Comparison between outcomes using preferred gain and prescribed gain formulae in children using hearing aids

Register Number: 09AUD036

A Dissertation Submitted in Part Fulfillment of Final Year
Masters of Science (Audiology)
University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE – 570 006

MAY 2011

To my Amma, Appa,
Kuttu
&
To Vijay sir

CERTIFICATE

This is to certify that this dissertation entitled **“Comparison between outcomes using preferred gain and prescribed gain formulae in children using hearing aids”** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration No: 09AUD036. This has been carried out the under guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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June, 2011

CERTIFICATE

This is to certify that this dissertation entitled **“Comparison between outcomes using preferred gain and prescribed gain formulae in children using hearing aids”** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore
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DECLARATION

This is to certify that this master's dissertation entitled **"Comparison between outcomes using preferred gain and prescribed gain formulae in children using hearing aids"** is the result of my own study under the guidance of Dr. Vijaya Kumar Narne, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore **Register No. 09AUD036**

June, 2011

Acknowledgement

My endless thanks to God Almighty, without whose blessings I wouldn't have been in this position.

I express my heartfelt gratitude to my Guide Dr. Vijaya Kumar Narne for his constant support, efficient guidance and patient listening throughout the course of this dissertation... Thanks a lot sir......

I thank Dr. S. R. Savithri, Director, AIISH, Mysore, for permitting me to carry out this study...

I would like to thank Prof. P. Manjula, H.O.D, Audiology, for permitting me to use the department...

I am extremely grateful to my amma, appa, kuttu, ammu, rakesh, nikhil, all my family members, and my beloved friends, without whom my world is meaningless. The love and care you have given to me and the faith you have in me has brought me a long way. You have given me the support, inspiration, encouragement, and strength to face the challenges in life.

My special thanks to Asha mam, Animesh sir, Sandeep sir, Sujeet sir, Prawin sir, Neeraj sir, Sreeraj sir, Baba sir, Devi mam, Mamtha mam, Geetha mam, Remadevi mam, Dhanalakshmi mam, Revathi mam for their informative lecturing and leading me to this position…

My special thanks to Jijo sir, Hemanth sir, Ganapathy sir, Sarath sir, Megha mam, Jithin sir, Prasanth sir, Sreela for their valuable suggestions and help throughout my dissertation….

My special thanks to Achaiah, who helped me from beginning….

Thanks to all the subjects participated in my study and the people who helped me in getting the subjects. I am sincerely thankful to all who directly or indirectly took part and helped me to complete this dissertation.

Thanks to all my loving seniors in AIISH Anuprasad, Chaaya, Vinu, Saroj, Rohit, Vijay, Vivek, Mohan, Giri, Lovedeep, had a nice time with you guys.

My sincere thanks to all my classmates who made my two years in AIISH colorful... the fun which I had with you all r unforgettable... I will miss u a lot... All the best for a bright future...

To some dear ones, it’s not right only to say thanks; my gratitude for you would last a life time. Love you all ...Wishly, Anoop, Nirmal, Adithya, Pavan, Keerthi, Praveen, Navdeep, Ranjeet, Akash, Prabash, Bharath, Akshay, Mukesh, etc… Keep in touch guys…………

My special thanks to all my juniors (Vipin, Prajeesh, Jobish Hemaraj, Saravanan, Prasad, Akshay, and Chandan, Zebu, Suman) for their wonderful friendship... Miss u all guys...

My special thanks to Anas sir, Shameem, Philip, Ananthan, Prasanth, George, Praveen, Vaishal, Ishack, Rinnu, Rakesh, Ramiz, Ann, Sethu, Vrinda, Divya, Aryechi, Jillu, Neethu........

Thanks to all my BSc classmates, seniors, juniors and staff for their support, love and care...

Thank you all...

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Chapter 1

Introduction

Technological advancement, has led to substantial research in the all areas including that of aural rehabilitation and surely, hearing aids are no exception. Various non-linear hearing aids are now available with complete digital technology. These non-linear hearing aids provide flexible adjustments to meet the desired amplification requirements for hearing impaired individual. As individuals with sensory-neural hearing loss experience an abnormal growth of loudness perception with the increase in input levels, these devices offer an excellent solution for their problem. They provide relatively more amplification for soft sounds and less amplification for loud sounds without manipulation of the volume control switch manually.

Prescriptive procedures for nonlinear hearing aids are based upon different underlying rationales. The idea behind these procedures is either to normalize loudness so that loudness recruitment can be compensated or to maximize speech intelligibility at various input levels (Byrne, 1996). Some of these fitting procedures use threshold and some others use supra threshold measurements as input data (Smeds, 2004). Threshold based procedures are mainly NAL-NL1 (Dillon, 1999; Byrne et al, 2001), FIG6 (Killion & Fikret-Pasa, 1993), and partly DSL[i/o] (Desired Sensation Level Input-Output, linear compression version; Cornelisse, Seewald & Jamieson, 1995). Supra threshold procedures are LGOB (Allen et al, 1990), IHAFF (Cox, 1995) and partly DSL[i/o]. Among the procedures described above, most commonly used procedure for prescribing hearing aids is NAL-NL1 (Dillon, 1999) and DSL[i/o] (Desired Sensation Level Input-Output, curvilinear compression version; Cornelisse, Seewald & Jamieson, 1995).

The prescriptive formulae, threshold based or suprathreshold based, gives the first approximation of gain required. Practical clinical experiences with prescriptive methods (Lyregagard, 1986; Libby, 1986: Sullivan, Levitt, Hwang & Hennessey, 1988; Dillon, 2001) show that the methods cannot eliminate the need for individual allowances and adjustments i.e. fine tuning of hearing aid. However, one should bear in mind that fine tuning of gain settings in the hearing aids is performed on prescribed gain. The prescribed gain should be a good approximation to preferred gain, which reduces the trial and error by the clinician and also to save time (Dillon, 2001).

Ching et al, (2010) assessed 48 children from Australia and Canada for preference of prescriptive procedures in various conditions. Results demonstrate that, majority of children in Australia preferred NAL-NL1 for 65 dB input level and 80 dB input level and in any other situations. In contradiction to this, children from Canada preferred DSL v.4.1 for any conditions. Similar to these Seewald et al., (2005) demonstrated that preferred gain in children was similar to DSL[i/o] when compared to other prescriptive procedures. Majority of these children were initially fitted with DSL[i/o] program. Similar to this, many other investigators also demonstrated similar results (Scollie, Seewald, Moodie & Dekok 2000; Ching, Hill, & Dillon 2008). The common theme noticed in these studies is that children preferred the hearing aid gain settings that have been prescribed in the initial fitting. All the above studies comparing preferred and prescribed gain were performed on western population. Till date, there is a dearth for studies comparing preferred gain and prescriptive gain settings in Indian context.

Need for the study

As it has been noticed in the past, the gain settings provided by the prescriptive formulae only, is not sufficient to provide the best outcome during the initial fitting itself. For an optimal fitting solution to be achieved, fine tuning in addition to the prescribed formulae becomes all the more important. To satisfy the user at the first fitting itself, we will have to be aware of the changes that have to be brought about along with the prescribed formulae. Therefore, it becomes imperative on our part to know the deviations that occur based on the needs of the user and the degree of hearing loss. Hence, based on the afore mentioned data, it becomes all the more important to study the differences between the preferred gain settings and the most commonly used fitting formulae i.e., NAL-NL1 and DSL[i/o]. These deviations can be studied using various parameters like studying the overall gain at various input levels, REIG data or assessing the aided thresholds

Need to study REIG data

First parameter that can be made use of is to measure the REIG data. Ching et al, (2010) measured REIG data to compare the gain settings and differences in gain prescribed by DSL v.4.1 and NAL-NL1 and they demonstrated that gain preferred by the subjects was similar to the gain prescribed by NAL-NL1 at 65 dB input level. Whereas, at low input level they preferred gain settings prescribed by DSL v.4.1. Similar to this study, many other investigators used REIG as a main measure to look for the differences in the gain settings between preferred and prescribed. In addition, Aazh et al, (2007) had shown that gain prescribed by software program (hearing fitting software) is inadequate by at least ±10 dB than original gain prescribed by prescriptive formulae. So, this becomes a very important parameter while measuring the data as this can lead to an erroneous decision while prescribing hearing aids.

2. Need to study aided thresholds

Aided thresholds are obtained, so that we can compare the thresholds obtained using different prescriptive formulae. DSL v.4.1 generally gives higher gain across the frequency (Ching et al, 2010). DSL v.4.1 prescription enabled children to hear speech more loudly and/or clearly. They also reported better hearing for soft and distant speech as well as sounds within the same surroundings (Ching et al, 2010).

Aim:

The aim of the present study was to compare the difference in gain settings for preferred gain with respect to NAL-NL1 and DSL[i/o] in children using hearing aids.

Objectives:

- To compare the differences in REIG scores across the three conditions (Preferred, NAL-NL1, DSL[i/o]) at 65 dB input level.

- To compare the difference in the aided thresholds obtained across the three conditions (Preferred, NAL-NL1, DSL[i/o]).

Chapter 2

Review of Literature

Cochlear hearing loss in children vary in terms of degree and configuration which creates a necessity for tailor made fitting of the hearing aid for every client. Most common practice in the clinics is to use a prescriptive procedure that takes care of approximate target amplification required for every individual. That is in prescriptive approaches, amplification characteristics required are being calculated based on hearing characteristics of the hearing-impaired individual. In general prescriptive procedures were derived from hearing characteristics and properties of speech spectrum. The prescriptive methods were changed over the years due to advancement in technology, better understanding of hearing characteristics and other factors affecting hearing aid performance.

Prescriptive selection procedures have had a long history and their references can be found even during 1930's. Knudsen and Jones (1935) proposed that the gain needed at each frequency was equal to the threshold loss at the same frequency minus a constant. This is also known as mirroring of the audiogram, because the shape of the gain frequency response equals the inverse of the shape of the hearing loss. The mirroring procedure follows a pattern such that there is a 1 dB increase in additional gain given to overcome every 1dB increase in hearing loss. But it can be deduced by the pattern that the gain prescribed maybe more than necessary at certain frequencies, where the hearing loss and the loudness growth will not be similar for all individuals. Hence, for all higher levels, the amount of gain would be excessive if all gain prescription methods follow mirroring procedure. Mirroring thus leads to excessive gain, especially for those frequencies with the greatest hearing loss (Dillon, 2001).

The next step in this regard was to provide required gain based on the person's most comfortable level (MCL) rather than on their thresholds. Watson and Knudsen (1940) suggested that speech should be amplified sufficiently to make speech energy audible and comfortable. Although their specific formula, incorporated MCL, but did not take into account the variation of speech energy across frequency. In 1944, Lybarger proposed half gain rule based on the observation that people chose the required gain which is approximately half of their hearing loss. Infact, half gain rule and raising speech to MCL, are both very similar .In cases of mild to moderate sensorineural hearing loss, the threshold of discomfort is little different from that in normal hearing individuals. As MCL is approximately half way between threshold of hearing and discomfort, every 2dB increase in hearing loss requires MCL to be raised by 1dB. This is why gain is approximately half of the hearing loss. But the primary aim is to raise speech to MCL, but the speech intensity across the frequency spectrum is not same, such as low frequency components are more intense than the high frequency sounds. Hence, half gain rule needs some modifications, like either increasing gain for high frequencies or by decreasing gain at low frequencies or both (Dillon 2001). Moreover, the half gain rule also needs to be modified for severe and profound hearing losses. When hearing thresholds are greater than 60 dB HL, discomfort thresholds are significantly above normal. So the relationship between threshold, MCL, and discomfort does not remain the same. In this case, MCL is elevated by more than half of the hearing threshold loss. Hence, the gain to be provided must be more than half of the hearing loss (Dillon, 2001).

With all the previous data, it is very clear that even more than 50 years ago, the basis for prescription for gain was based mainly on two auditory attributes, hearing threshold and supra-threshold loudness percept (such as MCL). The link between these is made clear in some procedures where threshold and discomfort levels are measured: but are used to estimate MCL by assuming that MCL bisects the person's dynamic range (Dillon. 2001).

1. Prescriptive Procedures

This complex and intertwining relationship between threshold and loudness perception provides the base for most current procedures for advanced non-linear hearing aids. So far, prescription procedures for non-linear devices can be broadly classified into two categories.

1. Loudness Based procedures : A few of them being Loudness Growth in Octave Bands (LGOB) (Allen, Hall, & Jeng, 1990), Independent Hearing Aid Fitting Forum (lHAFF) (Cox, 1995), ScalAdapt (Kiessling, Schubert, & Arehut, 1996).
2. Threshold Based procedures: Some of them being National Acoustic Laboratory Non-Linear, version 1 (NAL-NLI) (Dillon, 1999),F1G6 (Killon & Fikret-Pasa, 1993), Desired Sensation Level (input/output) (DSL[i/o]) (Cornelisse, Seewald, &Jamicson, 1995)

Nonlinear prescription can be viewed as specifying the gain-frequency response for several levels of input. Both, average gain and frequency response vary with input level. Alternatively, this can be viewed as specifying input-output curve at many frequencies. However, it is totally impractical to prescribe a hearing aid solely based on prescriptive methods as evaluation of the end results, such as fine tuning of the device according to individual needs is essential in all cases (Dillon, 2001). The following section deals with the various prescriptive formulae.

Loudness growth in half-octave bands (LGOB)

LGOB aims to normalize loudness. Here, the client has to rate loudness of narrow-band noises on a 7-point rating scale. The average level corresponding to each loudness category in a hearing impaired person is compared to levels needed in a normal hearing person. Now, for each input level, the gain needed to normalize loudness is found out and applied.

FIG6

This procedure specifies how much gain is required to normalize loudness, especially at medium and high-level input sounds. This is not based on individual measures of loudness but on hearing threshold. Rather, it uses loudness data averaged across a large population with similar degree of hearing loss. Gain is prescribed at input levels of 40, 65 & 95dB SPL and is interpolated for the rest. Generally, for low-level input sounds (40dB SPL), the basis for prescription of gain is that for mild-moderate degree of hearing loss patients should have aided thresholds 20dB above normal hearing threshold. For comfortable level (65dB SPL) input signals, the amount of gain prescribed for any degree of hearing loss is equal to the MCL of the normal hearing population. For high level (95 dB SPL) input signals, the gain prescribed is equal to the boost required to make it equally loud as in a normal hearing person (Dillon 2001).

CAMEQ

This procedure (Moore et al., 1999) aims to place as much of the speech spectrum information as possible above absolute threshold for a given overall loudness. This is achieved by amplifying speech such that, on average, the loudness is similar for a frequency range between 500-5000Hz. The most specific goal is to make the loudness same in each critical band. This goal can be described as amplifying speech so as to give a flat loudness pattern across frequencies. This also aims to achieve equal across different input levels and achieve same overall loudness as normal for speech over a wide input levels.

CAMREST

This procedure (Moore et al., 2000) determines the gain needed to restore perception of loudness to normal for speech like stimuli. This not only attempts to restore overall loudness to normal but also makes the relative loudness across frequency bands the same as ‘normal’. This also aims at normalizing loudness for speech over a wide range of input levels.

In the current day technology, most hearing aids are non – linear, multichannel. They mostly use prescriptive procedures such as NAL NL–1 and DSL[i/o]. The following section will describe these two formulae in detail.

NAL NL-1

The name NAL-NL1 stands for National Acoustics Labs, Non-linear, version 1 and was first described by Dillon in 1999. The underlying assumptions behind this procedure like its predecessors NAL-R and NAL-RP is to maximize speech intelligibility subject to the overall loudness of speech at any level being not more than perceived by a normal hearing person. The main objective of developing NAL-NL1 was to determine the gain for several input levels that would result in maximal effective audibility. This is neither based on loudness normalization nor equalization. However in this procedure the loudness of the signal is varied to such an extent where speech intelligibility is maximized (Byrne et al., 2001).

NAL NL-1 is based on two models: Loudness model (Moore & Glasberg, 1997) & Speech Intelligibility Index (SII). The only information required is the hearing thresholds and the speech spectrum levels input to the ear after amplification. One of the main criterions is that the loudness of an amplified speech should not be louder than that perceived by someone with normal hearing. If the lower levels result in higher SII, gain on the hearing aid will be reduced to achieve higher SII.

NAL NL-1 is based on a complex equation that specifies insertion gain at each standard 1/3 octave frequencies from 125Hz to 8000Hz. For speech input at any level, gain at each frequency was systematically varied with a high speed computer until the calculated speech intelligibility was maximized, but without the calculated loudness exceeding that loudness calculated for normal hearing people listening to speech at the same level. This procedure was repeated for many representative audiograms and the optimized gains for each audiogram, for each input level were found. As this was a very time consuming process, even for a single audiogram at a single input level, an equation was fitted to the complete set of optimized gains. This equation thus summarizes all the optimizations and can be applied to any audiogram. Alternately, the aid can be prescribed in terms of real ear aided gain (REAG). REAG is deduced from insertion gain by adding the adult average real ear unaided gain (REUG) to the insertion gain target (Dillon, 2001).

The NAL – nonlinear software program displays the results as either gain curves at different levels, or I/O curves at different frequencies. These curves can be for a 2 – cc coupler, an ear simulator, or the real ear. In case of real ear prescription, the gains can be either insertion gain or REAG. For multichannel hearing aids, crossover frequencies, compression thresholds, compression ratios and gains for 50, 65 and 80dBSPL input levels were also recommended by NAL software.

Amplification requirements for people with mixed losses are fulfilled in two steps. First, by applying the gain formula to the sensorineural part of the person's hearing loss (i.e. the bone conduction thresholds) and then calculating the gain equivalent to 75% of the conductive part of the loss (i.e., the air bone gap) and then adding them (Dillon, 2001).

DSL [i/o]

This fitting strategy is just like its predecessor DSL and is based on loudness equalization or normalization. Loudness normalization means that sounds that appear soft to a normal hearing person should be audible soft, after amplification, to the hearing-impaired person. Similarly, sounds that are comfortable or loud, for the normal hearing person should be comfortable or loud, respectively, after amplification for the hearing aid user. There are basically two aspects of normalization. First, the overall loudness of sounds is normalized. This means for any input level and frequency would be equally loud far a normal hearing individual and to a hearing impaired person after amplification Second, the relative loudness of each frequency components of complex sounds will be preserved. By equalization, it means that all frequency bands of speech will be amplified sufficiently to produce equal loudness of speech.

The name DSL[i/o] stands for Desired Sensation Level [Input/Output] and was first described by Cornelisse, Seewald and Jamieson in 1995. DSL[i/o] Method provides prescriptive targets for the fitting of wide-dynamic-range compression hearing aids. DSL[i/o]'s goals were to have loud sounds not exceed the individuals uncomfortable listening level, make speech undistorted and audible across a wide range of input levels without discomfort, and to normalize loudness (Cornelisse et al., 1995). DSL[i/o] utilizes low-compression thresholds to increase audibility of softer speech sounds. The DSL[i/o] method has the goal of fitting "the acoustic region corresponding to the extended normal auditory dynamic range into hearing-impaired individual's residual auditory dynamic range" (Cornelisse et al., 1995). The method is based on 'complete' compensation for recruitment, which in turn means restoration of dynamic range to normal and complete restoration of audibility of speech sounds.

3. Comparison of different prescriptive procedures

In the following section, an attempt has been made to compare amongst the various prescriptive methods and preferred gain settings. It can be said that even though there are a lot of fitting strategies for non-linear hearing aids, it is very difficult to definitely ascribe any one of them as the best. Also, it is important to know which rationale works best when listening to a range of input levels that hearing aid users are exposed to in real life situations. Here is a brief summary regarding the few studies that have been conducted in this regard.

Ching, Scollie, Dillon, Seewald, (2010), compared the relative effectiveness of the NAL-NL1 and the DSL v.4.1 prescription procedures for children with mild to moderately severe hearing loss. 48 subjects were taken for this study and this study was being conducted simultaneously in Australia and Canada. Evaluations for this study included speech perception tests, loudness ratings, paired comparison judgements of intelligibility, and children’s preferences and performances in real-world environments. This study was divided into various trial periods. During the first trial period, half of the participants received the NAL-NL1 and the other half the DSL v.4.1 prescription fitting. This was carried for 8 weeks after which, each participant received the other prescription for the second trial period of another eight weeks. During the third and fourth trial periods, both prescriptions were put into separate programs in their respective hearing aids for access using a remote control by the participants at all times. Each of the third and fourth trial periods were for duration of four weeks. At the end of each trial period, battery of tests was administered for assessment. Results indicated that the DSL v.4.1 procedure prescribed higher gain (0.5 to 4 kHz) than the NAL-NL1 prescription on average by 10 dB. It was also noted that across trials 1 and 2, more negative comments about noise disturbance was associated with DSL v.4.1 than with NAL-NL1, and positive comments about loudness comfort was associated with NAL-NL1 than with DSL v.4.1. They also reported that across trials 3 and 4, more positive comments about listening to soft speech and speech from a distance or behind were associated with DSL v.4.1 than with NAL-NL1. The authors concluded that, the findings imply that the gain requirements of children in real-life situations are not met prescribed either by NAL-NL1 or the DSL v.4.1 prescription. Hence, to achieve optimal audibility of soft speech, children need more gain than what is prescribed by NAL-NL1 and to achieve listening comfort in noisy places, children need less gain than what is prescribed by DSL v.4.1

Seewald, Moodie, Scollie, & Bagatto, (2005), compared NAL prescription, the CAMFIT procedure and DSL[i/o] in children. They found that for most of the audiometric configurations, the real-ear aided gain targets were similar in shape for the three prescriptive algorithms. And in contrast to popular assumptions, the DSL[i/o] algorithm did not always generate the maximum REAG target for a given audiometric profile. They also found that consistent with the habilitative audibility approach (Ling, 1989; Scollie, 2005), the DSL[i/o] algorithm generated the maximum REAG target the greatest percentage of time for the high frequencies. And finally consistent with the effective audibility approach (Ching, Dillon, Katsch, and Byrne, 2001), the NAL-NL1 prescriptive algorithm did not generate targets for all frequencies, especially for more severe-to-profound hearing losses.

Ching, Hill, Dillon (2008), examined the effect of variations in hearing-aid frequency response on real-life functional performance of children with severe to profound hearing loss. A cross-over design was used in a double-blind comparison of the NAL prescription with alternatives that produced either a BOOST or a CUT (6dB/octave from 500 Hz to 2000 Hz), relative to the NAL response. The functional performance of 30 children (aged 7 months to 16 years) when wearing hearing aids adjusted to each response over two to four weeks was assessed by using parents’ and teachers’ observations (PEACH and TEACH scales). Intelligibility judgments and self-reports were also obtained from school-aged children. Results indicated that on average, variations in frequency response resulted in differences in functional performance in real life. There were significant correlations between PEACH and TEACH, and also between children's intelligibility judgments and subjective reports from children and their parents and teachers. The findings support the use of the NAL response for initial fitting, and the evaluation of children's amplification needs by a systematic use of parents’ and teachers’ observations.

Scollie, Seewald, Moodie. & Dekok (2000), they compared preferred, NAL-NL1, NAL-RP, and DSL v.4.1 prescriptive formulas in children. The preferred listening levels (PLLs) of children with sensorineural hearing loss were elicited using conversation-level speech, heard through the children's own hearing aids. All hearing aids were fitted using the desired sensation level (DSL) method. Comparisons were made between the PLL and targets from the following prescriptive formulae: DSL version 4.1 and two versions of the National Acoustic Laboratories (NAL) procedure, including NAL revised for severe-profound losses (NAL)-RP and NAL nonlinear NAL/NL1. Results for this sample of children indicated that the PLL was similar to the DSL v.4.1 targets, and that, on average, NAL-RP/NL1 targets recommended less gain than that preferred by the majority of children.

Byrne, Dillon, Ching, Katsch, Keidser (2001), described a new procedure for fitting nonlinear hearing aids (National Acoustic Laboratories' nonlinear fitting procedure, version 1 [NAL-NL1]). The rationale is to maximize speech intelligibility while constraining loudness to be normal or less. Speech intelligibility is predicted by the Speech Intelligibility Index (SII), which has been modified to account for the reduction in performance associated with increasing degrees of hearing loss, especially at high frequencies. Prescriptions are compared for the NAL-NL1, desired sensation level [input/output], FIG6, and a threshold version of the Independent

Hearing Aid Fitting Forum procedures. For an average speech input level, the NAL-NL1 prescriptions are very similar to those of the well-established NAL-Revised, Profound procedure. Compared with the other procedures, NAL-NL1 prescribes less low-frequency gain for flat and upward sloping audiograms. It prescribes less high-frequency gain for steeply sloping high-frequency hearing losses. NAL-NL1 tends to prescribe less compression than the other procedures.

Snik, (1995), evaluated three of the methods (NAL-PD, POGO-II, DSL) by comparing the calculated and measured gain as a function of frequency in a selected group of profoundly hearing impaired children. Fair agreement was found for the modified NAL rule applicable in profoundly hearing impaired subjects and the DSL method. POGO-II gave most deviations in the result. POGO-II prescribed little gain at 250Hz and 500Hz. NAL-PD proved to be the most adequate rule for obtaining the desired insertion gain, immediately followed by DSL method

Ching, Newall, Wigney (1997), compared the gain and frequency response given by NAL-RP and DSL 3.authors found that NAL-RP procedure provides an adequate prescription of amplification on average. The discrepancies between prescribed and preferred characteristics implies the need of fine tuning

Ching, (2002), commented on effective amplification for children. Ching stated that the prescriptive targets produced by the two formulas are markedly different for people with severe hearing losses or for people with flat or steeply sloping losses. For flat losses, NAL-NL1 prescribes less low-frequency gain than DSL[i/o]. For severe and sloping losses, NAL-NL1 prescribes less high-frequency gain than DSL[i/o]. The prescriptions are similar for moderate, gently sloping losses. The DSL[i/o] assessment and verification protocols are well suited to children, and could also be used for adults. The targets are different because the two prescriptions have different rationales and, hence, different formulas for calculating gains. NAL-NL1 attempts to provide the best combination of gains at different frequencies to maximize calculated speech intelligibility. The prescriptive targets produced by the two formulas are markedly different for people with severe hearing losses or for people with flat or steeply sloping losses. For flat losses, NAL-NL1 prescribes less low-frequency gain than DSL[i/o]. For severe and sloping losses, NAL-NL1 prescribes less high-frequency gain than DSL[i/o]. The prescriptions are similar for moderate, gently sloping losses.

Ching, Hill, Birtles, Beecham (1999), A paired comparison test checked whether alternative frequency response works better than the NAL-RP prescription for speech intelligibility. Using a programmable hearing aid, a child compared speech amplified with the NAL-RP prescription to alternative amplification with either more low frequencies or less low and more high frequencies than the prescription. If alternative frequencies were found to be no better than prescription, the prescription was deemed optimal. Tests were completed on the children using phoneme identification task and teachers, observations of performance. Results of the paired comparison test indicate the NAL-RP prescription provides a good starting estimate of what was close to optimal.

Snik, Stollman (1994), reported that the insertion gain measured in children with symmetrical sensorineural hearing loss, who were fitted successfully with binaural hearing aids, was compared in retrospect to the calculated IG using two different prescriptive methods: the half gain rule (HGR) and the DSL. The measured and calculated values were in fair agreement with the results of both of the prescription methods. The desired saturated sound pressure levels calculated using the DSL method and those measured on a 2-cc coupler were in fair agreement.

Therefore, from the above studies it is very evident that children prefer the prescriptive formula which has been prescribed during the initial fitting of the hearing aid. The same has been noticed for speech perception studies as well. Hence, it is very important to measure the differences in the gain prescribed by the various prescriptive formulae, if any. This has been studied using REIG measures, aided threshold measurements and speech perception studies, if possible.

Chapter 3

Method

Participants

Ten (18 ears) participants, having sensory-neural hearing loss who had been clinically diagnosed as having cochlear hearing loss at Department of Audiology, All India Institute of Speech and Hearing, Mysore participated in the present study. All the participants were regular hearing aid users; the minimum duration of hearing aid use is more than one year. The age of the participant's ranged from 6-12 years with the mean age of 7.5 years. Pure tone average ranged from 93-110 dB HL. It was ascertained from a structured interview that none of these participants had any history of neurologic or otologic disorder. The demographic and audiological data of the participants, which includes degree of hearing loss, speech detection threshold, hearing aid being used and the duration of hearing aid use, is provided in Table 3.1. The pure-tone thresholds (average of both the ears) at octave frequencies of each participant have been provided in Figure 3.1.

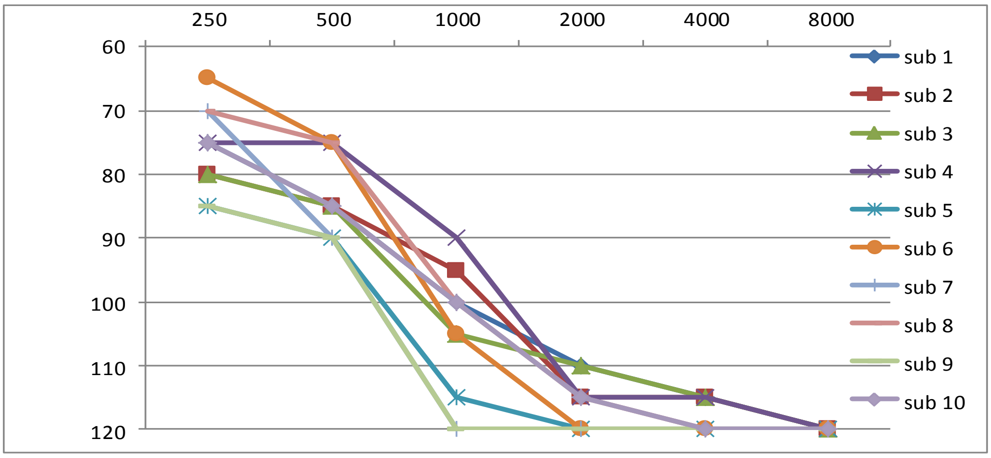

Fig: 3.1: Pure-tone thresholds as a function of frequency for all the participants.

S.I. No.	Age/ Sex	Pure Tone Average (dB)		Speech Detection Threshold (dB)		Hearing aid model	Duration of HA use
		Right	**Left**	**Right**	**Left**		
1	6/F	________	100	_______	75	Eclipse 2SP	24 months
2	6/M	101.66	101.66	85	85	Eclipse 2SP	18 months
3	12/ M	98.33	93.33	85	85	Eclipse 2SP	21 months
4	7/M	100	100	85	85	Eclipse 2SP	14 months
5	6/M	93.33	93.33	85	85	Eclipse 2SP	13 months
6	9/F	108.33	101.66	85	85	Eclipse 2SP	25 months
7	7/M	100	101.66	85	85	Eclipse 2SP	5 months
8	6/F	110	________	85	_________	Eclipse 2SP	15 months
9	6/F	96.6	108.33	85	85	Eclipse 2SP	24 months
10	10/F	110	93.33	85	85	Eclipse 2SP	20 months

Table 3.1*: Demographic and audiological data of participants with cochlear hearing loss.*

Pre-testing procedure

On Otoscopic examination, all participants had ear canals that were free from cerumen, debris or foreign body. This was followed by estimating audiometric thresholds for Air Conduction at 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz and 8000Hz and Bone Conduction at 250Hz, 500Hz, 1000Hz, 2000Hz and 4000Hz using Modified Hughson & Westlake procedure (Carhart & Jerger, 1959). The thresholds obtained were compared with pure-tone thresholds obtained during prior first hearing aid fitting. None of the participants had a shift in their threshold by more than 10 dB in air conduction or bone conduction mode in any of the frequencies. All the subjects had normal middle ear functioning and the same was confirmed by testing with GSI-Tympstar Immittance meter.

Test Environment

All the testing was conducted in an air conditioned, acoustically treated double room set up. The ambient noise levels inside the test room were within permissible limits (ANSI S3.1 1991).

Instrumentation

1. Orbiter OB-922 (Madsen Electronics, Denmark), two channel diagnostic audiometer calibrated (ISO 389-1) with supra aural head phones (Telephonics TDH-39), bone vibrator (Radio ear B-71), loudspeakers (Madsen) were used to assess the pure-tone threshold and the aided threshold.
2. Hearing aid type: Electone Eclipse 2 SP hearing aid was used in the present study. Above mentioned hearing aid incorporates features such as two-channel, adjustable cross-over frequency and dual / syllabic compression. The compression ratios are set by the software according to the specified prescriptive procedure. This particular model was selected because they are most commonly used by most of the participants.
3. FONIX 7000 hearing aid analyzer was used to check the electro-acoustic characteristics of the hearing aid and also the real ear aided gain (REAG) measurements.
4. Hardware and software to program the hearing aids. A personal computer connected to HIPRO for programming the hearing aid. The NOAH software

(version 3.1.2) and the hearing aid specific software (Electone) along with Win CHAP (Computerized Hearing Aid Programme for windows, version 2.82) were installed in this computer.

Procedure

1. Aided Threshold

Aided thresholds were found for puretone of 500Hz, 1000Hz, 2000Hz, 4000Hz, using preferred gain setting initially and the similar procedure was carried out using NAL-NL1 and DSL[i/o]. Puretone's were presented through loudspeakers placed at ear level, 0 degree azimuth and at a distance of 1 metre.

2. Speech Detection Threshold

Speech Detection Threshold was assessed using live voice presentation. The minimum intensity at which the subjects were able to detect the presence of sound was found. Speech was presented through the loud speakers placed at ear level, 0 ° azimuth and at a distance of 1 metre.

3. Real Ear Measurements

a. Real Ear Unaided Response (REUR)

This was measured for the subjects without wearing the hearing aid using FONIX 7000 hearing aid analyzer by using Digispeech as the stimuli at 65dBSPL as the input. The loudspeaker was kept at a distance of 12 inches and at 45 degree to the pinna (as specified in the FONIX 7000 user manual). A probe microphone was placed inside the subject's ear at a distance equal to the length of ear mould plus 5 mm. Before the stimulus was presented, leveling of the stimulus was done. The stimulus was presented and the output was represented in the form of a graph on the screen and once the graph on the screen was stabilized for more than 10 seconds, the input was stopped. Now, the graph was converted to real ear unaided scores and the values were noted down.

b. Real Ear Aided Response (REAR)

The subject's hearing aid was connected to the HIPRO using the programming cable and the HIPRO was connected to the computer. Once connected, the gain and program settings (preferred) in the hearing aid was noted down. And REAR was measured for the preferred gain. The values were noted down. The aided audiogram for the preferred gain was also found in free-field using Orbiter OB-922, two channel diagnostic audiometer. The hearing aid was re-programmed using NAL-NL1, and the REAR was measured and the values were noted down. Aided audiogram was found for NAL-NL1. Similar procedure was done using DSL[i/o].

REAR was measured for the preferred, NAL-NL1 and DSL[i/o] gain settings in all the subjects using the FONIX 7000 hearing aid analyzer by using Digispeech as the stimuli at 65 dB SPL as the input. The loudspeaker was kept at a distance of 12 inches and at 45 degree to the pinna (as specified in the FONIX 7000 user manual). A probe microphone was placed inside the subject's ear at a distance equal to the length of ear mould plus 5 mm. Before the stimulus was presented, leveling of the stimulus was done. The stimulus was presented and the output was represented in the form of a graph on screen and once the graph onscreen was stabilized for more than 10 seconds, the input was stopped. Now, the graph was converted to real ear aided scores and the values were noted down.

Comparisons across all the aided conditions were made and the results have been discussed in the next section.

Chapter 4

Results and Discussion

The present study was carried out with the aim to find out the difference between the outcomes of preferred gain settings and prescribed gain settings using NAL NL-1 and DSL[i/o] fittings strategies in children using hearing aids. The REIG and aided audiogram data were collected and tabulated for further analysis. Statistical analyses were done using SPSS Statistics Package (version 17).

The following statistical analysis were carried out on the data

- Descriptive statistics were carried out to find out the mean and standard deviations in the data

- One-way ANOVA (Analysis of Variance) was carried out to find out if there was any significant difference between the groups with the level of significance being 0.05

- Bonferroni post-hoc analysis was done to estimate which groups had a significant difference with the level of significance being 0.05.

1. Comparison of REIG

Using the REUR data and REAR data, the REIG (Real Ear Insertion Gain) data was calculated for each subject at each frequency for all the three conditions. This was calculated using the formula descried by Dillon (2001). REIG values were calculated only at octave and mid octave frequencies.

Real Ear Insertion gain (REIG) = REAG – REUG

REAG =Real ear aided gain, REUG = Real ear unaided gain

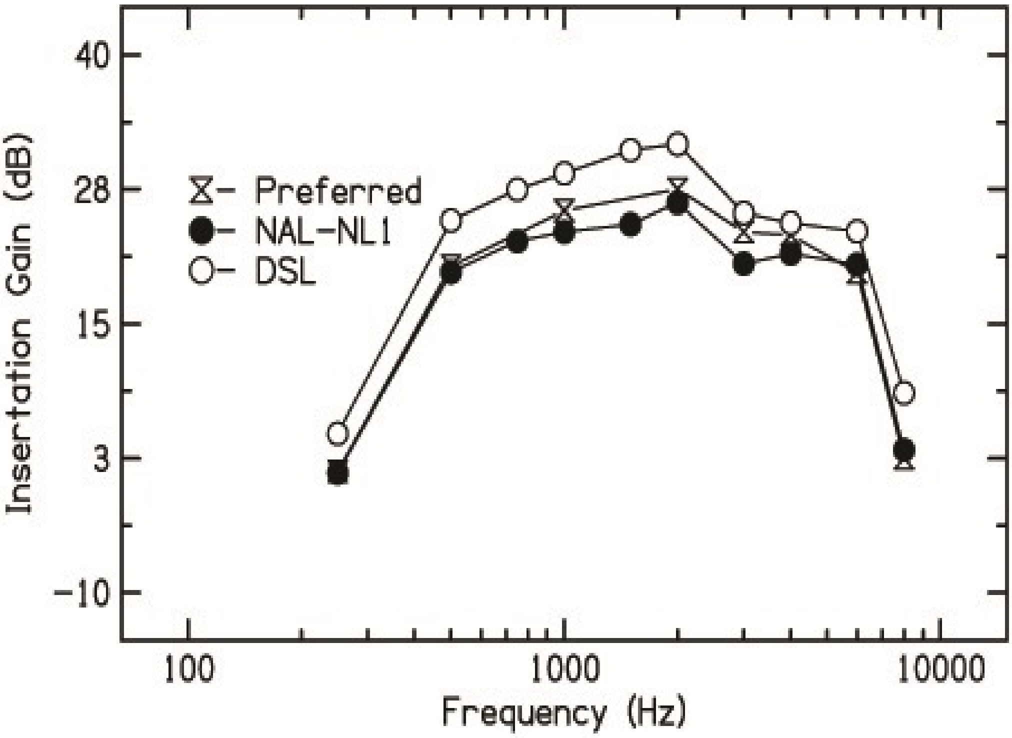

Figure 4.1: REIG values across frequencies for preferred, NAL-NL1 and DSL[i/o].

Figure 4.1 represents the mean values of the REIG scores across frequency for all the three conditions at 65 dB SPL input signal. As it can be seen from the figure, there is a difference in the mean value across frequency in the three conditions. At the low frequency region, till about 800Hz, REIG values of DSL[i/o] condition is greater than preferred condition and NAL-NL1. In the same region REIG is similar for NAL-NL1and preferred condition. At mid and high frequencies, REIG scores for the DSL[i/o] condition is higher than those observed for NAL-NL1 and preferred condition. At the high frequency region, for DSL[i/o] and preferred condition higher REIG than compared to NAL-NL1. At the extreme high frequency region, the mean scores have dipped in all the three conditions because the frequency response of the hearing aid is limited up to 4000 Hz to 5000 Hz.

One-way ANOVA was carried out to find out if the mean difference of REIG scores is significant in the three conditions at all the frequencies. The data of 8 kHz was not considered in the analysis. The analysis revealed that there was a significant difference between the conditions at 250 Hz ($F_{(2,490)} = 1.133$, $p<0.05$), 500 Hz ($F_{(2,810)} =1.005$, $p<0.05$), 1000Hz ($F_{(2,862)} =1.301$, $p<0.05$) input frequency, whereas for other higher frequencies no significant difference was noticed (2000Hz , 4000Hz and 6000Hz). Post-hoc Bonferroni analysis showed that there no significant difference across conditions except DSL[i/o] was different at 250Hz, 500Hz, 1000Hz , from other two conditions.

Results of the REIG indicate that preferred gain is approximately similar to NAL-NL1. Whereas gain prescribed by the DSL [i/o] is higher at low frequencies compared to other conditions. Ching et al, (2010), reported that DSL v.4.1 always provides higher gain when compared to NAL-NL1. Further they also reported that majority of the children preferred gain prescribed by NAL-NL1 at 65 dB input level compared to DSL v.4.1. The results of the present study are in accordance that those observed by Ching et al, (2010). Similar to the present study many other investigators also reported similar results (Ching et al, 1997, Snik et al, 1995, Ching et al, 2000). The precise reason for NAL-NL1 and preferred conditions is not known. A serious of studies conducted by Ching et al, (2010) reported that children from the Australia preferred NAL-NL1 over DSL v.4.1, on contrary children from the Canada preferred DSL v.4.1. These results shows that, children auditory system prefers the gain settings prescribed during initial fitting (may allow small variations), i.e children in Australia by default prescribed with NAL-NL1, similarly children from Canada were prescribed with DSL v.4.1. In the present study almost all the participants were prescribed with NAL-NL1 in the initial fitting. Because of the above reason, there was no significant difference between gain settings of NAL-NL1 and preferred condition.

2. Comparison of Aided Audiogram

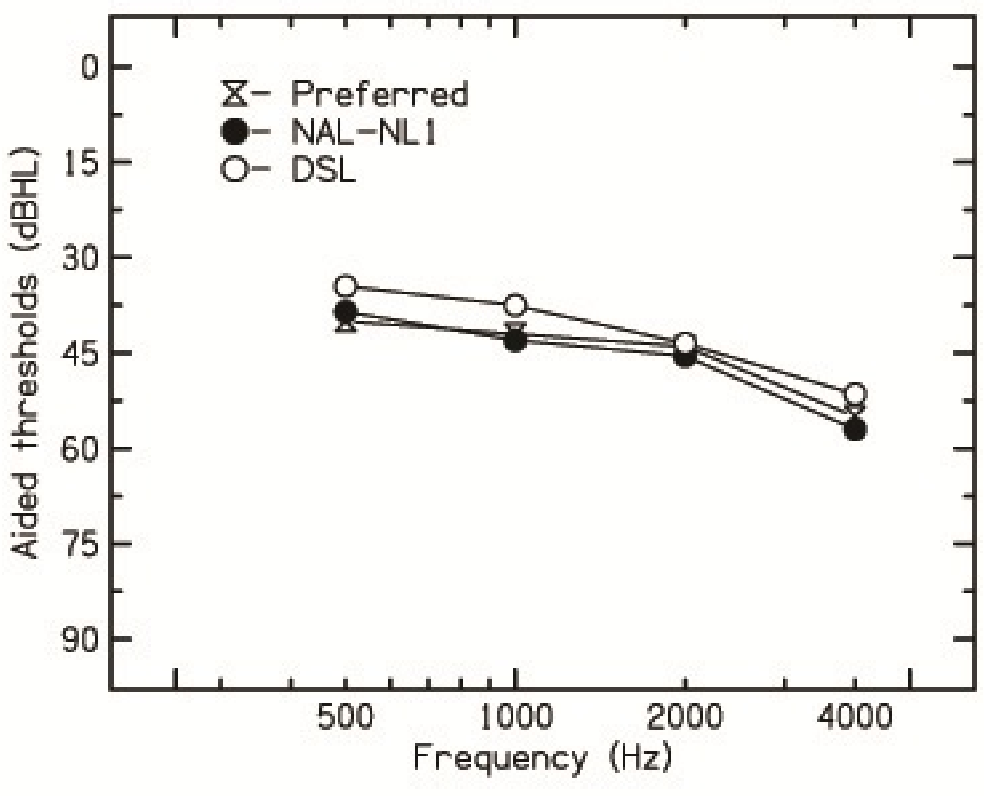

Figure 4.2: Aided thresholds as function of frequency for preferred, DSL[i/o] and NAL-NL1

Figure 4.2 shows the mean aided threshold values as a function of frequency across conditions. One can note that DSL[i/o] has slightly lesser thresholds compared to NAL-NL1 and preferred. According to a study by Ching et al, (2010), positive comments about listening to softly spoken speech as well as speech from a distance or behind were associated with DSL v.4.1 than with NAL-NL1, (Ching et al, 2010). Individual children in Australia consistently preferred either theNAL-NL1 prescription or the DSL v.4.1 prescription across trial periods and across different preference measures. Those children preferring the NAL-NL1 prescription did so because they were less troubled by loud sounds and reported hearing speech better in situations where there were competing noises. Those children preferring the DSL v.4.1 prescription did so because it enabled them to hear speech more loudly and/or clearly. They also reported better hearing for soft and distant speech as well as sounds within the environment.

Overall, the results demonstrate that the REIG scores for DSL [i/o] are higher al low and mid frequencies than preferred condition and NAl-NL1. At, high frequencies, REIG scores of preferred condition were similar to gain prescribed by DSL [i/o]. And also the aided thresholds for DSL[i/o] were better than the other conditions. Hence, the results of this present study warrant further research in this direction to cross-verify the results of the present study.

Chapter 5

Summary and Conclusion

The present study was carried out to compare the outcome measures between preferred gain settings and prescribed gain settings in children using hearing aids. The formulae that was taken for comparison were NAL-NL1 and DSL[i/o] (version 4.1) as these are the most commonly used prescriptive formulae used across the world. Ten (18 ears) participants, having profound sensory-neural hearing loss participated in the present study. All the participants were regular hearing aid users; the minimum duration of hearing aid use being more than one year. The age of the participant's ranged from 6-12 years with the mean age of 7.5 years. Hearing aid used in the present study was Electone Eclipse 2 SP.

For all these participants, Speech Detection Threshold (SDT) was found out, both in unaided and aided conditions. After this, REUR and REAR were measured at an input level of 65 dB SPL. REAR was measured under three conditions, i.e., preferred, NAL-NL1 & DSL[i/o], after programming the hearing aid, separately and the aided values were noted down.

The main findings of the present study were

- At the low frequency region, till about 800Hz, REIG values of DSL[i/o] condition is greater than preferred condition and NAL-NL1. In the same region REIG is similar for NAL-NL1and preferred condition. At mid and high frequencies, REIG scores for the DSL[i/o] condition is higher than those observed for NAL-NL1 and preferred condition. At the high frequency region, for DSL[i/o] and preferred condition higher REIG than compared to NAL-NL1.

- The analysis revealed that there was a significant difference between the conditions at 250 Hz, 500 Hz, 1000 Hz input frequency, whereas for other higher frequencies no significant difference was noticed (2000Hz, 4000Hz & 6000Hz).
- Results of the REIG indicate that preferred gain is approximately similar to NAL-NL1. Whereas gain prescribed by the DSL[i/o] is higher at low frequencies compared to other conditions.
- Comparison of aided data revealed that DSL[i/o] has slightly lesser thresholds compared to NAL-NL1 and preferred.

The results have shown that the gain prescribed by NAL-NL1 and the preferred gain settings is almost similar across frequencies. This may be due to the fact that during initial fitting, the hearing aid is programmed using NAL-NL1 and fine tuning is done based on the gain provided by NAL-NL1 during the initial fit.

In children, usually fine tuning is a difficult process when compared to adults. This is because the clinician is not able to arrive at the precise threshold at different frequency, because most often than not, the thresholds are established using behavioral tests in children. Hence, usually the gain given during the initial fit will be lower compared to the target gain prescribed. And also DSL[i/o] provides overall higher gain when compared to NAL-NL1 and preferred during the initial fit only. So this could be the reason why DSL[i/o] have better aided thresholds.

Future implications

- The comparisons in the present study were done based on the data of ten subjects, only. Probably the study can be carried on further by comparing it using more no of participants.
- More number of variables like degree of hearing loss, different input levels, duration of hearing aid use can be taken up and researched up on.

References

Aazh, H., & Moore, B. C. J. (2007). The value of routine real ear measurement of the gain of digital hearing aids. *Journal of American Academy of Audiology. 18,* 653–664.

Allen, J., Hall, J. L, & Jeng, P. (1990). Loudness growth in ½ octave bands (LGOB): a procedure for the assessment of loudness. *Journal of Acoustic Society of America. 88, 745-753.*

American National Standards Institute. (1991). Maximum permissible ambient noise levels for audiometric test rooms (ANSI S3.1-1991). New York: ANSI.

Bess, F.H., Dodd-Murphy, J., & Parker, R.A. (1998). Children with minimal sensorineural hearing loss: Prevalence, educational performance, and functional status. *Ear & Hearin,. 19(5)*, 339–354.

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

Byrne, D., & Dirks, D. (1996). Effects of acclimatization and deprivation on non-speech auditory abilities. *Ear Hearing,17(3 Supplement)*, 29S-37S.

Byrne, D., Dillon. H., Ching. T., Katsch, R.., & Keidser, G. (2001). NAL-NL1 procedure for fitting non-linear hearing aids: Characterstics and comparison with other procedures. *Journal of American Academy of Audiology, 12 (1*), 37-51.

Carhart, R., & Jerger, J. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders, 24*, 330–345.

Ching ,T.Y.C., Hill, M., & Dillon, H. (2008). Effect of variations in hearing-aid frequency response on real-life functional performance of children with severe or profound hearing loss. *International Journal of Audiology, 47(8),* 461–475.

Ching T.Y.C., Scollie S.D., Dillon H., Seewald R., Britton L., Steinber, J., Gilliver, M., & King, K. A. (2010b). Evaluation of the NAL NL1 and the DSL v.4.1 prescriptions for children: paired-comparison judgments and functional performance ratings. *International Journal of Audiology, 49*, S35–S48.

Ching, T.Y., Dillon, H., Katsch, R., & Byrne, D. (2001). Maximizing effective audibility in hearing aid fitting. *Ear Hearing, 22*, 212-224.

Ching, T.Y., Newall, P., & Wigney. D. (1997). Comparison of severely and profoundly hearing impaired children's amplification preferences with the NAL-RP and the DSL 3.0 prescriptions. *Scandinavian Audiology, 26(4),* 21-22.

Ching, T.Y.C. (2002). Effective amplification for hearing-impaired children. *Hearing Journal, 55(4),* 17-18.

Ching, T.Y.C., Britton, L., Dillon, H., & Agung, K. (2002). RECD, REAG, NALNL1: Accurate and practical methods for fitting non-linear hearing aids to infants and children. *Hearing Review, 9(8*), 12–20.

Ching, T.Y.C., Hill, M., & Dillon, H., (2008). Effect of variations in hearing-aid frequency response on real-life functional performance of children with severe or profound hearing loss. *International Journal of Audiology, 47 (8)*, 461–475.

Ching, T.Y.C., Hill, M., Birtles, G., & Beecham L. (1999). A Sound Foundation Through Early Amplification: Clinical use of paired comparisons to evaluate hearing aid fitting of severely/profoundly hearing impaired children. *Australian and New Zealand Journal of Audiology*, 21, 51–63.

Ching, T.Y.C., Hill, M., Birtles, G., & Beecham L. (1999). Clinical use of paired comparisons to evaluate hearing aid fitting of severely/profoundly hearing impaired children. *Australian Journal of Audiology*, *21(2)*,51-63.

Ching, T.Y.C., Scollie, S.D., Dillon, H., & Seewald, R. (2010). A cross-over, double-blind comparison of the NAL-NL1 and the DSL v4.1 prescriptions for children with mild to moderately severe hearing loss. *International Journal of Audiology*, *49*, S4–S15.

Ching, T.Y.C., Scollie, S.D., Dillon, H., Seewald, R., Britton, L., & Steinberg, J. (2010). Prescribed real-ear and achieved real-life differences in children's hearing aids adjusted according to the NAL-NL1 and the DSL v.4.1prescriptions. *International Journal of Audiology*, *49*, S16–S25.

Cornelisse, L.E., Seewald, R.C., & Jamieson, D.G. (1995). The input/output (i/o) formula: A theoretical approach to the fitting of personal amplification devices. *Journal of the Acoustical Society of America*, *97*, 1854–1864.

Cox, R.M. (1995). The Using loudness data for hearing aid selection: The IHAFF approach. *The Hearing Journal*, *48(2)*, 10-44.

Dillon, H. (1999). NAL-NL1. A new prescriptive fitting procedure for non-linear hearing aids. *The Hearing Journal*, *52(4)*, 10-16.

Dillon, H. (2001). *Hearing Aids*. Turramurra, Boomerang press.

Keidser, G., Carter, L., Chalupper, J., & Dillon, H. (2007). Effect of low-frequency gain and venting effects on the benefit derived from directionality and noise reduction in hearing aids. *International Journal of Audiology*, 46, 554– 568.

Kiessling, J., Schubert, M., & Archut, A. (1996). Adaptive fitting of hearing instruments by category loudness scaling (ScalAdapt). *Scandinavian Audiology*, *25,* 153–60.

Killion, M.C., & Fikret-Pasa, S. (1993). The 3 types of sensorineural hearing loss: Loudness and Intelligibility considerations. *The Hearing Journal*, *46(11),* 1-4.

Knudsen, V. O., & Jones, I. H. (1935). Artificial aids to hearing. *Laryngoscope*, 45, 48–69.

Libby, E.R. (1985). The 1/3-2/3 insertion gain hearing aid selection guide. *Hearing Instruments*, *3,* 27-28.

Ling, D. (1989). Foundations of Spoken Language for Hearing Impaired Children. Washington, DC: The Alexander Graham Bell Association for the Deaf.

Moore, B.C.J. (2000). Use of a loudness model for hearing aid fitting. IV, Fitting hearing aids with multi-channel compression so as to restore ‘normal’ loudness for speech at different levels. *British Journal of Audiology*, *34,* 165-177.

Moore, B.C.J., & Glasberg, B.R. (1997). A model of loudness perception applied to cochlear hearing loss. *Auditory Neuroscience, 3,* 289-311.

Moore, B.C.J., Peters, R.W., & Stone, M.A. (1999b). Benefits of linear amplification and multi-channel compression for speech comprehension in backgrounds with spectral and temporal dips. *Journal of Acoustic Society of America, 105,* 400-411.

of hearing aid gain. *British Journal of Audiology, 29*, 271–277.

Scollie, S.D. (2005). Prescriptive procedures for infants and children. In Seewald R, Bamford J, editors: A Sound Foundation Through Early Amplification 2004: Proceedings of the Third International Conference. Stäfa, Switzerland: Phonak AG, 91-104

Scollie, S.D., Seewald, R.C., Moodie, K.S.. & Dekok, K. (2000). Preferred listening levels of children who use hearing aids: Comparison to prescriptive targets. *Journal of American Academy of Audiology, 11,* 230–238.

Smeds, K. (2004). Is normal or less than normal overall loudness preferred by first-time hearing aid users? *Ear and Hearing, 25,* 159–172.

Snik, A.F.M., & Stollman, M.H.P. (1994). Measured and calculated insertion gains in young children. *British Journal of Audiolog,*.29, 7-11.

Snik, A.F.M., Borne, S., Brokx, J.P.L., & Hoekstra, C.(1995). Hearing aid fitting in profoundly hearing impaired children: Comparison of prescription rules. *Scandinavian Audiology, 24,* 225-230.

Sullivan, J. A., Levitt, H., Hwang, J., & Hennessey, A. (1988). An experimental comparison of four hearing aid prescription methods. *Ear and Hearing, 9,* 22–32.

Swan, I. R. C., & Gatehouse, S. (1995). The value of routine in-the-ear measurement

Watson, N.A., & Knudsen, V.O. (1940). Selective amplification in hearing aids. *Journal of Acoustic Society of America, 11,* 406-419.