily different from that of adults. For high-level sounds, the required gain for children and adults should be similar. This is because of three reasons as explained by Ching et al (2001). Firstly, loudness discomfort levels of children and adults do not differ significantly and secondly, providing excessive gain at this level can increase the risk of damage to residual hearing and thirdly, increased high-level gain does not increase speech intelligibility due to distortion and hearing desensitization. For medium-level sounds, empirical evidence (i.e. Snik & Stollman, 1995; Snik, van den Borne et al., 1995; Ching et al., 1996; Ching et al., 1999) showed the children's preferred/used gain were close to that prescribed by NAL-RP. Children however, may require more amplification for low-level sounds than adults as they lack the linguistic knowledge and further research is needed to determine the answer (Ching et al, 2001; Ching et al 2010a).

4.5 The relative effectiveness of the NAL and DSL procedures

4.5.1 Studies on adults

Mueller (2005) has reviewed the effectiveness of prescriptive methods used to fit hearing aids in adults. The effectiveness of the fitting formula was examined by referring to the subjective responses and preferred used gain by hearing aid users in real-world listening environments. A total of 136 potentially relevant studies were extracted from a database search. From the total, 11 studies that met the inclusion criteria, were reviewed. Eight of the studies supported gain similar to that prescribed by the NAL-R or NAL-RP procedure and three studies supported prescribed gain less than that recommended by the NAL procedure. Although most of the studies did not directly compare the performance of subjects fitted using the NAL and DSL procedures, they seemed to show the DSL method probably overestimates the required gain since the DSL procedure tends to prescribe higher gain than the NAL procedure. According to Mueller (2005) most of the studies focused only on gain-for-average level inputs and most of the subjects involved in the studies had previous experience using hearing aid gain not higher than that recommended by the NAL procedure. Moreover, the evidence can only be applied to adults with mild-to-moderately-severe sensorineural hearing loss. The studies that compared performance of the NAL and DSL procedures on adult hearing aid users are summarized below. Some of these studies have been presented in Chapter 2 and 3 with regard to the validation of the NAL and DSL procedures.

Moore et al (2001) compared the performance of hearing aids fitted according to three prescriptive procedures; the DSL[i/o] procedure; the CAMEQ procedure and the CAMREST procedure. Moore et al (2001) reported that because the CAMEQ procedure prescribes gain similar to the NAL procedure, the study can be considered to indirectly compare the performance of the NAL and DSL procedures. Ten adults with moderate hearing losses were fitted bilaterally with hearing aids. The effectiveness of the three fitting procedures was judged based on the amount of gain adjustment required to achieve the satisfactory fittings, speech test and self-report benefits. The results revealed that on average, the CAMEQ fitting required the least adjustment to achieve acceptable fitting and the DSL[i/o] fitting required the most gain adjustment. Most of the participants preferred lower gains than what were prescribed by the DSL[i/o] procedure, especially for high frequencies.

A similar study was conducted by Alcantara et al (2004) to compare the performance of the same three fitting strategies but on adults fitted unilaterally. Data gathered from 10 adults showed similar findings with those obtained from the Moore et al (2001) study. Both of the studies agreed that the DSL[i/o] procedure provided a less appropriate fitting for adults when compared with the CAMEQ and CAMREST.

The DLS[i/o], CAMEQ and CAMREST procedures were also compared among inexperienced versus experienced hearing aid users (Marriage et al., 2004). The results gathered from 20 experienced hearing aid users and 20 new users with mild to severe sensorineural hearing loss were consistent with the Moore et al (2001) and Alcantara et al (2004) studies. On average, the experienced and non-experienced hearing aid users both required less gain than what was prescribed by the DSL[i/o] procedure and the preference for less gain was more pronounced for the non-experienced group. The CAMEQ and CAMREST prescribed gains were found appropriate for the experienced users but for non-experienced users, approximately 3 dB of gain reduction relative to the prescribed gain was required.

The gain preference by non-experienced hearing aid users was also investigated by Smeds in 2004. Twenty one adults with mild to moderate sensorineural hearing loss and no hearing aid experience were involved in the study. The subjects were fitted with hearing aids based on two prescriptive methods; the NormLoudn method (aims to restore overall loudness to normal) and the LessLoudn method (aims to provide overall loudness that is less than normal). The results showed that the NormLoudn fitting did not improve speech recognition ability and overall, most of the subjects preferred the LessLoudn over the NormLoudn fitting. When the measured gain of the NormLoudn fittings were compared with the prescribed NAL-NL1 gain, it was found that both prescribed similar gain. The study suggested that prescriptive formulae that aim to restore overall loudness to normal or near to normal, such as the NAL-NL1 procedure and probably other prescriptive procedures such as the DSL[i/o] procedure, might be prescribing gain which is higher than is necessary for new hearing aid users.

Another study conducted by Jenstad et al (2007), further validated the use of DSL[i/o] procedure on adults. Twenty three adults with mild to moderately severe sensorineural hearing loss were recruited. Validation of the DSL[i/o] procedure was examined for an average input level and using multidimensional outcome measures (i.e. objective and subjective evaluations). Among the findings reported was, on average, an overall gain

reduction of 5 dB or a low frequency reduction of 5 dB from DSL[i/o] targets would likely to result in settings that optimized the outcome measures. The study confirmed that some modifications to the DSL[i/o] procedure were required to generate the appropriate hearing aid targets for adults and these modifications have been incorporated into the current version of DSL procedure (i.e. DSL*m*[i/o] or DSL v5). The DSL v5 procedure is the first version that allows for the protocol to be modified for adults compared to children and hence it should do better in adult studies than the earlier versions of DSL procedure. The use of DSL v5 procedure on adults was supported by Polonenko et al (2010). Their study showed that adults with mild to severe hearing losses had preferred listening levels (PLLs) that approximated the adult targets prescribed by the DSL v5 procedure (within 2.6 dB on average).

4.5.2 Studies on children

Snik et al (1995) performed a study to compare the hearing aid gain used by 16 profoundly hearing-impaired children to that prescribed by the POGO II, NAL-RP and DSL v3 methods. Hearing aid fitting for these children was optimized in an auditory habilitation program that involved related professionals and the children were considered as successful hearing aid users. Insertion gain measurement was conducted on the children and the average data were used to compare with the prescribed insertion gain. The results showed that the measured insertion gains were in fair agreement with both the NAL-RP and DSL v3 prescribed gain at most of the frequencies (within ± 5 dB). The NAL-RP prescribed gain was the closest to the desired gain, followed by the DSL v3 procedure while the POGO method prescribed gains which deviated most from the desired gain.

In a separate study by Snik and Stollman (1995), insertion gain was measured from 34 children who had been fitted successfully with hearing aids. The children were aged between 1.8 to 6.5 years old and had degree of hearing loss that ranged from mild to profound. Consistent with the previous study, the average used gain was within ± 5 dB of the average gain prescribed by the NAL and DSL procedures. For children with more severe hearing loss, a better match between the desired and the target gain was found with the NAL procedure.

Ching et al (1997) compared the gain and also frequency response slope preferred by a group of 21 severely and profoundly hearing-impaired children (37 test ears) to the

NAL-RP and DSL v3 prescriptions. Children listened with their own NAL-fitted hearing aids, to connected speech presented audio-visually at a comfortable listening level. Using paired-comparison tests, they were required to identify the frequency response that they judged as most intelligible. The difference between the prescribed and preferred three frequency average (3FA) gain was not significant for NAL-RP but was significantly different for DSL v3. The mean difference between the prescribed slope and preferred slope (500 – 2000 Hz) was smaller for NAL-RP (-0.29 dB/octave) than for DSL v3 (5.29 dB/octave). Out of the 37 ears, 33 agreed with the NAL-RP prescribed slope (within 6 dB/octave) as compared to 19 for the DSL v3 prescription.

A similar study was conducted by Ching et al (1999) on 22 severely and profoundly hearing-impaired children aged between 7 and 17 years old. The children's hearing aids were fitted according to the NAL-RP procedure which was assigned as the reference frequency response. Using paired-comparison test, the reference response was compared with alternative frequency response in order to determine the frequency response preferred by the children. On average, the children used 3 dB more gain (based on 3FA gain) than the NAL-RP prescription. Out of the 34 ears tested, the preferred frequency response slope of 32 ears agreed with the NAL-RP prescribed slope (within ± 6 dB/octave).

The preferred gain was compared with the prescriptive targets for a total of 43 children from the Ching et al study (1997, 1999). It was found 65% of the children used gain as prescribed by NAL-RP within ± 5 dB. When compared to DSL prescription, only 33% of the children used gain as prescribed by DSL within ± 5 dB and 55% used less gain than prescribed by the DSL prescription (Ching et al., 2001).

Study by Scollie et al (2000) however did not support findings from Ching et al (1997, 1999) that children's preferred gain was somewhat closer to the NAL prescription than the DSL prescription. Eighteen children with hearing loss ranged from moderate to profound and mean age of 10.8 years participated in the study that compared the children's preferred listening levels (PLLs) to the targets generated from the DSL v4.1 and NAL-RP / NAL-NL1 formula. The PLLs were measured when the children were listening with their DSL-fitted hearing aids, to speech material presented at conversational level. The results indicated no significant difference between the children's PLLs and DSL targets but there were significant difference between the PLLs and NAL target gains. For the DSL procedure, 66% of PLLs fell within ± 5 dB of target

while only 9% of PLLs fell within ± 5 dB of target gain prescribed by the NAL procedure. For NAL targets, 95% of the fittings provided insufficient gain to reach the PLLs. As hearing loss increased, the DSL procedure also tended to prescribed gain lower than what was preferred by the children.

4.5.3 Conclusions of earlier studies

Ching et al (2010a) pointed out that previous studies on children's gain preferences are inconclusive. Ching et al (2010a) further explained that the discrepancy in findings between studies can be due to several factors. Subjects' preferred hearing aid gain could be influenced by their previous listening experience. This means subjects who were accustomed to the NAL fittings would tend to prefer gain that approximates the NAL targets and likewise children who had already become accustomed to the DSL fitting would tend to prefer gain that approximates to that prescribed by the DSL procedure. It is therefore suggested that an acclimatization period with new hearing aid settings is necessary for subjects in order to determine the preferred hearing aid gain. In addition to previous listening experience, Ching et al (2010a) added that differences of subjects' characteristics (e.g. degree of hearing loss) and research design (e.g. stimulus type and level) between studies could also resulted in disagreement between their findings. A collaborative research between the National Acoustic Laboratories (NAL) and the University of Western Ontario (UWO) has been carried out in a recent year as an effort to evaluate the relative effectiveness of NAL-NL1 and DSL v4.1 prescriptions for children. The following section will discuss this in more detail.

4.5.4 The NAL/UWO study

The National Acoustic Laboratories and University of Western Ontario (NAL/UWO) study was published in the Special Issue of the *International Journal of Audiology*, volume 49(1), 2010. The study involved a total of 48 children (28 children from Canada and Australia respectively) with hearing loss ranged from mild to moderately severe and age ranged from 6.6 to 19.8 years old. Thirty eight children were fitted with the same hearing aid model while the remaining 10 children were fitted with a different hearing aid model. Individual real-ear-to-coupler-difference (RECD) values were used to derive the target gain from the NAL-NL1 and DSL v4.1 stand alone software. A four-period, two-treatment crossover design with double-blinded assessment was implemented in the

study. Briefly, the children wore their hearing aids fitted according to the NAL-NL1 and DSL v4.1 formula at different trial period. Access to both NAL-NL1 and DSL v4.1 prescriptions was given to all children at a subsequent trial period. Evaluation on the performance and preference of the NAL-NL1 and DSL v4.1 prescriptions was carried out using speech recognition tests, paired-comparison judgments of speech intelligibility test and loudness measurements. Functional hearing of the children was assessed using questionnaires and a diary filled in by the parents, teachers and the children themselves.

In summary, the study found for speech perception test in quiet and in noise, there were no significant difference in performance between the NAL-NL1 and DSL v4.1 prescriptions. The paired-comparison judgments of intelligibility revealed neither prescription was significantly preferred over the other. Assessment in real-world settings showed the NAL-NL1 prescription was more frequently reported as better in noisy listening environments whereas the DSL v4.1 fitting was reported better for listening to soft sounds. On average, 33% of children preferred NAL-NL1, 56% preferred DSL v4.1, and the remaining 10% had no preference. Children's prior listening experience and listening environments were found to influence their preferences for the prescription. The study concluded that neither the NAL-NL1 nor the DSL v4.1 was better in predicting the gain requirements for children. Rather, the study reported that the appropriate amplification characteristics were dependent on the listening environments, where the required or preferred gain tend to approximate the NAL-NL1 targets for noisy situations, but were closer to the DSL targets for listening to soft speech in quiet (Ching et al, 2010a).

4.6 Significance of present study

According to Ching et al (2010a), the research data published to date comparing the performance of the NAL and DSL procedures in children are still limited despite the fact that the two procedures are widely used by clinicians for hearing aid fitting. Hearing aid gain requirements for children with severe and profound hearing loss especially, is still unclear since previous studies had mixed results (Ching et al., 2002). Ching et al (1997, 1999) for instance, found the preferred gain by children with severe and profound hearing loss were closer to the NAL-RP prescription, but Scollie et al (2000) found children in their study preferred higher gain than what was prescribed by

the NAL-RP and NAL-NL1 procedures. These studies were conducted on the earlier versions of the procedures (i.e. NAL-R or NAL-RP versus DSL v3 or DSL v4). Except for the Scollie et al (2000) study, there is no published study to date that directly evaluates the benefits of the NAL-NL1 procedure (and also the DSL v5 procedure) in severely and profoundly hearing impaired children. Even though the NAL/UWO study compared the performance of NAL-NL1 and DSL v4, the study involved children with hearing losses that fall mostly in the range from mild to moderate degree. Hence the question remains as whether the research findings can be applied to children with severe to profound hearing loss. As explained in the Introduction Chapter 1, for developing countries like the Malaysia, most children with severe to profound hearing loss still rely on hearing aids. Thus, it is important to investigate the optimum hearing aid characteristics for children with hearing losses that fall in the severe to profound category, at least in the Malaysian scenario and other countries such as India where cochlear implant is dependent on self funding rather than a government based program.

4.7 Conclusions

To conclude, even though the main goal of the NAL and DSL procedures is the same, that is to amplify speech sounds to a level which is most comfortable and to maximize speech intelligibility while avoiding distortion, both prescriptive procedures developed different formulae or rationales to calculate the required gain in order to achieve this objective. This has resulted in substantially different hearing aid gain and frequency response prescribed by both procedures. Past studies have consistently shown that the hearing aid gain preferred by adults was closer to the NAL target gain and that the DSL procedure tends to prescribe higher gain than what was required by the adults. For children, further studies are required to examine the relative performance of hearing aid fitted according to the NAL and DSL procedures.

CHAPTER 5

Hearing Aid Fitting in Children

According to the 'Pediatric Amplification Protocol' published by the American Academy of Audiology (2004), the hearing aid fitting protocol for infants and children can be divided into four major sections : assessment, selection, verification and validation. It is not the intention of this chapter to present the pediatric fitting protocol in detail. Rather, this chapter aims to discuss some of the fitting guidelines or procedures which are relevant to the present research methodology. Discussion is focused upon audiometric assessment and hearing aid verification, as well as upon the objective and subjective tests used to evaluate the effectiveness of hearing aid fittings in children.

5.1 Audiometric Assessment

Hearing assessment is often considered as the first step in determining the candidacy of hearing aids and in selecting appropriate hearing aid characteristics. Hence, it is important to ensure that the hearing thresholds of individuals are accurately assessed. Audiometers are calibrated for an average adult with normal hearing, which corresponds to 0 dB on the dial in order that audiologists can easily define the hearing threshold levels of an adult by referring to the audiometer dial reading. The dial reading however can be misleading, or is not accurate, in representing the hearing threshold levels of infant and young children, as was explained by Marcoux and Hansen (2003). Children (age 0-5 years) have smaller ear canal sizes as compared to adults (Kruger, 1987; Bentler, 1989) and this will normally result in higher sound pressure levels (SPLs) generated at their ear canals when a stimulus is presented (Feigin et al., 1989). The differences in SPLs generated at the ear canal will in turn depend on the type of transducers used (i.e headphones, insert earphones, custom earmold or the loudspeakers used in free field). As a result of higher SPLs present at the ear canals, children tend to have 'better' hearing than adults if measurements are based on the audiometer dial reading (Ching & Dillon, 2003; Marcoux & Hansen, 2003). To overcome the mismatch between the hearing levels of children and adults measured using the audiometer, the NAL and DSL procedures have adopted different methods to determine hearing sensitivity for children (see Ching & Dillon, 2003 and Bagatto et al, 2005).

Briefly, NAL procedure recommends that clinicians to obtain the Equivalent Adult Threshold (EAT) instead of relying on audiometer dial reading to define hearing threshold levels for children. The EAT is defined as the threshold level that an average adult would have if the adult has the same threshold in dB SPL at the eardrum as the child. Audiometer dial readings in HL or SPL can be converted into EAT by using recommended transform functions and can be calculated manually or using the NAL-NL1 fitting software. Depending on the type of transducer used, the individual or average real-ear-to-coupler difference (RECD), real-ear-to-dial difference (REDD) and real ear unaided gain (REUG) are transform functions necessary to convert the dial reading to EAT (Ching & Dillon, 2003). Table 5.1 provides examples of formulae used to transform dial readings in HL to EAT.

Table 5.1 : Examples of formulae used for calculating the Equivalent Adult Threshold (EAT) from the audiometer dial reading for different types of transducers (Ching & Dillon, 2003 - with authors' permission)

Types of transducers	
Insert earphones (foam tip or earmold)	$EAT = HL_{dial} + RECD_{individual} - RECD_{average}$
Sound field	$EAT = HL_{dial} + REUG_{individual} - REUG_{average}$

HL dial is the audiometer dial reading, RECD average is the RECD for an average adult

To overcome the same problem, the DSL method specifies values of hearing thresholds in dB SPL as measured in the ear canals. The procedure involves measuring individual's hearing thresholds in dB HL and converting the values into dB SPL in the ear canal using transform functions. If insert earphones are used for instance, measured or predicted RECD values, together with the reference equivalent threshold sound pressure level (RETSPL) values, are required to convert hearing threshold in dB HL to dB SPL in ear canal (Bagatto et al., 2005). Table 5.2 provides the equation for converting the thresholds in dB HL to dB SPL in the ear canal. The use of this transform function was found to be valid and accurate in predicting hearing levels in real ear SPL (Scollie et al., 1998).

Table 5.2 : Examples of formulae adopted by the DSL method to convert hearing thresholds in dB HL to dB SPL in the ear canal for different types of transducers (Bagatto et al., 2005 - with authors' permission)

Types of transducers	
Insert earphones	$\text{dB SPL threshold (ear canal)} = \text{dB HL threshold} + \text{insert RETSPL} + \text{RECD}$
TDH-series earphones	$\text{dB SPL threshold (ear canal)} = \text{dB HL threshold} + \text{REDD}$
Sound field	$\text{dB SPL threshold (ear canal)} = \text{dB HL threshold} + \text{sound field loudspeaker RETSPL} + \text{REUG}$

RETSPL is the level that approximates the normal hearing threshold when presented at 0 dB HL.

5.2 Hearing Aid Selection and Verification

Hearing aid selection has become a more complicated procedure as compared to the situation in the past, following the advances of hearing aid technology and the availability of more hearing aid options. Hearing aid selection involves the process of deciding, for example, the appropriate hearing aid design, features and type of signal processing for the client (American Academy of Audiology, 2004). There are several factors that need to be considered when selecting an appropriate hearing aid, such as the degree of hearing loss, age, individual preference or listening needs, cost, comfort and goal of amplification.

The purpose of hearing aid verification is to ensure that hearing aid has been set to match targets generated by a prescriptive formula. Verifying prescribed real-ear gain is recommended in the hearing aid fitting protocol and this can be achieved by conducting real ear insertion gain (REIG) for adults and either real ear aided gain (REAG), or 2cc coupler tests utilizing individual RECD values for children.

5.2.1 REAG and REIG

The REAG is defined as the difference in decibels, as a function of frequency, between the SPL at a specified measurement point in the ear canal and the SPL at the field reference point, for a specified sound field, with the hearing aid (and its acoustic

coupling) in place and turned on. The REIG is defined as the SPL at the eardrum when aided minus the SPL at the eardrum when unaided. For REIG, the real ear unaided gain (REUG) needs to be measured before inserting in the hearing aid. The REUG refers to the gain measured at the unoccluded ear canal relative to the stimulus level (ANSI S3.46-1997). The REIG is the difference in gain between the REAG and the REUG:-

$$REAG - REUG = REIG$$

According to Ching and Dillon (2003), the difference between the REIG and the REAG is that the REIG is dependent on the REUG and hence the acoustic resonance of the individual's ear concha and ear canal. The REAG on the other hand, measures the gain when the hearing aid is already placed on the ear, therefore bypassing the measurement of ear canal resonances. Ching and Dillon (2003) added that for infant and young children or even for adults with atypical ear canal resonances, prescribed hearing aid gain should be based on REAG rather than the REIG as the prescriptive formulae normally use average adult REUG to derive the REIG targets. This is not appropriate for children who have different REUG due to the differences in the ear structures from adult ears. In other words, REIG targets derived based on adult REUG cannot be used to define the actual REIG required by children, who normally have different REUG. The REAG is more suitable because it provides the same gain from free field to eardrum for the same degree of hearing loss, irrespective of the REUG values. Another advantage of using the REAG is that it ensures the same amplified signal is present at child's eardrum, despite the changes of the acoustic resonance of the child's ear canal for the first few year of life. If REIG is used, subsequent insertion gain measurements need to be carried out to take into account the changes in ear canal resonance. Also, coupler gain prescriptive targets based on REAG targets are affected only by the difference between the coupler and real ear gain and no individual ear canal resonance will be required (Ching et al., 2002; Ching & Dillon, 2003). The REAG targets can be converted into required coupler gain by using average or individualized RECD which will be discuss next.

5.2.2 RECD

Valid and reliable probe-tube microphone measurements are often difficult to obtain from children. Infant and young children usually cannot remain quiet or sufficiently still

for the measurement nor can they tolerate the presence of the probe tube in their ear canals during the fine tuning process. As such, the RECD measurement was proposed to overcome the problem of implementing direct real ear assessment on children (Seewald, 1991; Moodie et al., 1994). The RECD values can be used to derive required coupler gain and this allows the hearing aid verification to be carried out using the 2-cc coupler instead on the child's ear. The required coupler gain can be calculated from the RECD values to predict the required real ear targets :

$$\text{Coupler gain targets} = \text{REAG} - \text{RECD}$$

Past studies had revealed that the RECD procedure is repeatable and can be used accurately to predict real ear aided performance (Moodie et al., 1994; Sinclair et al., 1996; Seewald et al., 1999). The authors of these studies had emphasized the advantages of utilizing RECD measurement in the process of fitting hearing aids to children. First, the procedure eliminates variability associated with free field probe-microphone or aided threshold testing. Second, hearing aid verification can be carried out using the 2cc coupler system and this approach does not require the child to be present as in the probe-microphone procedure. Finally, the degree of cooperation required from child is less compared to other methods of hearing aid fitting.

Different techniques have been proposed to conduct the RECD measurement. To increase the accuracy of hearing aid fitting, it is suggested that clinicians use a real-ear instrument coupled to the individual's custom earmold to perform the RECD measurement. Using individual's earmold for real-ear measurements will allow the acoustic characteristics of the earmold such as tubing and horn effects, to be included in the measurement (Ricketts & Bentler, 1995). To determine the insertion depth of the probe tube placed in the ear canal, three methods are available. The 6-kHz notch method requires clinician to insert the probe tube into the ear canal while observing the probe-tube measurement display. By presenting a warble tone at 6 kHz in free field, a minimum will occur in the ear canal at a region about 15 mm from the eardrum. The probe tip is then inserted in by an extra of 6 mm to ensure a 9 mm position from the eardrum is achieved (Sullivan, 1998; Storey & Dillon, 2001). When a child is less complaint, another approach is to place the probe tube using the average ear canal length of individuals. The recommended insertion depth is 28 mm for adult females and 31 mm for adult males from the intertragal notch, 20-25 mm for children and 11 mm from the entrance for infants (Moodie et al., 1994; Bagatto et al., 2006). Alternatively,

the probe tube placement can also be done by measuring 5 mm from the medial tip of the individual's earmold (Bagatto, 2001).

5.2.3 Test Signals

The test signal used to verify the hearing aid gain is considered important since it can affect the results of measurement. For non-linear hearing aids, it is necessary to verify the electroacoustic performance of hearing aid using different input levels. A common practice among clinicians and researchers is to use 50, 65 and 80 dB SPL representing soft, medium and loud sounds respectively, for the verification purposes (Dillon, 2001 pg 300). Another factor to consider is the type of test signal appropriate for use to measure the electroacoustic performance of hearing aid. Numerous studies have been conducted to compare the hearing aid output measured using different test signals from hearing aid analyzers. Most of these studies investigated whether hearing aid output measured using different types of test signals offered by analyzing systems were comparable with hearing aid output measured using real speech.

Stelmachowicz et al (1996) compared hearing aid gain measured using real speech (continuous discourse) with five non-speech test signals (swept pure tones, speech weighted composite noise, simulated speech, speech weighted warble tones and speech modulated noise). Twenty hearing aids with different types of circuit were tested in a 2cc coupler at input levels ranged from 50 to 80 dB SPL. The results showed that swept pure tones produced the greatest difference in gain from the gain for real speech (10 – 14 dB). Discrepancies in gain were more pronounced for non-linear hearing aids and at higher input levels. Simulated speech and speech modulated noise produced hearing aid gains that were closest to the gain for real speech.

In the Scollie and Seewald (2002) study, 41 hearing aids representing a range of hearing aid circuit types (e.g. analog/digital, linear/non-linear, single/multi channel) were set to DSL v4.1 targets for moderate, severe and profound hearing loss. The hearing aids were tested using pure tones, broadband test signals (i.e. composite noise) and modulated narrowband signals (i.e. warbled tones) and the results were compared to hearing aid levels measured using a real speech signal. In general, the speech-weighted signals (composite noise and warbled tones) provide a closer match to the real speech levels while pure tone signals tend to overestimate the aided speech output. The degree of mismatch between all the test signals and the real speech was greater for higher test

levels (85 dB SPL) and this error was more pronounced for profound hearing loss. For hearing aids with noise reduction algorithms, a modulated test signal (warbled tones) provides better match with the speech signal than the steady-state signals (i.e. pure tones and composite noise).

Keidser et al (2010) compared the spectra of nine speech-shaped signals from five analyzing systems. The test signals included were the modulated speech-shaped noise from Aurical, the composite noise from the Fonix system, two versions of the speech noise from the Avant REM Plus and recorded male speech from the Audioscan's Verifit. The other four test signals were the International Long-Term Average Speech Spectrum (ILTASS), the International Speech Test Signal (ISTS) and two International Collegium of Rehabilitative Audiology (ICRA) noises. The spectra of the test signals from four of the analyzing systems were measured in a sound-treated test booth. The spectra of a test signal from one analyzer was obtained from the University of Iowa. For the test signals measured in the test booth, the noises were played back at 70 dB SPL through the open test box loudspeaker. All measurements were made by recording the one-third octave levels on the spectrum analyzer of a sound level meter. The results showed most of the speech-shaped signals have spectra that is either similar to the ILTASS by Byrne et al (1994) or the American National Standards Institute (ANSI) specified speech spectrum. It was found that the speech noises from the Aurical and Fonix system have spectrums that were close to the ANSI spectrum while the new speech noise from the Avant, Audioscan and UNITY system have spectrums that more approximate the ILTASS by Byrne et al (1994). Since the derivation of targets for prescriptive procedures such as the NAL, DSL and Cambridge procedure were based on speech spectrum that more approximate the ILTASS by Byrne et al (1994), the authors suggested that test signals that have spectrum similar to the ILTASS would be more appropriate for hearing aid verification.

In conclusion, different types of test signals will generate different hearing aid output measured in analyzing systems and the degree of differences are dependent on the hearing aid circuit types, input levels, frequencies and degree of hearing loss. Test signals which have characteristics resembling real speech should be used for hearing aid fitting purposes.

5.3 Hearing Aid Validation

Hearing aids fitted according to prescriptive procedures using audiometric-derived gain is often considered as a starting point towards achieving an optimal fitting. It is essential that follow-up assessment or hearing aid evaluation is carried out to check whether a selected amplification characteristic during the hearing aid fitting process is optimal and satisfactory to the individual. Hearing aid validation allows the assessment of benefits and satisfaction experienced by hearing aid users and it should be regarded as an on-going process (American Academy of Audiology, 2004).

Validation can also be viewed as a process of assessing the outcome or the success of fitting a hearing device to the hearing-impaired individual. In assessing the hearing aid outcome, a multi-dimensional approach should be adopted in order to define the optimal fittings. For adults, the dimensions of hearing aid outcome should include assessments on for example, aided speech recognition ability, objective benefit in speech recognition, subjective measure/s of sound quality and measure/s of either subjective benefit, satisfaction, or use (Humes, 1999; 2003). Assessing hearing aid outcome in children is a very complex process and is generally undertaken using techniques which are different from those used with adults. Hearing aid evaluation in children is often driven by a need to ensure that a selected hearing aid setting is optimal for the development of speech and language skills. Hence, the dimensions of hearing aid outcome in children normally include auditory awareness, audibility of speech, speech intelligibility, accuracy of speech production, rate of language acquisition, loudness discomfort and social development (Stelmachowicz, 1999). This is generally in agreement with Arlinger (2001) who divided the dimensions of hearing aid outcome assessment in children into four main dimensions – audibility, speech recognition, subjective assessment of benefit and speech production.

The efficacy of hearing aids can be evaluated using two approaches – objective and subjective methods. An example of an objective measure is a speech recognition test. According to Humes (1999), a speech test is referred as an objective test, even though a response is required from the listener because the responses can be scored as correct or incorrect according to the test criterion. Subjective measures of performance on the other hand, rely entirely on the listener's judgment or opinion and have no external reference for evaluation. Examples of subjective measures include the loudness

judgment test, paired-comparison judgment of speech intelligibility test and self-report outcome measures.

5.3.1 Speech recognition tests

Speech tests are a direct and objective way to measure how much more clearly people can understand speech with their hearing aids than without them (Dillon, 2001 pg 351). According to Madell (2008b), speech tests can be an extremely valuable part of the clinical audiology test battery. It can be used to demonstrate benefit with hearing devices, demonstrate improvement in auditory function, identify problems that develop overtime, demonstrate habilitation and rehabilitation needs and assist in selecting an appropriate educational environment. The selection of speech materials for children is dependent on factors such as the child's vocabulary level, cognition ability and cooperation from the child. Mendel (2008) recommended the use of standardized speech materials to be included in the test battery for children. Most of the standardized test materials according to Mendel (2008) however, are suitable for children aged 3 and above. For infants and toddlers, different procedures have been proposed to assess speech performance. The Battery of Auditory Speech Perception Tests for Infants and Toddlers (BATIT) was developed to evaluate speech pattern contrast perception in children with age ranged from 6 months to 5 years of age (Eisenberg et al., 2007). It consists of four computerized tests : i) Visual Reinforcement Assessment of the Perception of Speech Pattern Contrasts (VRASPAC), ii) Play Assessment of Speech Pattern Contrasts (PLAYSPAC), iii) On-line Imitative Test of Speech Pattern Contrast Perception (OLIMSPAC) and iv) Video Speech Pattern Contrast Test (VIDSPAC). For all the four tests, the stimulus set and perceptual task are held constant but the response task required from the children changes according to their age. The VRASPAC is designed for children as young as 6 months old. In this test, children are conditioned to produce head turn when they hear or discriminate a speech sound. In PALYSPAC, children are required to perform a task (e.g. pushing a button) upon hearing the change of speech sound. The OLIMSPAC requires the child to repeat after the stimulus while the VIDSPAC measures speech pattern contrast perception using a video-game format. Eisenberg et al (2007) examined the use of BATIT in a small sample of children with normal hearing. While children by age of 7 months can be tested with the VRASPAC, there exists a period where children aged between 1 and 3 years of age cannot be assessed reliably with any of the four tests described above.

For older children and adults, attempts have been carried out to develop speech recognition tests that have higher validity and sensitivity. Examples of such speech recognition tests include the Hearing in Noise Test / HINT (Nilsson et al., 1994), the Quick Speech-in-Noise Test / QuickSIN (Killon et al., 2004), the Bamford-Kowal-Bench Speech-in-Noise Test / BKB-SIN (Bench et al., 1979; Etymotic Research, 2005) and the Words-in-Noise test / WIN (Wilson & Burks, 2005). The comparative sensitivity of these speech tests has been studied by Wilson et al (2007). The results of their study showed the QuickSIN and WIN were more sensitive in differentiating between the subjects with normal hearing and subjects with hearing loss. However, the authors suggested that since the BKB-SIN and HINT materials provide more semantic context and thus are easier, their use is more appropriate with young children or individuals with substantial hearing loss.

In the current study, the HINT was used as one of the speech materials to evaluate the performance of hearing aid fitting. The HINT measures the speech reception threshold (SRT) or the threshold level necessary for a listener to recognize the speech materials correctly 50% of the time. According to Nilsson et al (1994), the SRTs are derived from an adaptive testing where the presentation level of the stimulus is increased or decreased by a fixed amount, depending upon the listener's response to the preceding sentence. SRTs can be measured in quiet or in spectrally matched noise. The adaptive procedure has the advantage of avoiding ceiling and floor effects customarily associated with the percent intelligibility measured at fixed speech or noise levels. The HINT developed first in English, was reported to be a reliable and sensitive speech test by Nilsson et al (1994). Mendel (2007) compared the unaided and aided performance of 21 hearing aid users measured using sentence tests and self-assessment reports (the Hearing Aid Performance Inventory / HAPI). The results showed that the HINT is sensitive enough to serve as objective outcome measurement that documents subjective improvements in speech understanding with hearing aids. In another study by Peeters et al (2009) that measured subjective and objective improvement of speech intelligibility in noise offered by hearing aids with adaptive directional microphones and noise reduction systems, showed there was a moderate correlation between the HINT and the subjective measure using the Acceptable Noise Level task (ANL). The ANL measures listener's subjective responses to speech-in-noise performance. The study suggested both the HINT and ANL may be used to study the benefits provided by hearing aids.

The HINT is a standardized test that has been developed in many languages. The characteristics of the speech when they are spoken can affect intelligibility. These characteristics include the phonetic similarity of the words, the speaking rate and clarity of the speaker, the naturalness of the speaker's voice, the speaker's gender, and the speaker's dialect. The HINT speech materials attempt to address and control each of the above factors (Soli & Wong, 2008). For example short, simple sentences from children's books are used to control the lexical, grammatical, and utterance length factors. The selected talker was a native speaker with a professionally trained voice and all HINT speech materials for all languages were recorded and processed at the House Ear Institute in Los Angeles, USA according to the procedures described by Nilsson et al (1994). The noise was spectrally matched to the speech spectrum of the respective languages and thus the issue of effective masking does not arise for different speech materials. This standardized test allows direct comparison of studies using HINT in languages (Nilsson et al, 1994).

Ever since the speech tests were developed for use in clinical and research settings, they have been subjected to evaluation with regard to their reliability and validity. Early studies for instance agreed that popular speech tests were normally sensitive enough to differentiate between unaided performances versus aided performance, but were often not able to differentiate between configurations of hearing loss or between hearing aids performance with different frequency response settings (Carhart, 1965; Jerger et al., 1966; Edgerton et al., 1978; Schwartz et al., 1979). In hearing aid validation, speech tests alone cannot be used to document the overall benefits experienced by hearing aid users. For example, the traditional speech tests normally include word recognition tests measured at a fixed level and in quiet. This approach often does not reflect the ability to understand speech in realistic listening environments (Harford, 1988). One alternative is to measure the speech scores at different levels of presentation (Performance versus Intensity / PI function) as this method can provide more information in both research and clinical contexts (Boothroyd, 2008). The PI function measurement however, the disadvantage of requiring slightly longer time to complete the test (Dirks et al., 1982).

In the case of hearing impaired children, Stelmachowicz (1999) explained it is often difficult to obtain reliable results in speech recognition tests for children less than three years old. The author further explained that the speech materials for assessing young children are often limited to closed-set word tests which lack the sensitivity to

differentiate between hearing aid performances with different frequency response settings. With the implementation of newborn hearing screening, more and more children with hearing impairment are diagnosed at a younger age. Whenever speech tests on infants and toddlers cannot be carried out, alternative methods of auditory assessment, such as the use of parental questionnaires, is strongly recommended. Assessing speech discrimination ability in difficult to test populations with electrophysiologic tests has also gained more attention recently. The cortical event-related potentials (ERPs) test has the potential of providing valuable information on aided speech performance and it is possible that in future, this test will be incorporated into the existing test batteries for hearing aid evaluation in infants and young children (Korezak et al., 2005; Golding et al., 2007).

5.3.2 Paired-comparison judgments of speech intelligibility

Subjective judgments of hearing aid quality and intelligibility using paired-comparison procedure have been proposed as a clinical procedure for hearing aid fitting and evaluation ((Punch & Parker, 1981; Levitt et al., 1987). In the paired-comparison technique, the individual's judgment of preference, quality, intelligibility or other attributes are used to select a hearing aid. Hearing aid conditions are usually paired systematically within the structure of a tournament or adaptive procedure until the best hearing aid condition is identified based on the judgmental criteria (Eisenberg & Levitt, 1991). Past studies had looked at the sensitivity and the reliability of this test in adults as well as in children with and without hearing impairment. In a study conducted by Studebaker et al (1982), adult subjects listened to continuous discourse and were asked to judge which hearing aid reproduced speech more intelligibility. They found the paired-comparison judgments of speech intelligibility in noise was a reliable test for both subjects with and without hearing loss, even though the hearing impaired subjects performed somewhat less well and less consistently as compared to the normally hearing group. This finding agreed with another study by Levitt et al (1987), where the paired-comparison test was found to be more sensitive than a speech discrimination test in differentiating between the performances of hearing aids with different frequency response settings. The paired-comparison test was also found to be more sensitive than the subjective judgments of speech clarity using category rating, especially on the hearing impaired subjects (Eisenberg et al., 1997).

For children, Eisenberg and Levitt (1991) found the paired-comparison test could be used reliably by children with mild to moderately severe hearing loss to select the preferred hearing aid. They reported the technique is feasible for children at 6.5 years of age and occasionally younger. This is in agreement with the Ching et al (1994) study that reported the paired-comparison test is a reliable test in selecting the preferred hearing aid setting for children with severe to profound hearing loss at six years old and above. In addition, it was suggested that an audio-visual paired-comparison technique rather than auditory presentation alone can be used to increase the sensitivity of the test. This method can be implemented with simple audio-video equipment in a hearing clinic and has been reported by clinicians as a relatively quick and effective way to evaluate hearing aid frequency response provided to a child (Ching et al., 1999).

5.3.3 Loudness measures

Loudness measures are normally conducted clinically to ensure that the maximum power output (MPO) of hearing aid does not cause loudness intolerance to the wearer. Several studies in the past looked at the reliability of loudness discomfort level (LDL) measurements in children. Using pictorial representation of loudness categories, Kawell et al (1988) measured the aided LDL of 20 hearing impaired children aged between 7 to 14 years old. The data were compared with aided LDL's measured from 20 adults with a similar degree of hearing loss. The study demonstrated that LDL can be measured reliably in hearing impaired children as young as 7 years of age and there were no significant differences in LDLs between adults and children. Another study by Stuart et al (1991) which measured LDLs via insert earphones and a probe tube microphone system, agreed that reliable results can be obtained from their subjects with ages ranging from 7 to 14 years old. A different procedure was designed by Macpherson et al (1991) to determine the LDLs of 10 children with normal hearing. The procedure utilized training tasks to teach the concept "too much" through analogies. Despite the variability of responses at specific frequencies and individual test-retest differences, the procedure to measure LDLs was found to be feasible for children whose mental ages were at or above 5 years old.

5.3.4 Self-report inventories

The use of formal tests such as speech recognition normally produce results which do not reflect the individual functional performance in the real-world settings, nor can it define accurately overall satisfaction of the hearing aid wearer (Cox et al., 1991; Vidas et al., 1992). It is also possible that the speech tests are not sensitive enough to differentiate between different types of hearing aid signal processing (Stelmachowicz, 1999). Subjective-report measures allow patients to provide their opinions regarding the benefits and the overall satisfaction received from their hearing devices and is considered as an elementary tool for assessing hearing aid outcome. For infants or children who cannot be assessed reliably with a speech test, the use of parental questionnaires has become of great importance in allowing clinicians to gain information on their auditory performance (Stelmachowicz, 1999; Arlinger, 2001).

There are many advantages of using parental report. Participation of parents in the assessment process are cost effective, facilitate professional-parent collaboration, help parents to identify the child's strengths and needs and provide multiple contexts for information gathering (Crais, 1995). According to Boudreau (2005), parents or caregivers normally have extensive knowledge on their children's behavioral skills which professionals find difficult to assess. Even if the auditory performance of a child can be assessed in a clinical setting, the results might not reflect his/her true ability in real word settings. Vidas et al (1992) for example, compared children's speech performance in structured sessions and in unstructured settings. Questionnaire results were gathered from parents, educators and therapists for four children who used cochlear implants and were aged between 3 to 10 years. The study found that children's auditory performance assessed in formal and in formal settings were different. It was suggested that children might exhibit different behavioral skills (normally poorer performance) when they interact with different individuals in different environments.

A number of auditory inventories have been developed. Ching & Hill (2007) gave a list of children, parent and also educator questionnaires for assessing children's auditory performance. Examples of these questionnaires include the Meaningful Auditory Integration Scale (MAIS), the Infant-toddler Meaningful Auditory Integrated Scale (IT-MAIS), the Auditory Behavior in Everyday Life (ABEL), Client-Oriented Scale of Improvement – Child Version (COSI-C), the Screening Instrument for Targeting Educational Risk (SIFTER), Hearing Performance Inventory for Children (HPIC) and

the Parents' Evaluation of Aural/Oral Performance of Children (PEACH). The selection of these questionnaires is dependent on the age of the child, the degree of hearing loss, the targeted respondent and whether availability of normative data is necessary.

For the present study, the PEACH, TEACH (Teachers' Evaluation of Aural/Oral performance of Children) and SELF (Self Evaluation of Listening Function) are inventory scales that were used to evaluate the auditory performance of children in real-life settings. The PEACH scale was developed as a measure of functional performance in everyday life, based on a systematic use of parents' observations. The PEACH scale consists of 13 items or questions. The items were printed in the form of diary booklet. Parents are required to observe and record the child's behaviors in the PEACH booklet (Ching & Hill, 2007). The TEACH scale is designed to record teachers' observations of children's functional performance in a systematic way. The questions in TEACH are very similar to those found in the PEACH. There are 11 questions in TEACH. The SELF questionnaire was designed by the National Acoustic Laboratories to obtain feedback from children about their functional hearing. There are 12 questions in the SELF questionnaire which assessed the ability of children to listen in quiet, in noise, listen via telephone and response to environmental sounds. For each question in the SELF, a five-point scale (0-never, 1-seldom, 2-sometimes, 3-often, 4-always) is provided to assist the children in answering the question. Further details about the PEACH, TEACH and SELF in terms of the items, administration and technique of scoring the scales are explained in Chapter 6 and also under the methodology section of Chapter 8. The PEACH, TEACH and SELF scales were translated into the Malay language for the purpose of this study. The reliability of the PEACH scale in the Malay language has been investigated in the study and normative data for Malaysian children has been developed. In depth details about adapting the PEACH scales into the Malay language and the normative data, are given in Chapter 6.

5.4 Conclusions

This chapter discusses the approaches used to fit and to evaluate hearing aid performance in children. Some of the approaches were employed in the present. This includes the technical procedures for measuring hearing thresholds, for measuring individual RECD values, the test stimulus used to verify hearing aid fitting and the materials (e.g the HINT, PEACH, TEACH and SELF scales) used to validate the

performance of hearing aids. Chapter 7 and 8 contain an explanation of the details of these procedures and the materials used in the present study to conduct hearing assessment, hearing aid verification and hearing aid evaluation.

CHAPTER 6

Study I

The Parents' Evaluation of Aural/Oral Performance of Children (PEACH) Scale in the Malay Language: Data of normal-hearing children

Tian Kar Quar¹, Teresa Ching YC², Siti Zamratol-Mai Sarah Mukari³, Philip Newall⁴

¹*Macquarie University, Sydney, Australia*

²*National Acoustic Laboratories, Sydney, Australia*

³*School of Rehabilitation Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur*

⁴*Renwick Centre, Royal Institute for Deaf and Blind Children / University of
Newcastle, New South Wales, Australia*

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Abstract

The Parents' Evaluation of Aural/Oral Performance of Children (PEACH) scale was developed to assess the effectiveness of amplification for children, based on a systematic use of parents' observations of children's performance in real-world environments. **OBJECTIVE** : The purpose of the present study was to adapt the PEACH scale into the Malay language, and to collect normative data on a group of children with normal hearing. **STUDY SAMPLE** : The participants were parents of 74 children aged between 3 months and 13 years of age. Parents were requested to observe their children's auditory/oral behavior in everyday life and to record their observations in the PEACH booklet. **RESULTS** : High internal consistency (Cronbach's $\alpha = 0.93$) and item-total correlation were found (0.52 – 0.85). Similar to the published norms for English-speaking children, near-perfect scores were achieved by Malaysian children around 40 months of age. **CONCLUSIONS** : The adapted version can be used to evaluate amplification for children in the Malay speaking environment. The normative curve relating age to scores for the Malay PEACH can be used as a reference against which functional aural/oral performance of hearing-impaired Malaysian children can be evaluated.

Introduction

The importance of using subjective measures to evaluate hearing aid outcomes for young children has been documented by many researchers (Stelmachowicz, 1999; Arlinger, 2001). Many of these subjective measures involve the application of auditory inventories or questionnaires to quantify parents' or caregiver's observations of their child's auditory/oral skills in everyday listening situations. Parents spend a lot of time with their children in everyday environment and hence their reports are often considered more reliable and representative of the child's behavioral response than assessments conducted in structured settings (Dale, 1991; Boudreau, 2005). In addition, parental reports are cost-effective, facilitate professional-parent collaboration and help parents to identify the child's strengths and needs (Crais, 1995).

A number of auditory inventories have been developed for evaluations of children's auditory skills and the relative effectiveness of hearing devices provided to children (for a review, see Ching & Hill, 2007). The majority of these inventories are developed for

English-speaking populations and may not be appropriate for applications to populations with different linguistic and cultural backgrounds (Levinger & Ronen, 2008). Adaptation of a test based on one language and culture involves not only translating the material into the target language, but also conducting field tests to establish its reliability and validity (American Educational Research Association, 1985). Geisinger (1994) suggested that the internal consistency of an adapted test should be determined, and if possible, test-retest reliability should be evaluated. Establishing normative data is also an important part of the process, as it may not be appropriate to use norms from the original test with the adapted test.

In a study conducted by Hickson et al (2010), hearing aid outcomes were measured from a large sample of adults in Australia, using the international outcome inventory (IOI-HA). The results showed no significant differences between the outcomes measured in the study and those reported by Cox and Alexander (2002) using the English version. However, it was reported that some differences were found between the results obtained from an English-speaking context to those from the Netherlands (Kramer et al, 2002) or Germany (Heuermann et al, 2005). The study suggested the need to develop normative data for populations with different linguistic and cultural backgrounds. Furthermore, the availability of normative data in the specific language environment allows clinicians to 1) determine the relative effectiveness of amplification by comparing performance from individuals to empirical norms, 2) set realistic goals or targets for therapy, and 3) use the comparison as a counseling tool (Cox et al., 2003).

There are few publications that investigated the adaptation of auditory inventories for children and assessments of their validity and reliability. Two studies have been identified that reported such findings, but the inventories were restricted in their applications to specific populations. The first study evaluated the Meaningful Auditory Integration Scale (MAIS), a parental inventory that was designed to assess daily listening skills of profoundly hearing-impaired children over 7 years of age (Robbins et al., 1991). Weichbold et al (2004) assessed the reliability and validity of the MAIS in three different languages: English, German and Polish. They reported data collected both pre-operatively and post-operatively from 27 British, 37 Polish and 50 German parents of children with cochlear implants. The parents completed the adapted versions of the MAIS in their respective language. Results showed that each of the adapted versions had high internal consistency (Cronbach's alpha ranged from 0.87 to 0.95).

Split-half correlation coefficients were high at the preoperative condition ($r = 0.9$ to 0.92) but were lower at 6 months post-implantation ($r = 0.76$ to 0.89). Corrected item-total correlations were high for all items assessed, except for one item in the Polish version. The validity of each version was assessed by comparing the MAIS scores as rated by the parents with the Listening Progress Profile (LiP) scores as rated by the speech-language therapists. Correlations between the two test results were high (Pearson's $r = 0.73$ to 0.81) preoperatively but were lower at 6 months post-operatively ($r = 0.61$ to 0.79).

Another subjective measure, the LittleEARS Auditory Questionnaire (LEAQ), was developed to assess auditory behavior of children under the age of 2 years. It has been translated into 15 languages. Coninx et al (2009) reported an evaluation of the translated versions of the LEAQ, based on responses from about 48 parents for each version. The results showed high internal consistency and split-half reliability. Normative data generated from the study showed good agreement among many versions but some incompatibility for a few versions. The authors concluded that the LEAQ is a valid, language-independent tool for assessing the auditory behavior of infants and toddlers. Both the MAIS and the LEAQ are valuable clinical tools for evaluating auditory behaviors of children, but their applications are limited to those with profound hearing loss (MAIS) or those who are below 2 years of age (LEAQ).

The Parents' Evaluation of Aural/Oral Performance of Children (PEACH) scale (Ching & Hill, 2007) was developed for use with children from any age group and with hearing loss ranging from mild to profound degree. Unlike many other measures which provide checklists for parents to rate the presence and absence of listening skills in their children, the PEACH requires parents to write down examples of the auditory behavior of their children in real-world environments in response to each of the items. This method encourages parents to observe their child in real context, and provides an opportunity for the parents to report their observations freely instead of restricting their answers to the test agenda (Gillham, 2000). This technique also forms a basis for client-centered counseling. Upon completion of the PEACH scale, a structured interview technique is used by clinicians to clarify responses provided by parents or to check that the information given is accurate. The published normative data of the PEACH (Ching & Hill, 2007) enables the performance of hearing-impaired children to be related to that of their normal-hearing peers.

Sensitivity of the PEACH scale to variations in amplification characteristics has been demonstrated in two previous studies. Ching et al (2008) used the PEACH scale in addition to other measures to evaluate functional performance of children between 7 months and 16 years old with severe to profound hearing loss, while aided with hearing aids. The findings revealed significant differences in PEACH scores among different frequency responses; however, there was good agreement in the optimal frequency responses determined by parents' and teachers' observations of young children; as well as agreement between parents' observations and children's self-reports and paired-comparison judgments for older children. The PEACH was also found to have good test-retest repeatability. In another study, the PEACH was used to evaluate the relative effectiveness of the NAL-NL1 and the DSL v4.1 prescription for children with mild to moderately severe hearing loss (Ching et al, 2010a). The scale was found to be sensitive to changes in prescription, and was correlated with children's preferences measured using paired-comparison judgments and children's diaries. The validity of the PEACH has also been demonstrated for infants and young children in Golding et al (2007). Significant correlations were found between objective measures of cortical auditory evoked responses to speech stimuli and the PEACH results for a group of 31 infants and young children (aged between eight weeks and three years, five months) with hearing loss ranging from mild to profound degrees. A recent study also revealed a significant correlation between the PEACH scores and the receptive and expressive language of children measured using a standardized language test at three years of age (Ching et al, 2010).

The present study aimed to adapt the PEACH scale for use in the Malay language, to collect normative data and to assess reliability of the Malay PEACH scale.

Method

Subjects

The participants were parents of 74 children with normal hearing. The group was made of 38 boys and 36 girls aged between 3 months to 13 years old (mean age = 39.7 month, SD = 42.1). The distribution of age for the children is shown in Figure 1. These children had no history of ear or hearing problems or other disabilities as reported by their parents. There were 17 infants between 3 and 12 months of age, none of whom had

known complications in their birth history. From the total sample, eight children (aged between 6 to 13 months) were known to have undergone newborn hearing screening conducted in the local hospitals with passing results. A distortion product oto-acoustic emission (DPOAE) test was conducted on all the children to confirm their hearing status. Only parents of children who had passed the DPOAE test were included in the study. All parents were proficient in the Malay language; 81% were ethnic Malay, 16% were ethnic Chinese and 3% were ethnic Indian. Informed consent, in written form, was obtained from parents to participate in the study.

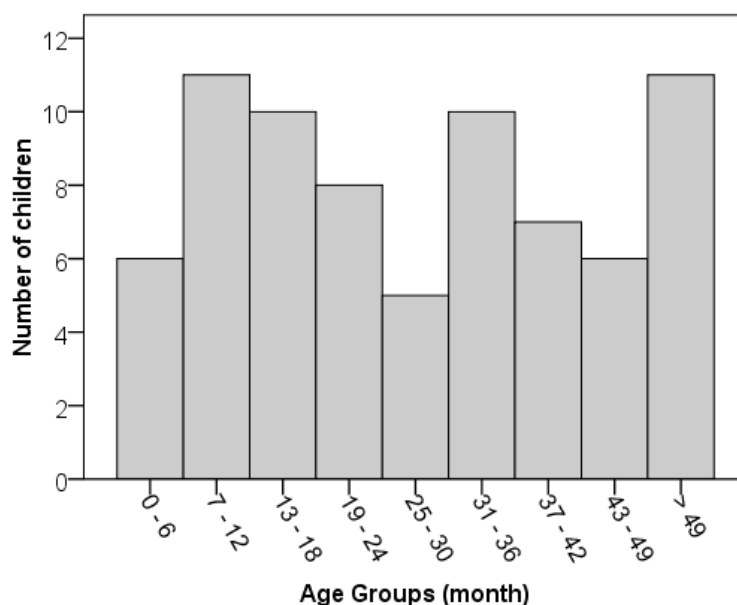


Figure 1 : Total number of children for different age groups.

Procedure

i) Adapting the PEACH into Malay language

A ‘back to back’ approach was used to translate the PEACH scale into Malay language (target language). The translation was carried out with care to maintain the original meaning of the content while ensuring the concepts were culturally suitable. In this process, very minor alterations were made to the content of the original PEACH scale. For instance, examples of noisy situations as described in the original English version include situations at home when the television, dishwasher, washing machine, radio, music are switched on or when children are in a train, on a bus, in a shopping complex

etc. The words ‘train’ and ‘dishwasher’ were eliminated in the Malay version since these items were not very common in the local culture. Other modifications were made on item 7 (“*When you are in a quiet place reading your child a story.....*”). For this item, the Malay version was translated as “*When you are in a quiet place reading/telling your child a story.....*”, since story reading might not be a common practice for certain families in the target population. The modifications made to the assessment tool were considered minor and not significant in distorting the original meaning.

The translated version of PEACH was reviewed by two audiologists who were native speakers of the Malay language. Subsequent to that, the Malay PEACH was translated back to English by a different person who is well versed in both languages to check for the accuracy of the translation. After minor revisions, the Malay version was reviewed by six parents to ensure that the content was easy to understand and culturally appropriate. The outcome of the parent assessment did not reveal the need for further modifications. The translated Malay PEACH scale was used for collecting data in the present study. Interested readers can access the material at <http://informahealthcare.com/loi/ija>

ii) Administering the PEACH scale

The administration and scoring methods closely followed the guidelines for the PEACH scale as described in Ching & Hill (2007), and outlined on the National Acoustic Laboratories website (www.nal.gov.au). This ensures that the normative data collected in the present study for the Malay PEACH can be directly compared with those reported for the original PEACH in English. Two research assistants were trained in the procedure and were responsible for administering the Malay PEACH to the participants. The PEACH booklet consists of 13 items. These items cover the assessments on i) use of amplification and loudness discomfort, ii) listening and communicating in quiet, iii) listening and communicating in noise, iv) telephone usage and v) responsiveness to environmental sounds. Items 1 and 2, which ask about the use of amplification and loudness discomfort were not administered to the parents in this study. A total of 11 items were thus used in the study. Because the PEACH scale has been designed for use with infants as well as school-aged children, some items have two alternatives. The parents were asked to focus on the alternative that was considered to

be more appropriate to the age or development of their child. For instance, item number 6 below:

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

OR

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

Parents were given two weeks to observe their children's listening behavior and to record examples of responses for each item in the PEACH booklet provided. When parents had completed the PEACH booklet, appointments were arranged for the research assistant to review the questionnaire with the parents. The purpose of the interview session, as outlined in the guidelines, was to enable the research assistant to ask further questions or to clarify any unclear examples of behavior reported.

iii) Scoring the PEACH scale

The research assistants scored each item on the basis of information provided, using a five-point scale ranging from 0 to 4. An item was given a score of zero if no examples were given or if the child did not demonstrate auditory response; score of 1 was given if one or two examples were given or the behavior occurred 25% of the time; score of 2 was given if three or four examples were given or the behavior occurred 50% of the time and a score of 3 was given if five or six examples were given or the behaviors occurred 75% of the time. A maximum score of 4 was given if more than six examples could be supplied by the parents or if the parents observed that the auditory behavior occurred more than 75% of the time (see Ching & Hill, 2007). The item scores were combined into two subscale scores, one for listening in Quiet, and one for listening in Noisy environments. Item scores were summed to derive an overall score.

iv) Test-retest reliability

In compliance with the research ethics requirements, parents were asked to contact the research assistant if they were interested to participate in the repeatability test. From this process, only nine parents volunteered to participate for the second time. A two week time interval was used between the first and second set of observations.

Analysis

Data obtained were analyzed using the SPSS version 16.0 for Windows. The internal consistency (ability of the scale to measure one single construct) of the items was examined by calculating the Cronbach's alpha coefficient. Corrected item-total correlations were calculated to examine the extent to which a single item contributes to the overall score of the scale. The relation between the children's age and the PEACH scores for the Quiet Subscale, Noise Subscale and overall scale was determined and used for generating the normative graph. Data from the Malay PEACH scale were compared with the original PEACH scale in English. Comparison between findings of adapted scales and their original scales are useful as they provide information on whether the adapted scale is valid or able to measure the same constructs after adaptation to a new linguistic group. Similarity of test results between the original and the adapted scale strengthens evidence for the validity of the scale in its adapted form (Hambleton & Patsula, 1998).

Results

Scale Analysis

Results of the analysis showed that the Cronbach's alpha value for the 11 items was 0.93. This indicates that the Malay PEACH has high internal consistency. The corrected item-total correlations for Malay PEACH were high (ranged from 0.52 to 0.85), similar to the values from the original scale (see Table 1).

Table 1 : Corrected item-total correlations for PEACH in Malay and PEACH in English

Item	Description	Malay	English	
		Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted	Corrected Item-Total Correlation
1	Respond to name in quiet	0.67	0.92	0.41
2	Follow verbal instructions in quiet	0.79	0.92	0.76
3	Respond to name in noise	0.57	0.93	0.42
4	Follow verbal instruction in noise	0.69	0.92	0.77
5	Follow story read aloud	0.84	0.91	0.60
6	Participate in conversation in quiet	0.85	0.91	0.49
7	Participate in conversation in noise	0.84	0.91	0.65
8	Participate in conversation in transport	0.73	0.92	0.75
9	Recognize voice of familiar persons	0.76	0.92	0.54
10	Participate in conversation on phone	0.52	0.93	0.57
11	Recognize sounds in environment	0.68	0.92	0.63

Relations between PEACH scores and age

Figure 2 shows the average PEACH scores of each item for different age groups. The age groups were divided into intervals of 6 months (ie, 0-6 months, 7-12 months etc) and were plotted on the 'x' axis. The 'y' axis denotes how frequently the behavior is observed for the item assessed. Score assignments were as follows: "0" score is perceived as never occurring, "1" for rarely occurring, "2" for sometimes, "3" for often and "4" if the behavior is perceived as always present and consistent. On average, parents observed that the children sometimes responded to their names when called and to environmental sounds at a very young age (3-6 months). For children below the age of 12 months, the average scores for following verbal instructions were 2 or less, revealing limited abilities to follow verbal instructions in quiet and in noisy real-life situations. Performance in quiet was better than in noise for all age groups. The ability

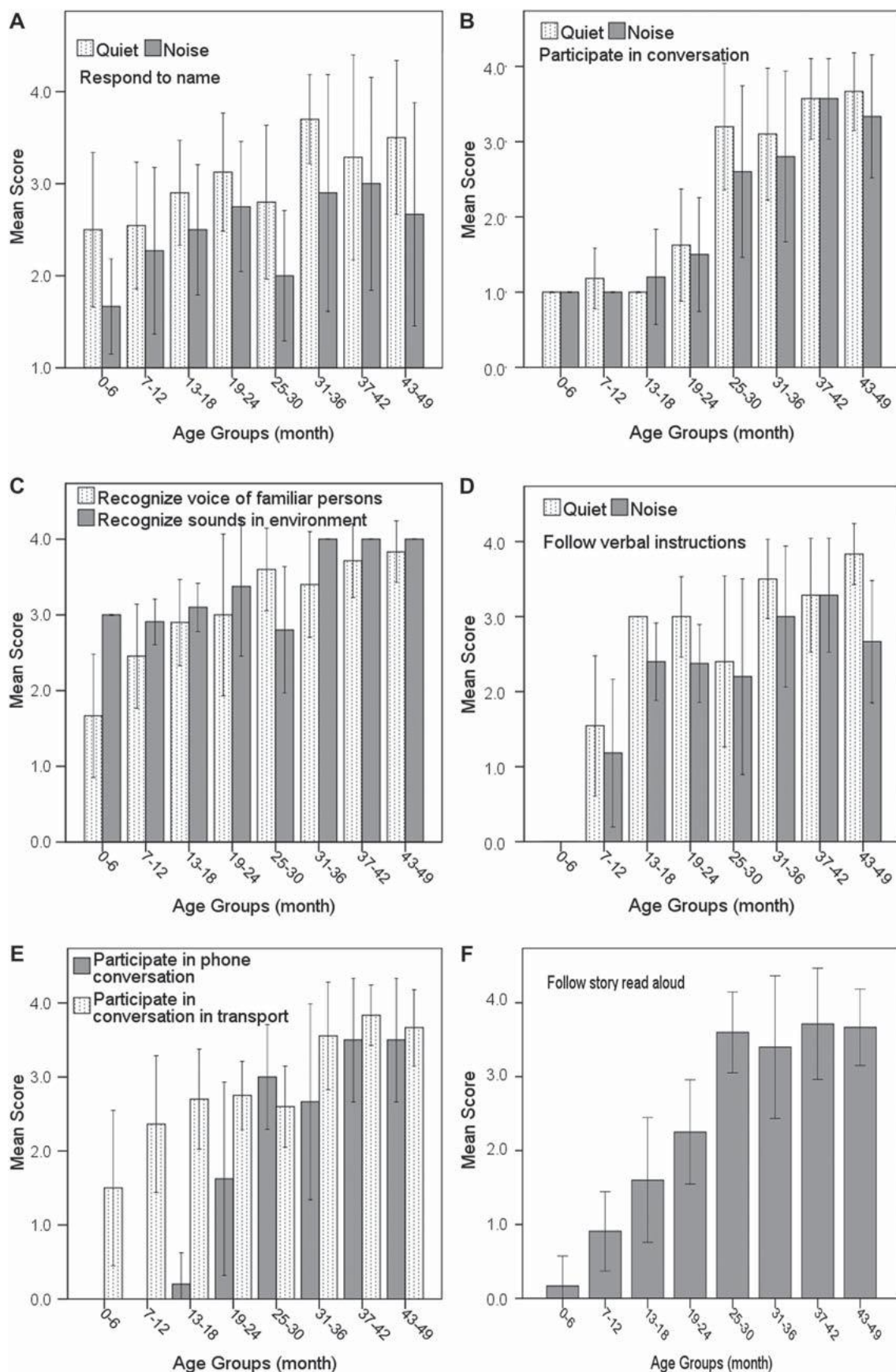


Figure 2 : Mean Malay PEACH scores as a function of age groups (month) for each item assessed in the scale. The ' y ' axis denotes how frequently the behaviors are observed (0 = never; 1 = rare; 2 = sometimes; 3 = often; 4 = always). Error bars show \pm 1 SD.

to follow a story read aloud, to participate in conversation and to participate in a phone conversation were rated as low/rare for children under the age of 24 months. The item ‘participation in conversation’, focuses on the child’s oral communicative skills in which the child’s tendency to initiate conversation (e.g. vocalize to get attention) and to participate in conversation (e.g. take turns to vocalize) are assessed. The average performance for this item was found relatively lower than the performance for item ‘participation in conversation in transport’ since the latter item focuses on a child’s reactions when someone talks or sings while traveling on the road.

The standard deviations obtained for each item according to the different age groups, ranged from 0 to 1.3, suggesting low variability of individual scores for each item. When analysis was performed to compare the boys’ and girls’ overall scores of the Malay PEACH, no significant difference was found between gender ($t(72) = 0.783$, $p > 0.05$).

The normative curves for the overall subscale, Quiet Subscale and Noise Subscale scores are illustrated in Figures 3, 4 and 5 respectively. The relationship between the PEACH scores and age can be represented by the following equation:

$$\text{Percentage score} = \frac{d}{(1 + \exp [-b (\log_2 (\text{age}/3) - c)])^w}$$

where age was expressed in months, and coefficients were estimated using a least squares procedure.

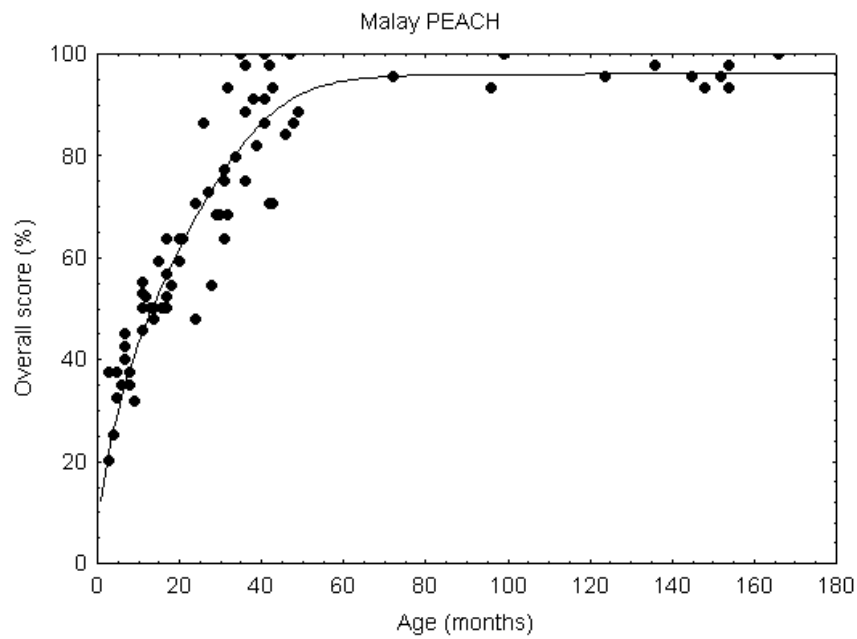


Figure 3 : Normative curve showing the overall score as a function of age for the Malay PEACH

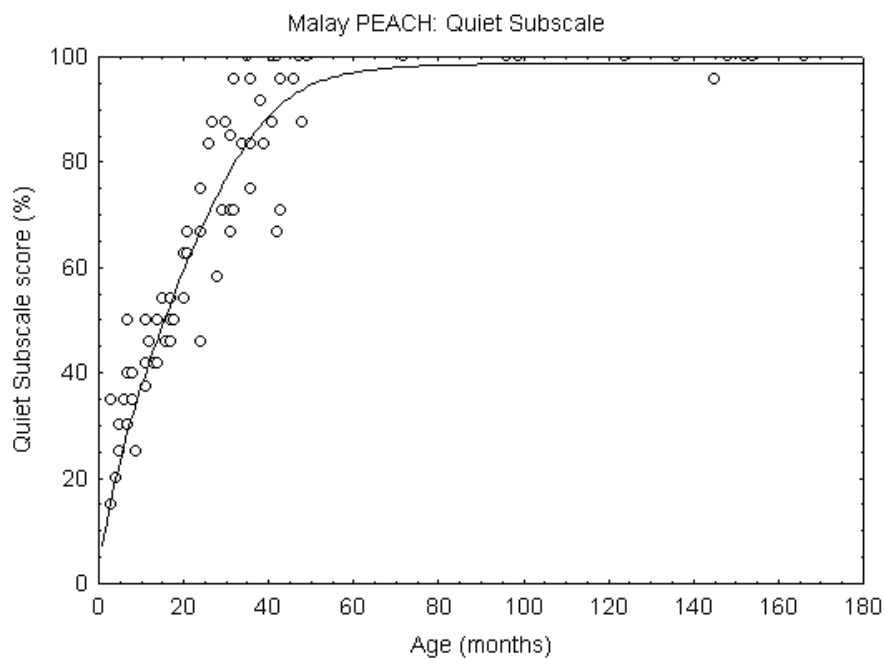


Figure 4 : Normative curve showing the score of the Quiet Subscale as a function of age for the Malay PEACH.

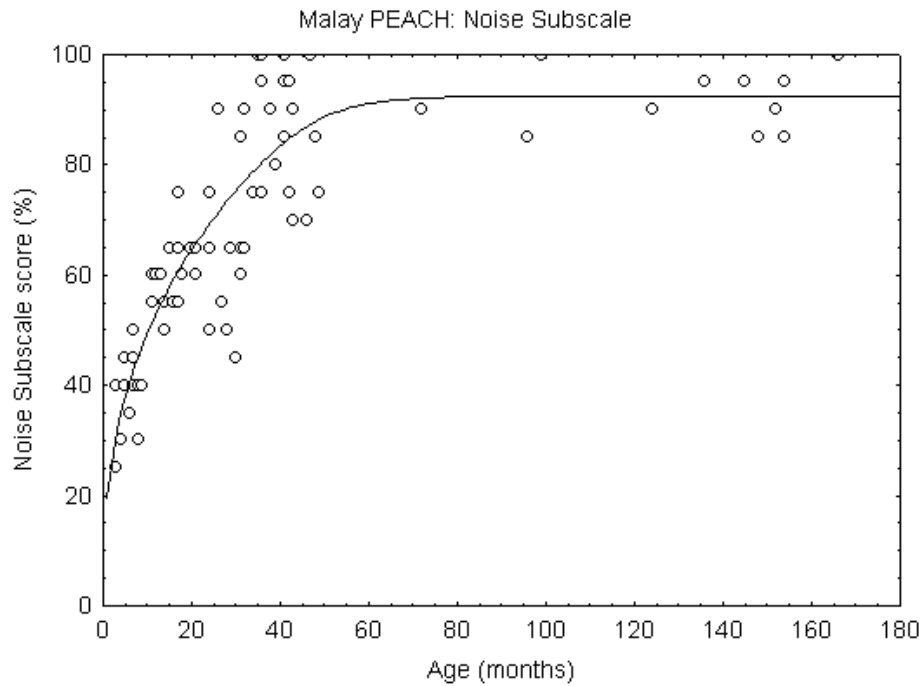


Figure 5 : Normative curve showing the score of the Noise Subscale as a function of age for the Malay PEACH.

Test-retest reliability

The Malay version of PEACH was administered twice on nine parents to determine the test-retest reliability. The mean score differences were small for the overall scores, Quiet Subscale and Noise Subscale scores (mean = -0.6; range = -0.7 to -3.3) Table 2 shows the mean differences of scores obtained from parents at different times and also the mean difference standard deviations.

Table 2 : Mean test-retest difference scores and standard deviations

	<i>1st mean</i>	<i>SD</i>	<i>2nd mean</i>	<i>SD</i>	<i>Mean score</i>	<i>SD</i>
	<i>score</i>		<i>score</i>		<i>difference</i>	
Total	64.5	19.7	65.2	17.9	-0.7	3.3
Quiet	62.2	22.5	66.5	20.6	-3.3	4.1
Noise	67.2	18.2	65	16.2	2.2	5.1

Discussion

This study was intended to assess the suitability of the PEACH scale for use in a population differing substantially in its culture and language from the population for which the assessment tool was originally developed. The scale was administered to parents of Malaysian children using the same method as that used for deriving the normative data for English children. Results from the study showed that the Malay PEACH has high internal consistency ($\alpha = 0.93$), suggesting the ability of the scale to measure one single construct. The corrected item-total correlation analysis was performed to examine the degree of contribution that each individual item had on the overall score of the scale. Each item in the Malay PEACH was found to have high item-total correlation, similar to PEACH scale in English (Ching & Hill, 2007). These findings provide some support for the appropriateness of the Malay PEACH for use in the target population. Investigation of the test-retest reliability showed that similar scores were obtained from nine participants when the adapted scale was administered twice, indicating high test-retest reliability. This finding, however was obtained from a very small sample of participants and thus should be regarded as a preliminary finding.

Normative curves for the Malay PEACH were fitted for the Quiet Subscale, Noise Subscale and for the overall score, as a function of age. The mean overall score showed that significant functional use of auditory skills was observed from the age of 6 months onwards, as in the original scale. As items in the PEACH scale assess the children's auditory behavior in response to speech stimulus in real-world environments (e.g. response to name, response to verbal instructions), the findings are consistent with the empirical data cited by Boothroyd (1997) that showed infants at 6 months of age demonstrated the beginnings of some auditory speech perception skills, and improvement continued throughout childhood. Studies that look at the development of language skills in children have shown that children as early as 8 to 10 months of age use gestures and vocalizations to communicate with other people (Dale, 1980; Reilly et al, 2006). Beyond the age of 2 years, children's pragmatic skills such as topic initiation and turn taking begin to develop more rapidly (O'Neill, 2007). Concurrent with the development of communication skills in children as reported in previous studies, the PEACH overall score was found to increase as a function of age.

When the overall PEACH scores for different age groups were compared to those reported in the original English scale (Ching & Hill, 2007), similar results were obtained around 40 months of age, where near-perfect scores were achieved by the children from both populations. For children younger than 2 years old, the Malay PEACH scores were found to be lower than the scores in the English version and increased at a more gradual rate than the English PEACH normative curve, as a function of age (see Figure 3). Analysis of each individual item (Figure 2) revealed that the ability of children to participate in conversation was reported by parents to be low for children under 24 months of age. As this item focuses on the assessment of the children's auditory/oral skills, different demographic factors such as socioeconomic status and race may have accounted for the discrepancies found between the scores of the original English version and the scores of the Malay version.

Various studies have found significant correlations between socioeconomic status and development of children's auditory/oral skills (Hart & Risley, 1992; Lawrence, 1997; Raviv et al, 2004; D'Angiulli et al, 2008; Keller et al, 2008). In a more recent study, Pungello et al (2009) investigated the effects of socioeconomic status, race and parenting on language development in early childhood and reported that African American children obtained lower scores for receptive and expressive language when compared with European American children. The authors suggested that parenting style (maternal sensitivity and negative intrusive maternal behavior), maternal education level, family stress, race, parent-child interaction and cultural difference are among factors associated with socioeconomic status which can affect language development of children. Previous studies have reported that Chinese parents, when compared to American and Canadian parents, are more restrictive, controlling or authoritarian and less affectionate (Chiu, 1987; Lin & Fu, 1990; Liu et al, 2005; Ang, 2006; Liu & Guo, 2010). Even though there were no studies on Asian children that examined the impact of parenting and cultural differences on children's auditory or oral behaviors, other studies in the western countries have found a possible link between parenting, ethnicity and culture with these behaviors (Hart & Risley, 1992; Keller et al, 2008; Pungello et al, 2009).

The present study required the parents to record their observations in a diary. While this technique of collecting parental information has several advantages as described in the introduction, it also has some limitations. The process is time-consuming and parents

may not comply with diary-keeping (Griffith et al, 1999; Golding et al, 2007). In the present study, parents who consented to participation in this research study did not have issues of compliance. Nonetheless, the time factor and parent compliance with diary-keeping or clinicians' skills in interviewing and interpreting scores (Golding et al, 2007) may potentially limit the effectiveness with which the PEACH can be applied in clinical settings. For this reason, a self-rating approach combined with the use of examples has been developed for clinical applications (freely downloadable from www.outcomes.nal.gov.au) Comparisons between the data collected using the interview method and the self-rating method in the Malay PEACH will need to be investigated in further research.

The present study reports an adaptation of the PEACH into the Malay language and normative data for 74 children. Further work will be necessary to establish norms for a larger sample of children, to investigate the test-retest reliability for the PEACH scale in Malay. Developing normative data for children with hearing impairment in the Malay-speaking environment will be useful for clinical applications. In this way, not only can the performance of children be compared to their normally hearing peers, but also to other children with similar degrees of hearing loss. In addition, it will be useful for future studies to investigate the sensitivity of the Malay PEACH for evaluating the relative effectiveness of different processing features in hearing aids.

Conclusions

Parental questionnaires are very useful tools for clinicians to obtain meaningful information regarding children's auditory performance in real life with amplification. The PEACH scale adapted into Malay was found to be reliable. The normative curve relating age to scores for the Malay PEACH can be used as a reference against which functional aural/oral performance of hearing impaired children in Malaysia can be evaluated.

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CHAPTER 7

Study II

Prescribed and achieved gain of hearing aids fitted according to the NAL-NL1 and DSL v5 procedure in children with moderately severe to profound hearing losses

7.1 Introduction

The National Acoustics Laboratories (NAL) and Desired Sensation Level (DSL) method are prescriptive procedures that many clinicians use to fit hearing aids to people with hearing impairment. Both prescriptive methods have different underlying rationales and numerous studies have been carried out, to compare the hearing aid gain (Byrne et al., 2001; Keidser et al., 2003; Seewald et al., 2005; Johnson & Dillon, 2011) and the effectiveness (Snik & Stollman, 1995; Snik, van den Borne et al., 1995; Scollie et al., 2000; Ching et al., 2001) between the earlier versions as well as the newer versions of the two procedures.

The National Acoustics Laboratories (NAL) in Australia together with the University of Western Ontario in Canada have collaborated to conduct a study that compared the hearing aid gain and frequency response of the NAL-NL1 and DSL v4.1 procedures as implemented in hearing aids and the relative effectiveness of the procedures for school-aged children with mild to moderately severe hearing losses (Ching et al., 2010a). In examining how well prescribed targets were matched in the children's hearing aids, Ching et al. (2010a) found that even though the differences in prescribed frequency response slopes were large between NAL-NL1 and DSL v4.1, the measured gain showed minimal difference between the two procedures on average, due to limitations of the hearing devices used. This finding is consistent with report by Smeds & Leijon (2001) that the differences of hearing aid gain prescribed can be reduced when they are applied to commercial hearing aids due to technical limitations and thereby the actual gain performance between prescriptive methods cannot be evaluated directly. According to Smeds & Leijon (2001), for severe to profound hearing losses, the prescribed gain and frequency response may be even harder to achieve in hearing aids.

The purpose of this study is to compare the gain and frequency response prescribed by the NAL-NL1 procedure and the DSL v5 to the achieved gain of hearing aids fitted to children with moderately severe to profound hearing losses.

7.2 Method

7.2.1 Participants

The research participants were 16 children and adolescents aged between 7 to 17 years old (mean = 12.7 years; SD = 28). They comprised of 14 boys and 2 girls. For the rest of the thesis presentation, the participants will be referred as ‘children’. Based on the four frequency average hearing threshold levels (4FA HTL) of 500, 1000, 2000 and 4000 Hz, the participating children had degrees of hearing losses that ranged from moderately severe to profound. Table 7.1 shows the mean, standard deviations and range of HTLs measured from the children. HTLs for individual ears were plotted in Figure 7.1. All children had bilateral sensorineural hearing loss except for one child who had a mixed hearing loss in one ear. Four children had asymmetrical audiograms, two of whom used hearing aids only in one ear/the better ear.

Eleven children were in mainstream schools and three of them were receiving special support in the classroom (it was an inclusive program). Five other children were in a unit for deaf children. Children with age appropriate developmental and milestones and with non-fluctuating hearing loss were included in the study. The information was obtained from the reports of other professionals (e.g. speech pathologists, pediatrician, audiologists and Ear, Nose and Throat specialists), found in the case files. A child with a significant case history which might affect the results, as reported in the case file was excluded from the study.

Table 7.1 : Mean hearing threshold levels (dB HTL) and standard deviations (SD) for the children at different frequencies

	250Hz	500Hz	1000Hz	2000Hz	4000Hz	4FA
Mean HTL	61.6	69.7	81.4	86.3	90.6	81.9
SD	20.1	21	21.2	18.3	16.5	17.7
Range	20 to 87.5	30 to 100	37.5 to 120	60 to 120	65 to 120	51.9 to 115

4FA (Four Frequency Average) – average hearing threshold of 500, 1000, 2000 and 4000Hz

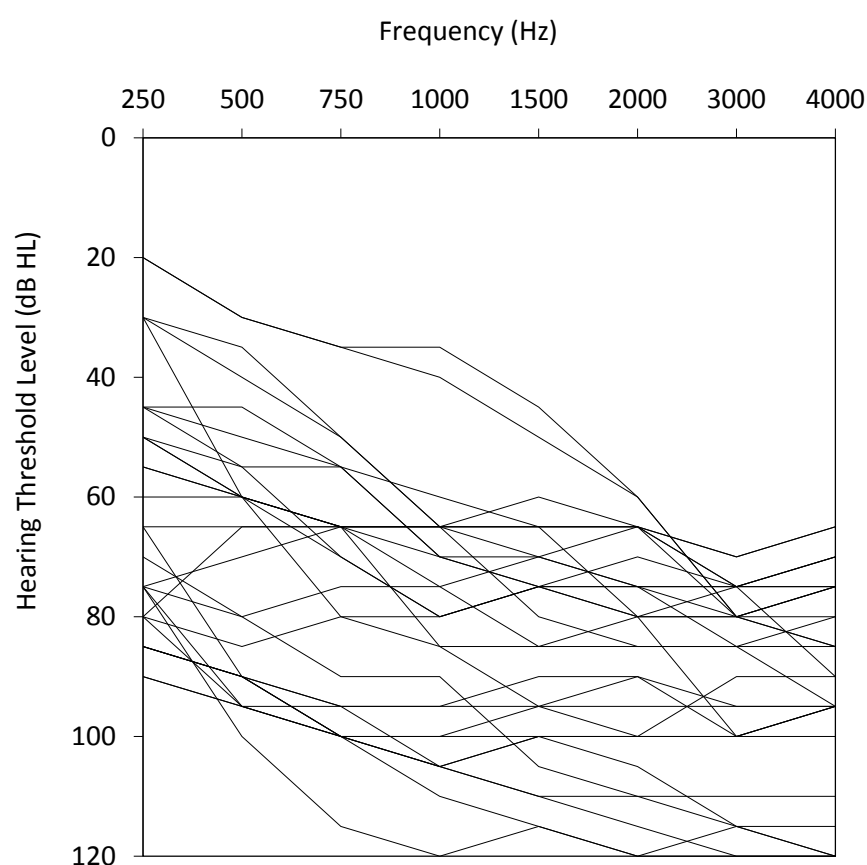


Figure 7.1 : Hearing threshold levels (HTLs) measured from each ear fitted with hearing aid (N = 30)

7.2.2 Hearing aid experience

All the children were experienced hearing aid users except for two children who had no previous hearing aid experience. The two children aged 11 and 12 years old, were diagnosed of having bilateral moderate to severe sensorineural hearing loss at about the same time when the present study commenced. The local audiologists diagnosed the hearing loss as congenital and suggested the late diagnosis was due to delayed action taken by family members despite suspected hearing problem at a younger age. For the experienced hearing aid users, two children were monaural hearing aid users while the remaining were binaural users. Three children were using analog hearing aids while seven children used digital hearing aids. Four other children had broken hearing aids and were not using any hearing devices when they initially enrolled in the study. These children were waiting for financial aid to purchase new hearing aids at the time when the study commenced.

Information regarding the gender, age, hearing thresholds for separate ears, age of diagnosis, etiology, age of amplification, hearing aid experience, types of hearing aid used by the children when the study was carried out and education for each child, is summarized in Table 7.2.

7.2.3 Location of study

The study was conducted at the Audiology and Speech Sciences Clinic in the School of Rehabilitation Sciences of the Universiti Kebangsaan Malaysia in Kuala Lumpur. All tests were carried out in double- walled, sound treated rooms.

7.3 Procedure

7.3.1 Hearing assessment

The children's hearing threshold levels were measured using the GSI 61 audiometer at 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000 and 8000 Hz. The ER3A insert earphone coupled to the child's own earmold was used to deliver pure tone stimulus to the child's ear. This type of transducer is highly recommended when assessing pediatric population because of the accuracy in measuring the individual's hearing loss and to

Table 7.2 : Information on gender, age, age of diagnosis, 4FA HTL, age of amplification, hearing aid experience and school placement for each child

Child	Gender	Age of diagnosis	Etiology	Age	4FA HTL		Age of fitting	Hearing aid experience	Hearing aid	Duration of using own aid	Education
		years/months			left	right	years/months	years/months		years	
1	F	2 / 6	unknown	11	63.3	63.3	2 / 6	8 / 6	Canta 770-D	6	Mainstream
2	M	1+	unknown	10	66.3	65	2	8	Siemens Artist e2e	5	Mainstream
3 *	M	12	unknown	12	71.3	73.8	12	0	*	*	Mainstream
4	M	1 / 2	unknown	15	62.5	71.3	2	13	Eartone	1	Inclusive
5	M	3	unknown	12	105	86.3	3	9	Supero 412	4	Mainstream
6^	M	6	unknown	15	52.5	51.3	6	8 / 9	Phoenix 203	3	Inclusive
7	M	4+	unknown	17	92.5	92.3	5	11	Audinet PPCL	10	Inclusive
8^	M	6 / 4	unknown	16	72.5	71.3	6 / 8	14 / 4	Picoforte PPCLP	9	Deaf unit
9	M	2	unknown	7	98.8	95	2	5	Naida III UP	4	Mainstream
10 #^	M	6	unknown	14	75	76.3	7	6 / 6	No record		Deaf unit
11@	M	6	unknown	16	NR	115	6	10	PPCL 4+	10	Mainstream
12@ #^	M	No record	Hereditary	15	72.5	NR	8	6 / 9	Siemens Music Pro	2	Deaf unit
13 *	M	10	unknown	11	70	70	10 / 4	0	*	*	Mainstream
14	M	1 / 9	unknown	13	98.8	106.3	2	11	Widex Brava	5	Deaf unit
15	M	2	unknown	9	108.8	78.8	2 / 6	8	Widex B32	5	Deaf unit
16	F	2	Rubella	13	110	95	2	11	Siemens Triano SP	5	Mainstream

4FA – average hearing threshold of 500, 1000, 2000 and 4000 Hz

* Non-experienced hearing aid user

@ Monaural hearing aid user

Sign language as primary language

^ Not using hearing aids when the study commenced

facilitate subsequent hearing aid fitting (Ching & Dillon, 2003). These earphones also have the advantages of being light in weight and have improved interaural attenuation. Since children are more readily to accept their custom earmold as opposed to the foam tip, it is recommended coupling the insert earphones to child's own earmold (as in the case of the present study) during the assessment (Bagatto et al., 2005). Hearing thresholds for each child were established using the Hughson-Westlake "ascending method".

Otoscopic examination was carried out on all children to check for any external ear canal anomalies, discharging ear and excessive ear cerumen. Tympanometry measurement with the GSI TymStar middle ear analyzer was carried out to rule out middle ear pathology.

7.3.2 RECD measurement

The real-ear-to-coupler difference (RECD) was the difference between the output measured in the HA-2 coupler and the output measured in the ear canal for the same input signal. The individual RECD was measured on each child in the present study to facilitate hearing aid fitting process, which is discussed in section 7.3.4. The RECD values were measured on the fitted ears using the Siemens UNITY probe microphone system. The measurement was carried out using the UNITY insitu headset and a 70 dB SPL pink noise as the test signal (Siemens UNITY manual, 4.6 compatible). To measure the coupler output, the probe tube used in real ear measurement and a 10cm receiver tube were attached to the UNITY handle. The handle together with the tubes, were inserted into the 2-cc coupler adapter for measurement of the sound pressure level (SPL) in the coupler. To measure SPL in the ear canal, the probe tube was placed inside the ear canal and the receiver tube was connected to the child's own earmold using a small adapter. In order to determine the insertion depth of the probe tube placement, the probe tube was placed beside the child's earmold and its marker was adjusted so that it was flush with the outside surface of the earmold and the tip extended 5 mm beyond the earmold tip. When inserting the probe tube, the marker was placed at the intertragal notch (Bagatto, 2001). Some earmold lubricant was applied to prevent slit-leak and also to ease the placement of earmold into the ear canal. All children had full shell earmold with standard tubing and no vent.

7.3.3 *Hearing aid selection*

All children involved in the present study were fitted with new Phonak Naida V Super Power (Naida V SP) behind-the-ear hearing aids. The hearing aid was designed for moderately severe to upper range of profound hearing loss. It is a fully programmable digital hearing aid with 16 channels, data logging features, 4 manual programs and other advanced features. All the advanced features such as sound recover and feedback manager were deactivated for the purpose of this study. Table 7.3 presents the features available in the Naida V SP hearing aid and the features selected for the purpose of the present study (www.phonak.com). Technical descriptions of the hearing aid are presented in Appendix 4 for Naida V SP along with other families of Naida hearing aid.

7.3.4 *Hearing aid fitting*

Hearing aids were fitted on each child based on the real-ear-aided-gain (REAG) approach (Ching & Dillon, 2003; Bagatto et al, 2005). To derive targets for different input levels and for maximum power output (MPO) of the hearing aid, individual RECD values and audiometric hearing threshold in dB HL were entered into the NAL-NL1 (Dillon, 1999) and DSL v5 (Seewald et al., 2005) stand alone software. Table 7.4 shows other parameters selected from the NAL-NL1 and DSL v5 stand alone software to define their respective targets. The same parameters were selected for both procedures to derive the targets with the exception of three parameters. For instance, the DSL v5 procedure provides targets for hearing aid up to 16 channels while the NAL-NL1 procedure provides targets up to 4 channels. In pediatric fitting, the DSL v5 method does not recommend binaural corrections (Scollie et al., 2005) but the binaural versus monaural fitting needs to be selected for the NAL-NL1 method, in order to define the targets. Other difference of parameter includes the selection of compression threshold. In the NAL-NL1 procedure, the default compression threshold was selected so that wideband speech at 52 dB SPL will activate the compression while the compression threshold prescribed by the DSL v5 procedure is dependent on the degree of hearing loss. The DSL v5 procedure prescribes compression thresholds ranging from 30 dB SPL to about 70 dB SPL re free field, as a function of hearing level. The compression threshold generally increases as the hearing threshold increases. The theory and formula for prescribing compression threshold based on hearing level are

hypothesis-driven and hence studies are required to evaluate the effectiveness of the procedure (Scollie et al., 2005).

Table 7.3 : Naida V SP – feature descriptions and selection for use in present study

Features	Description	Selected Feature
SoundFlow	Seamless real-time adaptation to changing sound environments by blending 2, 3 or 4 base programs	Off
Channels	Fully programmable digital hearing instrument	16 channels
PowerProcessing	Selects the amplification strategy from non-linear to linear, depending on the audiometric configuration and hearing loss	Undefined
BassBoost	Delivers extra low frequency gain and output for instant improvement of subjective loudness perception	Off
Manual Programs	Up to 4 manual accessible hearing programs	2 programs
SoundRecover	Compress and shift high frequencies into an area of audible hearing	Off
WhistleBlock Technology	The new benchmark in feedback elimination	Off
Directionality	As much directionality as you need	Off
Real Ear Sound	Simulates the performance characteristics of the pinna	On
NoiseBlock Processing	Analyzes and recognizes sounds different from speech and automatically reduces them	Off
WindBlock Management	The ultimate comfort in wind noise management	Mild
QuickSync	Binaural volume and program control	Off
DataLogging	Knowing how and when you use your hearing instrument	On
Connectivity EasyFM, EasyPhone, EasyAudio, EasyBluetooth	4 automatic programs for FM, using the phone, binaural stereo streaming of audio signal and hands free binaural mobile phone use	FM activated if necessary

Table 7.4 Parameters selected in the NAL-NL1 and DSL v5 stand alone software to generate their respective targets based on hearing threshold levels (dB HL)

Parameters	NAL-NL1	DSL v5
Transducer	Insert mold	Insert mold
RECD type	HA2 mold	HA2 mold
Number of channels	4	16
Number of hearing aids	Bilateral / Unilateral	Bilateral
Venting	None	None
Program	Not available	Quiet
Target type	Coupler gain	Coupler gain
Compression threshold	52 dB SPL	Depending on hearing level

Once the hearing aid targets were produced by the respective NAL-NL1 and DSL v5 stand alone software, the hearing aids were pre fitted using the Phonak fitting software (iPFG 2.5a) via the NOAHLINK interface. The pre fit procedure was applied by selecting the appropriate prescriptive rules (e.g NAL-NL1 or DSL v5), individual RECD values, earmold parameters, binaural or monaural fitting and previous hearing aid experience. The volume control feature and other advanced features (bassboost, sound recover, noise suppression system, feedback manager) except for data logging feature were deactivated in the hearing aid.

7.3.5 Hearing aid verification

To verify the pre fitting, the hearing aid gains were measured using the Siemens UNITY HA2-2cc coupler and the results were compared to the gain targets prescribed by the NAL-NL1 and DSL v5 procedures respectively. The hearing aid gains were adjusted to match as closely as possible, to the prescribed targets by both procedures at each frequency. This was carried out first with the 65 dB input level followed by the 50, 80 and 90 dB SPL input level. Each time when the gain adjustment was made at any one input level, measurement of gains previously obtained at other input levels will be repeated to ensure the respective gains remained unchanged.

The test stimuli used to verify the hearing aid fitting was the International Collegium of Rehabilitative Audiology (ICRA) noise produced by the Siemens UNITY analyzing system. The type of ICRA noise used was a speech noise shaped for a male voice at

normal vocal effort (URGN-M-N). The ICRA noise was first introduced in 1997 for hearing aid testing and psychophysical evaluation (Dreschler et al., 2001). It consists of a set of broadband noise signals with the following parameters : i) speech noise shaped according to normal, raised and loud vocal effort; ii) speech noise shaped according to the gender of the speaker; and iii) modulated speech noise which can be further divided into highly modulated, moderately modulated and slightly modulated. Based on these parameters, nine test signals were created which are displayed in Table 7.5. For all of the test signals, the spectral and temporal properties are carefully controlled and are representative of real speech characteristics.

Other than the ICRA noise, the UNITY also includes the ILTASS and ISTS as test signals. A study by Keidser et al (2010) showed the ILTASS offered by the UNITY system was found most closely match with the ILTASS by Byrne et al (1994). Hence hearing aid verification with this signal will probably provide a more valid and accurate results and should be preferred for future research and clinical use. Nonetheless, the type of ICRA noise (URGN-M-N) used in the present study was reported as comparable with the spectral of real speech (Keidser et al., 2010) and therefore it is appropriate for hearing aid verification purposes as well. The MPO of hearing aid was verified at each test frequency using a 90 dB pure tone signal measured in the coupler.

Table 7.5 : Overview of the nine standard noises that have been selected for the ICRA CD with test signals (Dreschler et al, 2001)

<i>Track</i>	<i>Character of the noise</i>	<i>Short name</i>	<i>Type of modulations</i>	<i>Gender</i>	<i>Vocal output</i>	<i>Duration (min)</i>
1*	Continuous normal	Normal	Unmodulated	Male	Normal	2
2	Continuous raised	Raised	Unmodulated	Male	Raised	2
3	Continuous loud	Loud	Unmodulated	Male	Loud	2
4	One-speaker female	Female	One-speaker	Female	Normal	5
5	One-speaker male	Male	One-speaker	Male	Normal	5
6	Two-speaker	2-sp	Two-speaker	Mixed	Normal	10
7	Babble normal	6-sp normal	Multi-speaker	Mixed	Normal	20
8	Babble raised	6-sp raised	Multi-speaker	Mixed	Raised	10
9	Babble loud	6-sp loud	Multi-speaker	Mixed	Loud	10

* *ICRA noise used in the present study*

7.4 Results

7.4.1 RECD values

RECD were measured from 30 ears that were fitted with hearing aids. Table 7.6 shows the mean RECD obtained for separate ears and also RECD averaged for both ears. ANOVA with repeated measures revealed no significant difference between the left and right ear RECD values ($F(1,13) = 1.858$, $p > 0.05$).

Table 7.6 : Mean RECD (dB) and standard deviation (SD) for left and right ears

Frequency (Hz)	250	500	1000	2000	4000
RECD (Left Ear)	2.8	6.1	9.6	15.1	11.8
SD	4.9	3.4	3.8	3.3	3.7
RECD (Right Ear)	1.8	5.4	9.6	14.5	10.8
SD	3.9	3.4	2.8	2.3	4.3
RECD (Left + Right)	3.2	5.8	9.6	14.8	11.3
SD	2.8	3.2	3.3	2.8	3.9

7.4.2 Prescribed and achieved gain

The gains prescribed by the NAL-NL1 and DSL v5 procedures as well as the gains achieved in hearing aids fitted based on the two procedures were analyzed by examining the individual data and mean values. Figure 7.2 shows the prescribed gains (top panel) and the achieved gains (bottom panel) at low frequency (250 – 1000 Hz), for 30 ears and at different input levels. The diagonal line in the graph indicates same prescribed or achieved gain for the DSL v5 and NAL-NL1 procedures. Individual data that falls above the diagonal line means that the DSL v5 prescribed or achieved gain is higher than the NAL-NL1 prescribed or achieved gain. As shown in the top panel of Figure 7.2, DSL v5 tends to prescribe more gain than NAL-NL1 for most of the tested ears. For six ears with profound hearing losses and one ear with mixed hearing loss, the NAL-NL1 procedure prescribed higher low-frequency gain than DSL v5 at soft input level. The bottom panel of Figure 7.2 is almost a mirror of the prescribed gain shown in the top panel. This suggests the prescribed gain difference between prescriptions were achieved in the hearing aid fitting, for most of the tested ears at the low frequency region.

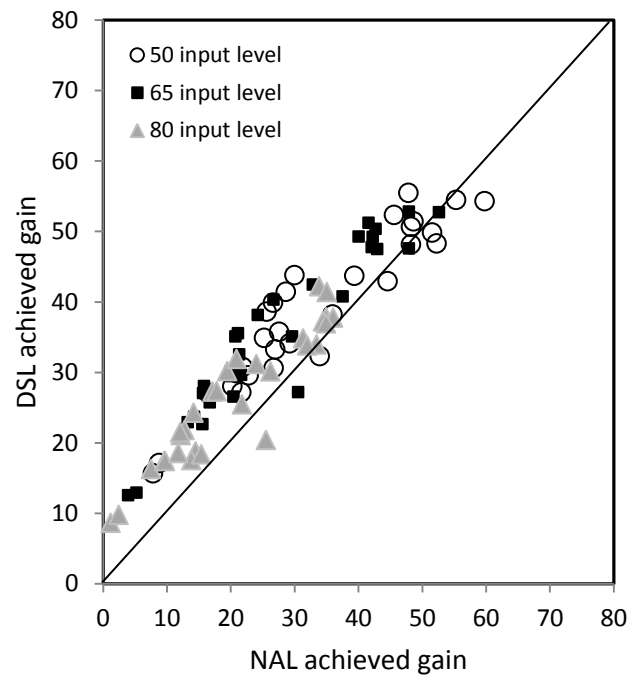
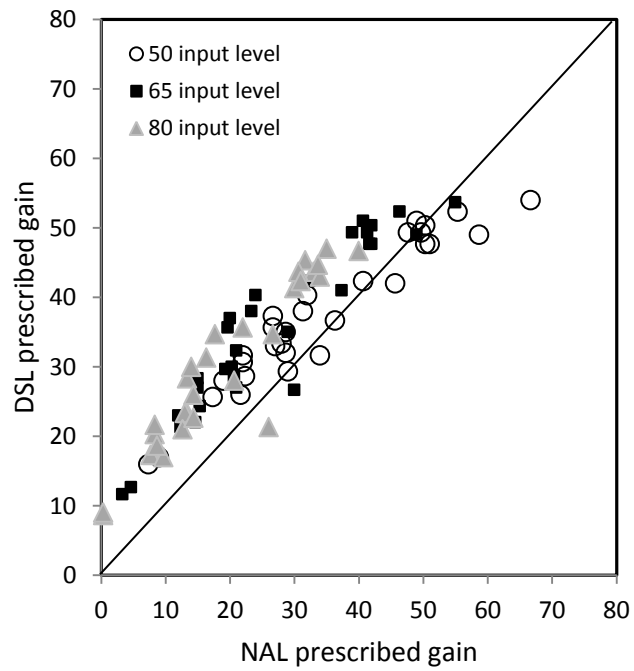


Figure 7.2 : Prescribed and achieved low-frequency gain (250 – 1000 Hz) at different input levels for individual ears (N = 30)

For high-frequency gain (2000 – 4000 Hz), the NAL-NL1 and DSL v5 prescribed gains are shown in the top panel of Figure 7.3 while the NAL-NL1 and DSL v5 achieved gains are shown in the bottom panel of the same figure. The results revealed that DSL v5 prescribed more high-frequency gain than NAL-NL1 for all the tested ears at all input levels. The bottom panel of Figure 7.3 shows the achieved high-frequency gains were higher for most of the ears fitted according to the DSL v5 procedure. However, the achieved gain difference between prescriptions did not match the prescribed gain difference between prescriptions for some of the individual data.

The mean low and high-frequency gains prescribed by the NAL-NL1 and DSL v5 procedures together with the mean achieved gains for both procedures are summarized in Table 7.7. On average, DSL v5 prescribed more gain for both low and high frequencies at low, medium and high input levels. Across input levels, the mean difference in prescribed gain between prescriptions ranged from 2.9 to 10.4 dB for low frequency and 11.3 to 18 dB for high frequency. The mean difference in achieved gain between prescriptions ranged from 5.3 to 7.9 dB for low frequency and 9.3 to 14.9 dB for high frequency, across the input levels.

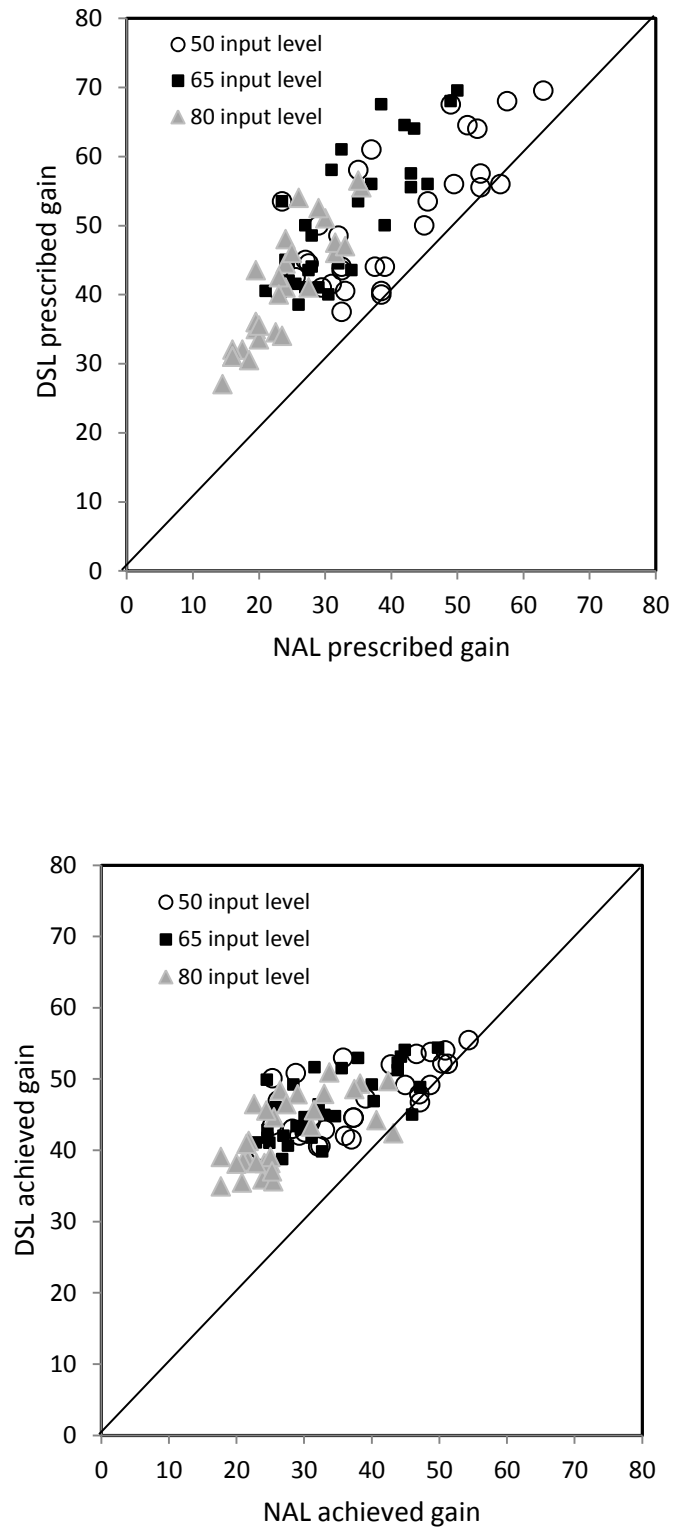


Figure 7.3 : Prescribed and achieved high-frequency gain (2000 – 4000 Hz) at different input levels for individual ears (N = 30)

Table 7.7 : Mean prescribed and achieved gain for low frequency (250 – 1000 Hz) and high-frequency (2000 – 4000 Hz) for the NAL-NL1 and DSL v5 procedures at different input levels

Formula	Level		<i>Prescribed gain (dB)</i>		<i>Achieved gain (dB)</i>	
			<i>Low frequency</i>	<i>High frequency</i>	<i>Low frequency</i>	<i>High frequency</i>
NAL	50	Mean	34.5	39.4	33.3	37.7
		SD	15.0	11.3	14.0	9.3
	65	Mean	26.9	32.8	27.6	33.8
		SD	13.7	8.3	13.3	8.0
	80	Mean	19.2	23.4	20.5	27.4
		SD	11.1	6.0	10.6	7.2
DSL	50	Mean	37.4	50.7	38.6	47.0
		SD	10.3	9.7	10.9	4.8
	65	Mean	35.5	50.8	35.5	46.4
		SD	12.0	9.6	11.7	4.8
	80	Mean	29.6	40.5	26.3	42.3
		SD	11.6	8.5	9.2	5.0

7.4.3 Prescribed and achieved frequency response slopes

The frequency slopes prescribed by the NAL-NL1 and DSL v5 procedures as well as the frequency slopes achieved in hearing aids fitted based on the two procedures were analyzed by examining the individual data and mean values. Figure 7.4 shows the prescribed frequency slopes (top panel) and the achieved frequency slopes (bottom panel) at low frequency (250 – 1000 Hz), for 30 ears and at different input levels. For majority of the tested ears, the NAL-NL1 procedure prescribed steeper low-frequency slopes (up to a difference of 11 dB/octave) than DSL v5 for all input levels. Figure 7.5 shows the prescribed frequency slopes (top panel) and the achieved frequency slopes (bottom panel) at high frequency (1000 - 4000 Hz), for 30 ears and at different input levels. The data showed that the NAL-NL1 procedure prescribed negative values for most of the ears (80%) while the DSL v5 prescribed slopes were mostly positive in value. In this case, the largest slope difference observed was 21 dB/octave for one ear with mixed hearing loss and 19 dB/octave for another ear with sensorineural hearing loss.

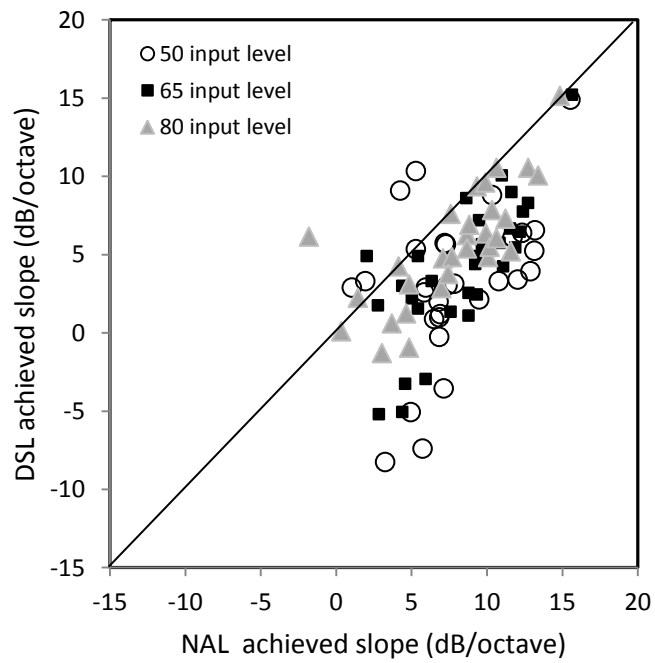
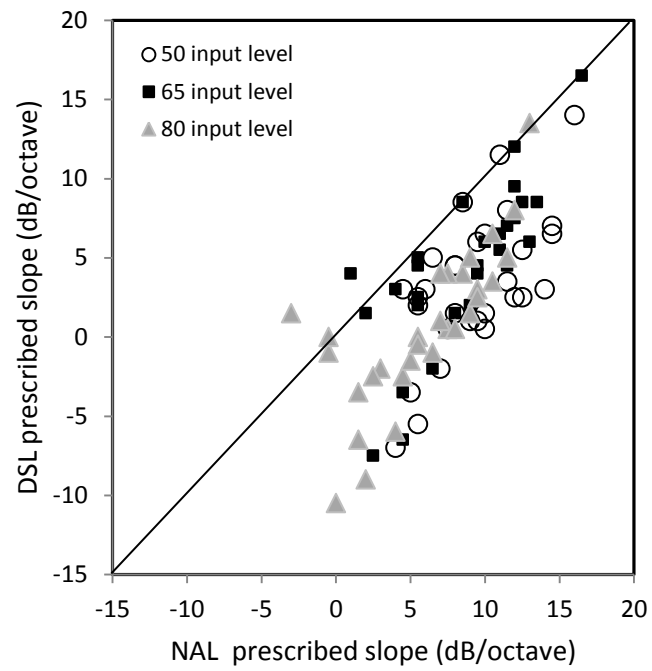


Figure 7.4 : Prescribed and achieved low-frequency slopes (250 - 1000 Hz) at different input levels for individual ears (N = 30)

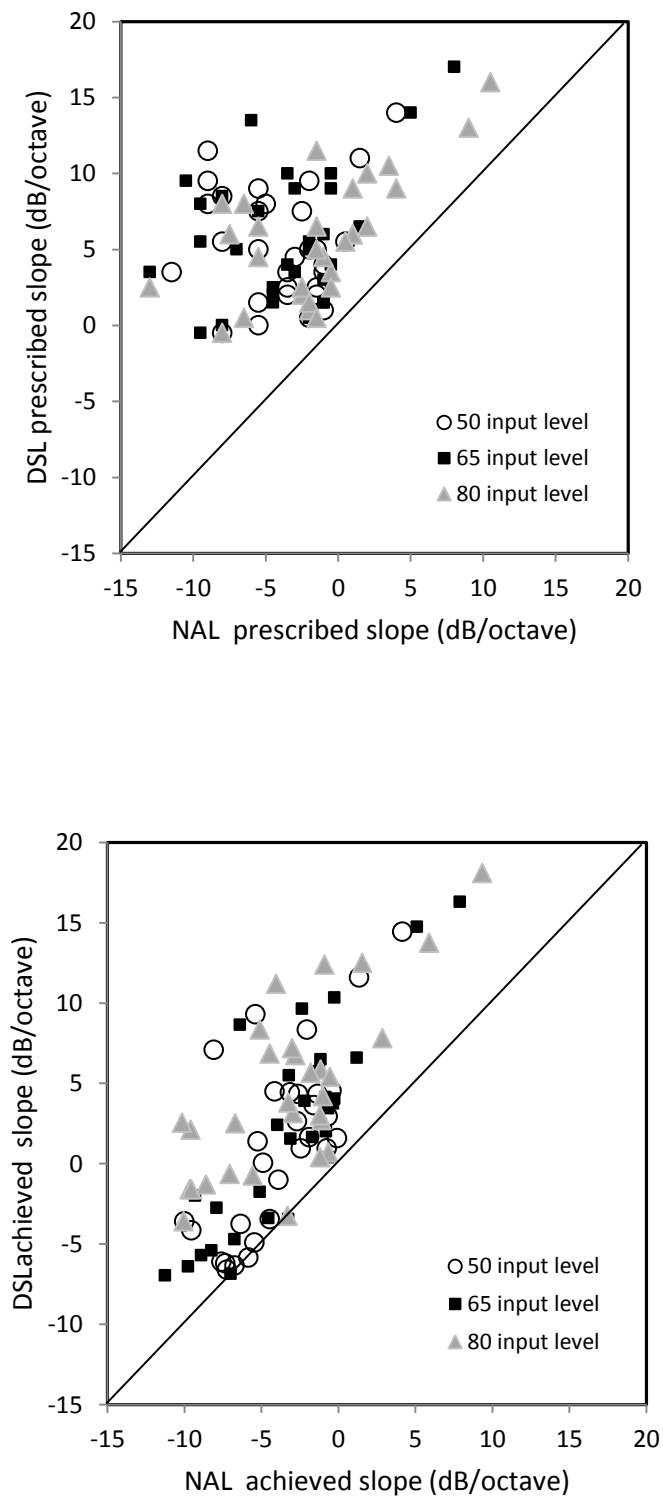


Figure 7.5 : Prescribed and achieved high-frequency slopes (1000 – 4000 Hz) at different input levels for individual ears (N = 30)

The mean prescribed and achieved frequency slopes for low and high frequency at different input levels can be viewed in Table 7.8. On average, the NAL-NL1 procedure prescribed steeper low-frequency slopes for all the input levels. For high-frequency slope, the NAL-NL1 procedure prescribed negative values as opposed to positive values prescribed by the DSL v5 procedure for all input levels. Across input levels, the mean difference in prescribed slope between prescriptions ranged from 4.4 to 6 dB/octave for low frequency and 7.2 to 9.4 dB/octave dB for high frequency. The mean difference in achieved slope between prescriptions ranged from 2.3 to 4.7 dB/octave for low frequency and 5.1 to 7.7 dB for high frequency, across the input levels.

Table 7.8 : Mean achieved and prescribed frequency slopes for low-frequency (250 – 1000 Hz) and high-frequency (1000 – 4000 Hz) for the NAL-NL1 and DSL v5 procedures at different input levels

Formula	Level		<i>Prescribed slope (dB/octave)</i>		<i>Achieved slope (dB/octave)</i>	
			<i>Low</i>	<i>High</i>	<i>Low</i>	<i>High</i>
			<i>frequency</i>	<i>frequency</i>	<i>frequency</i>	<i>frequency</i>
NAL	50	Mean	9.3	-4.0	7.9	-3.9
		SD	3.3	3.6	3.6	3.3
	65	Mean	8.5	-3.7	8.4	-3.2
		SD	3.8	4.6	3.5	4.3
	80	Mean	5.9	-1.5	7.8	-3.2
		SD	4.2	4.9	3.9	4.7
DSL	50	Mean	3.3	5.4	3.2	1.2
		SD	4.5	3.7	4.9	5.6
	65	Mean	4.1	5.9	4.1	2.1
		SD	5.0	4.3	4.5	6.2
	80	Mean	0.6	5.7	5.5	4.5
		SD	5.0	4.0	3.7	5.3

The mean MPOs derived from both prescriptions are displayed in Table 7.9. The results showed on average, both prescriptions prescribed similar MPO targets, with DSL v5 prescribing slightly higher MPOs for all the tested frequencies.

Table 7.9 : Prescribed maximum power output (MPO) for the NAL-NL1 and DSL v5 procedures at different frequencies

Formula		<i>Frequency (kHz)</i>				
		0.25	0.5	1	2	4
NAL	Mean	98.6	104.9	106.3	105.1	110.1
	SD	9.8	10.8	10.6	9.3	10.8
DSL	Mean	105.3	107.6	110.9	112.7	112.5
	SD	8.7	8.2	9.5	7.2	9.4

7.4.4 Achieved versus prescribed gain

To examine how well the prescribed hearing aid targets were achieved in the hearing aids, the mean prescribed gain was subtracted from the mean achieved gain at each tested frequencies respectively, for the NAL-NL1 and DSL v5 procedures. Figure 7.6, 7.7 and 7.8 shows the mean achieved minus prescribed gain for both prescriptions at low, medium and high input levels. Positive values indicate the achieved gains were higher than the prescribed gain and vice versa. For soft input level (50 dB SPL) shown in Figure 7.6, the achieved gains were close to the NAL-NL1 target gains for all the tested frequencies. The mean achieved minus prescribed gain was within ± 3 dB with standard deviations ranging from 1.6 to 3.6 dB across the frequencies. When the hearing aids were fitted according to the DSL v5 procedure, the mean achieved gains met the prescribed gains (within ± 2 dB, SD ranged from 1.5 to 3.1 dB across frequencies) for frequencies up to 2000 Hz. At 4000 Hz, the mean achieved minus prescribed gain was -7.3 dB (SD = 10.4), suggesting under amplification.

For medium input level (65 dB SPL) shown in Figure 7.7, the difference between the NAL-NL1 mean achieved and prescribed gains was very small (within 1 dB, SD ranged from 0.7 to 2 dB) suggesting close agreement between the achieved and prescribed gain for all frequencies. Similar results were also obtained for the difference between the DSL v5 achieved and prescribed gains for frequencies up to 2000 Hz. At 4000 Hz, the mean achieved minus prescribed gain was -7.8 dB (SD = 11 dB) suggesting under

amplification. For high input levels (80 dB SPL) shown in Figure 7.8, the mean achieved gains for NAL-NL1 were in rather good agreement with the prescribed gain except at 2000 Hz where most of the hearing aids provided higher gain than required (mean achieved minus prescribed gain = 7.5 dB, SD ranging from 2 to 5 dB across frequencies). For the same input level, the mean achieved gain for DSL v5 were below the target at 250 Hz (mean = 8.1dB; SD = 5.1 dB) but above the target at 2000 Hz (mean = 4.1dB; SD = 2.3 dB).

The difference between the achieved and prescribed MPO for NAL-NL1 and DSL v5 are illustrated in Figure 7.9. The results showed that most of the hearing aids matched the prescribed MPO for the NAL-NL1 and DSL v5 procedures (mean difference within ± 1 dB) at frequencies between 250 and 2000 Hz. The achieved MPO was on average, 5 dB below the DSL v5 target and 6 dB below the NAL-NL1 target at 4000 Hz.

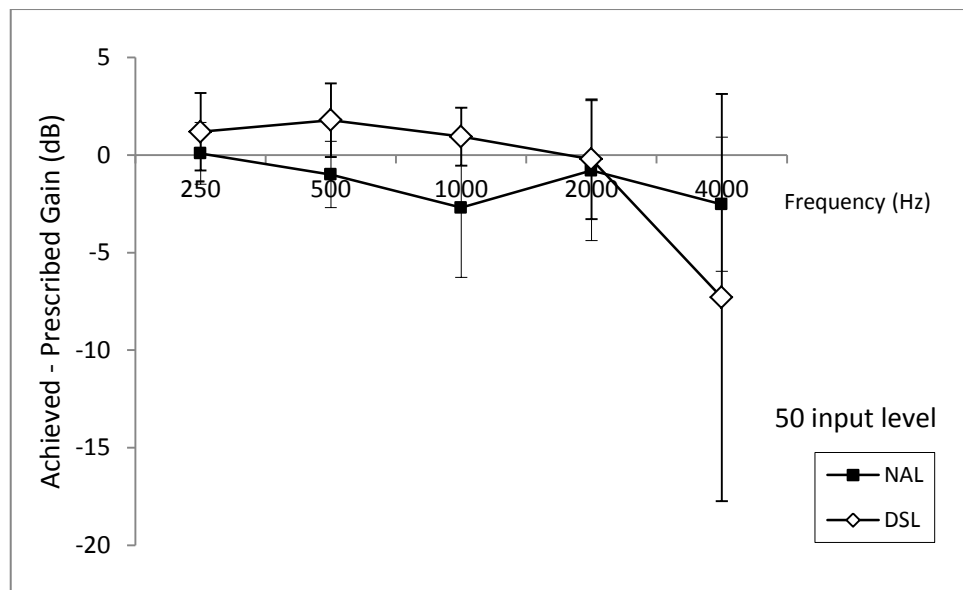


Figure 7.6 : Mean difference between the achieved and prescribed gain for the NAL-NL1 and DSL v5 procedures at 50 input level

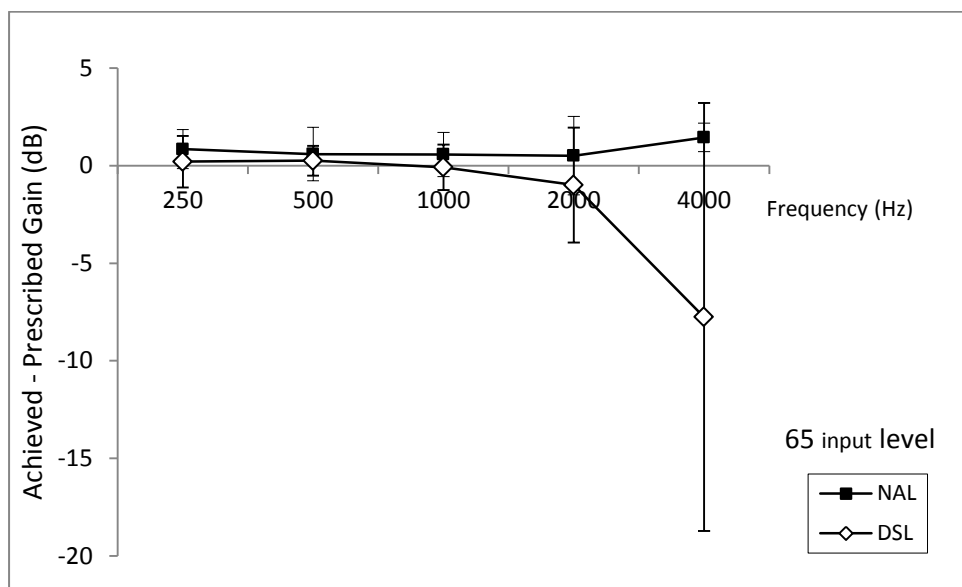


Figure 7.7 : Mean difference between the achieved and prescribed gain for the NAL-NL1 and DSL v5 procedures at 65 input level

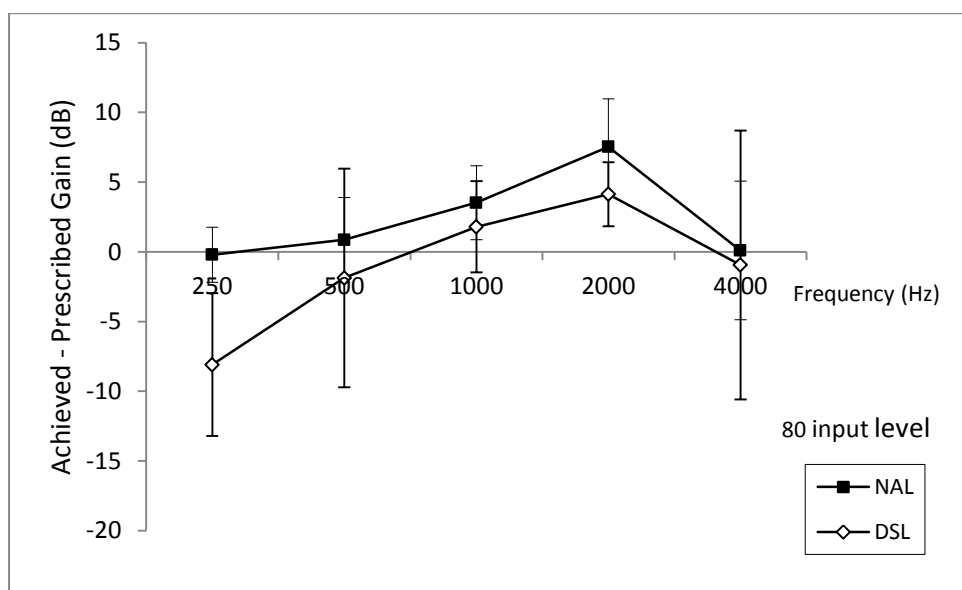


Figure 7.8 : Mean difference between the achieved and prescribed gain for the NAL-NL1 and DSL v5 procedures at 80 input level

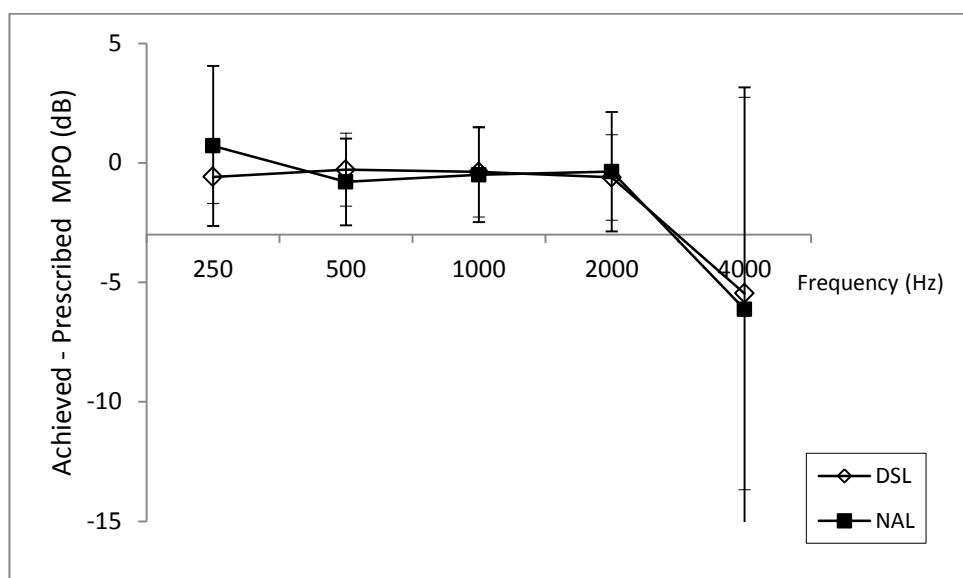


Figure 7.9 : Mean difference between the achieved and prescribed MPO for the NAL-NL1 and DSL v5 procedures

To examine how well the prescribed frequency slopes were achieved in the hearing aids, mean achieved and prescribed slopes for low frequency (250 – 1000 Hz) and high frequency (1000 – 4000 Hz) at different input levels were calculated. In Figure 7.10, the open diamonds represent the mean difference between NAL-NL1 and DSL v5 achieved low-frequency slope while the filled squares represent the mean difference between NAL-NL1 and DSL v5 prescribed low-frequency slope. Close agreement between the achieved difference and prescribed difference could be found for soft and medium input levels. At 65 dB SPL input levels, the achieved difference was almost equal to the prescribed difference. A larger discrepancy however was observed between the achieved difference and prescribed difference at 80 dB SPL input level (mean difference = 3.1 dB/octave). For the high-frequency slope, the mean achieved difference was found not to meet the prescribed difference at soft and medium input levels as shown in Figure 7.11. The prescribed slope difference at soft and medium input levels were -9.5 and -10 dB/octave respectively, whereas the achieved slope difference at soft and medium input levels were -5.3 and -5.6 dB/octave respectively. This means that the achieved slope differences at soft and medium input levels were reduced as compared to the prescribed slope differences.

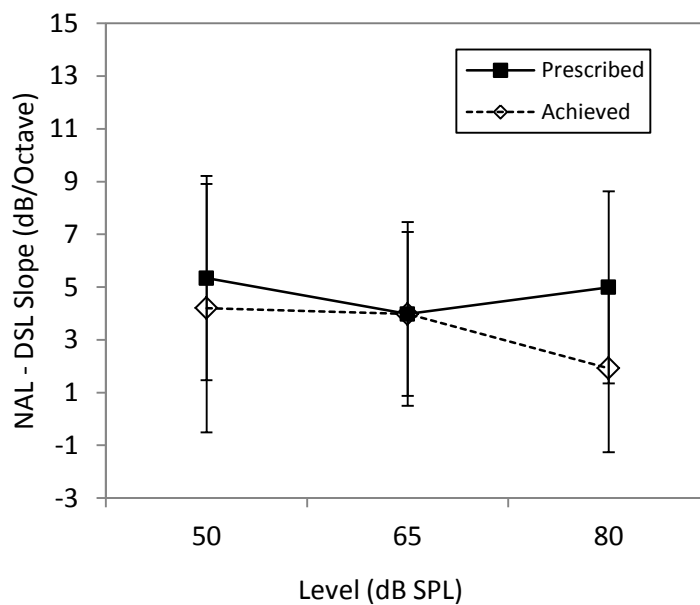


Figure 7.10 : The mean difference of prescribed and achieved **low-frequency** slope (250 – 1000 Hz) between the NAL-NL1 and DSL v5 procedures at different input levels

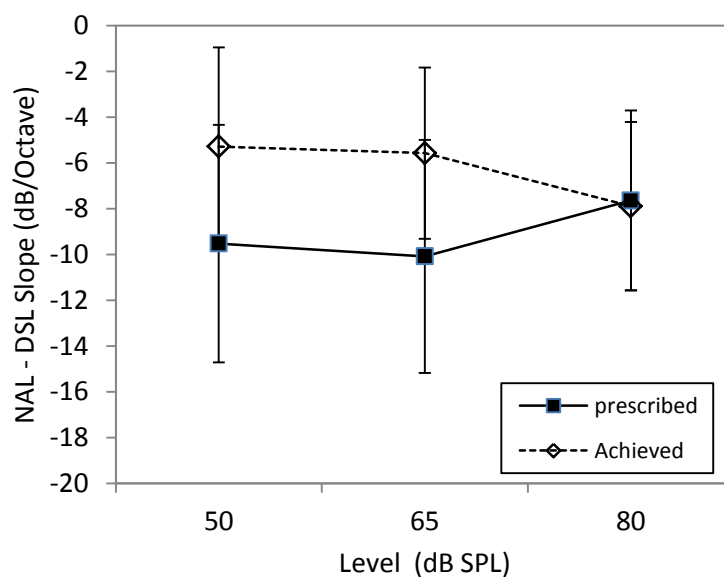


Figure 7.11 : The mean difference of prescribed and achieved **high-frequency** slope (1000 – 4000 Hz) between the NAL-NL1 and DSL v5 procedures at different input levels

7.5 Discussion

7.5.1 Comparing RECD values with other studies

Previous studies have shown that ears with non-occluding wax and normal middle ear function generally show small (< 3 dB at 500 to 4000 Hz) differences in RECD between the left and right ear (Munro & Buttfield, 2005; Munro & Howlin, 2010). Consistent with previous studies, the present study found no significant difference between RECD values measured from the left and right ear. For this reason, the RECD values were averaged across ears for discussion purposes. The mean RECD values obtained in this study were higher than those reported in other studies that measured RECD on children of similar age (Bagatto et al., 2002; Munro & Howlin, 2010; Ching et al., 2010b). Higher RECD values were observed especially at high frequencies (2000 Hz and above) when compared with the other studies. In the Ching et al (2010b) study, RECD were measured from 48 school-aged children from Canada and in Australia. The mean RECD found in this study was between 0.3 – 3.9 dB higher than the RECD reported in Ching et al study from 250 to 1000 Hz. The mean difference increased to 7.5 dB and 9.8 dB when compared with children from Australia and Canada at 2000 Hz respectively. At 4000 Hz, the mean RECD difference was large when compared with Canadian children (8.3 dB) but relatively small (2.9 dB) when compared with Australian children. The children in Canada had significantly lower RECD than the Australian children at 4000 Hz as reported in the Ching et al study and this explains why larger differences are observed between RECD of children in the present study and children in Canada.

Factors such as the insertion depth of the probe tip, earmold acoustics, measurement transducer and ear canal structure could affect the RECD measurement results. The location of the probe tip in relative to the eardrum normally will affect the RECD at 3000 Hz and beyond (Dirks & Kincaid, 1987; Chan & Geisler, 1990). The investigator of this study determined that the probe tube extended by 5 mm from the medial tip of the earmold before it was placed in the ear canal, a method similar to the one carried out by the investigators from Canada in the Ching et al (2010b) study. Even if same steps were taken to place the probe tube, the location of the probe tip in relative to eardrum would still vary depending on the earmold length. The majority of the children in the present study had severe to profound high frequency hearing losses. Thus, it is possible that their hearing aids had been customized to have longer soundbore (other than

making full shell earmold) with the intention to avoid acoustic feedback. This is very likely since most of the children in the present study did not have feedback problems even though high gains were provided to them with the experimental hearing aids. If the soundbore of earmolds used in the current study were longer than those used on the Canadian study, the probe tip would be nearer to the eardrum which in turn would result in smaller residual ear-canal volume. Under these conditions, higher output was likely to be measured at the ear canals. On the other hand, investigators in Australia used the 6000 Hz notch technique to place the probe tube to ensure the probe tip was within 9mm from the eardrum. It is possible that the probe tube insertion depth in the current study was similar to the Australia procedure and hence smaller mean difference was found between the two groups at 4000 Hz. This factor alone however could not explain the relatively large RECD observed at 2000 Hz when compared with either the Australia or Canada data, since the location of probe tip at ear canals normally have larger effect from 3000 Hz and above as mentioned earlier on.

The measured RECD values are also dependent on the type of measurement transducer and earmold tubing used. Munro and Salisbury (2002) measured the RECD values of 18 adults using the Audioscan RM500 real-ear analyzer. Comparisons were made between RECD measured using the ER-3A insert earphone and the Audioscan original insert earphone with three different coupling methods: i) foam tip; ii) earmold with tubing length of 25mm; and iii) earmold with normal tubing length –between 35 to 40 mm. Overall, the mean results showed that RECDs measured with the Audioscan original insert earphone were higher than RECDs measured with ER-3A insert earphone from 500 to 2000 Hz, regardless of the coupling methods used. A significantly larger RECD (9 dB) at 1500 Hz was observed when the RECD measurement was conducted using the Audioscan RM500 original transducer coupled to the earmold with normal tubing (40 mm) as opposed to the RECD measured using the ER-3A insert earphone coupled to the earmold with the same tubing in length. In the present study, the UNITY original transducer (insitu headset) was used, which was coupled to child's own earmold with normal tubing length. The type of transducer and coupling method used might have caused the mean RECDs to peak from around 1500 to 2000 Hz in the present study.

Another factor contributing towards the RECD difference at high frequency may be difference in ear canal size. Shahnaz and Davies (2006) found Chinese young adults had significantly lower ear-canal volume in tympanometry measurements than their

Caucasian counterparts. For smaller ear-canal volume, the RECD values are normally higher particularly at high frequencies due to the higher SPL generated at ear canals (Feigin et al., 1989). It is possible that ear canal size together with the other reasons discussed above, resulted in the higher RECD values measured at 2000 Hz and 4000 Hz in the present study. If the difference in RECD values measured was caused by the difference of ear canal size, this will have significant implications on clinical practice, since average RECD values used for hearing aid fitting purposes are often based on data collected largely from one ethnic group.

7.5.2 *NAL and DSL prescriptions*

The gains prescribed by NAL-NL1 and DSL v5 procedures were examined separately for the low frequency (250 – 1000 Hz) and high frequency (2000 – 4000 Hz). Individual data revealed that DSL v5 prescribed higher low-frequency gain most of the time, except for six ears with profound hearing losses and for one ear with mixed hearing loss. For these ears, the NAL-NL1 procedure prescribed almost equal or higher low-frequency gain (up to 13 dB) than DSL v5 for soft input levels. For medium level, the NAL-NL1 procedure prescribed higher low-frequency gain than the DSL v5 procedure (up to 4 dB) for one ear with profound hearing loss and one ear with mixed hearing loss. It should be noted that the compression threshold (CT) for the NAL-NL1 prescriptions was fixed at the default setting of 52 dB SPL for broadband speech while the DSL v5 procedure prescribed variable CT based on hearing levels and frequencies. In general the DSL v5 prescribes higher CT as the hearing loss increases (Scollie et al, 2005). A relatively high CT could result in the lower gain prescribed for soft input levels. This could explain why, for some individuals in this study, DSL v5 prescribed lower gain than NAL-NL1 for soft input level (Byrne et al, 2001).

In the high-frequencies (2000 – 4000 Hz), DSL v5 consistently prescribed higher gain than NAL-NL1 for any degree of hearing loss investigated in this study. Greatest difference of high-frequency gain between prescriptions was found to be 30 dB for one child with profound hearing loss. These findings were consistent with the report by Seewald et al (2005) which stated that the DSL[i/o] formula did not always generate the maximum real ear aided gain (REAG) target, but for high frequencies, the DSL[i/o]

produced the highest REAG target most of the time when compared with other generic algorithms such as the NAL-NL1 and CAMFIT procedures.

The frequency response slopes prescribed by NAL-NL1 and DSL v5 were examined for the low-frequency slope (250 – 1000 Hz) and the high-frequency slope (1000 – 4000 Hz) separately. On average, NAL-NL1 prescribed steeper low-frequency slope than DSL v5. The mean slope differences (NAL – DSL) were 5.4, 4 and 5 dB/octave for soft, medium and high input levels respectively. These results were similar to those in the Ching et al study (2010b) where the difference in prescribed low-frequency slope between NAL-NL1 and DSL v4.1 was 5 dB/octave for soft and high input levels but less for medium input level. Although previous studies compared prescriptions involving the earlier versions of DSL with the NAL-NL1 formula, the findings from such comparisons should be similar to those in the present study since the new DSL procedure does not differ a great deal from the previous version in prescribing gain for children in quiet conditions (Scollie et al, 2005, 2006).

For high-frequency slope however, the DSL v5 procedure prescribed higher mean values than the NAL-NL1 procedure with mean differences of 9.4, 9.6 and 7.2 dB/octave for soft, medium and high input levels respectively. In majority of the tested ears, the NAL-NL1 procedure prescribed negative values for the high-frequency slope as opposed to the positive values prescribed by the DSL v5 procedure. This indicates reduction of high-frequency gains prescribed by the NAL-NL1 procedure for most of the ears. Many of the children in the present study had severe to profound high frequency hearing losses. When hearing loss is profound at the high frequencies, the NAL-NL1 procedure prescribes less high-frequency emphasis since audibility in this frequency region with profound loss contributes less to speech intelligibility than audibility in other frequencies with less severe hearing loss (Ching et al, 1998, 2001). On the other hand, the DSL v5 method attempts to normalize loudness at each frequency for an input range that is important for speech understanding (Scollie et al, 2005). The different rationale of the two procedures therefore account for the difference in high frequency emphasis between prescriptions. In addition, the targets in the present study were derived based on the individual RECD values. The RECD values obtained in the study were high (up to 14 dB) for the higher frequency regions. This contributes to the higher target gain prescribed by the DSL v5- procedure but not the NAL-NL1

procedure and hence resulting in the larger discrepancy of prescribed high-frequency gain between the two procedures.

7.5.3 *Achieved versus prescribed gain*

The study shows that prescribed gain by both the NAL-NL1 and DSL v5 procedures were achieved at most of the tested frequencies. When the hearing aids were fitted according to the DSL v5 procedure, the achieved gain met the prescribed gain for frequencies up to 2000 Hz but was on average 8 dB below the target at 4000 Hz for soft and medium input levels. The under achieved-gain at 4000 Hz led to the reduction of slope difference between the NAL-NL1 and DSL v5 fittings for high frequency region, at soft and medium input levels. Analysis on individual data suggested that 7 children with profound sensorineural hearing losses had hearing aids which were underamplified at 4000 Hz for the DSL v5 fitting. This means that achieved gains for more than 50% of the children were still either in good or fair agreement (0.2 to -8 dB) with the gain prescribed by the DSL v5 method at 4000 Hz. For high input level, NAL-NL1 targets were met at all frequencies except at 2000 Hz where achieved gain was on average 7.5 dB above the target. The same happened to DSL v5 fittings in addition to under amplification at 250 Hz by 8.1 dB thereby leading to steeper frequency response slope than prescribed. Ching et al (2010b) suggested the constant compression ratio across input levels and output limiting could cause gain at certain input levels failed to meet the targets. For instance, if the gain at low frequency for the DSL v5 fitting were increased to meet the targets for high input levels, the gain at soft input levels would also increase leading to over amplification and higher compression ratios than those prescribed.

The achieved MPO for both NAL-NL1 and DSL v5 fittings were also in good agreement with the prescribed MPO except for few children who had achieved MPO below what was prescribed by the two procedures at 4000 Hz. In general, the study showed the achieved gain could meet the gain prescribed by both the NAL-NL1 and DSL v5 procedures at most of the tested frequencies. The achieved gains were very close to the gain prescribed by NAL-NL1 at all the frequencies especially at medium input level (within ± 1 dB). This indicates that precise fitting can be performed by current commercial hearing aids. The flexibility of gain adjustment offered by current

commercial hearing aids was also supported in studies conducted by Aazh and Moore (2007) and Polonenko et al (2010). Mismatch between measured REIG and target gain prescribed by the NAL-NL1 procedure was investigated by Aazh and Moore (2007). Digital hearing aids with four, six and seven gain ‘handles’ were fitted to 42 ears. The results showed that after adjusting the frequency-gain response of hearing aids to meet the targets, 83% of the measured REIGs were within ± 10 dB of the targets. The study also found that the chance for meeting the target gains was higher for hearing aids with more gain ‘handles’ or channels. In Polonenko et al (2010) study, 30 adults with acquired hearing loss were fitted with digitally programmed multichannel hearing aids based on the DSL v5 adult procedure. The hearing aids used had between 6 and 20 channels. The results showed that 95% of the fittings fell to within 5.8 to 8.4 dB of targets across frequencies and these fittings were reported as meeting the clinical guideline for matching the achieved gains to the targets. These studies (i.e Aazh & Moore, 2007; Polonenko et al., 2010) however, involved adults with hearing losses ranging from mild to severe degree and the accuracy of fittings was only investigated for medium input levels. The results might be different for hearing loss that falls in the severe to profound category or in children where the prescribed gains are likely to be higher in relative to the prescribed gains for adults. The present study showed good fit-to-targets in hearing aids fitted to children with moderately severe to profound hearing loss. Despite this finding, it should be noted that the hearing aid model used in the present study was high-end hearing aid which might not be accessible to many of the hearing impaired people due to cost factors. Hence, it remains essential to investigate the flexibility of more commonly used hearing aids in achieving the desired fittings.

The prescribed low-frequency slopes were achieved for both prescriptions, suggesting the difference of low-frequency slope between prescriptions were preserved in the fittings. For high-frequency slope, the mean differences of frequency slope between prescriptions were reduced at low and medium input level. Individual data suggests for some of the children with profound hearing losses at high frequencies, the DSL v5 prescribed gains at 4000 Hz were under achieved. This has resulted in the reduction of achieved slope difference as compared to the prescribed slope difference. Although the achieved slope difference was reduced, there was still an average of about 5 dB/octave slope difference between prescriptions, for the low and medium input levels. Different results were obtained from the Ching et al (2010b) study which showed that even though the NAL-NL1 and DSL v4.1 prescribed substantially different frequency slopes,

the slope difference achieved in the hearing aids was minimal. Hearing aid features (e.g 16 channels in the present study versus four channels from the Ching et al study) could be one of the reasons that the slope difference between prescriptions was larger in the present study as compared to the Ching et al (2010b) study (Aazh & Moore, 2007). The good fit-to-targets achieved in the present study increases the validity of the second study that examined the relative performance of hearing aids fitted according to the NAL and DSL procedures.

7.6 Conclusions

The present study on moderately severe to profound hearing losses showed that the NAL-NL1 and DSL v5 prescribed substantially different overall gain, low and high-frequency response slopes. The difference in frequency response prescribed by both procedures highlights the importance of conducting research to compare the performance of hearing aids fitted according to the two mostly used generic methods, especially on children who cannot provide feedback with regard to the benefits of their hearing aid fittings. The targets for both procedures could be achieved by the hearing aids fitted to the children for all the tested frequencies, except at 4000 Hz where the prescribed gain of DSL v5 was under achieved for profound hearing losses. The relative effectiveness of the respective prescription on speech perception and functional performance of children will be reported in the next chapter.

CHAPTER 8

Study III

Evaluation of real-world preferences and performance of hearing aid in children with moderately severe to profound hearing loss fitted according to the NAL-NL1 and DSL v5 procedures

8.1 Introduction

Hearing loss in children can cause delay in the development of receptive and expressive communication skills, poor academic achievement and social isolation. Providing hearing aids may be considered to be a very important intervention to help children with hearing loss. The hearing aid characteristics need to be selected with care to ensure the children are able to experience the optimum benefits from the hearing aids. A practical way to select appropriate hearing aid amplification according to Dillon (2001) is to use a prescriptive procedure.

The National Acoustic Laboratories (NAL) and Desired Sensation Level (DSL) prescriptive procedures are widely used by clinicians to fit hearing aids to children with hearing impairment. Studies on children who used hearing aids fitted according to the different procedures have yielded mixed results with some studies showing a preference for the NAL procedure (Snik et al., 1995; Ching et al., 1997; Ching et al., 1999; Ching, Dillon & Byrne, 2001) and some studies showing a preference for the DSL procedure (Snik & Stollman, 1995; Jenstad et al., 1999; Jenstad et al., 2000; Scollie et al., 2000).

A recent study conducted by the National Acoustic Laboratories (NAL) together with the University of Western Ontario (UWO) compared the performance and preferences of children who used hearing aids fitted according to the NAL-NL1 and DSL v4 procedures (Ching et al., 2010a). The NAL/UWO study was carried out with the intention of addressing research design limitations in previous studies (i.e differences in subjects' characteristics, technical limitations of hearing aids and subjects' previous hearing experience) that might have resulted in inconclusive findings. Using a cross-over, double-blind, four-period design, the study evaluated hearing performance of 48 school-aged children with mild to moderately severe hearing loss in Australia and in

Canada. The children were fitted with new hearing aids adjusted to meet targets prescribed by the NAL-NL1 and DSL v4 procedures. After extended periods of familiarity with each of the procedures, the children were assessed using a loudness rating test, speech tests, paired-comparison judgments of intelligibility tests and functional performance scales. On average, there was no significant difference between the procedures for speech perception. In real life, children preferred the DSL v4.1 prescription for listening to soft speech and the NAL-NL1 prescription for listening in noisy situations. The study also found that on average, preference for the NAL-NL1 prescription was associated with lesser degrees of hearing loss. Thus the question remains if the preference for gain is associated with the degree of hearing loss, rather than the type of prescription per se.

The aim of the present study was to compare the performance of the NAL-NL1 procedure and the latest version of the DSL procedure (DSL v5) among school-aged children with moderately severe to profound hearing loss. The relative performance of the two procedures was assessed using speech tests, paired-comparison judgments of speech intelligibility tests and questionnaires completed by the parents, teachers and the children themselves. The following section describes about the methodology used to carry out the study. The methodology describes the participants' characteristics and the materials used, how the hearing aid fitting was carried out for the NAL-NL1 and DSL v5 procedures and finally the procedure used to evaluate the relative performance of hearing aid fitted based on the two procedures.

8.2 Method

8.2.1 Participants

Twenty children were initially recruited from the audiology clinics of Universiti Kebangsaan Malaysia (UKM) and General Hospital in Kuala Lumpur. Three children withdrew from the study at the initial stage due to parents difficulties in committing in the study. Another child who rejected the hearing aid fitted, had to be excluded from the study. Hence a total of 16 children aged between 7 to 17 years old (mean = 12.7 years; SD = 2.8) participated in this study. The children included 2 girls and 14 boys with degree of hearing losses that ranged from moderately severe to profound (four frequency average (4FA) at 500, 1000, 2000 and 4000 Hz = 81.9 dB HL, SD = 17.7,

range = 51.9 – 115 dB HL). Further details of participants' hearing threshold levels, hearing aid experience and school placement has been described in the previous chapter (Chapter 7). Briefly, all children had sensorineural hearing loss except for one child who had mixed hearing loss in one ear. This child and three other children had asymmetrical audiograms. Two children in the study used one hearing aid while the remaining children were binaural hearing aid users. Except for two children, all were experienced hearing aid users. Eleven children were in mainstream schools with three of them receiving special support in classroom (inclusive program). Five of the total children were in a unit for deaf children.

All participants involved in the present study read the subject informational form and signed the subject consent form. For each visit to the location of study, participants were paid expenses to cover their travel costs.

8.2.2 *Materials*

The study was conducted using speech tests, paired-comparison judgments of speech intelligibility tests and real life measures. For the speech tests, a consonant discrimination test (Computer-based Malay Auditory Discrimination Assessment or COMADAS), and the Malay Hearing in Noise Test (MyHINT) were used. For children who could not perform in the MyHINT, a closed-set word test was used instead. HINT is a sensitive and reliable test that can be used to assess the improvements in speech understanding with hearing aids. Studies have also found moderate correlation between subjective measures and the HINT, suggesting the HINT can be used to document the benefits of hearing aid (Mendel, 2007; Peeters et al., 2009). In addition, HINT materials provide more semantic context as compared to other speech tests such as the Quick Speech-in-Noise Test (QuickSIN) and the Words-in-Noise test (WIN) and thus, their use is more appropriate with young children or individuals with substantial hearing loss (Wilson et al., 2007).

For real life measure, auditory inventory scales or questionnaires filled in by parents' teachers and the children themselves were used in the study. This includes the Parents' Evaluation of Aural/Oral Performance of Children (PEACH), the Teachers' Evaluation of Aural/Oral Performance of Children (TEACH), and the Self Evaluation of Listening Function (SELF). These same scales were used in the Ching et al (2010) study and thus

comparison can be made for the results obtained from their study and the present study. The PEACH and TEACH can be used to evaluate the effectiveness of amplification for children and it was found that the scales have good reliability and sensitivity (Ching & Hill, 2007; Ching et al., 2008). Details on the items, administration and scoring of the three scales will be explained under the procedure section.

8.2.3 Hearing aid fitting

Prior to hearing aid fitting, hearing assessment and a real-ear-to-coupler difference (RECD) measurement was carried out on each child. Details of the procedures of hearing assessment, RECD measurement and hearing aid fitting were presented in Chapter 7. Briefly, hearing threshold levels were measured using the ER3A insert earphone coupled to the child's own earmold. The RECD measurement was carried out using the Siemens UNITY probe microphone system. The RECD values were derived from the stimulus output measured in a HA-2 coupler and in the child's ear canal. When the hearing assessment and RECD measurement were completed, the children went home and returned to the clinic again on a different day for hearing aid fitting and hearing aid trial.

A common hearing aid model (i.e. Phonak Naida V SP Standard) was fitted to all the children in the study. This behind-the-ear hearing aid has 16 channels, four memory programs and a data logging feature. To program the hearing aid, individual audiometric hearing thresholds in dB HL and RECD values were entered into the NAL-NL1 (Dillon, 1999) and DSL v5 (Seewald et al., 2005) stand alone software to derive the 2cc coupler target gains for different input levels. The hearing aid gain and frequency response were adjusted to meet the targets prescribed by the NAL-NL1 and DSL v5 procedures at 50, 65 and 80 dB SPL input levels. The maximum power output (MPO) at each frequency was also adjusted to match the MPO values prescribed by the respective fitting procedures. The extent to which the gain, frequency response and MPO achieved in hearing aid matched the prescribed targets is described in detail in Chapter 7.

The hearing aid volume control and hearing aid advanced features such as noise reduction circuit, feedback manager and sound recover (frequency compression) were disabled for the purpose of this study. Two separate memory programs in the hearing

aids were activated in order to store frequency responses adjusted based on the NAL-NL1 and DSL v5 prescriptive formula.

8.2.4 *Test procedure*

This is a cross-over, four period trial of prescriptions study. During the first two periods, each lasting six weeks, children had access to one prescription only. During the third and fourth trial period, each lasting three weeks, children had access to both the prescriptions via their hearing aid remote controls. The investigator was not blinded to the test condition (single blinding was used in the study). The research procedure is similar to the procedure used in the NAL/UWO study (Ching et al, 2010a). The following section describes the test procedure. The test procedure is summarized in Figure 8.1.

Trial Period 1(6 weeks) : Prior to the hearing aid trial, instructions were given to the children on how to use the hearing aid. An informal check was done involving clapping and talking very loudly to make sure that each child did not experience any discomfort.

Three children experienced acoustic feedback when they were fitted with the DSL v5 prescription. A new and tighter fitting earmold was made for each child, to prevent the feedback. For these children, the RECD measurement with the new earmold was repeated and the hearing aid was re-adjusted according to the new RECD values.

In trial 1, half of the children were randomly assigned to receive only the NAL-NL1 prescription while the other half were assigned to the DSL v5 prescription alone. The children underwent a six week home trial with the hearing aids. During the trial period, children were instructed to fill in the Self Evaluation of Listening Function (SELF) scale, and their parents were asked to complete the Parents' Evaluation of Aural/Oral performance of Children (PEACH) scale (Ching & Hill, 2007). The children's school teachers were also invited to take part in this study by completing the Teacher's Evaluation of Aural/Oral performance of Children (TEACH). The purpose was to evaluate the children's functional hearing in real life with the hearing aid prescriptive procedure assigned to them. At the end of the first trial period, children returned to the clinic to complete the following tests : paired-comparison judgments of speech intelligibility and speech perception using both the NAL-NL1 and DSL v5 settings.

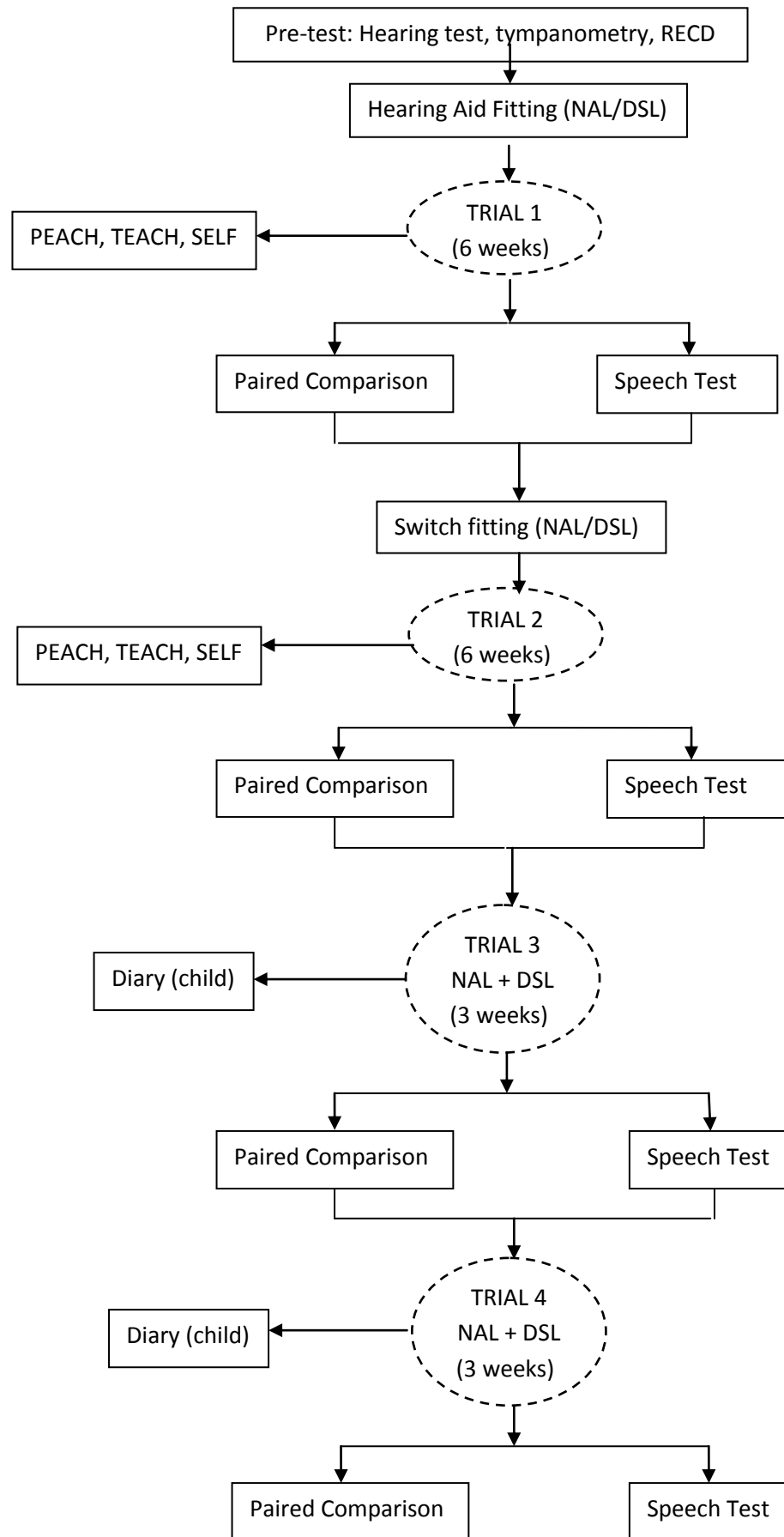


Figure 8.1 : Flowchart showing the research procedure.

The completed PEACH, SELF and TEACH questionnaires were collected at the end of the test session. An interview session was also conducted between the investigator and the respondents (parents, teachers and children) separately, to verify the responses or answers written by them in the questionnaires.

Trial Period 2 (6 weeks) : At the end of the first home trial, children's hearing aids which had been fitted according to NAL-NL1 prescription in the previous trial, were switched to DSL v5 prescription and vice versa. This was followed by another six weeks of home trial with the hearing aids. The same evaluations as for the first trial period were conducted at the end of the second trial period.

Trial Period 3 (3 weeks) : Both the NAL-NL1 and DSL v5 prescriptions were activated in the different program so the children could access both prescriptions via the tactronics push-button on their hearing aids. The default memory program was set to be the same as the prescription assigned to the child on the first trial. The children were allowed to switch between these two programs whenever they wished in the third trial session for three weeks. During this trial, children were also required to fill in a short diary which allowed them to compare the performance of the two programs in different listening situations. By the end of the three weeks trial, children returned to the clinic to repeat the paired-comparison judgments tests as well as the speech perception tests.

Trial Period 4 (3 weeks) : To avoid bias among children towards the prescription set as the default memory program during the third trial, the default program was counterbalanced in the fourth trial session. This meant that the relative positions of the two programs in trial 3 were reversed. The paired-comparison tests and speech perception tests were repeated at the end of the trial session.

For any trial session described above, further adjustment to the hearing aid gain or hearing aid fine tuning was not carried out unless the children showed discomfort for loud sounds, then the MPO setting was reduced. The children were advised to get accustomed to the hearing aid settings. If the child rejected the hearing aid, the procedure was to counsel the child to try out the hearing aid again to see if he or she could accept the hearing aid. It was found that all children who participated in the study had no experience of loudness intolerance. Most of the children could accept the hearing aids either fitted based on the NAL-NL1 or DSL v5 procedures even though

some commented that the hearing aids sounded different (i.e. louder or softer) from their own hearing aids at the beginning of the fitting. Only three children had difficulty accepting the hearing aids fitted based on both the NAL-NL1 and DSL v5 procedures. Two of these children were new hearing aid users and one child had not been using hearing aids for more than a year. The difficulty of accepting the hearing aids were reported by parents and teachers, after the hearing aid fitting session. For these children, the investigator visited the children in the schools to provide counseling to them. Throughout the test procedure, the children, parents and teachers were unaware of the type of hearing aid prescription fitted to the children.

8.3 Evaluation of the NAL-NL1 and DSL v5 Performance

Prior to each test session carried out to evaluate the performance of the NAL-NL1 and DSL v5 prescriptions, the hearing aid frequency response and MPO were measured in the 2 cc coupler to ensure that they were consistent with the fitted or verified values. Tympanometry was also conducted to rule out middle ear problems before each evaluation test. One child in the study had influenza and showed a Type C tympanogram. The child was given another appointment for the evaluation test. After checking the hearing aid and conducting the tympanometry measurement, the following procedures were undertaken to evaluate the performance of the NAL-NL1 and DSL v5 prescriptions.

8.3.1 Data logging

One application of the data logging feature in the Phonak Naida hearing aid is that it can measure the duration and frequency of hearing aid usage. It measures the total hours of hearing aid usage and also calculates the average hours of usage per day. This feature was used to compare the duration (in average hours per day) of the NAL-NL1 and DSL v5 prescriptions being used by children, in trial 1 and 2. In addition, the data logging feature provides information on the frequency (defined as a percentage) of usage for different memory programs. This feature was used to compare how frequently the NAL-NL1 and DSL v5 prescriptions were used by the children when they had access to both programs in trial 3 and 4.

The results recorded by the data logging feature was viewed by connecting the hearing aid to the Phonak fitting software and reading the memory of the hearing aid. This was

carried out before other evaluation tests (i.e paired-comparison tests and speech tests) were performed. In this way, it allowed the investigator to check if the children were using the hearing aids consistently. Through this process, one child with no hearing aid experience was found to be using the hearing aid for an average of only 2 hours per day. The child was counseled to use the hearing aid more often and another appointment was arranged for the child to come for testing.

8.3.2 Speech Tests

i) Consonant discrimination test

A consonant discrimination test was administered to the children using the Computer-based Malay Auditory Discrimination Assessment or COMADAS (Ting et al., 2005). The test consists of 18 Malay consonants recorded from a male talker in a VCV context, where V represents the carrier vowel /a/. The consonants consist of /b/ /tʃ/ /d/ /f/ /g/ /h/ /dʒ/ /k/ /m/ /n/ /ŋ/ /p/ /s/ /ʃ/ /t/ /v/ /z/. Each consonant is replicated giving a total of 36 items in a test list. The speech material was presented from a computer laptop connected to a digital equalizer, an amplifier and a loudspeaker. Using a sound level meter, the master volume of the amplifier was adjusted until the speech material presented in quiet reached 65 dBA at 1 m from the loudspeaker. The position of the amplifier volume control representing the 65 dBA level was then marked. This process of calibration was conducted daily, to make sure the signal level was stable. The process of calibration was also carried out each time before the test session began. During the test, children were seated 1 m from the loudspeaker at 0 degree azimuth. The children responded to the stimulus by pointing to the possible consonant on a laminated template that displayed all the tested consonants (Appendix 5). The responses given by the children were entered into the computer by the tester to calculate the scores. The consonants were presented in a randomized order within each test list.

ii) Hearing in Noise Test (HINT)

The children version of the Malay HINT (MyHINT) (Md. Yusof, 2006) was used to test sentence perception. The children MyHINT was adapted from the original adult MyHINT (Quar et al., 2008). It consists of 13 phonemically balanced lists with 10 short sentences in each list (Appendix 6) and is suitable for children aged five years old and above. Each sentence comprised of three to five words (six to nine syllables) and is presented by a native Malay male speaker.

The speech material was presented using the HINT PRO Biologic System Corp hardware and the HINT PRO software (version 7.0.3). During the test, the test stimuli were presented from a loudspeaker located 1 m away and at 0 degree azimuth from the child. The child's task was to repeat the sentences after they were presented. The test was conducted first in quiet and then in noise. The sentence lists presented in quiet and noise were counterbalanced for both prescriptions. This means each sentence list was presented in all test conditions for both prescriptions. For each test condition, the Sentence Reception Threshold (SRT) was obtained. The SRT is defined as the lowest level in dBA (quiet) or dB SNR (noise) where the subject can identify 50% of the speech material correctly. To determine the SRT, the sentence level for test in quiet and the noise level for test in noise were adaptively adjusted depending on child's response for the preceding sentence. All words in the sentence must be repeated correctly (Nilsson, et al., 1994; HINT Pro user's manual, 2005).

For children who were not able to perform using the HINT adaptive procedure due to limited language ability, a non-adaptive procedure was used instead. In this case, the sentence list was presented at a fixed level in quiet and at fixed SNRs (i.e. 65 dBA in quiet and at 0, +5 and +10 dB SNR). Sentences were then scored in percentage, according to the number of words correctly identified.

iii) Word Test

A closed-set, picture pointing Malay word test was conducted on children who were unable to complete the HINT test. The speech material was originally from the Evaluation of Auditory Responses to Speech (EARS) assessment tool developed by Allum-Mecklenburg (1996). The EARS has been adapted into the Malay language (Mukari & Abdul Hamid, 2008). One of the sub tests in the EARS (i.e, the monosyllabic, trochee, spondaic and polysyllabic word test or MTP) was selected as the word test for this study. It consists of 12 picture words spoken by a male talker (Appendix 7). The 12 words were presented in a randomized order, to produce 10 test lists. In each test list, each word was presented twice, making a total of 24 words per list. The speech material was available in a compact disc format with each test list saved in different track numbers. Also available in the different track numbers, are the lists of words presented in noise at two different choices of SNRs (0 dB SNR and +10 dB SNR). The noise consists of a Malay four multi-talker babble which has been recorded

and embedded in each of the word list. For the purpose of this study, the 0 dB SNR was selected to present the word in noise.

The word test was presented via a computer CD player connected to a digital equalizer, an amplifier and a loudspeaker. The words were presented 1 m from the child, at soft level (50 dB A), medium level (65 dBA) in quiet and in noise (0 dB SNR). The intensity level of the speech was determined by adjusting the master volume of the amplifier and the computer volume until the desired level was reached by using a sound level meter. The positions of the volume control representing different intensity levels were marked and daily calibration was carried out to make sure the signal levels were stable. The process of calibration was also carried out each time before the test session began.

Prior to every speech test, the child was presented with one practice list for familiarization purposes. The speech tests were conducted at the end of each home trial. At each test session, one speech list was used to assess the NAL-NL1 and the DSL v5 prescription respectively. In trial 1 and 2, the children were first tested with the prescription that they were using in the home trial, followed by the other prescription. In trial 3 and 4, they were first tested with the prescription that was set as the default program, followed by the other prescription.

8.3.3 Paired-comparison judgments of speech intelligibility tests

Paired-comparison tests of speech intelligibility were administered after the speech tests. Children were presented, audio-visually with Malay children's stories read by a male native speaker at 65 dB A. The stories were popular among the local children and were selected with help from a speech pathologist. The recording of the audio-visual material was carried out at Macquarie University. A 14 inch television monitor was positioned next to a speaker which was placed 1 m away from the child at 0 degree azimuth. Before implementing the test, the children's hearing aids were activated by connecting them to the Phonak fitting software (iPFG 2.5a) via the NoahLink wireless interface. The children were instructed to listen to the story with one prescription and then with the other one. A switch box was given to the child for him/her to 'select' the prescription while listening to the story. The children were able to switch back and forth as many times as they liked before deciding which prescription provided them maximum speech intelligibility. The switching between prescriptions was actually

performed by the investigator via the fitting software. This process was repeated 10 times and the prescription was randomized to avoid bias preference towards any one switch position. Table 8.1 shows how the NAL-NL1 and DSL v5 prescriptions were randomized in representing the position of the switch box used by the children to ‘select’ the prescription.

Table 8.1: Paired-comparison judgment of speech intelligibility tests. The table illustrates how the DSL v5 and NAL-NL1 prescriptions were randomized to represent the A and B position of the control switch box

Presentation	Switch Position A	Switch Position B
1	DSL	NAL
2	NAL	DSL
3	NAL	DSL
4	DSL	NAL
5	DSL	NAL
6	NAL	DSL
7	DSL	NAL
8	NAL	DSL
9	DSL	NAL
10	NAL	DSL

8.3.4 Functional hearing evaluation

The effect of the two prescriptive methods on the child’s real life functional performance was evaluated using the PEACH, SELF and TEACH scales. These auditory inventory scales were found to be sensitive in detecting the differences in hearing aid characteristics (Ching et al., 2008; Ching et al., 2010d). Furthermore, comparison can be made between the results obtained from the present study and results from the NAL/UWO study that used the same scales. The three assessment scales were translated and adapted into the Malay language for use in the present study. Adaptation of the PEACH scale into the Malay language is explained in Chapter 6.

The translated versions of PEACH, TEACH and SELF were administered to the parents, teachers and children at the end of trials 1 and 2. All the respondents were given instructions by the investigator to complete the questionnaire. As part of the PEACH and TEACH questionnaires, parents and teachers were also requested to

compare the children's performance between prescriptions by completing a difference rating for each item by using a five-point scale (-2 = much worse, -1 = a bit worse, 0 = no difference, +1 = a bit better, +2 = much better). The comparative rating was completed at the end of the second trial period. Individual comments were also gathered after the children had experienced both prescriptions in trials 1 and 2.

(i) Parent's Evaluation of Aural/Oral Performance of Children (PEACH)

The PEACH scale (Appendix 8) was developed as a measure of functional performance in everyday life, based on a systematic use of parents' observations. In general, an observation period of one week is considered reasonable for obtaining a representative sample of the auditory behavior of a child in everyday life, and practical for parents to observe and record the behaviors in the PEACH booklet. The PEACH scale contains items that focus on aural/oral behaviors in speech communication situations in real life. The items of the outcome measure were constructed by a team of professionals including teachers of the deaf, early intervention teachers and audiologists. Depending on the auditory skills of the child, the PEACH can be used to evaluate the effectiveness of amplification for children from any age group with hearing loss ranging from mild to profound degree and is found to have good reliability and sensitivity (Ching & Hill, 2007; Ching et al., 2008). For children with normal hearing, a ceiling effect is observed at the age of approximately four years.

The PEACH scale consists of 13 items or questions. The topics covered include :

- i) Use of amplification and loudness discomfort
- ii) Listening and communicating in quiet
- iii) Listening and communicating in noise
- iv) Telephone usage
- v) Responsiveness to sounds in the environment

The items were printed in the form of diary booklet in which written instructions were provided together with space under each item for parents to write down their observations. Because the questionnaire has been designed for use with older children as well as for use with infants, some questions have two alternatives. Parents should focus on the alternative that is more appropriate to the age or development of their child.

There are three main applications of the PEACH. First, it can be used to evaluate the effectiveness of amplification. By using the PEACH, the parents are able to identify areas of concern which then will help the audiologists to evaluate the effectiveness of the child's hearing aid performance and fine tune them if necessary. Second, it can be used to compare the change in amplification. For example, the audiologist may want to compare the child's oral/aural abilities with and without the hearing aid or with hearing aids of different settings. Third, it can be used as a counseling tool to help the parents of recently diagnosed children to understand the difficulties the child is experiencing as a consequence of their hearing loss and subsequently after hearing aid fitting to highlight the benefits of hearing aid use (Ching & Hill, 2007; Ching et al., 2008).

In the following section, the administration of PEACH and scoring technique used in the present study will be explained. All information given can be found in the NAL website (www.nal.gov.au).

Administration of PEACH

When a copy of the PEACH booklet was given to the parent, the "guidelines for parents" found in front of the booklet was explained to the parent to help them fill up the questionnaire. The guidelines specify that the parents need to read through all the questions first so that it will give them an idea of what to observe. The parents were requested to be as specific as they could when writing down examples of behavior as they will be used to score the PEACH at the end. For example, for question 6;

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

For the above question, the answer given may be ;

"Olivia was in the dining room watching TV when I called her from the kitchen (5 meter away). She turned her head the first time I called her name".

Parents were reminded to write down as many examples as they could of the displayed and also NOT displayed behavior. They were also reminded to carry the booklet with

them and write down as soon as they notice the behavior. When the observation period was over, an appointment was arranged for the investigator and the parent to go through the questionnaire. The purpose of the meeting was to enable the investigator to ask further questions or to make clarification on any unclear examples of behavior reported by the parents. An interview technique rather than a questioning technique was adopted to avoid “yes-no” responses and to increase the accuracy of the information obtained (Ching & Hill, 2007).

Scoring

Each question was scored on the PEACH score sheet (Appendix 9) using a five-point scale as followed :

Scoring	
0	Never : The child never exhibits the behavior, no examples are given. The parent can't think of a time when the behavior has occurred. The behavior occurs 0% of the time
1	Seldom : The child exhibits the behavior but only one or two examples are cited. And/or the behavior occurs 25% of the time
2	Sometimes : Three or four examples are cited. And/or the behavior occurs 50% of the time
3	Often : Five or six examples of the behavior are given and/or the behavior occurs 75% of the time
4	Always : Numerous examples (more than six) are given and/or the behavior occurs more than 75% of the time. The parent can't think of an example when the behavior hasn't occurred

Score in percentage was calculated for performance in quiet (Quiet subscale), in noise (Noise subscale) and in total.

For each of the question assessed, the parents were also requested to compare and to rate the performance of the two hearing aid prescriptions fitted to their children. This was carried out at the end of trial 2. Parents were interviewed to find out if one hearing aid prescription was much worse, worse, same, better or much better than the other hearing aid prescription. Examples were required to be given by parents to support their rating and the following five-point scale was used for scoring.

Scoring	
-2	Much worse : The parent says that the child's performance is much worse (for the question concerned) using the current amplification compared with the previous amplification and can cite two or more examples to demonstrate this
-1	Worse : The parent says that the child's performance is worse (for question concerned) using the current amplification compared with the previous amplification and can cite one example to demonstrate this
0	Same : The parent says that there is no difference in the child's performance using the current amplification compared with the previous amplification (for the question concerned)
1	Better : The parent says that the child's performance is better (for the question concerned) using the current amplification compared with the previous amplification and can cite one example to demonstrate this
2	Much better : The parent says that the child's performance is much better (for the question concerned) using the current amplification compared with the previous amplification and can cite two or more examples to demonstrate this

(ii) *TEACH (Teachers' Evaluation of Aural/Oral performance of Children)*

TEACH (Appendix 10) is designed to record teachers' observations of children's functional performance in a systematic way. The questions in TEACH are very similar to those found in the PEACH. Like the PEACH, some questions consist of two alternatives where the teachers need to choose the one that best describes the child's aural/oral behavior. There are 11 questions in TEACH which address the following topics :

- i) Use of amplification and loudness discomfort
- ii) Listening and communicating in quiet
- iii) Listening and communicating in noise
- iv) Responsiveness to sounds in the environment

The administration and scoring of TEACH is the same as in PEACH.

(iii) *SELF (Self Evaluation of Listening Function)*

The SELF questionnaire (Appendix 11) was designed by the National Acoustic Laboratories to obtain feedback from children about their functional hearing. There are 12 questions in the SELF questionnaire which assessed the ability of children to listen in quiet, in noise, listen via telephone and response to environmental sounds. Similar questions and scoring technique to those used for the PEACH and TEACH scales are used in the SELF, so that comparison can be made to see if reports from children correlate with those from their parents and teachers. For each question in the SELF, a

five-point scale (0-never, 1-seldom, 2-sometimes, 3-often, 4-always) is provided to assist the children in answering the question. For the purpose of this study, the investigator went through each question in the SELF questionnaire with the children at the beginning, to make sure they understand the content and also to familiarize them with the questionnaire.

(iv) Children's diary

On the third and fourth trial when the children had access to both prescriptions via the hearing aid remote control, they were required to complete a short diary (Appendix 12) which compared the performance of the two prescriptions at different listening situations. The investigator went through the diary with the children at the beginning to make sure they understand the content and also know how to use the diary. The diary included questions that asked if the children found the prescriptions to be different, which prescription they preferred more and by how much. In addition, six items relating to different listening conditions were also included in the diary. For each item, the children were asked to compare and to rate the performance of one program over the other one as either much better (2), slightly better (1), same (0), slightly worse (-1) or much worse (-2). All children were requested to try both of the prescriptions in different listening environments so that they could compare their performance.

8.3.5 Hearing aid usage and loudness discomfort

The PEACH, TEACH and SELF questionnaires also examined hearing aid usage and loudness discomfort. These items were analyzed separately and thus were not included in the functional hearing assessment presented above. The item on hearing aid usage was scored based on a five-point scale (0-Never, 1-Seldom, 2-Sometimes, 3-Often, 4-Always) and the scale was reversed for loudness discomfort.

8.4 Results

8.4.1 Consonant discrimination test

Results were obtained from 15 children. One child who had difficulty performing the test was not included in the experiment. This child, aged nine, had severe to profound

hearing loss and attended the school for the deaf. Figure 8.2 shows the total numbers for each phoneme correctly identified by all children, for both the NAL-NL1 and DSL v5 prescriptions. The results were obtained by adding the number of phonemes correctly identified in each test session and from each child. The graph shows that the abilities of children to discriminate each phoneme were very similar for both the NAL-NL1 and DSL v5 prescriptions. The mean consonant scores in percentage, the standard deviations (SD) as well as the range of scores for both prescriptions obtained at the end of each four trials, are presented in Table 8.2. As shown, the differences in mean scores between prescriptions were small. The scores were highly variable across the children (11.1 to 100 percent). Using the General Linear Model repeated measures analysis, with prescription and trial as the independent variables, the results indicated that the main effect of prescription was not significant ($p = 0.18$). However, the main effect of trial was significant ($F(3, 36) = 5.159$, $p = 0.03$) suggesting the mean scores were significantly better over time for each prescription.

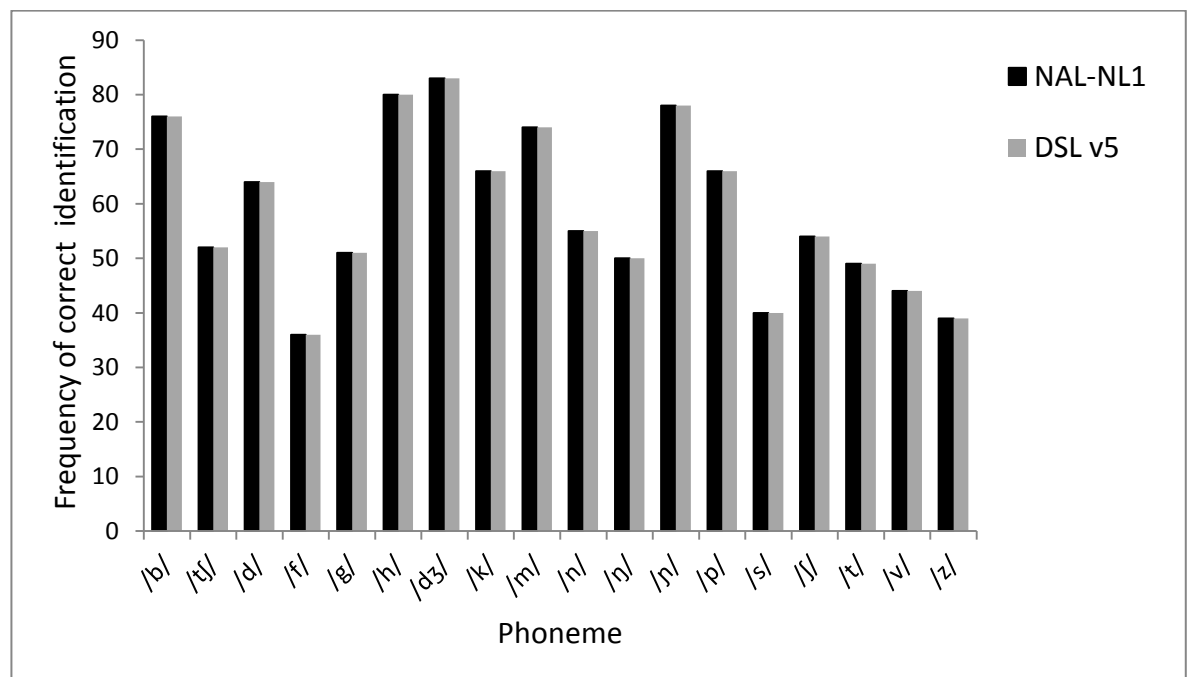


Figure 8.2 : The total number of phonemes being correctly identified for the NAL-NL1 and DSL v5 prescriptions. The total numbers (frequency) were obtained by adding up the scores from all children and test sessions.

Table 8.2 : Mean consonant scores, standard deviation (SD) and range of consonant score by prescription and trial

		Trial 1	Trial 2	Trial 3	Trial 4
NAL-NL1	Mean	50.2	49.3	52.4	51.8
	SD	26.5	28.9	29.1	28.2
	Range	16.7 – 94.4	19.4 - 100	13.9 - 100	13.9 – 97.2
DSL v5	Mean	49.4	51	52.8	58.5
	SD	29.6	29.5	28.9	28.6
	Range	11.1 - 100	2.8 – 97.2	16.7 – 97.2	11.1 - 100

8.4.2 *Speech recognition tests*

The sentence reception threshold (SRT) of the Malay HINT was measured from seven children. The other nine children were not able to complete this task due to high linguistic demands. For these children, all had severe to profound hearing loss. One child attended the inclusive program, two children were in the normal school and the other six children were in the deaf unit.

For each trial session, the mean SRT was calculated for both prescriptions. The results are displayed in Figure 8.3(a), for SRT measured in quiet and Figure 8.3(b), for SRT measured in noise. In quiet, the mean SRTs for DSL v5 prescription were slightly lower/better than the NAL-NL1 prescription for all test trials. When averaged across trials, the mean SRT difference between prescriptions was 3.5 dB. The General Linear Model repeated measure analysis revealed a significant main effect of prescription ($F(1,6) = 17.130, p < 0.01$) and trial ($F(3, 18) = 6.765, p = 0.01$). No significant interaction between prescription and trial was found ($p = 0.44$). In noise, the mean SRT averaged across trials for the DSL v5 prescription was slightly lower/better (1.2 dB SNR) than the NAL-NL1 prescription. However, there was no significant difference between the NAL-NL1 and DSL v5 prescription for SRT in noise ($p = 0.81$). In noise, a significant main effect of trial was found ($F(3, 18) = 6.285, p < 0.01$).

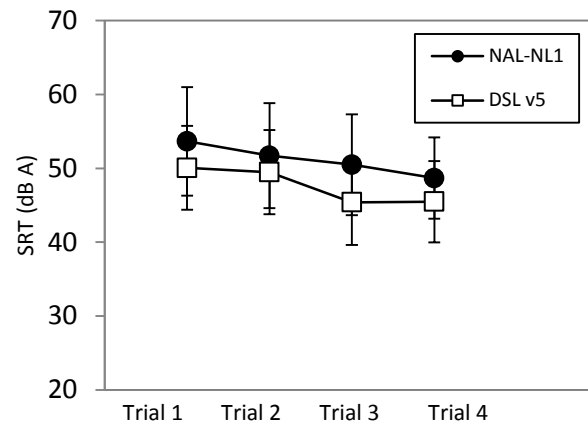


Figure 8.3(a) : Mean sentence reception threshold (SRT) in quiet by prescription and trial

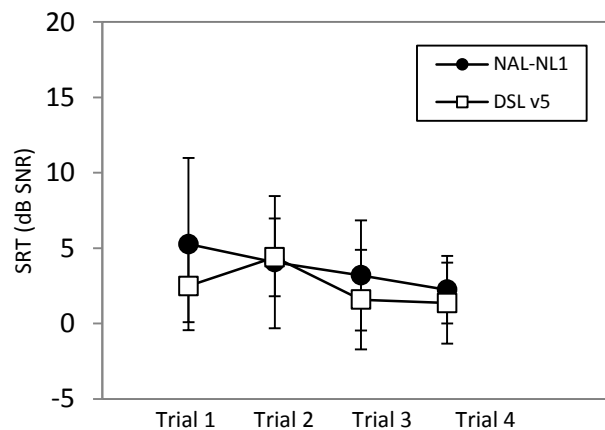


Figure 8.3(b) : Mean sentence reception threshold (SRT) in noise by prescription and trial

The HINT non-adaptive procedure was implemented on four children with hearing losses that ranged from severe to profound because they could not cope with the adaptive procedure. A fixed level and SNR was presented to these children and the sentences were scored by the number of words correctly identified. Each prescription was tested four times on each of the children. At a SNR equal to +5 dB, only two children could perform the task and therefore it was felt that the results from this group should not be included in the results section of the study. Five other children with profound hearing loss were tested with the closed-set word test at medium level, soft level and at SNR = 0 dB. The mean scores (in percentage) for the HINT and word test are shown in Table 8.3. On average, the scores for DSL v5 were higher than the scores for NAL-NL1 for all the test conditions. In general, the differences of mean scores

between prescriptions for speech test conducted in noise were found larger as compared to the mean score differences for tests conducted in quiet. For the HINT, the mean score difference between prescriptions was 9.6 percent for quiet and 12 percent for noise. For the word test in quiet, the mean score difference between prescriptions was only 1.9 percent for words presented at medium level and increased to 8.6 percent for words presented at soft level. In noise, the mean score for the word test showed even larger discrepancy between the prescriptions (16.5 percent). Statistical analysis however, revealed no significant differences between prescriptions for all speech tests conducted either using the HINT or close-set word material in quiet and in noise.

Table 8.3 : Mean scores (%) and standard deviation (SD) for HINT and word test presented at different intensity levels and SNRs

		HINT (65 dB A)	HINT (SNR = +10 dB)	Word test (65 dB A)	Word test (50 dB A)	Word test (SNR = 0 dB)
NAL-NL1	Mean	50.1	34.0	79.6	64.0	60.7
	SD	22.0	25.0	18.6	33.5	32.8
DSL v5	Mean	59.7	46.0	81.5	72.6	77.2
	SD	16.1	20.4	15.7	22.3	18.6

Individual scores are displayed in Figure 8.4(a), for HINT presented in quiet and Figure 8.4(b), for HINT presented at SNR equal to +10 dB. For HINT presented in quiet, 11 scores were higher with the DSL v5 prescription while five scores were higher with the NAL-NL1 prescription. A similar pattern of results was observed for HINT presented in noise where 11 scores were higher with the DSL v5 prescription and five scores were higher with the NAL-NL1 prescription. Note that child 1 and child 4 who performed better in quiet with the DSL v5 prescription also had higher scores in noise with the same prescription.

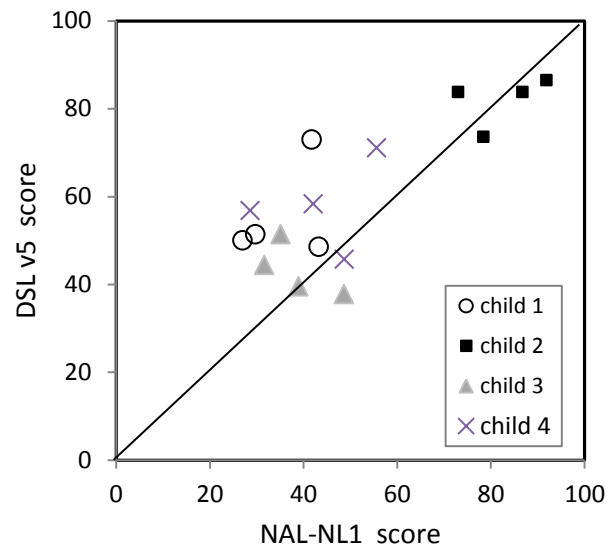


Figure 8.4(a) : Individual scores (in percent) for different prescriptions measured with HINT presented at 65 dB A in quiet

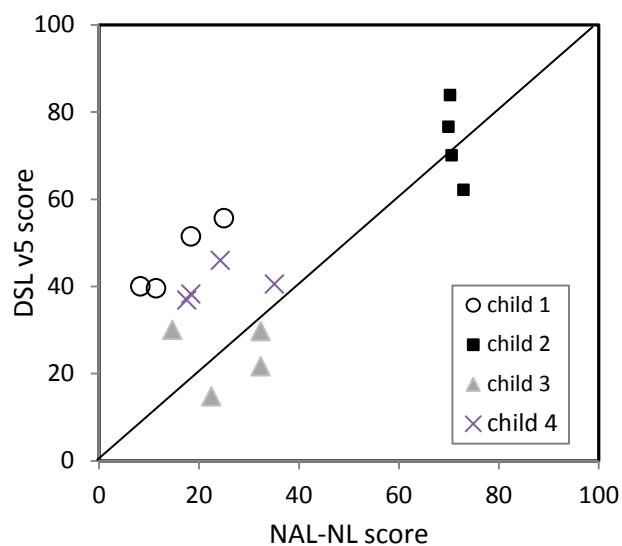


Figure 8.4(b) : Individual scores (in percent) for different prescriptions measured with HINT presented at SNR +10 dB

For the word test, individual scores are illustrated in Figure 8.5(a), (b) and (c) for medium, soft level and at SNR = 0 dB respectively. Two children did not participate in all the assessments. Child 1 for instance, was tested twice instead of four times for each prescription. Similar scores between prescriptions were observed from most of the children for words presented at medium level. For speech presented at a soft level and in noise however, differences in prescription scores were more obvious for three children while the remaining children had scores approaching the ‘ceiling’ effect for

both prescriptions. For soft words, two out of the three children performed better with the DSL v5 prescription and one child performed better with the NAL-NL1 prescription most of the time. For words in noise, two out of the three children performed better with the DSL v5 prescription. One child (child 3) did better for soft words using the NAL-NL1 prescription but consistently did poorer for words in noise using the NAL-NL1 prescription. This child had profound hearing loss where the NAL-NL1 prescribed higher gain for soft input level than the DSL v5 procedure. The poor performance in noise with the NAL-NL1 prescription was consistent with the parents report. The child however, reported he liked the variation of loudness and ability to hear ‘distanced sounds’ with the NAL-NL1 prescription and hence preferred the NAL-NL1 more than the DSL v5 prescription.

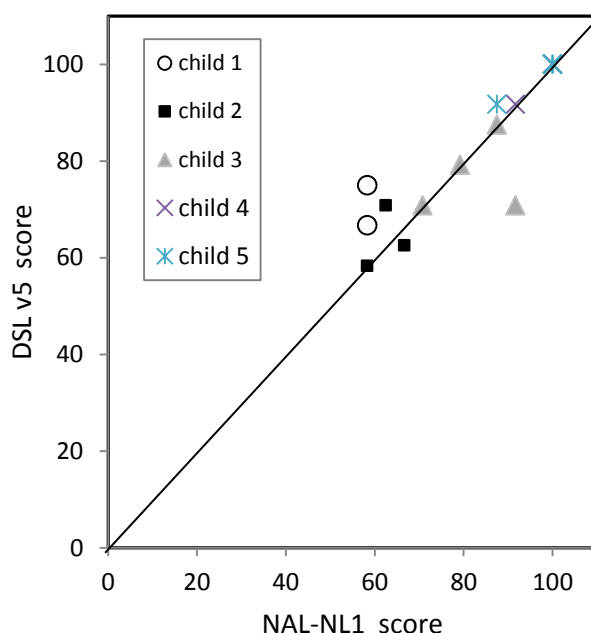


Figure 8.5(a) : Individual scores (in percent) for different prescriptions measured with the word test presented at 65 dBA in quiet

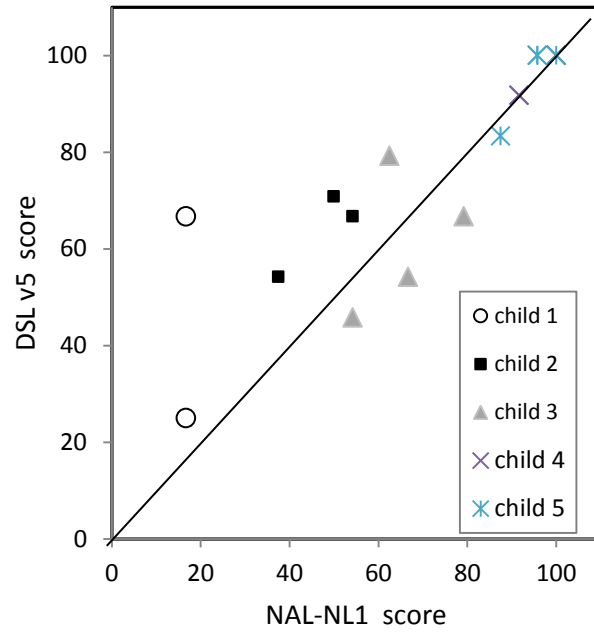


Figure 8.5(b) : Individual scores (in percent) for different prescriptions measured with the word test presented at 50 dBA in quiet

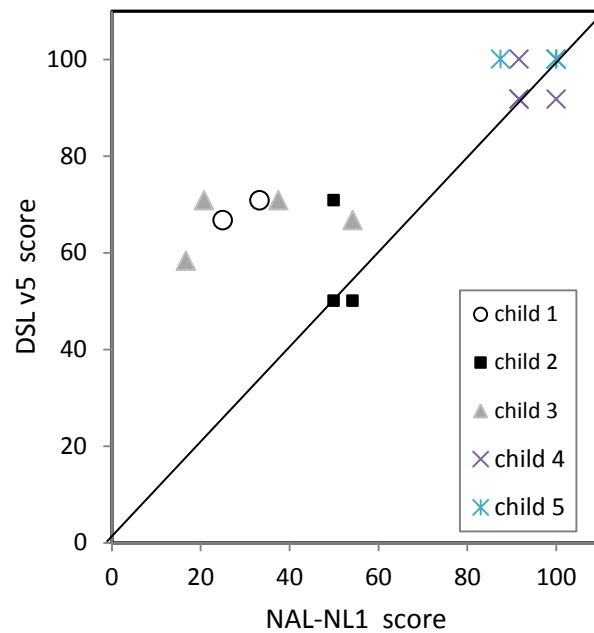


Figure 8.5(c) : Individual scores (in percent) for different prescriptions measured with the word test presented at SNR = 0 dB

8.4.3 Paired-comparison test

Paired-comparison judgments of intelligibility were completed by 15 children at the end of each trial. For each trial, children were required to perform the paired-comparison task 10 times making a total of 40 comparisons for each child. The binomial distribution was used to determine the criterion for defining the preference of one prescription over the other as significant and not due to chance. Based on the calculations, if one prescription is chosen 26 times or more, the probability of it happening by chance is 4%. Hence, results where children chose one prescription 26 times or more over the other prescription were considered significant. Based on this criterion, it was found that nine children (60%) had a significant preference and that of these, seven children preferred the DSL v5 prescription and two children preferred the NAL-NL1 prescription. The proportions of children who had significant preferences was similar to the results in the NAL/UWO study on Canadian children (66 %) (Ching et al, 2010d).

8.4.4 Functional hearing evaluation

(i) PEACH, TEACH and SELF

The functional performance of children was assessed using the PEACH, TEACH and SELF questionnaires completed by parents, teachers and the children themselves. Respondents filled in the questionnaires twice; once for the assigned prescription in trial 1 and for another prescription in trial 2. The questionnaires were completed by 14 parents for PEACH, 15 teachers for TEACH and all 16 children for SELF. For each questionnaire, the mean total scores as well as the Quiet and Noise subscale scores were calculated (Ching & Hill, 2007). In calculating the scores, the question regarding telephone usage was not included since many of the children reported not using or rarely using the telephone. The results are displayed in Figure 8.6(a) for PEACH, Figure 8.6(b) for TEACH and Figure 8.6(c) for SELF. On average, the DSL v5 had higher scores than NAL-NL1 for all the subscales and questionnaires evaluated. The differences of mean scores between prescriptions were small for PEACH (2.1 percent for total score) and TEACH (3.1 percent for total score) but relatively bigger for SELF (6.9 percent for total score). The Quiet subscale scores were consistently higher than the Noise subscale scores suggesting the functional performance of children was better in quiet than in noise. The General Linear Model repeated measures analysis was used to analyze the data with scale as dependent variable and prescription and listening

condition as independent variables. The results showed a significant main effect of prescription for PEACH ($F(1, 13) = 6.869, p = 0.02$), TEACH ($F(1, 14) = 5.533, p = 0.03$) and also SELF ($F(1, 15) = 10.339, p < 0.01$). The main effect of listening conditions was also significant for PEACH ($F(1, 13) = 24.698, p < 0.01$), TEACH ($F(1, 14) = 20.423, p < 0.01$) and SELF ($F(1, 15) = 6.062, p = 0.03$). No significant interactions between prescriptions and listening conditions were found in all the scales ($p > 0.05$). Spearman's rank-order correlation was conducted to analyze the relationships among the scales. Results showed that the PEACH scores were significantly correlated with the TEACH scores ($r(13) = 0.616, p = 0.03$) but no significant correlations were found between the SELF scores with either PEACH ($p = 0.08$) nor TEACH scores ($p = 0.16$).

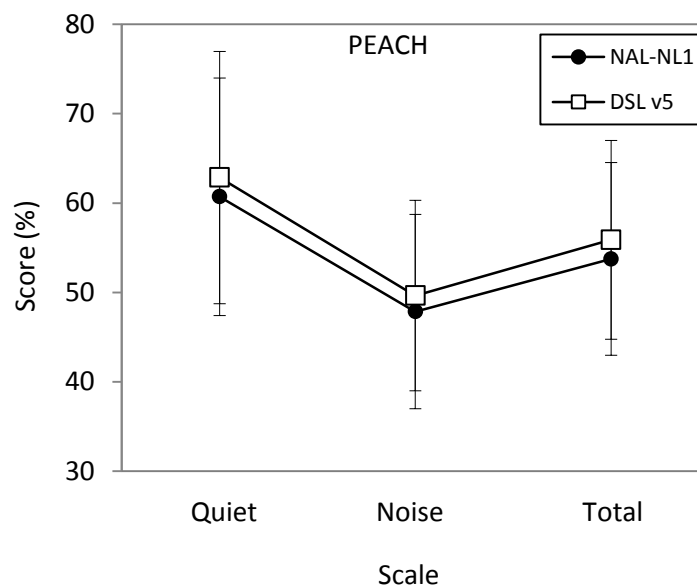


Figure 8.6(a) : Mean PEACH scores by prescription, for the quiet, noise and total subscales

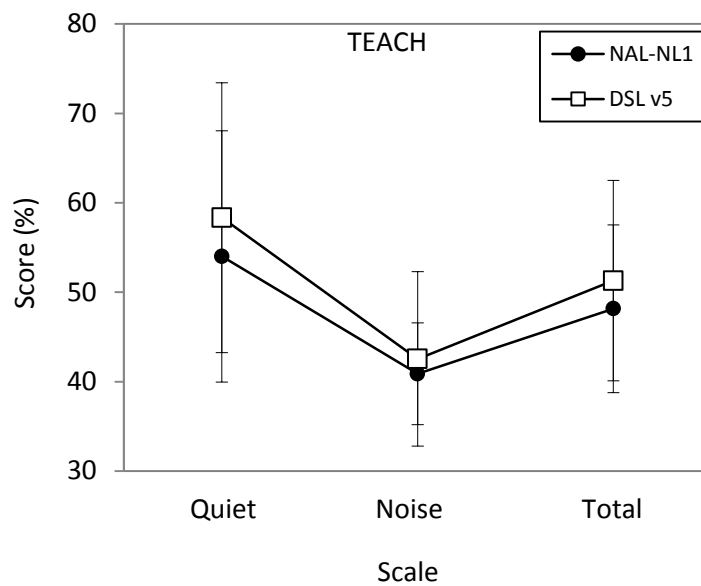


Figure 8.6(b) : Mean TEACH scores by prescription, for the quiet, noise and total subscales

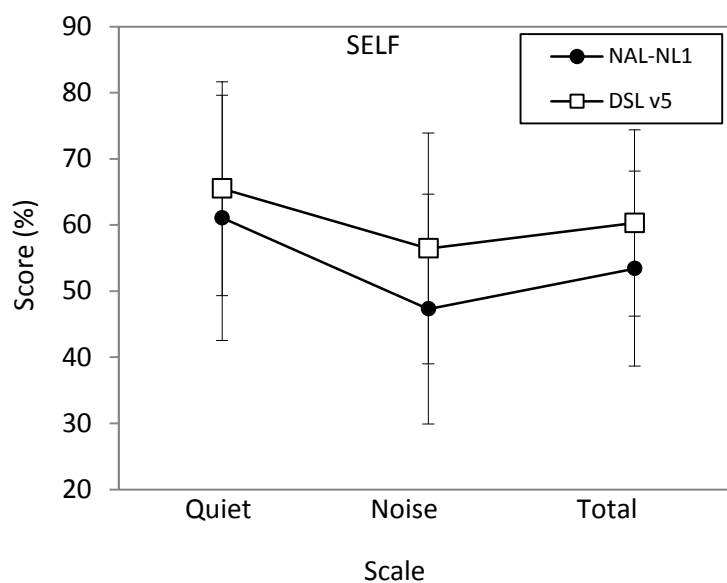


Figure 8.6(c) : Mean SELF scores by prescription, for the quiet, noise and total subscales

During the interview sessions, parents and teachers were also asked to compare performance of the two prescriptions for each question in the questionnaires. For every question, respondents rated the performance of prescriptions as either the same, slightly better, much better, slightly worse or much worse. The mean rating for each question

are illustrated in Figure 8.7. On average, DSL v5 were perceived by parents and teachers as either the same or slightly better than NAL-NL1 for all questions with the largest difference (0.5 of a rating category) being observed for the question on ‘respond to name in quiet’. Spearman’s rank-order showed the ratings provided by parents and teachers to compare prescriptions were significantly correlated with each other ($r(13) = 0.675, p = 0.01$).

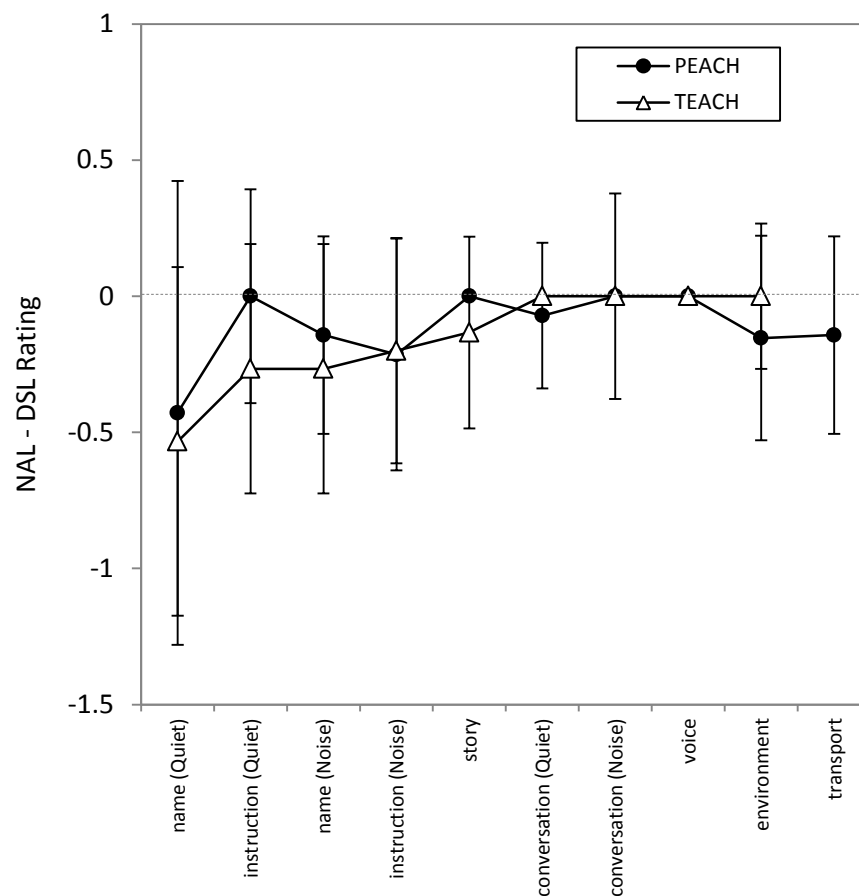


Figure 8.7 : Mean ratings provided by parents (PEACH) and teachers (TEACH) for different listening situations. Positive values indicate a preference for the NAL-NL1 prescription and negative values indicate a preference for the DSL v5 prescription

(ii) Children’s ratings and preference

On the third and fourth trials, children had access to both prescriptions/programs via a tactronics push-button. Default program set on the hearing aids were counterbalanced for both trials. A short diary was given to each child per trial and the objective was to

find out the preferred program and also the program ratings provided by the child on different listening conditions. Fifteen children completed trials 3 and 4 and were subjected to data analysis. One child (the youngest in the group) was assisted by his mother with the task of changing program everyday and also in completing the diary. Table 8.4 shows the number of children who preferred the NAL-NL1 and DSL v5 program in trial 3 and 4. At the end of trial 3, eight children preferred DSL v5, four preferred NAL-NL1 and three had no overall preference. All the three children who had no overall preference, stated they preferred DSL v5 for quiet situations and NAL-NL1 for noisy situations. In trial 4, one of the three children who expressed no overall preference, indicated a preference for the DSL v5 prescription. The other children expressed the same preferences as before and two children had no overall preference at the end of both trials 3 and 4. For subsequent discussion, the preference reported in trial 4 will be taken as the children's final preference.

Table 8.4 : The number of children who preferred the NAL-NL1 and DSL v5 prescription

	Preference		
	NAL-NL1 preference	DSL v5	No
Trial 3	4	8	3
Trial 4	4	9	2

The child's diary also included six items which were related to different listening conditions. For each item, the children were asked to compare and to rate the performance of one program over the other one as either much better (2), slightly better (1), same (0), slightly worse (-1) or much worse (-2). Spearman's rho revealed a significant correlation between the ratings in trial 3 and trial 4 suggesting consistency of responses given by the children ($r(15) = 0.678$, $p = 0.01$). Thus, the ratings were averaged across trials and the results are presented in Figure 8.8. The positive values in Figure 8.8 denote a preference for NAL-NL1 and negative values indicate a preference for DSL v5. The DSL v5 on average was rated as slightly better than NAL-NL1 for all the items except for the item "talking in the shopping mall" and "talking in the restaurant" in which the NAL-NL1 was rated as slightly better. The children's ratings were found to be marginally correlated with the parents' ratings ($p = 0.07$) but were not significantly correlated with the teachers' ratings ($p = 0.523$). Spearman's rho analysis

indicated that the children's ratings were significantly correlated with their final preference for prescription ($r(13) = -0.804, p < 0.01$). The relationship between results from the laboratory test (paired-comparison judgments of speech intelligibility tests) and the children's preferred prescription was also investigated. The Spearman rho analysis revealed a significant correlation between the paired-comparison test results and the children's final preference of prescription ($r(8) = 1.00, p < 0.01$).

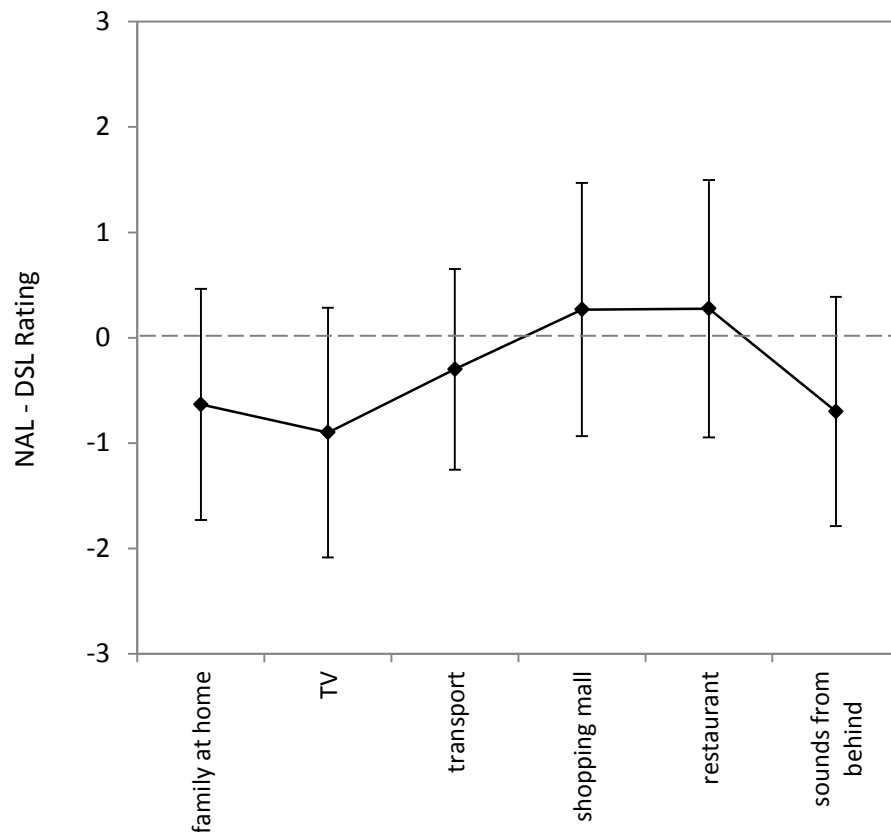


Figure 8.8 : Mean ratings provided by children for different listening situations. Positive values indicate a preference for the NAL-NL1 prescription and negative values indicate a preference for the DSL v5 prescription

(iii) Individual comments

General comments were gathered from 15 parents and teachers at the end of trial 1 and 2 and from 15 children at the end of the final trial period. The purpose was to obtain more or additional information with regard to the performances of both prescriptions. A face-to-face interview session was carried out between the investigator and respondents and all comments given were written down. Most of the parents and teachers provided

comments related to listening situations which had already been addressed by the PEACH and TEACH questionnaires. This was not unexpected since the PEACH and TEACH require respondents to be detailed or specific in providing feedback on functional performance in a wide range of listening situations. The comments were analyzed by grouping the number of respondents who provided the same feedback as presented in Table 8.5. Eight parents (53%) and six teachers (40%) reported that the children felt the DSL v5 was noisy. According to the parents and teachers, about half of these children complained DSL v5 being noisy/loud especially at the initial stage and were less bothered by the problem at the end of the study. Comments which were more frequently reported include *‘with DSL my child response was quicker and consistent when I call’* (27% of parents and 33% of teachers); *‘with DSL my child need less repetitions’* (33% of parents and 27% of teachers); *‘with NAL I need to raise my voice’* (33% of parents). Other less commonly reported comments were *‘with DSL my child could response even when I called from far’*, *‘with DSL my child responded better when I talked to him inside the car’*, *‘with DSL my child sometimes will search for sounds’*, *‘with NAL my child always turn up the radio and the TV volume’*.

From the children’s feedback, nine (60%) reported the NAL-NL1 prescription was too soft. Two out of these children reported they got used to the soft sounds at the end of the study. Table 8.6 shows the comments made by each child and their preferred prescriptions.

8.4.5 Hearing aid usage and loudness discomfort

Hearing aid usage and loudness discomfort were analyzed from the PEACH, TEACH and SELF scales completed during trials 1 and 2. On average, the children used their hearing aids often, as reported by the parents, teachers and the children themselves. The General Linear Model analysis showed no significant main effect of scale ($p = 0.08$), prescription ($p = 0.08$) and interaction ($p = 0.24$) between the two variables. The mean loudness discomfort scores for DSL v5 were significantly lower than NAL-NL1 ($F(1,12) = 10.108$, $p = 0.01$) for all the scales suggesting children experienced loudness discomfort more frequently with DSL v5. Overall, the children reported that they experienced loudness discomfort more frequently than was observed and reported by their parents and teachers for both the NAL-NL1 and DSL v5 prescriptions.

Table 8.5 : Individual comments from parents, teachers and children with regard to the performance of hearing aid fitted according to the NAL-NL1 and DSL v5 procedures. The number indicates total of respondents who provided the same comments

Respondent	Number	Comments
Parents	5	My child complained DSL is noisy at the beginning
	3	My child complained DSL is loud/noisy (throughout)
	2	With DSL, my child responded even when I called from far (e.g kitchen, upstairs, behind closed door)
	4	With DSL, my child's response was quicker and more consistent when I call
	1	With NAL, my child responded even I called from far (NAL-NL1 prescribed higher low-frequency gain than DSL v5 for soft input)
	2	With DSL, my child need lesser repetitions in quiet
	3	With DSL, my child need lesser repetitions in noise
	1	With DSL, my child could overhear conversation
	2	With DSL, my child followed instructions better inside the car
	1	With DSL, my child need lesser repetitions when used telephone
	2	With DSL, my child sometimes search for sounds
	5	With NAL, I need to raise my voice
	2	With NAL, my child need to turn up the TV and radio volume
Teachers	4	Child complained DSL is noisy at the beginning
	2	Child complained DSL is noisy (throughout)
	5	With DSL, child's response was quicker when I called
	1	With DSL, child could response when I called from far (e.g. corridor)
	3	With DSL, child need lesser repetitions in quiet
	3	With DSL, child need lesser repetitions in noise
	2	With DSL, child looked more focus / response more appropriate in class
	1	With DSL, child was more involved in conversation
	1	With DSL, child was less involved in conversation
	2	With DSL, child was more alert of sounds
Child	7	NAL is too soft (throughout)
	2	NAL is too soft at the beginning but I am use to it now
	1	With NAL, I could tell sounds if they are soft or loud, I could hear sounds from far (e.g. baby cried from next house)
	1	I feel NAL is clearer (child with mixed hearing loss)
	1	With NAL, I could understand speech better in noisy places
	2	NAL is more comfortable. DSL is noisy

Table 8.6 : Comments from each child with regard to the performance of hearing aid fitted according to the NAL-NL1 and DSL v5 prescription

Child	Comments	Preference
1	NAL is soft. With DSL, I could hear neighbour walking up their stairs and when their baby cried	DSL
2	NAL is soft	DSL
3*	With NAL, sometimes people's voices are very soft (for both quiet and noisy places). Prefers DSL in quiet but NAL in noisy situations	No preference
4	NAL is sometimes very soft but comfortable when its' very noisy	DSL
5	NAL was soft at the beginning but later OK.	DSL
6	Can understand speech better with NAL in noisy places. Prefer DSL in quiet and NAL in noise	No preference
7	NAL is soft. DSL is very noisy sometimes (at the beginning)	DSL
8	DSL is too loud and noisy	NAL
9	NAL is very soft initially but later ok	DSL
10#	Like NAL because can tell the loudness difference, can hear the surrounding sounds better (e.g. baby cried next door, people called from upstairs, people talk outside)	NAL
11@	NAL is clearer	NAL
12*	Prefer NAL because more comfortable. DSL is noisy sometimes	NAL
13	NAL is soft	DSL
14	Did not comment	DSL
15	DSL was noisy at the beginning but now I like it because it's louder	DSL

* (new hearing aid user)

(Profound loss. NAL prescribed higher low-frequency gain for soft input level)

@ (mixed hearing loss)

8.4.6 Data logging

In trials 1 and 2, the data logging feature was used to investigate the duration of hearing aid usage for each prescription. The duration of hearing aid usage was presented in the data logging system as the average hours of use per day. On average, the children used the hearing aids for 9 hours per day for both prescriptions. Paired t-test revealed no significant difference between the amount of hours used for NAL-NL1 and DSL v5 prescription ($p = 0.45$). Spearman's rho showed that the logged hours were significantly correlated with the hearing aid use reported in PEACH, TEACH and SELF but for DSL v5, logged hours were found not significantly correlated with TEACH.

In trials 3 and 4, the data logging feature was used to examine the frequency (in percentage) of each prescription being used when child could switch between programs. Table 8.7 shows the results when averaged across ears. On average, children used the default program more often than the alternative program and they used the DSL v5 program slightly more often than the NAL-NL1 program (mean total difference = 14.2 percent). General Linear Model repeated measures analysis was used to analyze the data with data logging information as dependent variable and prescription, ear and default program as independent variables. The analysis showed no significant main effect of prescription ($p = 0.17$), ears ($p = 0.34$) or default program ($p = 0.59$). However, there was a significant interaction between the prescription and the default program ($F(1,12) = 16.869$, $p < 0.01$). The mean values showed that when the DSL v5 prescription was set as the default program, the children tend to use the DSL v5 program more often. The same thing occurred when the NAL-NL1 prescription was set as the default program, where the children tended to use the NAL-NL1 program more often but to a lesser degree compared to the frequency of using the DSLv5 program, when it was set as the default program (Figure 8.9). The frequency of using a prescription was found to be significantly correlated with the children's overall preferred prescription ($r(12) = 0.102$, $p < 0.01$) suggesting that on average, the children used their preferred prescription more often than the alternative prescription.

Table 8.7 : Data logging showing the frequency of NAL-NL1 and DSL v5 prescription being used (in mean percentage) when either the NAL-NL1 or the DSL v5 was set as the default program

Default program	NAL	SD	DSL	SD
NAL	62 %	37.4	38 %	37.4
DSL	23.7 %	29	76.1 %	29
Total	42.8	38.3	57	38.3

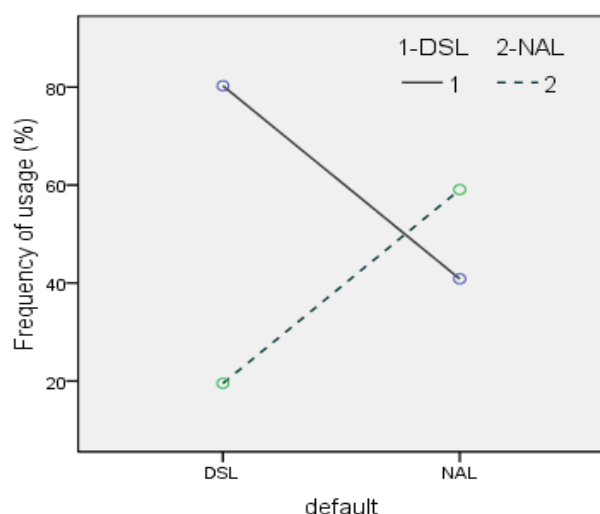


Figure 8.9 : Frequency of using hearing aid (in mean percentage) by prescription and default program as recorded from data logging

8.4.7 Factors influencing child's preference

Children's HTLs and previous hearing aid experience were investigated to determine if they correlated with the children's preference for prescription. The Spearman test revealed no significant correlation between the children's choice of prescription and their 4FA HTL (500, 1000, 2000 and 4000 Hz). Previous hearing aid experience was analyzed based on the 4FA 2-cc coupler gains measured from the child's own hearing aid and was then compared to the values with the prescribed couple gains preferred by the child. The 4FA coupler gains were averaged across ears at medium input level. Two new hearing aid users together with four children who did not have their own hearing aids at the time of the study were excluded from the analysis. Results from the remaining 10 children are shown in Table 8.8. The results suggest no clear pattern of relationship between the children's preferred experimental gains and their own hearing

aid gains. Three children preferred prescriptions that had gains closer to their own hearing aid gains while six children's preferred gains were not consistent with their own hearing aid gains. Figure 8.10 further illustrates the relationship between the prescribed coupler gain, the coupler gain measured from child's own aid and the preferred prescription. To demonstrate this, 4FA coupler gains measured from 18 hearing aids belonged to the children, were subtracted from the 4FA coupler gains prescribed by the NAL-NL1 and DSL v5 procedures respectively. The x-axis in Figure 8.10 denotes the difference of own hearing aid gain and the prescribed gain by the NAL-NL1 procedure while the y-axis shows the same thing but for the DSL v5 procedure. The filled diamonds represents the 'ears' that preferred the DSL v5 prescription and the cross symbol represents the 'ear' that preferred the NAL-NL1 prescription. The figure shows that gains measured from the children's own hearing aids were mostly below the optimal gain required by both the NAL-NL1 and DSL v5 procedures (ranged from 1 dB to 20 dB). This is shown by the positive values (prescribed gains were higher than own hearing aid gains). There are also few individual data points (5 out of 18 ears) that show

Table 8.8 : Four frequency average (4FA) coupler gain measured from child's own hearing aid as compared to 4FA coupler gains prescribed by the NAL-NL1 and DSL v5 procedures for medium input level. The children's preferences for prescription are also shown. The symbol * represents children who preferred a prescription that prescribed gains closer to their own hearing aid gains

Child	NAL prescribed coupler gain	DSL prescribed coupler gain	Coupler gain of child's aid	NAL – own hearing aid gain	DSL – own hearing aid gain	Preferred prescription
1	23.2	32.5	21.5	1.7	10.9	DSL
2	24	34.3	19.3	4.8	15.1	DSL
3	26	33.1	46.4	-20.3	-13.3	DSL *
4	39.7	47.1	34.3	5.4	12.8	DSL
5	46.7	52	43.5	3.2	8.4	DSL
6	43.5	52.2	58.2	-14.8	-6	DSL *
7	59.1	58	39.8	19.3	18.2	NAL
8	43	49.1	53.8	-10.8	-4.6	DSL *
9	44.2	48.1	44.3	0.95	3.8	DSL
10	49	48.7	37.5	11.4	11.2	DSL

4FA – average hearing threshold of 500, 1000, 2000 and 4000 Hz

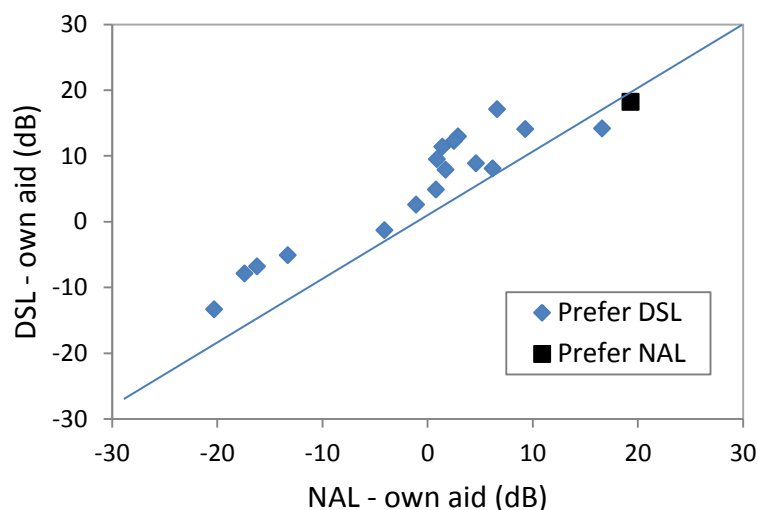


Figure 8.10 : Difference between prescribed 4FA coupler gain and coupler gain measured from the child's own hearing aid. X-axis shows difference between NAL-NL1 and own hearing aid gain. Y-axis shows difference between DSL v5 and own hearing aid gain (N = 18 ears). 4FA refers to four frequency average of 500, 1000, 2000 and 4000 Hz

the children's hearing aid gain was higher than the gain prescribed by both procedures (up to -20 dB difference). These children, who seemed already accustomed to loud amplification from their own hearing aid use, preferred the louder prescription (i.e the DSL v5 prescription). The figure also suggests for some of the data (10 ears), the differences between child's own hearing gain and the prescribed gain were higher for the DSL v5 prescription (i.e they deviated more from the DSL v5 prescription). Despite this, all children in this category preferred the DSL v5 prescription.

8.5 Discussion

8.5.1 Speech recognition test

The mean consonant recognition scores obtained from this study were found to be lower and had high variability as compared to the values reported in the NAL/UWO study (Scollie et al, 2010c). This is possibly due to the greater severity of hearing loss in the current cohort and hence the poorer auditory discrimination skills in the present study compared to the previous study. The consonant discrimination test presented in quiet

and at medium sound levels revealed no significant difference between prescriptions. This finding is consistent with the NAL/UWO study which implemented the test not only at medium level but also at soft and loud levels.

The sentence test for this study was assessed using the Malay HINT. Two methods were used to implement the test; the first method used the adaptive procedure to measure the SRT and the second method used the non-adaptive procedure on children who could not cope with the adaptive method. For this non-adaptive method, the test signal in quiet and the SNR were fixed and the test was scored by the number of words correctly identified in each sentence. Based on the overall mean scores, the DSL v5 prescription was found to have better speech scores than the NAL-NL1 prescription across the two methods of assessment and for all the tested conditions (in quiet and in noise). However, statistical tests revealed a significant difference in performance between prescriptions only for the HINT (adaptive method) conducted in quiet. For this, the mean results indicated that the SRT for the DSL v5 prescription was 3.5 dB lower than the NAL-NL1 prescription. This suggests the children in the study performed better with the DSL v5 prescription for sentences presented at soft levels and in quiet. This seems to correlate with some of the individual reports from the NAL/UWO study as well as from the present study where the use of the DSL prescription was associated with better understanding of soft speech. The DSL v5 on average, provided higher 4FA gain (5.9 dB) than the NAL-NL1 for soft input levels (see Chapter 7). For this reason, it was possible that with the DSL v5 prescription, the children required a lower intensity level than required by the NAL-NL1 prescription to achieve similar speech results. Consistent with the NAL/UWO study, no significant differences were found between the prescriptions for the HINT conducted in noise even though the mean SRTs (in dB SNR) were lower/better for the DSL v5 prescription in all except one test trial.

For word tests presented at medium levels, children using both prescriptions performed equally well with some of the children's scores reaching the 'ceiling effect'. Differences of performance were more obvious for words presented at soft levels and in noise. For both test conditions, more individual data had better scores with the DSL v5 prescription than with the NAL-NL1 prescription.

8.5.2 *High-frequency amplification*

Results presented in Chapter 7 showed that the DSL v5 procedure consistently prescribed more high frequency gain than NAL-NL1 (up to 30 dB at 4000 Hz). It was hypothesized that greater audibility of high frequency sounds will lead to better speech perception since many of the consonants have more high frequency energy (Maroonroge & O. Diefendorf, 1984). Past studies that looked at the contribution of high-frequency audibility or amplification to speech discrimination performance have yielded inconsistent results. Ching et al (1998) examined the contribution of audibility to speech recognition from 40 adults with sensorineural hearing loss ranging from mild to profound degree. Among the findings were that increased audibility does not necessarily increase speech performance and sometimes can even degrade the speech intelligibility in severe to profound hearing losses. For people with an 80 dB HL hearing loss or greater at 4000 Hz, minimal or zero dB sensation level should be provided at this frequency region. The results were consistent with the Hogan and Turner (1998) study. Nine adults with high-frequency hearing loss were tested with nonsense syllables that were low-pass filtered at different cutoff frequencies and the results were compared with performance of participants with normal hearing. The study found as the hearing loss exceeds 55 dB HL especially at 4000 Hz and above, providing additional audibility at this frequency region would not improve speech performance but sometimes could result in decreased speech performance. Another study by Turner and Cummings (1999) also agreed that providing audible speech to high frequency regions where hearing loss exceeds 55 dB HL, does not improve speech performance. In contrast, providing low-frequency audibility even if the thresholds exceeds 55 dB HL, will improve speech recognition.

Contrary to the above findings, some other studies found emphasis of audibility at high frequency regions can be beneficial to speech intelligibility. In a study carried out by Sullivan et al (1992), nonsense syllables test and subjective ratings of speech intelligibility and speech quality were conducted on 17 adults with steeply sloping high-frequency hearing loss. Results showed nonsense syllable recognition improved as the upper cutoff frequency increased, particularly for tests in noise. However, subjects rated the quality of speech intelligibility as poorer for stimulus presented at highest cutoff frequency (6000 Hz). The benefits of providing audible speech in noisy conditions has also been supported by other studies (Turner & Henry, 2002; Hornsby & Ricketts, 2003). In the Turner and Henry study (2002), five normally hearing subjects and 13

subjects with various degree of hearing loss were selected. A nonsense phoneme test was conducted with the presence of multitalker babble as noise. The results showed improved speech recognition with increased audible on speech signal, regardless of the degree of hearing loss. Using multiple low-and high-pass filter cutoff frequencies, Hornsby and Ricketts (2003) compared sentence recognition in noise between subjects with moderate-to-severe sensorineural hearing loss and subjects with normal hearing. The results showed that subjects with hearing loss could benefit from audible high-frequency information to improve speech understanding. Plyler and Fleck (2006) compared sentence recognition from 20 subjects using hearing aids fitted with high-frequency audibility (fitted according to DSL[i/o] procedure) and low-frequency audibility. Results showed improved speech score in noise for the hearing aids with high-frequency amplification. Hornsby and Ricketts (2003) suggested that differences in subjects' characteristics (e.g degree and configuration of hearing loss) and experimental procedure (e.g. quiet versus in noise) between past studies, might be among the reasons why some studies support the benefits of high-frequency audibility while some do not.

The effect of high-frequency audibility on children's speech performance has been investigated by Stelmachowicz et al (2001). Eighty adults and children with normal hearing and hearing impairment (20 subjects per group) participated in the study. The nonsense syllables containing three fricatives, produced by a male, female, and child talker, were low-pass filtered at 2, 3, 4, 5, 6, and 9 kHz. The results showed for all speakers, both groups of children performed more poorly than their adult counterparts at similar bandwidths. For male speaker, maximum performance was reached at a higher bandwidth (5000 Hz) for the children and also the hearing-impaired adults but not for the normal-hearing adults. The study suggested the importance of high-frequency audibility for children to develop speech. The study however, involved children with moderate to moderately severe hearing loss (HTL ranged from 40 to 70 dB HL at 2000 and 4000 Hz) and therefore could not be generalized to children with severe to profound hearing loss.

Conclusions regarding the impact of high-frequency amplification on speech perception could not be made for the present study. The achieved versus prescribed gain for high frequency was investigated in Chapter 7. The DSL v5 procedure prescribed substantially more high-frequency gain than the NAL-NL1 procedure, regardless of the

degree of hearing loss. Overall, the achieved gains were in good agreement with the NAL-NL1 targets for all frequencies and with the DSL v5 targets for frequencies up to 2000 Hz. The DSL v5 targets at 4000 Hz were underachieved for seven children with profound sensorineural hearing losses (average of -21 dB for medium input level). Despite the under achieved target at 4000 Hz for these children, individual data revealed that their hearing aid gains fitted according to the DSL v5 procedure at 4000 Hz were still higher as compared to the NAL-NL1 fitting (on average of 15 dB higher at medium levels). Achieved gain for the remaining nine children under assessment was in good agreement with the DSL v5 targets right up to 4000 Hz (less than 10 dB difference).

Despite the extra amplification provided by the DSL v5 prescription at high frequencies in the present study, the phonemic confusion analysis from the consonant confusion test revealed no difference in terms of the children's abilities to discriminate the consonants. It may be possible that the consonant test presented at conversational level and in quiet, was not sensitive enough to detect any differences of performance between the NAL-NL1 and DSL v5 prescriptions. Past studies have found significant difference in performance for hearing aids with different amplification characteristics, using consonant confusion tests conducted at soft levels (Davies-Venn, 2009) and also in noise, as explained in the earlier paragraph. However, most of these studies involved moderate to severe hearing losses. More than 50 % of the children in the present study had profound loss at 4000 Hz (exceeding 80 dB HL). It is unclear providing whether high-frequency audibility will be beneficial to them.

8.5.3 *Hearing aid acclimatization*

Auditory acclimatization refers to a systematic improvement in auditory performance over time that is not resulted from task, procedural or learning effects. There has been much debate about the phenomena of auditory acclimatization, with some studies supporting the existence of auditory acclimatization (Cox & Alexander, 1992; Cox et al., 1996; Philibert et al., 2002; Philibert et al., 2005; Vestergaard, 2006) while some studies showed no evidence of the phenomenon (Bentler et al., 1993; Saunders & Cienkowski, 1997; Surr et al., 1998; Flynn et al., 2004). In addition, vast majority of these studies were carried out on adults and thus very little is known about auditory acclimatization in children.

The present study found the consonant scores and SRT of HINT measured in quiet and in noise improved significantly from trial 1 to trial 4. When the consonant recognition scores obtained in the first trial were compared with scores obtained in the last trial, there was an improvement of 1.6 and 9.1 percent for the NAL-NL1 and DSL v5 respectively. The SRT of HINT measured in quiet, improved significantly by 5 dB and 4.6 dB for the NAL-NL1 and DSL v5 prescription respectively while SRT measured in noise showed a significant improvement of 3.1 dB and 1.1 dB for the NAL-NL1 and DSL v5 respectively. This suggests that children's speech performance improved over time for both the prescriptions. This finding is consistent with the findings of the NAL/UWO study, and also some other studies which suggested that the improvement of speech recognition abilities is possibly associated with hearing aid acclimatization experienced by the subjects (Horwitz & Turner, 1997; Kuk et al., 2003; Munro & Lutman, 2003; Scollie et al., 2010c).

Kuk et al (2003) examined the evidence of hearing aid acclimatization in 20 adults with severe-to-profound hearing loss. Subjects were fitted with experiment hearing aids and the hearing aid performance was evaluated at the initial fitting, one month and at three months post-fitting. Sentence test conducted in quiet and in noise showed improvement at one month post-fitting. Subjective measures using questionnaires and speech test revealed the performance of the experiment hearing aids were significantly better than the subjects' own hearing aids for the initial and the subsequent evaluations. The study suggested that the improvement of performance was related to the hearing aid acclimatization. Munro and Lutman (2003) investigated the evidence of acclimatization on new hearing aid users with mild to moderately severe hearing loss. All subjects were fitted with hearing aids monaurally while the non-fitted ear was used as the control. Speech test was conducted using the Four-Alternative Auditory Feature (FAAF) test, over a 12-week period. Benefit scores (aided minus unaided) were calculated for the test and control ears to compare the speech recognition abilities over the time period of study. The results showed clear acclimatization at higher presentation level (69 dB SPL) and minimal acclimatization at lower level (55 dB SPL).

In contrast, Saunders and Cienkowski (1997) showed little evidence of acclimatization from a group of 48 subjects with mild to moderate hearing loss (24 experienced hearing aid users and 24 new hearing aid users). Performance of hearing aids was measured using the CID W-1 spondees and the HINT, at the initial fitting, 30, 60 and 90 days post-fitting. No significant improvement of speech performance was seen over the 4

months period of assessment. The author concluded even if acclimatization is present, the effect is small and probably not significant in clinical practice. In another study by Flynn et al (2004), 21 children aged between 6 to 12 years old were selected for the purpose of investigating the benefits of multiple-channel non-linear hearing aid on children with severe hearing loss. Word tests in quiet and in noise were measured at 2 weeks, 8 weeks, 6 months and 12 months following the fitting of the hearing aids. The results showed small and non significant improvement of speech scores over the time which suggested no evidence of acclimatization. It is possible that the speech materials selected were not sensitive enough to detect the presence of acclimatization especially for the words presented in quiet since the speech scores obtained were near to the ceiling effect.

In the NAL/UWO study, subjects' loudness ratings for different prescriptions were reported to have changed over the time and this finding indicated that the subjects acclimatized to whichever prescription new to them. For this reason, the finding of the study reported that the improvement of speech recognition experienced by the subjects was very likely due to hearing aid acclimatization rather than learning effect. The acclimatization effect cannot be inferred from loudness rating evaluations in the present study since such test was not carried out. However, there were children who reported that a prescription which they thought was too loud or too soft at the initial trial, became acceptable (not too loud or soft) on subsequent trials. This might provide some evidence that children in the present study experienced hearing aid acclimatization. According to Moore (2002), the human peripheral auditory function appears to mature by the end of the first few post-natal months. Developmental changes of function in the central auditory system, by contrast, appear to continue for several years. Likewise, auditory perception of children is poorer than adults and continues to improve through early adolescence (Boothroyd, 1997). It is possible that due to the developing auditory system, children and adolescents are more susceptible to auditory adaptation and acclimatization than adults. It should be noted however that two children in the present study were new hearing aid users and four other children had non-functional hearing aids at the time this study began. One child was reported to be not wearing any hearing aids for a period of more than one year. Furthermore, some of the children had their own hearing aids that might not been optimally fitted. Kuk et al (2003) explained when individuals have been sufficiently deprived of the acoustic stimuli and are later given a chance to utilize them, acclimatization is likely to happen.

8.5.4 *Functional hearing evaluation*

The children's real-life hearing performance were assessed using questionnaires (PEACH, TEACH and SELF) and comparison rating scales provided by the parents, teachers and children. Scores from the PEACH, TEACH and SELF scales were calculated as the total scores, scores for the Quiet subscale and scores for the Noise subscale. As expected, the scores for the Noise subscale were significantly lower (13 percent) than the quiet scores across the three scales. There were significant differences between prescriptions. Across all scales, the mean scores for the DSL v5 prescription were significantly higher (2 – 6 percent) than those for the NAL-NL1 prescription. This finding is not consistent with the NAL/UWO study that showed no significant difference between the NAL-NL1 and DSL v4 prescriptions assessed using the PEACH and TEACH scales.

The PEACH was found significantly correlated with the TEACH, suggesting the parents and teachers agreed on the performances of both prescriptions in real life. However, neither the PEACH nor TEACH was found significantly to be correlated with the SELF. This implies that the children's self-report on the performance with the two prescriptions using the scale (SELF) did not agree with the outcome provided by their parents and the teachers. Each scale was administered twice to the respondents at a different time. The disadvantage of this technique is that it relies on memory and the listening conditions, which can vary considerably from time to time during the assessment period (Preminger & Cunningham, 2003). This approach might be more difficult for children who need to recall the benefits of different prescriptions used at different times and possibly in different listening conditions. If that is the case, it is possible that the children's reports in the SELF scale are not reliable for comparing the benefits of the NAL-NL1 and DSL v5 prescriptions. In trials 3 and 4, the children had access to both prescriptions at the same time. The children's ratings were found to be repeatable across the two trials, correlated with the children's preferred program and were marginally correlated with the parents' ratings, but not significantly correlated with the teachers' ratings. This method might be more reliable because it allows the children to evaluate each amplification characteristic at the same time, and for the same listening situations (Preminger & Cunningham, 2003).

Parent versus child self-report of hearing aid outcome has not received much attention in past studies. Kopun and Stelmachowicz (1998) examined the correlation between

parents' perceptions of their child's listening disability and the child's perception, using a modified version of the adult Abbreviated Profile of Hearing Aid Benefit (APHAB) questionnaire. The questionnaire was given to 37 parents and children aged between 10 to 16 years old and with hearing loss ranging from mild to severe degree. The results showed poor correlation ($r = 0.13$ to 0.47) between the child and parental scores for each of the four subscales (i.e. Ease of Communication, Background Noise, Reverberation and Aversiveness). Other studies had compared parent-child assessment of quality of life in children using cochlear implants, with results showing discrepancies between the assessments provided by the parents and children (Chmiel et al., 2000; Huber, 2005; Warner-Czyz et al., 2009). Saunders et al (2005) pointed out that self-reported hearing aid outcome is strongly influenced by individuals' beliefs, as well as other factors such as personality, individual expectations, attitudes and manual dexterity. In our study for instance, one child reported one of the prescription as acceptable but the mother reported that she had to raise her voice each time she talked to the child. The discrepancies of outcome provided by children and parents suggest that it may be useful to combine child and parental report for counseling purposes, as reported by Kopun and Stelmachowicz (1998). The mismatch between parent and child in self-report might also suggest that it is necessary to define the success of hearing aid fitting based not solely on intrinsic factors (e.g speech, emotional and psychosocial achievement from the child himself or herself), but also on the overall ratings and satisfactions as reported by parents, family members and related professionals.

The ratings, when averaged across individuals, showed the parents and teachers rated the DSL v5 as either the same or slightly better than NAL-NL1 for all the items. The item "respond to name in quiet" was rated as most different between the prescriptions while the item "participation in conversation in quiet", "participation in conversation in noise" and "recognize familiar voice" were rated with no difference between prescriptions. The children on average, rated DSL v5 as slightly better for listening to family members, watching TV, understand speech in car/bus and for detecting people calling from behind. Disagreement can be observed between the children and the adults' ratings on items related especially to noisy conditions. While parents and teachers agreed that DSL v5 was slightly better for listening in shopping mall and in restaurant, children tended to rate NAL-NL1 as better than DSL v5 for the same items. This finding is consistent with the NAL/UWO study on Australian children which showed on average the children perceived the NAL-NL1 procedure as better in noisy places such

as restaurant, playground and shopping mall (Scollie et al, 2010e). Nevertheless, the preferences of children for one prescription over the other prescription for listening in noisy environments should be interpreted with care as the preference can be influenced either by listening comfort or clarity of speech, as explained by Scollie et al (2010c). Furthermore, research has shown that preferred frequency response based on speech-quality judgments do not necessarily correlate with speech perception ability (Gabrielsson et al., 1988; Sullivan et al., 1988; Leijon et al., 1991; Sullivan et al., 1992)

8.5.5 *Child's preference and individual comments*

The children's preferences for prescriptions were consistent across trials. Many of the children could identify the prescription they preferred by the end of trial 2. Nine children (60%) preferred the DSL v5 prescription, four children (27%) preferred the NAL-NL1 and two children (13%) preferred neither. The two children who expressed a lack of overall preference stated they preferred DSL v5 in quiet and NAL-NL1 in noise. The children who preferred the NAL-NL1 prescription include one new experienced hearing aid user, one child with severe sensorineural hearing loss, one child with mixed hearing loss and one child with profound hearing loss. The child with severe hearing loss preferred NAL-NL1 because it was not as noisy as the DSL v5 prescription. For the other two children, the child with mixed hearing loss preferred the NAL-NL1 prescription because it was clearer as compared to the DSL v5 prescription while the child with profound hearing loss stated he liked the NAL-NL1 prescription because he could tell sounds were not equally loud and could hear the soft/distanced sounds better. For these two children, the NAL-NL 1 procedure prescribed slightly higher low-frequency gain (250 – 1000Hz) than the DSL v5 procedure for all input levels.

In the NAL/UWO study, the majority of the Canadian children reported an overall preference for DSL v4.1 prescription while overall preferences of Australian children were split between prescriptions (Ching et al, 2010d). The children's preferences in the present study were found to be highly correlated with their paired-comparison judgments of intelligibility assessed in the clinical setting. This finding is consistent with the NAL/UWO study which suggested the paired-comparison test can be a valid method for selecting the appropriate amplification characteristics (Ching et al, 2010d).

Parents and teachers commented that children responded better when called, less repetitions were required for them to follow instructions and demonstrated greater awareness of environmental sounds (searching) with the DSL v5 prescription. Children preferred the NAL-NL1 prescription for better listening comfort in noisy situations.

Half of the children commented that the DSL v5 prescription was noisy or too loud, but about 50% of these children also reported adaptation to the loudness over the time. Loudness discomfort was also assessed using the PEACH, TEACH and SELF. The results indicated that the DSL v5 prescription was more frequently associated with loudness discomfort at a significant level. Despite this, some of the children's preferences for the DSL v5 prescription showed that their preferences were not affected by listening comfort. This agreed with a study conducted by Keidser et al (2007) on adults with similar degree of hearing loss which found their subjects' preferences on the choices of compression parameters fitted to their hearing aids were mostly dominated by speech understanding rather than the annoyance of noise. Nevertheless, hearing aid loudness discomfort should be regarded as an important aspect that can affect hearing aid outcome. Hickson et al (2010) found that comfort with loud sounds was one of the hearing aid attributes that was significantly associated with hearing aid satisfaction. The study measured the hearing aid outcome at six months post-fitting for a large sample of adults. The participants filled in the international outcome inventory (IOI-HA) with additional questions about hearing aid satisfaction, hearing aid attributes and clinical service. The results revealed positive outcomes were related to the satisfaction with hearing aid attributes such as aid comfort, clarity of tone, and sound and comfort with loud sounds. Hence, it is important that clinicians looked at these hearing aid attributes to improve the outcome. In the case of this study, applying some of the hearing aid technologies such as noise reduction circuits (which were not activated for the purpose of this study) might perhaps help to reduce the loudness discomfort experienced by some of the children.

8.5.6 *Data logging*

The data logging showed that the children used their hearing aids for an average of 9 hours per day and the hours recorded did not differ significantly between the prescriptions. The logged hours for both prescriptions were also found to be correlated with the duration of hearing aid use as reported by the parents, teachers and children in

the questionnaires. This is consistent with other studies (Haggard et al., 1981; Humes et al., 1996) that found the objective and subjective measures of hearing aid use are strongly correlated with each other. Both methods can be used reliably to measure the hearing aid use even though the subjective estimates tend to be higher than the objective estimates.

The results showed overall, children used the DSL v5 prescription more often during the trials 3 and 4 (by 14.2 percent). They also tended to use the default program more often, than the second program even though these differences were found not significant. However, there was significant interaction between prescription and default programs suggesting that children tended to use the default program more often but the frequency of using the default program varied depending on which prescription was set as the default program. It was found when DSL v5 was set as the default program, children would use that program more frequently as compared to the use of the NAL-NL1 program when it was set as the default program. Individual data revealed about half of the children used their preferred program most of the time (up to 98 % in usage) and used very little of the second program across trials. This indicates that the children did not fully utilize the different memory programs activated in their hearing aids. This is consistent with feedback gathered from some of the children stating they did not like having two different programs in their hearing aids. Only two children (with sloping mild to severe hearing loss) reported that the multiple memory function was beneficial to them. These findings did not support the findings in the NAL/UWO study in which children expressed a preference for having access to both programs and would probably benefit from hearing aids with multiple memory program (Scollie et al, 2010e). Past studies have also indicated the benefits and satisfactions experienced by hearing aid users who had access to different frequency responses in their hearing instruments, but many of these studies focused on adults with mild to moderated hearing loss (Ringdahl et al., 1990; Keidser, 1995; Keidser et al., 1995; Jerram & Purdy, 2001). Little is known about the benefits of multiple memory hearing aids for children with severe to profound hearing loss. It could be that children in the present study had certain priorities for their daily listening tasks (e.g. speech understanding) which could be achieved by a single frequency response and switching away from this preferred frequency response was perceived as affecting their priorities. It may also depend on what programs are available. Presumably if really useful and/or different programs were available, they would be used.

There were two new hearing aid users involved in this study. The data logging showed these children used their hearing aids the least (average of 4 hours per day). This finding agreed with the results from Keidser et al study (2008) on adults. The study revealed on average, the new user group used their hearing aids significantly less when compared to the experienced users. The hearing aid usage among the new users did not increase over the 13 months of observation period. The findings from Keidser et al study suggested that for individuals with prolonged period without amplification, a longer time frame (more than 13 months) might be required for them to adapt to their hearing aids.

8.5.7 Factors influencing child's preference

Children's HTLs and previous hearing aid experience were investigated to determine if they correlated with the children's preference for a prescription. The Spearman test revealed no significant correlation between the children's choice of prescription and their 4FA HTL. No relationship was found between children's preferred prescriptions and their previous hearing aid experience. This finding is different from the NAL/UWO study (Scollie et al., 2010e) and other studies (Ching et al., 1997; Scollie et al., 2000) which showed that children's preferences were biased towards the prescription with which they were more familiar in their previous hearing experiences. In other words, Canadian children who were accustomed to the DSL fitting in their previous hearing experience, would tend to prefer the DSL prescription and likewise with the Australian children who were accustomed to the NAL fitting previously, would tend to prefer the NAL prescription. It should be noted however that for the present study, the relationship between the children's preference and previous hearing aid experience was analyzed based on only 10 children since two other children were new hearing aid users and the other four children had broken or lost hearing aids at the time of the study.

For the two new hearing aid users involved in the study, one preferred the NAL-NL1 prescription and another child expressed no overall preference. In a review study conducted by Convery et al (2005), data from three relevant studies (Cox & Alexander, 1992; Horwitz & Turner, 1997; Humes et al., 2002) were analyzed to examine whether new hearing aid users prefer less gain than do experienced users and whether the gain preferences of new hearing aid users change over time. To eliminate the effect of audiogram configurations on the analysis, the actual preferred gain was referenced to the NAL-R targets. The NAL 2cc coupler targets were calculated and compared with

the used or preferred gain of the subjects. The results showed that the average difference in preferred gain levels relative to the NAL-R prescription does not exceed 2 dB and this difference was not statistically significant. The analysis also revealed no significant change in preferred gain among new users over the first 12 months of amplification.

A study later conducted by Keidser et al (2008) suggested gain preference and adaptation among new hearing aid users were dependent on the degree of hearing loss. The study on adults, involved 50 new and 26 experienced hearing aid users. Gain preferences for medium input level in real life were assessed at one month, four months and 30 months post-fitting for the new users and at one month post-fitting for the experienced users. The study found new hearing aid users with mild hearing loss selected, on average, approximately the same gain deviation from the NAL-NL1 target (-3.9 dB) as did experienced users with the same degree of hearing loss. Also, the preferred gain among the new users did not change significantly over the 13 months of hearing aid use. On the other hand, new hearing aid users with more than mild hearing loss preferred, on average, 6 dB less gain than did experienced users with similar degree of hearing loss and this difference was reduced to 4 dB at 13 months post-fitting. The findings from Keidser et al study suggested that for new hearing aid users, particularly those with more than mild hearing loss, a longer time frame (more than 13 months) might be required for them to adapt to their hearing aids and to determine their actual gain preferences.

8.5.8 *Confounding factors*

It is well known that different compression parameters such as the compression threshold, compression ratio, attack and release time can affect speech recognition ability and speech-quality judgment in patients fitted with non-linear hearing aids and that the performances of these parameters are dependent upon the signal presentation level, signal-to-noise ratio and degree of hearing loss (Neuman et al., 1994; Dillon, Storey et al., 1998; Neuman et al., 1998; Barker & Dillon, 1999; Boike & Souza, 2000; Barker et al., 2001; Souza, 2002; Keidser et al., 2007; Davies-Venn et al., 2009). In the NAL/UWO study, the compression thresholds and maximum power outputs were assigned common values for both the NAL-NL1 and DSL v4.1 procedures (Ching et al, 2010b). The present study has a slightly different aim in that it intended to evaluate the

effectiveness of the two prescriptions based on their original formulae. The compression threshold (CT) for NAL-NL1 prescriptions was fixed at the default setting of 52 dB SPL for broadband speech while the DSL v5 prescribed variable CT. In general the DSL v5 prescribes higher CT as the hearing loss increases (see Figure 3.3 of Chapter 3). Hence, the extent to which the compression parameters of the prescriptions had on their respective prescribed gains and how the interactions between the two variables would affect the children's performance was not investigated in the present study.

8.6 Conclusions

The speech tests, paired-comparison judgment of speech intelligibility tests and subjective measures in real life showed that children with moderately severe to profound hearing loss required gains and frequency responses which were closer to the DSL v5 prescription than the NAL-NL1 prescription, at least for quiet listening environments. Overall, there were more children who preferred the DSL v 5 procedure than the NAL-NL1 procedure. Future research is required to find out the required or preferred hearing aid gains of children with conductive or mixed hearing loss and children who have long term auditory deprivation (new hearing aid users) since our data showed children in these categories preferred the NAL-NL1 procedure more.

Note : Children participated in the study returned the Phonak Naida V SP hearing aid at the end of the study. Fine tuning was made on the child's own hearing aids to achieve the desired settings. For three children, the preferred settings could not be achieved with their own hearing aids and hence they were fitted with the Phonak Naida hearing aids which were purchased via the local funding. Children with broken or no hearing aids were fitted by either new hearing aids purchased via the local funding or hearing aids loaned by the Audiology Clinic, UKM at the end of the study.

CHAPTER 9

Summary and Conclusions

This chapter summarizes the research procedure and findings. Limitations of the present research and suggestions for future studies are also presented in this chapter.

9.1 Research aim and procedure

The current research compares the NAL-NL1 and DSL v5 procedures as well as evaluates the relative effectiveness of the two prescriptive formulae in children with moderately severe to profound hearing loss. Previous research undertaken has mostly compared the prescriptive strategies in children with mild to moderately severe hearing loss (Ching et al., 2010a). In developing countries such as Malaysia and India, cochlear implants are accessible to only affluent people and hence hearing aids are still prescribed to hearing losses in the higher range and hence the current research provides knowledge of clinically significance.

Sixteen children aged between 7 to 17 years old participated in the current research. All children were fitted with a hearing aid (Phonak Naida V SP) that provided the options of toggling between the two prescriptions with settings based on the NAL-NL1 and DSL v5 procedures. The relative performance of the NAL-NL1 and DSL v5 procedures was evaluated using the laboratory tests and field tests. The laboratory tests involved speech tests, paired-comparison judgments of speech intelligibility tests and data logging assessment. The field tests included hearing aid trial and subjective assessment using questionnaires. The PEACH, TEACH and SELF are questionnaires used to gather information with regard to the children's hearing performance in real-life listening environments. The three questionnaires were translated into Malay language for use in this study. Subjective ratings were also provided by the parents, teachers and children to compare the performance of the two prescriptive procedures.

9.2 Research findings

9.2.1 Adaptation of questionnaire

A study was conducted to assess the reliability as well as to develop normative data for the PEACH scale adapted into the Malay language. Parents of 74 children aged between 3 months to 13 years old and with normal hearing completed the PEACH scale. Results showed the Malay PEACH scale had high internal consistency and corrected inter-item correlations. The test-retest reliability was high but was regarded as a preliminary study since the result was based on a relatively small sample size. Normative curve for the overall score of Malay PEACH was compared to normative curve of the English version. As in the results from English PEACH, near-perfect scores were achieved by around 40 months of age, but for the younger age groups (3 to 24 months), the overall scores were found lower than the scores of the English version. Differences in culture, parenting style and socioeconomic status were associated with the difference of aural/oral performance observed from the two populations. Overall, the Malay PEACH scale is a reliable and useful tool for assessing aural/oral performance of children from any age range. Suggestions were made for future studies to assess the sensitivity of Malay PEACH and also to establish normative data for children with hearing impairment.

9.2.2 Prescribed and achieved gain

The hearing aid gains prescribed by the NAL-NL1 and DSL v5 procedures were analyzed from 30 ears. The results showed substantially different gain and frequency response slopes prescribed by the two procedures. The DSL v5 procedure prescribed more overall gain and more high-frequency slope than the NAL-NL1 procedure. The NAL-NL1 procedure prescribed more or steeper low-frequency slope for vast majority of the test ears. The difference of frequency response gain can be associated with the difference of fitting rationales adopted by the two procedures. The NAL-NL1 aims to amplify overall loudness at a level equal or no greater than that perceived by a normal-hearing person listening to the same sounds while the DSL v5 procedure aims to amplify speech sounds at each frequency to a level perceived as equally loud by people with normal hearing.

The measured or achieved gain obtained from the NAL-NL1 fittings showed good agreement with the prescribed gain at all the test frequencies for soft and medium input

levels. Good agreement between the achieved and prescribed gain was also observed for the DSL v5 fittings at all frequencies except for 4000 Hz where the gains for this frequency were underachieved for some of the children with profound hearing losses. This was due to the high gain prescribed by the DSL v5 procedure which was either limited by the current hearing aid technologies or the fitting range (for moderately severe to upper range of profound loss) of the hearing aid used in the study. Nevertheless, the good agreement between the prescribed and achieved gain for both prescriptions at most of the frequencies showed that precise hearing aid fitting can be obtained with current commercial hearing aids. The differences of gain and frequency response slopes achieved in hearing aids fitted according to the NAL-NL1 and DSL v5 procedures has increased the validity of the present study to compare the relative performance of the two prescriptive formula.

9.2.3 NAL versus DSL performance

The relative performance of NAL-NL1 and DSL v5 procedures was assessed using a series of laboratory and field tests. A consonant discrimination test, HINT and closed-set word tests were used as the speech tests. Statistical analysis revealed a significant difference between prescriptions only for the HINT sentence reception threshold (SRT) measured in quiet. In this case, the SRT measured from the HINT was significantly better with the DSL v5 prescription than the NAL-NL1 prescription.

Paired-comparison judgments of speech intelligibility showed nine out of 15 children or 60% of the children significantly judged one prescription as clearer than the other prescription. Out of these nine children, seven judged the DSL v5 prescription as more intelligible while two children judged the NAL-NL1 prescription as more intelligible.

Parental, teacher and children self-report questionnaires as well as subjective ratings were used to assess the functional hearing of children using the NAL-NL1 and DSL v5 prescription. The DSL v5 prescription was found to be significantly better than the NAL-NL1 prescription measured from the PEACH, TEACH and SELF questionnaires. Subjective ratings showed on average, the parents and teachers rated the DSL v5 prescription as either the same or slightly better than the NAL-NL1 prescription for different listening conditions. Significant correlations were found between the PEACH and TEACH and between the parents' ratings and the teachers' ratings. The results from

SELF did not correlate with either the PEACH or the TEACH suggesting the children did not agree with the parents' and teachers' reports.

Subjective ratings of the children showed that the children rated the DSL v5 prescription as better than NAL-NL1 for quiet listening environments, but for noisy conditions, the NAL-NL1 prescription was rated as better than the DSL v5 prescription. Out of 15 children, nine children stated they preferred the DSL v5 prescription while four children preferred the NAL-NL1 prescription and two other children had no overall preference at the end of the study. The children's choices of prescriptions were found to correlate with their subjective ratings and the paired-comparison judgments of intelligibility test.

Hearing aid loudness discomfort and hearing aid use were also analyzed in the study. The results showed the DSL v5 prescription was more associated with loudness discomfort experienced by children than the NAL-NL1 prescription. The study also showed that for most of the children who reported loudness discomfort with the DSL v5 prescription, became accustomed to it at the end of the study.

The hearing aid usage was assessed using subjective measures and objective measures (data logging). The hearing aid usage for both prescriptions as reported by the parents and children were found correlated with results obtained from the hearing aid data logging feature. The data logging showed that overall, the children used more often of the DSL v5 prescription than the NAL-NL1 prescription. The data logging feature also showed that the children did not fully utilize the multiple memories in hearing aid. Further research is required to investigate the relative benefits of providing this hearing aid feature to children with severe to profound hearing loss.

In conclusion, the laboratory and field tests suggest that in quiet listening environments, the performance of the DSL v5 prescription was consistently better than the NAL-NL1 prescription. Mixed results were obtained for noisy listening situations. Even though the DSL v5 procedure was perceived as better than the NAL-NL1 procedure in noisy situations by the parents and teachers, the average ratings from children and speech tests in noise did not support this and did not show a significant difference between prescriptions. Overall, there were more children (nine children) who preferred the DSL v5 prescription as compared to the number of children (four children) who preferred the NAL-NL1 prescription.

9.3 Research limitations

i) A single-blind approach was implemented in the study where only the participants (i.e. children, parents and teachers) were not aware of the prescriptions assigned to the children. Hence, the study is subjected to argument that the findings could be under the influence of bias from the investigator. This can be overcome if a different person or an assistant is responsible in assigning the NAL-NL1 and DSL v5 prescriptions to the children and the investigator to conduct the evaluation tests. The assistant will be responsible to assign and to activate the appropriate prescription in the hearing aid program, carry out the coupler measurement to verify the prescription every time before the test session begins and to record information from the data logging feature for each prescription. It can be that the investigator in charge of assigning the prescription to the children while the assistant run the evaluation tests. Whichever way, the person conducting the evaluation tests should not be aware of the prescription being tested. Unfortunately this could not be implemented in the study as the investigator had difficulties getting the suitable person or assistant to commit in the research.

ii) Due to the level of language required for the sentence test, some children experienced a floor effect with the HINT. A closed-set word test was conducted on these children. Each type of the speech test was limited by the small sample size of children and the lack of statistical power. Furthermore, the speech tests used in the study were limited by the materials available in the Malay language and also the format of presentation. For instance the close-set word test was pre recorded only at two fixed SNRs. There were few children who experienced a ceiling effect and could not be tested with other speech tests.

iii) Children that fit into the research criteria were invited to participate in the present study; for instance if they had severe to profound hearing impairment, had sufficient speech and language skills and preferably enrolled in mainstream classes. This purposive sampling might have resulted in a group of participants who were homogeneous, that is individuals with certain types of characteristics such as personality traits, intelligence levels and listening requirements. In a cross-sectional survey that involved 205 adults with mild to moderately-severe hearing loss, Cox et al (2007) investigated patient variables such as personality traits as a predictor of self-report hearing aid outcomes. It was found that hearing problems, hearing aid expectations and general aversiveness of sounds were related to patient's personality

and all these attributes had an effect on the self-report hearing aid outcomes. Many of the children involved in the study demonstrated some ability in auditory-verbal communication. Madell (2008a) explained that the selection of appropriate hearing technology is dependent on the child's auditory and communication needs. For instance, if a child is in a sign language program and does not rely on audition for communication, then hearing aids that merely provide sound awareness may be sufficient.

iv) The present study was dominated by males (88%) of the participating children. Keidser and Dillon (2006) reported on a study conducted at NAL which looked at gender effect on gain preference. The study found adult female hearing aid users, on average, preferred 2.3 dB less gain than did male hearing aid users. Female without hearing aid experience especially, preferred less gain than prescribed by the NAL-NL1 procedure (-5.2 dB on average). It is not clear if children of different gender have different gain preferences.

v) In the study, only the PEACH was validated in the Malaysian population and normative data was developed for children with normal hearing. The reliability of the TEACH and SELF in the Malay language was not investigated in the study. It is suggested that the validation of these scales to be carried out in future and also the development of normative for children with hearing impairment.

9.4 Future studies

i) Studies that compared performance of different prescriptive formula have focused primarily on adults and children with sensorineural hearing loss. There were some indications from the present study that children with a conductive element present in their audiograms, preferred the NAL-NL1 prescription more than the DSL v5 prescription. Also, children who have long term auditory deprivation preferred gain closer to the NAL-NL1 prescription, when they were fitted with hearing aids for the first time. Further research is required to understand more about the gain requirements or preferences for this category of children.

ii) The RECDs measured from the children participated in this study were found to be higher than in children of similar age in other studies. RECD values used for hearing aid fitting purposes are often based on data collected largely from one ethnic group. It is not

certain if different ethnic groups (e.g. Asian and Caucasian children) have different RECD values.

iii) The Ching et al (2010) study has led to the conclusion that children on average prefer a few dB more gain than that prescribed by the NAL-NL1 procedure. As such, the NAL-NL2 procedure prescribes a different amount of gain for adults and children. Generally, the NAL-NL2 prescribes slightly more gain for children relative to the NAL-NL1 procedure, with a highest increase of 4 dB for soft input levels. More gain emphasis is given to soft input levels as this will likely to improve speech intelligibility and is far less likely to cause noise-induced hearing loss than for loud input levels. In addition, the NAL-NL2 procedure prescribes higher compression ratio relative to the NAL-NL1 procedure, for children (Keidser & Dillon, 2006). Although the NAL-NL2 and DSL v5 procedure are more similar to one another now than the predecessors of NAL-NL1 and DSL v4, the procedures continues to show variation in terms of the frequency-gain prescribed by the two procedures for adult fittings. The variation or differences of gain-frequency prescribed by the NAL-NL2 and DSL v5 procedures might be greater for children (Johnson & Dillon, 2011). It will be important for future study to investigate the differences of amplification characteristics prescribed by the NAL-NL2 and DSL v5 procedures and to validate the effectiveness of the procedures in children.

9.5 Clinical implications

Infants and young children are often left using their hearing aid at settings determined by a clinician until they are able to express their preferences. It is therefore very important to ensure appropriate amplification characteristics are selected for children. The present study showed the importance of using validated prescriptive procedures in fitting hearing aids to children. The majority of the children's own hearing aids in this study, were found not to match the targets prescribed by the NAL-NL1 or DSL v5 procedures. For some of the children, the hearing aid gain was far below the target and for one child, over fitting occurred. For these children, the parents and the children could tell the differences before and after the hearing aids had been adjusted to match the targets. Such findings also indicate the need to look at the practices of fitting hearing aids to children in Malaysia and to improve them if necessary. The study suggested that for children with severe to profound sensorineural hearing loss, the clinicians should fit

the hearing aids according to the DSL v5 procedure for a start. Probe tube microphone measurement should be carried out to make sure the hearing aid meet the targets prescribed by the DSL v5 procedure at octave frequency. If valid and reliable results of direct real ear measurement cannot be obtained, for example from infants and young children, RECD measurement should be used to verify the hearing aid fitting. It is best that individual RECD values be used instead of predicted RECD values for verification purposes. Subsequent to the hearing aid verification, hearing aid adjustment or fine tuning should be carried out with care, based on parent's report and the child's report if possible. The PEACH, TEACH and SELF translated into the Malay language in this study can serve as very useful clinical tools. School teachers and clinicians can rely on the scales to evaluate the auditory performance of children, to manage, to counsel and also to educate the parents. The PEACH is one of the auditory inventory scales recommended in the UWO Pediatric Audiological Monitoring Protocol (UWOPedAMP) (Bagatto et al., 2011). Other auditory scales included in the UWOPedAMP are the LittleEARS' Auditory Questionnaire and the Ontario Infant Hearing Program (OIHP) Amplification Benefit Questionnaire. Adaptation of these auditory scales into the Malay language should be carried out in future so they can be incorporated into the hearing fitting protocol in Malaysia.

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APPENDIX 1

Photos of the Test Site



The Audiology and Speech Sciences Clinic of Universiti Kebangsaan Malaysia, Jalan Temerloh, Kuala Lumpur



One of the test booths used for conducting hearing assessment



The layout of a test booth used for hearing aid fitting purposes



The layout of a test booth used for speech tests

APPENDIX 2

Macquarie University Research Ethics Approval



14 November 2008

Ms Quar Tian Kar
No 6, Jalan SS22A/2
Damansara Jaya
Petaling Jaya 47400
Selangor
Malaysia

Reference: HE22AUG2008-D06060

Dear Ms Quar

Final Approval

Title of project: "Comparing the effectiveness of NAL-NAL2 and DSL v5 prescriptive formula in school aged children"

Thank you for your recent correspondence. Your response has addressed the issues raised by the Ethics Review Committee (Human Research) and you may commence your research.

Please note the following standard requirements of approval:

1. Approval will be for a period of twelve (12) months. At the end of this period, if the project has been completed, abandoned, discontinued or not commenced for any reason, you are required to submit a Final Report on the project. If you complete the work earlier than you had planned you must submit a Final Report as soon as the work is completed. The Final Report is available at: http://www.research.mq.edu.au/researchers/ethics/human_ethics/forms
2. However, at the end of the 12 month period if the project is still current you should instead submit an application for renewal of the approval if the project has run for less than five (5) years. This form is available at http://www.research.mq.edu.au/researchers/ethics/human_ethics/forms. If the project has run for more than five (5) years you cannot renew approval for the project. You will need to complete and submit a Final Report (see Point 1 above) and submit a new application for the project. (The five year limit on renewal of approvals allows the Committee to fully re-review research in an environment where legislation, guidelines and requirements are continually changing, for example, new child protection and privacy laws).
3. Please remember the Committee must be notified of any alteration to the project.
4. You must notify the Committee immediately in the event of any adverse effects on participants or of any unforeseen events that might affect continued ethical acceptability of the project.
5. At all times you are responsible for the ethical conduct of your research in accordance with the guidelines established by the University http://www.research.mq.edu.au/researchers/ethics/human_ethics/policy

If you will be applying for or have applied for internal or external funding for the above project it is your responsibility to provide Macquarie University's Research Grants Officer with a copy of this letter as soon as possible. The Research Grants Officer will not inform external funding agencies that you have final approval for your project and funds will not be released until the Research Grants Officer has received a copy of this final approval letter.

ETHICS REVIEW COMMITTEE (HUMAN RESEARCH)
LEVEL 3, RESEARCH HUB, BUILDING C5C
MACQUARIE UNIVERSITY
NSW, 2109 AUSTRALIA

Ethics Secretariat: Ph: (02) 9850 6848 Fax: (02) 9850 4465 E-mail: ethics.secretariat@mq.edu.au
http://www.research.mq.edu.au/researchers/ethics/human_ethics

APPENDIX 3

Subject's Informational and Consent Form

PARENT INFORMATIONAL AND CONSENT FORM

Date :

Dear Parent,

Name of the project: "Comparing the effectiveness of two hearing aid fitting settings in children"

I would like to invite your child to participate in a research project that is being conducted as part fulfillment of the Doctorate Degree in audiology under the supervision of Emeritus Prof. Philip Newall and Dr Mridula Sharma. The aim of this study is to compare the performance of hearing aid fitted with two different settings and to find out which one is more beneficial to children with hearing impairment.

Your child will be required to take a hearing test and to attend two sessions of hearing aid fitting. Your child will be fitted with hearing aids provided by a hearing aid company. After each hearing aid fitting session, your child will need to try the hearing aids at home and in school for 4 months. Your child will need to come to our clinic to do some listening tests with the hearing aids and to fill up a questionnaire with regards to his/her hearing experience when using the new hearing aid settings. At the end of all tests, the hearing aids need to be returned to the investigator so they can be used by the next child or participant. I will ensure that your child's own hearing aids are adjusted properly after returning the hearing devices used for the research.

The actual assessment will be carried out at the Audiology Clinic in Jalan Temerloh, Kuala Lumpur. Travel expenses will be paid for each trip to the clinic.

Confidentiality

Should you decide to allow your child to be in the study, I would like to seek your permission for me to have access to information or personal details related to this study. Any information or personal details gathered in the course of the study are confidential. No individual will be identified in any publication of the results. I would also be happy to share all the tests' results with you. I will provide you by hand or post, a summary of the research results at the end of the study.

If you would like your child to be in this study, please sign the consent form at the end of this letter. You are free to withdraw your consent at any time, without having to give a reason and without adverse consequence. If you have any question about the study, please feel free to contact me and I will be happy to discuss the study with you.

Yours Sincerely,

Quar Tian Kar
Postgraduate Student
Ph: +614 15900132(Australia)
+60126227574(Malaysia)
Email : tian_kar.quar@student.mq.edu.au

Emeritus Prof. Philip Newall
Supervisor
Ph: +612 9850 8779
Email : Philip.Newall@ling.mq.edu.au

Dr Mridula Sharma
Supervisor
Ph : +612 9850 4863
Email : Mridula.Sharma@ling.mq.edu.au

Consent Form

I (the parent or guardian of the participant) have read (or, where appropriate, have read to me) and understand the information above, and any questions I have asked, have been answered to my satisfaction. I agree to have my child participate in this research, knowing that I can withdraw at any time. I have been given a copy of this form to keep

Name of the participant's parent or guardian :... .. (block letters)

Signature of the participant's parent or guardian:... .. Date:

Name of participant (child) :.....(block letters)

Signature of participant (child) :.....Date :.....

Investigator's Name:... .. (block letters)

Investigator's Signature:... .. Date:

Please also note that the ethical aspects of this study have been approved by the Macquarie University Ethics Review Committee (Human Subjects). If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Ethic Committee through its Secretary (+612 9850 7854 or email to ethics@mq.edu.au).

Alternatively, you may also contact the Department of Audiology & Speech Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur (+603 2691 4230) in relation to any ethical concerns about this research. Any complaint you make will be treated in confidence and investigated fully, and you will be informed of the outcome.

Acknowledgement

This is to acknowledge the "Research Enhancement Fund" of Macquarie University, New South Wales for providing the fund to pay for the participants' travel expenses in this study and also the hearing aid company for loaning their hearing aids for this study.

Participant / Investigator Copy

PARENT INFORMATIONAL AND CONSENT FORM

Date

Dear Parent,

Name of the project: “Comparing the effectiveness of two hearing aid fitting settings in children”

I would like to invite you to participate in a research project that is being conducted as part fulfillment of the Doctorate Degree in audiology under the supervision of Emeritus Prof. Philip Newall and Dr Mridula Sharma. The aim of this study is to compare the performance of hearing aid fitted with two different settings and to find out which one is more beneficial to the children with hearing impairment.

As a participant of this research, you are required to make observation on your child’s listening behavior with his/her hearing aids at home. You will need to do the observation two times with each observation last for about one week. During the observation period, you are required to fill in a questionnaire concerning your child’s hearing ability. At the end of the observation period, the researcher will discuss with you, the completed questionnaire. You will meet with the researcher at the Audiology Clinic in Jalan Temerloh, Kuala Lumpur and you will be paid for any travel expenses involved.

If you would like to participate in this study, please sign the consent form at the end of this letter. You are free to withdraw your consent at any time, without having to give a reason and without adverse consequence. The data that we collect from you may be used for publication in future, but that data won't identify you in any way. At the end of the study, I will provide you by hand or post, a summary of the research results.

If you have any question about the study, please feel free to contact me and I will be happy to discuss the study with you.

Yours Sincerely,

Quar Tian Kar
Postgraduate Student
Ph: +614 15900132(Australia)
+60126227574(Malaysia)
Email : tian_kar.quar@student.mq.edu.au

Emeritus Prof. Philip Newall
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Email : Philip.Newall@ling.mq.edu.au

Dr Mridula Sharma
Supervisor
Ph : +612 9850 4863
Email : Mridula.Sharma@ling.mq.edu.au

Consent Form

I have read (or, where appropriate, have read to me) and understand the information above , and any questions I have asked, have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw at any time. I have been given a copy of this form to keep

Name of the participant : (block letters)

Signature of the participant : Date:

Investigator's Name: (block letters)

Investigator's Signature: Date:

Please also note that the ethical aspects of this study have been approved by the Macquarie University Ethics Review Committee (Human Subjects). If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Ethic Committee through its Secretary (telephone +612 9850 7854 or email to ethics@mq.edu.au).

Alternatively, you may also contact the Department of Audiology & Speech Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur (+603 2691 4320) in relation to any ethical concerns about this research. Any complaint you make will be treated in confidence and investigated fully, and you will be informed of the outcome

Acknowledgement

This is to acknowledge the "Research Enhancement Fund" of Macquarie University, New South Wales for providing the fund to pay for the participants' travel expenses in this study and also the hearing aid company for loaning their hearing aids for this study.

Participant / Investigator Copy

TEACHER INFORMATIONAL AND CONSENT FORM

Date

Dear Teacher,

Name of the project: “Comparing the effectiveness of two hearing aid fitting settings in children”

I would like to invite you to participate in a research project that is being conducted as part fulfillment of the Doctorate Degree in audiology under the supervision of Emeritus Prof. Philip Newall and Dr Mridula Sharma. The aim of this study is to compare the performance of hearing aid fitted with two different settings and to find out which one is more beneficial to the school aged children with hearing impairment.

As a participant of this research, you are required to make observation on your student’s listening behavior with his/her hearing aids at school. You will need to do the observation two times with each observation last for about one week. During the observation period, you are required to fill in a questionnaire concerning your student’s hearing ability. At the end of the observation period, the researcher will collect and discuss with you, the completed questionnaire. If you are able to meet with the researcher at the Audiology Clinic in Jalan Temerloh, Kuala Lumpur, any travel expenses involved will be paid to you.

If you would like to participate in this study, please sign the consent form at the end of this letter. You are free to withdraw your consent at any time, without having to give a reason and without adverse consequence. The data that we collect from you may be used for publication in future, but that data won't identify you in any way. At the end of the study, I will provide you by hand or post, a summary of the research results.

If you have any question about the study, please feel free to contact me and I will be happy to discuss the study with you.

Yours Sincerely,

Quar Tian Kar

Postgraduate Student

Ph: +614 15900132(Australia)

+60126227574(Malaysia)

Email : tian_kar.quar@student.mq.edu.au

Emeritus Prof. Philip Newall

Supervisor

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Email : Philip.Newall@ling.mq.edu.au

Dr Mridula Sharma

Supervisor

Ph : +612 9850 4863

Email : Mridula.Sharma@ling.mq.edu.au

Consent Form

I have read (or, where appropriate, have read to me) and understand the information above, and any questions I have asked, have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw at any time. I have been given a copy of this form to keep

Name of the participant : (block letters)

Signature of the participant : Date:

Investigator's Name: (block letters)

Investigator's Signature: Date:

Please also note that the ethical aspects of this study have been approved by the Macquarie University Ethics Review Committee (Human Subjects). If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Ethic Committee through its Secretary (telephone +612 9850 7854 or email to ethics@mq.edu.au).

Alternatively, you may also contact the Department of Audiology & Speech Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur (+603 2691 4230) in relation to any ethical concerns about this research. Any complaint you make will be treated in confidence and investigated fully, and you will be informed of the outcome.

Acknowledgement

This is to acknowledge the "Research Enhancement Fund" of Macquarie University, New South Wales for providing the fund to pay for the participants' travel expenses in this study and also the hearing aid company for loaning their hearing aids to the children participating in this study.

Participant / Investigator Copy

CHILD INFORMATIONAL AND CONSENT FORM

Date

Dear children,

Name of the project: “ Comparing hearing aid performance with different settings”

I would like to invite you to take part in my research project. The purpose of my project is to find out what hearing aid setting is suitable for children with hearing loss.

If you take part in this project, you will need to wear hearing aids given by a hearing aid company. I will adjust the hearing aids so that they will have different settings. You need to try the new hearing aid settings at home and in school for 4 months and later tell me which setting you like. You also need to write down on a form to tell me how good you can hear with the new hearing aid settings. You will be asked to come to our clinic to do some listening tests so that I know if you can hear speech better or not with the new hearing aid settings. At the end of all tests, you need to return the hearing aids to me so they can be used by other children who want to participate in this study. I will make sure your own hearing aids settings are adjusted properly after you return the hearing aid used for the study.

All tests will be carried out at the audiology clinic in Jalan Temerloh, Kuala Lumpur. I would be happy to share all the test results with you. I will write out a summary of the test results and pass it or post it to your house.

If you would like to take part in this study, please sign the consent form at the end of this letter. If you want to stop taking part in this study, you can do that at any time during the study. If you have any question about the study, please feel free to ask me and I will be happy to discuss the study with you.

Yours Sincerely,

Quar Tian Kar

Postgraduate Student

Ph: +614 15900132(Australia)

+60126227574(Malaysia)

Email : tian_kar.quar@student.mq.edu.au

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Supervisor

Ph : +612 9850 4863

Email : Mridula.Sharma@ling.mq.edu.au

Consent Form

I have read (or, where appropriate, have read to me) and understand the information above , and any questions I have asked, have been answered to my satisfaction. I agree to participate in this research, knowing that I can withdraw at any time. I have been given a copy of this form to keep

Your name :... .. (block letters)

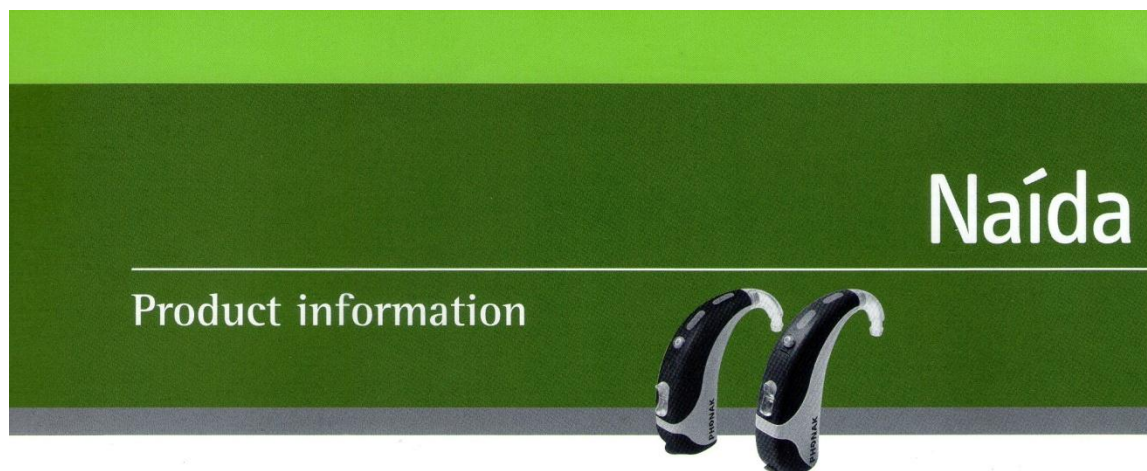
Your signature :... ..Date:

Investigator's Name:... .. (block letters)

Investigator's Signature:... ..Date:

Participant / Investigator Copy

APPENDIX 4



Naída is a new and outstanding product line with a broad spectrum of innovations. Naída UltraPower, designed for profound hearing losses, and Naída SuperPower, specially designed for moderately-severe to severe hearing losses. It is based on the newest wireless chip technology from Phonak, CORE, offering CableFree Fitting, QuickSync coordination and the comfort of wireless connectivity.

The unique combination of SoundRecover, WhistleBlock Technology, PowerProcessing and BassBoost offers exceptional levels of audibility and clarity. With SoundRecover (non-linear frequency compression) the wearer will hear more high frequency sounds essential for speech understanding. Feedback is effectively suppressed without gain loss, thanks to the new advanced WhistleBlock Technology.

Key features

Naída III SP / Naída III SP Jr*, Naída III UP / Naída III UP Jr*

- 6 channels
- PowerProcessing
- BassBoost
- SoundFlow Standard
- 2 programs + 2 dedicated to FM and/or T-coil
- SoundRecover
- WhistleBlock Technology
- NoiseBlock Processing
- Omnidirectional microphone
- Wind & Weather protection
- WaterResistant
- EasyFM
- EasyPhone
- EasyAudio
- EasyBluetooth
- FM solutions: design-integrated or universal
- myPilot command center
- iCom communication interface
- iView status viewer
- Secure 'n Stay retention
- Naída SP: 13 size GenX batteries
- Naída UP: 675 standard batteries
- 18 colors including 2 patterns
- CableFree Fitting
- AudiogramDirect

Naída V SP/Naída V SP Jr*, Naída V UP/Naída V UP Jr*

- 16 channels
- PowerProcessing
- BassBoost
- SoundFlow Advanced
- 4 manual programs (free configuration)
- SoundRecover
- WhistleBlock Technology
- NoiseBlock Processing
- Digital AudioZoom
- WindBlock Management and Wind & Weather protection
- WaterResistant
- EasyFM
- EasyPhone
- EasyAudio
- EasyBluetooth
- FM solutions: design-integrated or universal
- myPilot command center
- iCom communication interface
- iView status viewer
- Real Ear Sound
- QuickSync
- Secure 'n Stay retention
- Naída SP: 13 size GenX batteries
- Naída UP: 675 standard batteries
- 18 colors including 2 patterns
- CableFree Fitting
- AudiogramDirect



* Junior models will be delivered with a mini hook and a tamperproof battery compartment

PHONAK life is on

Fitting software

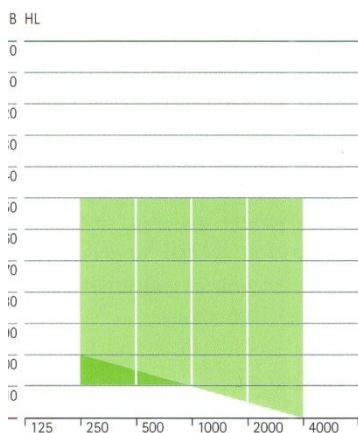
For Naída SP: iPFPG version 2.1 or higher, Noah compatible
For Naída UP: iPFPG version 2.0 or higher, Noah compatible

Hardware

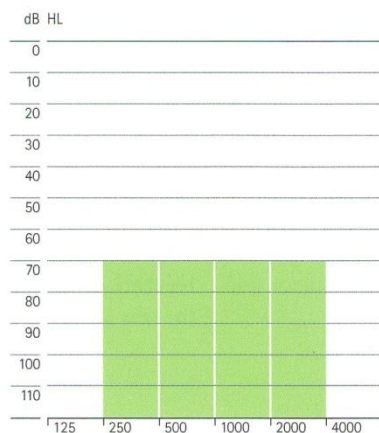
- PC (IBM compatible)
- iCube CableFree Fitting or NOAHlink or HI-PRO

Fitting range

Naída SuperPower
All models



Naída UltraPower
All models







Technical description





- Transparent hook
- Sound outlet
- Miniature microphones with Wind & Weather Protector (WaterResistant)
- Program switch
- Access to programming plug
- Digital volume control
- Serial number
- Battery compartment with ON/OFF switch
- Wind & Weather Protector (WaterResistant) for battery compartment
-) Design-integrated FM



Key features

The complete range of data sheets is available on www.phonak.com

		Junior		Junior
SuperPower	Naída III SP	Naída III SP Jr	Naída V SP	Naída V SP Jr
				
Performance profile	HE7/HE7 680	HE7/HE7 680	HE7/HE7 680	HE7/HE7 680
Maximum Power Output (dB SPL)				
2 cc coupler	140/133	140/133	140/133	140/133
Ear Simulator	141/138	141/138	141/138	141/138
Maximum gain (dB)				
2 cc coupler	75/68	75/68	75/68	75/68
Ear Simulator	80/73	80/73	80/73	80/73
Frequency range – 2 cc coupler (Hz)	<100 – 6400	<100 – 6400	<100 – 6400	<100 – 6400
Frequency range – Ear Simulator (Hz)	<100 – 6900	<100 – 6900	<100 – 6900	<100 – 6900
Battery size	13 GenX	13 GenX	13 GenX	13 GenX
Working current (mA)	1.3	1.3	1.3	1.3
Pediatric models with mini hook and tamperproof battery compartment		✓		✓

		Junior		Junior
UltraPower	Naída III UP	Naída III UP Jr	Naída V UP	Naída V UP Jr
				
Performance profile	HE7/HE7 680	HE7/HE7 680	HE7/HE7 680	HE7/HE7 680
Maximum Power Output (dB SPL)				
2 cc coupler	141/135	141/135	141/135	141/135
Ear Simulator	144/139	144/139	144/139	144/139
Maximum gain (dB)				
2 cc coupler	82/75	82/75	82/75	82/75
Ear Simulator	85/80	85/80	85/80	85/80
Frequency range – 2 cc coupler (Hz)	<100 – 4900	<100 – 4900	<100 – 4900	<100 – 4900
Frequency range – Ear Simulator (Hz)	<100 – 5000	<100 – 5000	<100 – 5000	<100 – 5000
Battery size	675	675	675	675
Working current (mA)	1.3	1.3	1.3	1.3
Pediatric models with mini hook and tamperproof battery compartment		✓		✓

Naída colors:

Beige (01), Brown (03), Taupe (35), Light gray (04), Black (06), Hightech gray (12), Gray (23), Blond (49), Chestnut brown (50), Pure transparent (13), Red transparent (36), Blue transparent (37), Purple transparent (38), Palladium/Black (70), Safari stripes (B3), Savannah beauty (B4), Light pink (33), Light blue (34)

APPENDIX 5

Subjects' Template of Malay Consonants

a _____ a

B	C	D
F	G	H
J	K	M
N	NG	NY
P	S	SY
T	V	Z

APPENDIX 6

Malay HINT (Child List)

List 1

Pasar itu sangat bersih
Budak itu menjerit
Jalan itu sangat licin
Dia terlupa minum pagi
Kakak pakai topi merah
Pokok itu berdiri
Pisang itu belum masak
Murid itu sangat rajin
Dia belanja saya makan
Duit abang sudah habis

List 2

Pokok itu sudah berbuah
Ubat demam itu manis
Datuk pakai kasut biru
Dia mencari kawannya
Kasut adik sudah hilang
Giri mengajar di sekolah
Dia membasuh rambut
Emak menyusun bunga
Pantai itu sangat cantik
Kucing suka makan ikan

List 3

Mereka beli biskut
Kakak ambil selimut
Kasut sekolah saya koyak
Sungai ini banyak udang
Lantai itu berkilat
Dia menipu kawannya
Cermin mata itu pecah
Abang pergi memancing
Kucing dan anjing bergaduh
Dia dikejar lembu

List 4

Ayah membeli ubat
Ayam itu sudah digoreng
Orang ambil duit saya
Dia menari atas pentas
Pasar ini agak sibuk
Datuk naik kapal terbang
Ibu panaskan sup itu
Dia melukis rumahnya
Ada orang ketuk pintu
Dia menjual keretanya

List 5

Buku adik sudah koyak
Air kopi itu manis
Laman rumahnya bersih
Pisau itu sangat tajam
Dia memanjat tangga itu
Mereka suka dengar radio
Pokok durian berbuah
Jam itu terlalu mahal
Dia seorang pemalas
Angin bertiup kencang

List 6

Kotak mancis itu kosong
Mereka main guli
Budak itu tendang bola
Dalam kotak ada buku
Pintu itu tidak berkunci
Saya suka makan mi sup
Radio sedang berbunyi
Kakaknya merajuk lagi
Harga buku itu mahal
Dia melompat pagar

List 7

Dia suka makan rojak
Beg sekolah adik berat
Rumahnya di tengah sawah
Kakak bermain dengan adik
Dia pergi ke kedai runcit
Mereka mengetuk pintu
Mata pisau itu tajam
Rumah itu sudah buruk
Kek itu sudah masak
Dia minum kopi saya

List 8

Dia beli payung baru
Budak itu terjatuh tangga
Rambutan itu masam
Abang makan telur goreng
Dia dikejar anjing
Ibu membasuh baju
Mereka suka balik kampung
Enjin lori itu mati
Dia duduk atas bangku
Monyet suka makan pisang

List 9

Ibu masak nasi goreng
Mereka pecahkan tingkap
Dia sudah bayar hutang
Ayah pergi menjala
Baju budak itu cantik
Dapur itu masih panas
Kereta itu berhenti
Pintu kereta terbuka
Ayah pergi memancing ikan
Air kolam itu sejuk

List 10

Cikgu mengunci almari
Tangannya terkena api
Meja itu sudah buruk
Mereka pergi melancong
Buah tembikai ini manis
Tingkap dapur sudah bersih
Dia membuka pintu
Kuku adik sangat panjang
Emak suka tanam sayur
Basikal saya hilang

List 11

Masakan itu masin
Lampu itu sudah rosak
Ibu menjahit langsir
Dia basuh kakinya
Anjing kejar budak itu
Ibu ajar adik buat kek
Dia balik lambat hari ini
Dia menegur kawannya
Dia melompat ke bawah
Dia jumpa dompet saya

List 12

Ibu menyikat rambut adik
Orang tua itu risau
Abang memanjat tingkap
Mereka suka lagu nasyid
Hari ini panas terik
Bilik tidur ini besar
Dia membuang sampah
Dia menolong saya masak
Kek ini sungguh sedap
Makanan itu murah

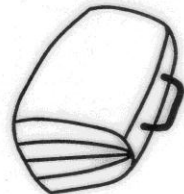
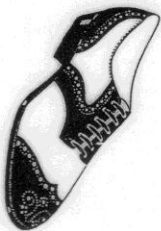
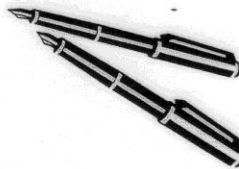
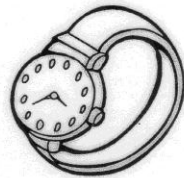
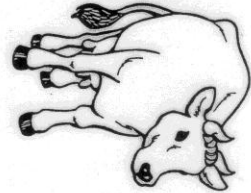
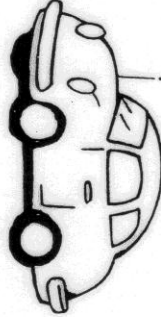
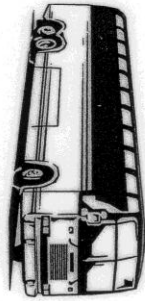
List 13

Kedai tutup hari Ahad
Adik pakai baju baru
Harga baju itu mahal
Buah itu berwarna kuning
Bapa petik kelapa
Ibu memanggil anaknya
Lembu hitam itu sakit
Dia demam selsema
Dia suka main badminton
Beg ini sangat murah

APPENDIX 7

Word Test (Subject's Template)

MTP 12 E



EARS Malay adaptation SZM, BAH, NM & NHAW

APPENDIX 8

P.E.A.C.H Diary

Developed by Teresa Ching & Mandy Hill
Copyright 2005 Australian Hearing
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Child's name: _____
Date of Birth: _____
Parent/Care giver completing PEACH: _____
Date completed: _____

Pre interview checklist

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

During that week:

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

Has your child been well/healthy? Yes /
No

Have the hearing aids been working properly? Yes /
No

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

Date: _____ Time: _____

Observation dates

Please observe your child from _____ to _____

Guidelines for parents

What is the PEACH?

The PEACH (Parents' Evaluation of Aural/oral performance of Children) is a questionnaire designed to record how your child is hearing and communicating with his/her hearing aids/cochlear implant at the moment. To complete the questionnaire you need to observe your child for at least one week, and record your observations for 13 questions. The topics covered include:

- USE of amplification & Loudness DISCOMFORT
- listening and communicating in QUIET
- listening and communicating in NOISE
- TELEPHONE usage
- responsiveness to sounds in the ENVIRONMENT

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

Why use it?

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

How do I do it?

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

Question 6 you might write:

"Olivia stopped and crawled to me when I called her name from the kitchen (5 metres away)."

- Write down as many examples as you can for each question. Your audiologist will score each question based on the number of examples you give.
- If your baby/child doesn't respond record those examples too.
- If you have many examples of the same type of behaviour that's okay just record the behaviour every time it occurs.
- Only record examples of behaviour that you have observed during the time period designated by your audiologist.

Helpful Hints

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

What happens next?

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

USE OF DEVICE & LOUDNESS DISCOMFORT

Questions 1 & 2

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

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

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

LISTENING IN DIFFERENT SITUATIONS

Questions 3-12

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

OR

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

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

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

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

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

OR

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

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

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

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

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

OR

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

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

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

OR

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

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

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

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

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

OR

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

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

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

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

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

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

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

OR

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

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

ENVIRONMENTAL SOUNDS Question 13

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

APPENDIX 9

Score Form for PEACH scale

<p>Parents' Evaluation of Aural/Oral Performance of Children (PEACH)</p> <p>Child's Name: _____</p> <p>D.O.B: _____</p> <p>Pre-Interview Questions</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 5%; text-align: center;">1</td> <td style="width: 95%;">Child's use of hearing aids/cochlear implant*</td> </tr> <tr> <td style="text-align: center;">2</td> <td>Is your child upset by loud sounds</td> </tr> </table> <p><small>* If score ≤ 1 do not proceed, investigate cause.</small></p> <p>PEACH Items</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>No.</th> <th>Scale</th> <th>Item Description</th> </tr> </thead> <tbody> <tr><td>3</td><td>Quiet</td><td>Respond to name in quiet</td></tr> <tr><td>4</td><td>Quiet</td><td>Follow verbal instructions in quiet</td></tr> <tr><td>5</td><td>Noise</td><td>Respond to name in noise</td></tr> <tr><td>6</td><td>Noise</td><td>Follow verbal instructions in noise</td></tr> <tr><td>7</td><td>Quiet</td><td>Follow story read aloud</td></tr> <tr><td>8</td><td>Quiet</td><td>Participate in conversation in quiet</td></tr> <tr><td>9</td><td>Noise</td><td>Participate in conversation in noise</td></tr> <tr><td>10</td><td>Noise</td><td>Participate in conversation in transport</td></tr> <tr><td>11</td><td>Quiet</td><td>Recognise voice of familiar persons</td></tr> <tr><td>12</td><td>Quiet</td><td>Converse on the phone</td></tr> <tr><td>13</td><td>Noise</td><td>Recognise sounds in the environment</td></tr> </tbody> </table>	1	Child's use of hearing aids/cochlear implant*	2	Is your child upset by loud sounds	No.	Scale	Item Description	3	Quiet	Respond to name in quiet	4	Quiet	Follow verbal instructions in quiet	5	Noise	Respond to name in noise	6	Noise	Follow verbal instructions in noise	7	Quiet	Follow story read aloud	8	Quiet	Participate in conversation in quiet	9	Noise	Participate in conversation in noise	10	Noise	Participate in conversation in transport	11	Quiet	Recognise voice of familiar persons	12	Quiet	Converse on the phone	13	Noise	Recognise sounds in the environment	<p>Respondent: _____</p> <p>Interviewer: _____</p> <p>Date: _____</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th colspan="5">Frequency of reported behaviour</th> </tr> <tr> <th>Never</th> <th>Seldom</th> <th>Sometimes</th> <th>Often</th> <th>Always</th> </tr> <tr> <td style="text-align: center;">0</td> <td style="text-align: center;">1</td> <td style="text-align: center;">2</td> <td style="text-align: center;">3</td> <td style="text-align: center;">4</td> </tr> <tr> <td style="text-align: center;">4</td> <td style="text-align: center;">3</td> <td style="text-align: center;">2</td> <td style="text-align: center;">1</td> <td style="text-align: center;">0</td> </tr> </table> <p style="text-align: center;">(Use scoring key 1)</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <th>Never</th> <th>Seldom</th> <th>Sometimes</th> <th>Often</th> <th>Always</th> </tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> <tr><td style="text-align: center;">0</td><td style="text-align: center;">1</td><td style="text-align: center;">2</td><td style="text-align: center;">3</td><td style="text-align: center;">4</td></tr> </table>	Frequency of reported behaviour					Never	Seldom	Sometimes	Often	Always	0	1	2	3	4	4	3	2	1	0	Never	Seldom	Sometimes	Often	Always	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
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APPENDIX 10

T.E.A.C.H Diary

Developed by Teresa Ching & Mandy Hill
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Child's name: _____
Date of Birth: _____
Teacher completing TEACH: _____
Date completed: _____

Pre interview checklist

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

During that week:

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

Has the child been well/healthy? Yes /
No

Have the hearing aids been working properly? Yes /
No

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

Date: _____ Time: _____

Observation dates

Please observe the child from _____ to _____

Guidelines for teachers

What is the TEACH?

- The TEACH (Teachers' Evaluation of Aural/oral performance of Children) is a questionnaire designed to record how the child is hearing and communicating with his/her hearing aids/cochlear implant at the moment. To complete the questionnaire you need to observe the child for at least one week, and record your observations for 11 questions.

The topics covered include:

- USE of amplification & Loudness DISCOMFORT
- listening and communicating in QUIET
- listening and communicating in NOISE
- responsiveness to sounds in the ENVIRONMENT

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

Why use it?

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

How do I do it?

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

"When reading a story Olivia responded to, "Where's the plane?" and pointed out other objects as well on request the first time I asked."

- Write down as many examples as you can for each question. The audiologist will score each question based on the number of examples you give.
- If the baby/child doesn't respond record those examples too.
- If you have many examples of the same type of behaviour that's okay, just record the behaviour every time it occurs.
- Only record examples of behaviour that you have observed during the time period designated by the audiologist.

Helpful Hints

- Identify certain noisy and quiet times of the day to observe the child and collect examples.

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

What happens next?

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

USE OF DEVICE & LOUDNESS DISCOMFORT

Questions 1 & 2

1. I would like to know how often the child is wearing his/her hearing aids and/or cochlear implant. Can you tell me about the child's routine for wearing his/her hearing aids/cochlear implant in the last week?
2. Has the child complained about / or been upset by any loud sounds in the last week. (He or she may startle and/or cry, cover his/her ears, pull his or her hearing aids off, complain or show some other signs of discomfort)?

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

LISTENING IN DIFFERENT SITUATIONS

Questions 3-12

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

OR

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

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

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

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

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

OR

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

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

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

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

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

OR

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

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

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

OR

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

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

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

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

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

OR

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

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

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

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

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

OR

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

ENVIRONMENTAL SOUNDS Question 11

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

APPENDIX 11

SELF Questionnaire

Child's name: _____ Date _____
Date of birth _____ Examiner _____

Please tick (✓) the appropriate box.

1. How often do you wear your hearing aid/cochlear implant?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

2. Are you bothered / upset by any loud sounds?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

3. Do you understand your teacher well/ follow your teacher's instructions when it's quiet in class?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

4. Do you follow a story that is read aloud?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

5. Do you understand your friend who sits next to you/ your classmates when it's quiet in class?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

6. Do you understand your friends talking to you when it's noisy?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

7. Do you follow what the teacher says when it's noisy? In the playground?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

8. Do you understand your mum/dad/ brothers/ sisters when it's quiet at home?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

9. Do you understand your mum/dad/ brothers/ sisters when it's noisy? At home? in a shopping centre?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

10. Do you understand your mum/dad/ brothers/sisters travelling in a car/bus/train?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

11. Do you recognise familiar people's voices without seeing them? On the phone?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

12. Do you recognize sounds in the environment?

Never		Seldom		Sometimes		Often		Always
0		1		2		3		4

Examples

APPENDIX 12

Children's Diary

Name : _____ Date : _____
 Trial III / IV P1 : _____ P2 : _____

1. Is program 1 different from program 2 ?

A lot different _____ A bit different _____ No difference _____

2. Overall, which program do you like or prefer (> 75%) ?

Program 1 _____ Program 2 _____

3. For the program you prefer, is it much better, a bit better or about the same as the other program ?

Why ? : _____

4. For each item below, mark (v) inside the appropriate box.

	Program 1 is _____ than Program 2				
	Better	A bit better	Same	A bit worse	Worse
When talking to your parents, brother or sister at home WHY ?					
When watching TV at home WHY ?					
When listening inside the car or bus WHY ?					
When listening inside the shopping malls WHY ?					
When listening inside the restaurants or school canteen WHY ?					
When listening on the telephone WHY ?					
When people call from behind WHY ?					

APPENDIX 13

Re: permission to use figures and tables

Wednesday, 14 December, 2011 8:47 AM

From:

"seewald@nca.uwo.ca" <seewald@nca.uwo.ca>

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To:

"Tian Kar Quar" <quartiak@yahoo.com>

Cc:

"philip.newall@ridbc.org.au" <philip.newall@ridbc.org.au>

Dear Yian Kar Quar,

It is good to hear from you. It sounds as if you have made great progress on this important work.

I believe that I can give you permission to include these tables and figures in your dissertation. I am happy to do this. However, if one day, you wish to publish any of the already published figures you will need to obtain permission from the publisher (JASA or Trends in Amplification). Personally, I don't feel that it is necessary for you to go through all of this for the dissertation itself.

I look forward to learning something new from your findings.

Please pass along my best regards to Dr. Newell.

Richard