COMPARISON OF THRESHOLD - BASED PRESCRIPTIVE FORMULAE FOR NON-LINEAR HEARING AIDS

Reg. No. 02SH0020

An independent project in part fulfillment for the first year
M.Sc. (Speech and Hearing) to University of Mysore, Mysore.

All India Institute of Speech and Hearing
Manasagangothri
Mysore - 570006

May - 2003

Dedicated to the Lord Almighty

Every good gift & every perfect gift is from
above & cometh down from the
Father of lights, with whom is no variableness,
neither shadow of turning.
(James 1:17)

CERTIFICATE

This is to certify that this Independent Project entitled **"COMPARISON OF THRESHOLD - BASED PRESCRIPTIVE FORMULAE FOR NON-LINEAR HEARING AIDS"** is a bonafide work in part of fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No. 02SH0020).

Mysore
May, 2003

Dr. M. **JaySram**
Director
All India Institute of Speech and Hearing
Mysore - 570 006

CERTIFICATE

This is to certify that this Independent Project entitled **"COMPARISON OF THRESHOLD - BASED PRESCRIPTIVE FORMULAE FOR NON-LINEAR HEARING AIDS"** has been prepared under my supervision and guidance. It is also certified that this project has not been submitted earlier in any other University for the award of any Diploma or Degree.

Guide

Dr. K. Rajalakshmi
. Lecturer
Department of Audiology
All India Institute of Speech and Hearing
Mysore - 570 006

Mysore

May, 2003

DECLARATION

This Independent Project entitled **"COMPARISON OF THRESHOLD - BASED PRESCRIPTIVE FORMULAE FOR NON-LINEAR HEARING AIDS"** is the result of my own study under the guidance of Dr. K. Rajalakshmi Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore and not been submitted earlier in any other University for the award of any Diploma or Degree.

Mysore,

May, 2003 Reg. No. 02SH0020

ACKNOWLEDGEMENTS

"Blessed is the man that endureth temptation : for when he is tried, he shall receive the crown of life, which the Lord hath promised to them that love him." (James 1:12)

I would like to offer my heartfelt gratitude to Dr. K Rajalakshmi, Lecturer, Department of Audiology, All India Institute of Speech and Hearing, for her guidance, patience and support throughout this project

I thank Dr. M. Jayaram, Director, All India Institute of Speech and Hearing, Mysore, for gving me an opportunity to do this project

Ajith Sir and joby Sir - You have been my constant help for the completion of this project

Nilesh - Thanks for your suggestions and giving me a good start

Thanks to A charya Sir, for helping me with the statistical analysis.

Thanks to all the subjects who have participated in my study for their patient cooperation.

Daddy and Mummy- God has blessed me'with two greatest assets that I can ever have in my life. You have loved me to the maximum and never ever have denied any of my wishes.

Sichy, Simichechi, Aliyan and Babychayan - Thanks for your constant inspiration, motivation, advce, affection, support, care and all that you have done to my life. I will always remain as your 'aniyathipraxu'.

Ponnu, Ammu, Amaluttan and Daniel - You add the color to my life. Nanty love you lot.

Sethu and Ponnu - My best medicines for all my worries.

My B.Sc. Classmates - We were "unique". Miss you lots.

Thanks to Shereen, Regu, Banu...and all my classmates for givingme a good time

Mili, Deema, Rajani, Bhuvana and Amy - Thanks a lot for those fun-filleimaments' and your moral support.

I also thank all my other Seniors and Juniors who have helped me in every possible way.

Thanks to Softouch people for rnaking my work into this form.

"I have set the Lord always before me because he is at my right hand, I shall not be moved. Therefore my heart is glad, and my flesh also shall rest in hope" (Psalms 16:8,9).

TABLE OF CONTENTS

INTRODUCTION

Hearing is one of the most important senses of man. It forms a vital link to the world of communication. Hearing is essential for the acquisition of speech and language. The hearing mechanism is also essential for monitoring one's own speech production. In addition, hearing also enables an individual to make judgements regarding the location of the different sound sources in the environment (Yost, 1994).

The essence of a hearing loss thus has its effect on communication and the resulting impact on cognitive, speech, language and psychosocial development and functioning (Vernon & Andrews, 1990, as cited in Katz, 1994). The impact of a hearing loss that has its onset during adulthood depends on several factors. These include the age of onset (i.e., prevocational or post vocational), nature, degree & configuration of hearing loss, life style & occupation of the person and perceived handicap.

Amplification represent the single most important rehabilitation tool available to the hearing impaired population (Ross & Giolas, 1978; Bess & McConnell, 1981). Amplification devices provide a valuable communicative link between the hearing impaired listener and his acoustic environment.

A hearing aid can be defined as an amplification device capable of amplifying the sound reaching a person's ear. In non-linear hearing aids, gain changes with the input intensity in some prescribed form. With the help of modern digital technology, characteristics of these hearing aids can be tailored to individual needs with the help of comparative and prescriptive rules.

The comparative hearing aid selection technique evaluates a number of hearing aids on the patient with hearing impairment, conduct some type of formal or informal speech based measurement with each hearing aid and then pick the best performing hearing aid for fitting. This technique is a direct descendant of the well-known procedure described by Carhart (1946, as cited in Libby, 1988).

The prescriptive approach refers to the tailoring of frequency response curve of a hearing aid in conformance with the client's audiogram (Ross, 1978, as cited in Katz, 1978). The prescriptive hearing aid evaluation method is based on the assumption that, given either a patient's pure tone auditory thresholds, most comfortable level (MCL), or uncomfortable level (UCL) the appropriate amount of gain for each frequency can be calculated mathematically and optimum aided speech intelligibility can be obtained through a pre-determined formula. There are numerous prescriptive formulae like POGO, NAL, one-third-gain rule, Berger procedure etc that are designed for linear hearing aids. But these formulae cannot be used with non-linear digital hearing aids because these formulae consider hearing aid as a linear amplifier. To overcome this, there are some threshold -based formulae developed specially for non-linear hearing aids. These formulae intend to give different gain output for different inputs. NAL-NLI, DSL I/O, FIG6 are few of the threshold based prescriptive formulae used for non-linear hearing aids. There are few studies in the literature that have compared these formulae.

Byrne, Dillon, Ching, Katsch and Keidser (2001) compared NAL-NLI procedure with other prescriptive formulae like DSL I/O, FIG6 and IHAFF and found that NAL-NLI prescribes less low frequency gain for flat and upward sloping audiograms and less high frequency gain for steeply sloping high frequency hearing losses. Also NAL- NLI tends to prescribe less compression than the other procedures and all procedures differ considerably from one another for some audiograms.

Kamp, Margolf-Hackl and Keissling (2001) compared DSL I/O with a loudness based fitting strategy and found that DSL I/O provided higher gain and better sound quality than the loudness based approach. Similarly, NAL-NLI was compared with a loudness normalization rationale (IHAFF) by Keidser and Grant (2001) found that IHAFF prescribed more gain than NAL-NLI.

It is clear from the above studies that for the same pure tone threshold each of these formulae prescribe significantly different gains. So it is very difficult to compare the benefit of one fitting procedure over another, thus no single evaluation method seems to be considered superior over any other method consistently. It was emphasized that it is necessary for the evaluation and fitter of the hearing aid to utilize a broad array of procedure and tailor the procedure to specific requirement of each potential hearing aid user.

Need **for** the **study**

A number of prescriptive procedures have been used in order to fit the hearing impaired, individual with suitable hearing aids. Though, we know that response difference exist among various prescriptive procedures, but there is no conclusive evidence in literature to show, that the speech intelligibility varies from one procedure to another. Hence this study was undertaken.

Aim of the study

The aim of the study was to compare three threshold- based prescriptive formulae NAL-NL1, DSL I/O and F/G 6 in quite and noise and across various degrees and audiometric configurations using speech identification scores.

REVIEW OF LITERATURE

The principle aim of any hearing aid selection and fitting strategy is to ensure that environmental sounds, especially conversational speech is audible without being excessively loud. Thus the selected instrument should maximize an individual's communication ability under everyday listening conditions. The hearing aid must provide appropriate amplification to maximize speech recognition and comprehension, provide good sound quality and provide amplification that is comfortable. To achieve this, the frequency gain response of the hearing aid must be shaped to compensate for the loss of loudness as a result of the impaired hearing. The hearing aids help to make the speech signal audible and to transfer the long-term average speech spectrum into the residual dynamic range of the individual. If the residual dynamic range is reduced, the input signal has to be shaped by output limiting to avoid the output levels exceeding the uncomfortable loudness levels i.e., the hearing instrument should be fitted in such a way that the normal dynamic range of sounds is transformed into the narrow dynamic range of the hearing impaired. This should be accomplished without altering the loudness relationship between sounds. The hearing aid must make speech intelligible without making it uncomfortably loud and deliver a pleasing or natural quality in the sound of voice and music. Internal noise, whether electrical or mechanical in origin should be reduced below the patient's threshold. Finally the maximum acoustic output that the instrument can produce must not cause pain or serious discomfort (Davis et. al., 1946).

It is important to assess the benefit of a hearing aid whether a function, which provides benefit in one situation, may degrade performance in another and to verify the type and degree of hearing loss for which a particular hearing aid is best suited.

The outcome of a hearing aid fitting should be assessed in both subjective and objective terms. Hearing aid benefit concerns the subjective assessment of the extent to which the hearing aid reduces impairment and handicap caused by the hearing loss. The impairment typically concerns two main dimensions-sound quality and speech recognition. Sound quality is a subjective quantity that can be assessed using systematic and scientifically validated methods. (Gabrielsson, Schenkman, & Hagermah, 1988). Speech recognition performance can be evaluated using both subjective and objective test methods.

Subjective assessment is based on how well the user perceives the benefit of the aid in real life situation and is therefore of high validity but the results are more difficult to quantify in absolute values than those obtained by means of speech recognition tests in the laboratory. The latter however obviously suffer from less validity because of the need to use standardized test material and listening situations.

The prediction of speech discrimination problems for a patient's environment based on performance with phonetically balanced words is risky. While it is generally true that lower speech discrimination scores lessen the understanding of speech, it is not possible to determine from unaided scores what the person's speech intelligibility will be with an instrument. Unaided speech discrimination scores are a function of sensation level (SL). If the sensation level is inadequate, the speech discrimination will be poor. This is especially true when high frequency residual hearing is limited to 80-90 dBHL. The Speech Recognition Threshold (SRT) reflects the contribution of low and mid frequency hearing sensitivity. Speech discrimination based only on the SRT may not be maximum because a sensation level of 10-20 dB may be insufficient. Furthermore, speech discrimination in quiet does not reflect the electro acoustic performance of the hearing aid in the presence of competing noise and background speech.

The speech- in-noise tests have been used to compare hearing aids (Jerger & Hayes, 1976; Moore, Lynch & Stone, 1992).

Evaluating speech recognition in quiet may not provide a realistic index of communicative difficulty in everyday situations because they are often characterized by competing noise (Jerger & Hayes, 1976; Dirks, Morgan & Dubno, 1982; Plomp, 1986; Gi1chouse & Haggard, 1987). Hearing impaired listeners typically exhibit poorer speech recognition in noise than normal hearing subjects (Carhart & Tillman, 1970; Driks et. al., 1982; Beattie, 1989). Performance on speech-in-noise tests may enable the clinician to provide hearing impaired individuals or family members with more realistic expectations of unaided and or aided auditory performance in everyday situations (Jerger & Hayes, 1976).

A second reason for adding noise to speech is to increase the difficulty of the test in an effort to identify differences among hearing losses or hearing aids (Dillion 1983; Plomp, 1986; Moore et. al., 1992). Speech stimuli such as sentences, spondees and monosyllables are too easy to separate normal hearing from mild hearing losses (Carhart, 1965).

Testing in quiet may not reveal differences between hearing aids. Loven and Hawkins (1983) state that the addition of noise to speech may change the structure of the test so that whatever ability is measured in quiet may not be the same ability measured when speech is mixed with noise. Consistent with this statement is the observation that speech recognition errors are differentially affected by the addition of background noise (Dubno & Levitt, 1981).

Hearing aid selection can be done by different procedures like;

(1) Comparative procedure:

We compare the performance of different hearing aids on the patient like Speech Recognition Threshold (SRT), Speech Identification Score (SIS), or intelligibility and select the best of speech.

(2) Prescriptive procedure:

Based on audiological findings, we select the MPO, gain, category etc., for the hearing aids.

(3) Combined comparative and prescriptive procedures:

Here we select, few hearing aids based on the subjects audiological findings and then check the performance of those hearing aids on the subject.

The earliest methods of selecting hearing aids were suggested by hearing aid manufactures and dispensers of hearing aids. These methods are based on the principle of selective amplification. This refers to the tailoring of frequency response curve of a hearing aid in conformance with the client's audiogram (Ross, 1978 as cited in Katz, 1978).

The prescriptive hearing aid evaluation method is based on the assumption that given either a patients pure-tone auditory thresholds, most comfortable listening levels and or loudness discomfort levels, the appropriate amount of gain for each frequency can be calculated mathematically and optimum aided speech intelligibility can be obtained through a pre-determined formula.

The prescriptive methods of hearing aid evaluation have its limitations. Most of the formulae are based on auditory threshold measurements, yet listeners with impaired hearing do not use their hearing aids at threshold audibility. Each fitting formula gives a different gain and frequency spectrum prescription so that selection of proper formula becomes an issue among audiologists. The user is not personally involved in this selection method and therefore does not know what to expect until the hearing aid arrives from the manufacturer.

Over the past few decades, there has been a dramatic shift in the way the hearing instruments were selected and fitted with many audiologists turning to the theoretically based prescriptive methods. Humes and Houghton (1992) attribute the following factors for such a trend. Firstly, to overcome the fundamental problems of the comparative approach. Secondly, evidences suggest that the gain characteristics of the hearing instrument should be individually tailored to the person's hearing loss. Finally, it is more feasible to use methods that require matching of observed gain to prescribed gain characteristics on an individual basis.

Proponents of prescriptive amplification suggest that the gain of the hearing aid should increase in the frequency regions where the hearing loss increase so that the impnired listener could attain better audibility. The hearing aid gain prescriptions often incorporate an adjustment to compensate for the fact that normal speech contains more low frequency energy than high frequency energy. These prescriptions generally provide less low frequency gain and greater high frequency gain.

There are numerous prescriptive formulae available. Some of the prescriptive procedures utilize the thresholds while others utilize the Most Comfortable Level.

The 'threshold based procedures' have the advantage that they are applicable to almost all the patients since they require only the ability to detect the presence of a sound. Threshold based prescriptive formulae are efficient, easily calculated and applicable to a wide variety of hearing aid candidates including children and elderly.

The other procedure specifies that speech signal should be selectively amplified so as to place them within the most comfortable listening level. This prescriptive formulae is based on measuring the Most Comfortable Level or Most Comfortable Level range at various audiometric frequencies, others have used Uncomfortable Level (UCL) measures to calculate target frequency gain response.

The loudness-based procedures have the apparent advantage of providing more genuine information about a patients auditory functioning. But the major disadvantage of this procedure is that not all patients can make loudness judgements. The test-retest reliability is better with threshold procedures.

It has been noted that no significant hearing aid procedure can be used for all hearing impaired individuals because of the limitation of each method. The question arises as to which of the numerous methods available should one use to select the hearing aid for a patient.

Selection of non-linear hearing aids:

Although the objective of a non-linear fitting are similar to those of a linear fitting, the method used to accomplish these objectives can be much more complicated.

The earlier fitting rules such as the half gain rule, POGO, NAL-R offers a single gain target for a hearing loss because linear hearing aids provide same gain for all input levels. Fitting methods for non-linear hearing aids offer more than one target because they provide different gain for different input levels. The philosophy of non - linear hearing aid fitting lies in equalizing versus normalizing the loudness of adjacent speech frequencies.

NAL - NL1 fitting method

The name NAL - NL 1 stands for National Acoustic Lab, Non-Linear version 1 was given by Dillon (1998). The aim of NAL - NL1 is 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. The gain frequency response that achieves this varies with input level and thus the procedure is for nonlinear hearing aids:

NAL - NL1 method tries to equalize rather than normalize the loudness relationships among the speech frequencies NAL - NL 1 prescribes more low cut below 1000 Hz thus providing less low frequency emphasis of speech. It usually prescribes less gain than other procedures in the region of greatest hearing loss. It also tends to prescribe lower compression ratios and high compression threshold than the other procedures. (Byrne et. al., 2001).

The NAL - NL1 prescribes cross over frequencies, compression ratios, compression thresholds, low and high level gains but not compressor attack and release times. Thus NAL - NL1 procedure offers an important potential improvement over existing prescriptive procedures by explicitly maximizing intelligibility within the constraints of loudness comfort.

According to Dillon (1998), the main objective of developing NAL - NL 1 was to determine the gain for several input levels that would result in maximal effective audibility. The one constraint as with other NAL methods, was that the overall aided loudness perceptions for the whole, total aided speech signal had to be less than or equal to that for speech. To calculate NAL-NL1 gain targets, gain calculations were performed for 52 people with various audiometric configurations for input levels from 30 to 90 dB SPL, in 10 dB increments that induces lot of number crunching. For most types of hearing loss the mid frequencies of speech were found to be similar in loudness to the lower and higher speech frequencies. The end aim was thus achieved in equal loudness at all speech frequency brands, along with maximal speech intelligibility.

Ching, Dillon, Richard and Byrne (2001) stated that NAL - NL1 procedure was derived from the speech intelligibility index method for calculating predicted speech intelligibility from hearing threshold level and speech level was adopted. Loudness was calculated using the loudness model proposed by Moore and Glasberg (1997 as cited in Smeds & Leijon, 2001). Both models include allowances for effects of hearing loss estimated on the basis of hearing threshold level. An optimization process was used to determine for each input level, the required real ear gain at different frequencies to maximize effective audibility for a range of audiometric configurations. An equation was fitted to the final optimized gain to derive the NAL - NL1 prescriptive formulae.

NAL - NL1 procedure like any prescriptive procedure that calculates required gain from hearing threshold level and input levels is essentially based on average requirements and does not account for individual differences. NAL - NL1 considers level distortion and hearing loss desensitization effects on speech intelligibility of people with different degrees of hearing losses, it will clearly be different from other procedures that consider only audibility.

DSL I/O:

Seewald et.al. (as cited in Smeds & Leijon, 2001) gave the method desired sensation level input / output. Cornelisse, Seewald and Jamieson (1995) described a prescription approach that may be quite appropriate for fitting compression hearing aids. The Desired Sensation Level (DSL) approach that they have developed prescribes the desired output of the hearing aid of each of the several input levels. The method generates a desired I/O function that is based on the dynamic range of the listener at a particular frequency. Currently this method is designed to fit full dynamic range compression instruments. This has now evolved in DSL 4 version, which provides targets for both linear and non-linear hearing aids (Cornelisse, et. al. 1995).

DSL (4) software:

This includes DSL I/O algorithm in addition to the old DSL procedure. The DSL I/O algorithm adjusts for either linear or Wide Dynamic Range Compression (WDRC) hearing aids, particularly applicable for instruments with very low compression knee points. The DSL (4.0) also includes a speech spectrum for use with adults. The DSL (I/O) algorithm provides 2cc coupler gain and output targets and real ear gain for pure-tone input ranging from 45 dB SPL to 100 dB SPL. Also provides the targets for aided sound field thresholds and Uncomfortable levels upper limit of comfort that are predicted. Targets are then adjusted to the compression knee point that has been selected.

The addition to this, the DSL I/O algorithm calculates desired compression ratios for nine different frequencies ranging from 250 Hz - 6000 Hz. This calculation of the compression ratio is based on the relationship between the patient's dynamic range and the UCL value. These nine compression ratios are useful when fitting a multi-band instrument and one can select the ratio for the frequency that falls in the centre of a given band. Verification of the DSL I/O targets can be accomplished through ear canal Sound Pressure Level (SPL) measurement Real Ear Aided Response (REAR) and Real Ear Saturation Response (RESR) or Real Ear Insertion Gain (REIG).

DSL includes more than just the prescriptive targets. It encompasses a set of recommended assessment and verification procedures that are designed to be accurate and feasible, even with infants or young children.

The general goals of the DSL method are to amplify average level speech to the desired sensation level of each frequency and to make a wide range of input levels audible and comfortable, without distortion.

Acoustic Mapping with DSL (i/o):

Seewald, et.al. (1997) proposed acoustic mapping with DSL (I/O). DSL (I/O) is best described as an acoustic mapping algorithm.

- Within a frequency band, the algorithm maps on input acoustic region into an output acoustic region when the dynamic range (dB) of the o/p region is equal to the input region. Then the algorithm applies linear gain (i.e., compression ratio is 1:1).
- When the input dynamic range is greater than the output dynamic range, then the algorithm applies compression (i.e., compression ratio is > 1:1).
- When compression ratio is less than 1:1, then the I/O algorithm applies expansion.

- The o/p dynamic range used in the DSL (I/O) algorithm is the acoustic region that corresponds to the hearing impaired listener's residual auditory area, i.e., from the threshold of audibility to the upper limit of comfort (real ear SPL).
- The recommended input dynamic range used in DSL (I/O) algorithm corresponds to an extended normal auditory area i.e., from the normal hearing threshold of audibility to the hearing impaired listener's upper limit of comfort (SPL in sound field). When the extended input dynamic range and an exponent value of 1 are used in the DSL I/O algorithm then the real ear target output for speech, corresponds closely to the ear target output obtained using the original DSL linear gain algorithm (i.e., DSL V 3.1) across a wide range of hearing losses at all audiometric frequencies (Cornelisse, Seewald & Jamiesan, 1995). In this case, the DSL (I/O) algorithm can be described as loudness equalization. The goal of loudness equalization is to apply an acoustic transform to the input signal such that the hearing-impaired listeners perceived loudness of speech is equal across frequency bands. That is speech is amplified to approximate the MCL contour.

To calculate the target gain using DSL I/O the following method is used.

TG = AIR (UCL + TS - 1) / UCL

The value of TS is given in the table.

	250 Hz	500 Hz	750 Hz.	1 kHz	1.5 kHz	. kHz.	. kHz	5 kHz	6 kHz
TS	16.7	11.3	6.9	7.2	4.9	3.3	1.4	0.3	10.4

TG = Target gain, AIR=Air threshold, UCL=uncomfortable level, I=input level in dB

FIG 6

This is a rule especially designed for non-linear hearing devices developed by M.C. Killion in 1994 as cited in Smeds and Leijon, 2001.

It is a computer-based approach to fitting non-linear hearing aids that have wide dynamic range compression, and has a low compression knee point, but not restricted to those with K-AMP processing. The name of the prescriptive method came from figure 6 in the article 'three types of sensory hearing loss'. The method of calculating gain and frequency response is based on the gain estimates shown in fig.6 of article by Killan and Fikret - Pasa, (1993). The 2 principles are normalization and equalization. FIG 6 is based on the average loudness data that relates equal loudness and threshold curves. The individual patient's loudness judgements are not used in the calculation. When entering the patients' audiometric thresholds the program automatically calculates the fitting curves and provides frequency specific targets for three input levels i.e., 40 dB SPL, 65 and 95 dB SPL. FIG 6 calculates insertion gain targets and 2cc coupler response targets. In FIG 6 we choose three target gain curves because the available loudness growth data indicate that individuals with sensori-neural loss typically need less gain for intense sounds than for weak sounds. A typical choice of 40, 65 and 95 dB SPL were made as an input level of 40 dB SPL represents the weaker elements of conversational speech. Fig.6 estimates the gain required to provide aided sound field threshold of 20 dB HL. A level of 65 dB SPL (50 dB HL) represents conversational speech. A level of 95 dB SPL represents normally loud speech and music.

Desired compression ratios, based on the predicted dynamic range, are displayed for two input ranges (40 dB SPL to 60 dB SPL to 95 dB SPL) for both a low frequency range (500 Hz - 1000 Hz) and a high frequency range (2000 Hz - 4000 Hz). These compression ratios are helpful in instruments with two or three channels. It restores normal loudness for low level, comfort level and high-level sounds. Target gain for three input levels are computed. Fig.6 can also be used by dispenser to select proper hearing aid matrix as it calculates 2cc coupler targets for BTE, ITE and CIC hearing instruments. The dispenser can use this to select the desired hearing aid matrix.

Calculation method for target gain. The calculation targets gain on the basis of three levels 40 dB, 65 dB, and 90 dB. The calculation of this rule is used in the following method.

Target gain by low entrance level (40 dB)

TG = 0 dB for OdB to 20 dB AIR

TG = AIR - 20 dB for 20 dB to 60 dB AIR

TG = AIR - 20 dB - 0.5 (AIR - 60 dB) for AIR > 60 dB

(Gain at 6k and 8k < = Gain at 4k).

Target gain by medium entrance level (65 dB)

TG = 0 dB for 0 dB to 20 dB AIR

TG = 0.6 (AIR-20dB) for 20 dB to 60 dB AIR

It i = 0.8* AIR - 23 dB for AIR > 60 dB

(Gain at 6K and 8k < gain at 4k)

Target gain by high entrance level (90 dB)

TG = 0 dB for 0 dB to 40 dB AIR

TG = 0.1 (AIR - 40 dB) 1.4 for AIR > = 40 dB

(Gain at 6K and 8K < = Gain at 4K)

TG = Target Gain, AIR = Air Threshold

Studies related to the non-linear prescriptive formulae.

Byrne, Dillon, Ching, Katsch and Keidser (2001) compared NAL-NLI with other prescriptions for DSL I/O, FIG 6 and a threshold version of IHAFF procedures. They found that for an average speech input level, the NAL-NLI prescription is very similar to those of the well-established NAL-Revised profound procedure. Compared with 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 NLI tends to prescribe less compression than the other procedures. All procedures differ considerably from one another for some audiograms.

A similar comparative study was done by Scollie, Seewald, Moodie, and Dekok (2000), on children with sensori-neural hearing loss. The preferred listening levels (PLL) of these children were elicited using conversation level speech heard through the children's own hearing aids. All hearing aids were fitted using the DSL method. Comparisons were made between the PLL and targets from the following prescriptive formulae DSL version 4. land two versions of NAL procedure, including NAL-RP for severe to profound losses and NAL-NLI. Results for this sample indicated that the PLL was similar to DSL targets and that on average, NAL-RP or NAL NL 1 targets recommended less gain than that preferred by majority of children in this study.

Keidser, Brew and Peck (2003) compared two generic formulae, DSL I/O and NAL-NL-1 with other proprietary fitting methods in terms of the gain prescribed. They found that DSL I/O consistently prescribes more gain than NAL-NL at frequencies where the hearing loss is severe. It does so because DSL I/O is aiming at restoring loudness and ensuring audibility. However NAL-NL1 includes a desentization factor because it is believed that hearing impaired listeners have reduced ability to extract useful information from speech at frequency where the hearing loss is severe.

With respect to hearing loss configuration dependency, the loudness normalization and loudness mapping methods seem to prescribe gain independent of hearing loss configuration.

In contrast, the gain prescribed by NAL-NL1 at each frequency depends on the degree of loss at several frequencies. The data collected at NAL in the 1980's showed that the gain frequency response preferred by hearing-impaired listeners varied in a hearing loss configuration - dependent way.

Keidser and Grant (2001) compared loudness normalization rationale (IHAFF) with a speech intelligibility maximization rationale (NAL NLI) in laboratory tests and in the field by twenty-four subjects with flat and steeply sloping loss. On average, for input levels between 50 and 80 dB SPL, IHAFF prescribed more low frequency gain than NAL-NLI for subjects with flat loss and IHAFF prescribed more high frequency gain than NAL-NLI for subjects with steeply sloping loss. Further IHAFF prescribed on average, higher compression ratios than NAL-NLI. The authors also recommended using NAL-NLI rationale in a two-channel device when fitting clients with sloping loss and for clients with flat loss. The number of compression channels is probably unimportant.

It was cited in this article that, FIG 6 amplification targets were calculated for each of the twenty-four subjects and the average for responses for each type of hearing loss at 50, 65 and 80 dB input were compared with the corresponding responses prescribed by NAL-NLI and IHAFF. On average, FIG 6 prescribed less gain than IHAFF across all frequencies for all three hearing loss groups and all three input levels. After an adjustment for overall gain level, the gain difference between FIG-6 and NAL-NLI were similar to the gain differences between IHAFF and NAL-NLI tested ih this study. Therefore the outcome of this study regarding the differences between IHAFF and NAL-NLI is likely to apply to FIG 6 for input levels between 50 and 80 dB S|PL, but this conclusion needs to be investigated.

From this study, it can be concluded that when two fitting rationales prescribed Substantially different responses for a 65 dBSPL input and these differences Were achieved in the fitting, then the subjects preferred NAL-NLI. Even when the difference between fittings was small, the subjects preferred and performed better with NAL-NLI when listening in a low frequency weighted background noise.

Stelrjiachowicz et al., (1998) compared three threshold based prescriptive methods in tkvo device independent methods DSL I/o (Cornellise et al., 1995) and FIG 6 (Killion & Fikret - Pasa, 1993) and one device specific method used for a particular type of hearing aid (Audiogram plus, used for Resound BT2, BTP) with loudness scaling (LGJOB) (Allen et al 1990). The actual gain used by forty-nine hearing impaired subjects previously fitted using the loudness scaling procedures, was compared to the prescribed gain for three threshold based fitting methods. The comparison showed that for most types of hearing losses and input levels DSL I/O and FIG 6 prescribed more gain than the subjects actually used. But it is difficult to draw conclusion from this study because the gain used by the subjects was measured using a broadband signal while the two generic methods prescribe gain of narrow - band signals and these data are difficult to compare.

Another comparative study was done by Smeds and Leijon (2001) on six threshold based prescriptive methods for nonlinear hearing instrument for a standard audiogram and three simulated listening situations. Their results indicated that there is a large difference between prescribed gain of FIG 6 and DSL I/O and implemented gain. FIG 6 gain is fairly normal loudness and DSL I/O tends to make the input signal louder than normal. The highest speech intelligibility index value was for DSL I/O and FIG 6. For FIG 6 the measured gain - frequency response gave substantially higher gain in the mid frequency region than the original prescription.

A study by Wesselkamp, Margolf, Hackl and Kiessling (2001) compared two different hearing instrument fitting strategies in the laboratory and in a field test with regard tu the benefit of hearing aid users and their satisfaction with the fitting DSL I/O fittings based on hearing threshold and UCL for the subject were evaluated Vs a prescriptive fitting method based on unaided loudness scaling 21 subjects were fitted diotically with both fitting strategies implemented in a digital hearing instrument. The patients tested both fitting strategies sequentially in a 4+4 week field trial using a cross over study design SRT measurements sound quality rating and paired comparison of sound quality were performed for all conditions (unaided, DSL I/O fitting and loudness based fitting). In addition, subjective benefit and preference were assessed with questionnaires. Speech audiometry did not reveal significant difference between two fittings. DSL I/O fitting showed superior results in most sound quality tests and in the self-assessment of communication abilities while the loudness-based approach was slightly preferred in noisy environment. The result seemed to be influenced by the higher gain predicted by DSL I/O. The study provides no evidence that effort spent on loudness scaling leads to improved fitting results.

Moore, Alcantara and Marriage (2001) compared three procedures - DSL I/O, with two other loudness based procedures - CAMEQ and CAMREST for the initial fitting of hearing aids with multi-band compression, bilaterally fitted to experienced users and found that the prescribed gain by DSL I/O was greater than preferred gains especially at high frequencies. When compared to CAMEQ and CAMREST, DSL I/O required more adjustment of the prescribed gains to achieve satisfactory fits than CAMEQ and CAMREST. SRT in noise did not differ much for the three procedures. Overall CAMEQ and CAMREST, procedures gave more satisfactory initial fits than the DSL I/O procedure for experienced hearing aid users fitted bilaterally.

A comparative study on prescribed 2cm3 coupler gain for two threshold based methods and two methods based on loudness scaling was done by Ricketts (1996). The results showed that threshold based prescription methods gave steeper gain frequency responses (less gain at lower frequency and more gain at higher frequency) than methods based on loudness scaling. The threshold-based methods gave significantly higher speech intelligibility index scores than the methods based on loudness scaling.

Souza and Bishop (2000) studied the effects of non-linear amplification for different audiometric configurations. The purpose of their study was to determine whether increase in audibility with non-linear amplification improved speech recognition to a comparable degree for listeners with sloping sensory neural loss as for a comparison group of listeners with flat sensory neural loss. Consonant recognition was examined as a function of audibility with wide dynamic range compression (WDRC) amplification and with linear amplification. For linearly amplified speech, listeners with flat and sloping loss showed similar improvements in recognition given the same increases in audibility. Results for non-linearly amplified speech indicated that the listeners with flat loss showed a greater rate of improvement as audibility increases than the listeners with sloping loss. This difference is largely due to superior performance by the listeners with sloping loss for low audibility speech in comparison to equivalent group performance for high-audibility speech.

A study on speech discrimination measures was done by Green, Day and Bamford (1989) of the benefit provided by four different hearing aid selection procedures were determined on a group of experienced hearing aid users. The effect of selection procedure on benefit was little influenced by degree of hearing loss but considerably influenced by configuration of loss (flat, sloping or irregular). For patients with gently to steeply sloping losses, the prescriptive methods of selection were shown to provide more benefit than the other methods studied.

METHOD

The study was undertaken to compare the different threshold based prescriptive formulae for nonlinear hearing aid fitting using speech identification scores across various degrees and patterns of hearing loss.

Subjects

Forty-four subjects above 18 years of age with acquired sensory neural hearing loss were selected. All the subjects had good speech identification score of above 60%. They underwent ENT checkup and were cleared of any external or middle ear problems. All the subjects had south Indian languages as their mother tongue. The subjects chosen were classified as follows depending on the degree and pattern of hearing loss and whether they were already using hearing aid or naive users:

I. Based on degree of loss

	No. of subjects	PTA
Mild-	9	26-40
Moderate-	16	41-55
Moderately severe -	11	56 - 70
Severe-	8	71-90

* Modified from Lloyd and Kaplan (1978)

II. Based on audiogram configurations

	Number of subjects	
Flat loss	18	A flat loss has <5 dB rise or fall per octave
Gradually sloping	17	5-12 dB threshold increase per octave
Sharply sloping	9	15-20 dB threshold increase per octave

By Carhart (1945) and Lloyd and Kaplan (1978)

III. Based on hearing aid use

Existing Behind-the ear hearing aid users - 11

Naive users - 33

Instrumentation

- Auricle programming instrument was used to program the hearing aid.
- The clinical audiometer Madsen OB922 with matching speakers was used to present stimuli and noise.
- A digital hearing aid Siemens TCI combi was used.

Test material

Two sets each of 20 phonetically balanced words developed by Maya Devi (1974) were used for speech identification testing.

Test environment

Both the digital programming and speech audiometry was done in a sound treated room where the ambient noise was within the permissible limits (ANSI 1997, as cited in Wilber, 1994).

Procedure

- The patient's audiogram was fed into the Auricle programming instrument and the hearing aid was connected and programmed using three prescriptive formulae - NAL-NLI, DSL I/O and FIG-6 one after another. In order to nullify the order effect, the order of programming was randomly varied.
- After each programming, the various parameters of the hearing aid were adjusted to fine tune and optimize with the target gain ideally.
- Speech identification score using Phonetically Balanced words in Kannada was found out in different situations. These situations include
    1. Unaided - quiet
    2. Aided - quiet
    3. Unaided - noise } Using speech noise at 0 dB SNR
    4. Aided - noise }

The scores were then tabulated and analyzed using paired t test to find which prescriptive formula gives the best speech identification score across various degrees and patterns of hearing loss.

RESULTS AND DISCUSSION

The aim of the study was to compare three prescriptive formulae - NAL-NLI, DSL I/O and FIG 6 in terms of their speech intelligibility in quiet and noisy condition across various degrees and patterns of hearing loss.

The data obtained was statistically analyzed using paired t-test (Garret, 1979). The results obtained are shown in the following tables.

Whole sample

Quiet			
Formula	**Mean**	**SD**	**t-value**
NAL-NL1	15.0909	2.7179	-119 NS
DSLI/O	15.1136	2.9588	
DSLI/O	15.1136	2.9588	1.062 NS
FIG 6	14.8182	3.0899	
NAL-NL1	15.0909	2.7179	1.463 NS
FIG 6	14.8182	3.0899	

Noise			
Formula	**Mean**	**SD**	**t-value**
NAL-NL1	13.5909	2.8718	.992 NS
DSL I/O	13.3409	3.2916	
DSL I/O	13.3409	3.2916	1.022 NS
FIG 6	13.0682	3.3438	
NAL-NL1	13.5909	2.8718	2.558*
FIG 6	13.0682	3.3438	

* $p < 0.05$

Table I shows the mean, standard deviation and t-value for the whole sample in quiet and noise conditions.

The analysis of t-scores for the whole sample indicates that there is no significant difference obtained in the speech identification score (SIS) across the three formulae under quiet condition. However, in the noisy condition, there is a significant difference at 0.05 level of significance (LOS) in the SIS between the formulae NAL-NLI and FIG 6 and NAL-NLI was found to be better but, no significant difference was observed between NAL-NLI and DSL I/O and also between DSL I/O and FIG 6 under noisy condition.

The above observation may be because that NAL -NL1 prescribes more low cut below 100 Hz thus providing less low frequency emphasis, which in turn reduces noise whereas DSL I/O and FIG 6 do not have any low frequency cut off.

Mild

Quiet			
Formula	**Mean**	**S.D.**	**t-value**
NAL-NL1	17.4444	2.8771	-.426 NS
DSLI/O	17.5556	2.8771	
DSL I/O	17.5556	2.8771	4.000**
FIG 6	16.8889	3.0185	
NAL-NL1	17.4444	2.8771	1.474 NS
FIG 6	16.8889	3.0185	

* *$P < 0.01$

Noise			
Formula	**Mean**	**SD**	**t-value**
NAL-NL1	15.7778	3.4921	-1.890 NS
DSLI/O	16.3333	3.0822	
NAL-NLI	15.7778	3.4921	1.890 NS
FIG 6	15.2222	3.7342	
DSL I/O	16.3333	3.0822	2.857*
FIG 6	15.2222	3.7342	

* $p < 0.05$

Table II - Mean, standard deviation and t-value for mild hearing loss cases in quiet and noise.

The analysis of data using 't' test indicate that there is a significant difference obtained between the scores using DSL I/O and FIG 6 in the quiet condition and DSL I/O gave a better score. No significant difference in the scores was obtained between NAL-NLI and DSL I/O and between NAL-NLI and FIG 6.

Under noisy condition, DSL I/O gave a significant difference at 0.05 level with FIG 6 and no significant difference is obtained between NAL-NLI and DSL I/O and also between NAL-NLI and FIG 6.

Though statistically there was a significant difference between DSL I/O and FIG 6 but clinically there is no considerable difference between the speech identification scores and Nal-NLl and DSL I/O.

Moderate

Quiet			
Formula	Mean	S.D.	**t-value**
NAL-NL1	15.1875	2.0402	-.745 NS
DSLI/O	15.4375	1.8962	
DSL I/O	15.4375	1.8963	-.344 NS
FIG 6	15.5625	1.7877	
NAL-NLI	15.1875	2.0402	-.859 NS
FIG 6	15.5625	1.7877	

Noise			
Formula	Mean	SD	**t-value**
NAL-NLI	13.5625	1.8608	.590 **NS**
DSLI/O	13.2500	2.3238	
DSLI/O	13.2500	2.3238	-.739 **NS**
FIG 6	13.62.50	1.7078	
NAL-NLI	13.5623	1.8608	-.174 **NS**
FIG 6	13.6250	1.7078	

Table III: Mean standard deviation and t value for moderate hearing loss cases under quiet and noisy situations.

The results of 't' test indicate that both in quiet and noisy conditions, no significant difference is obtained in the SIS scores across the three different formulae.

Moderately severe

Quiet			
Formula	**Mean**	**S.D.**	**t-value**
NAL-NLI	**14.0909**	**2.6629**	**-.350** **NS**
DSLI/O	**14.2727**	**3.4378**	
DSL I/O	**14.2727**	**3.4378**	**1** **NS**
FIG 6	**13.8182**	**3.7635**	
NAL-NLI	**14.0909**	**2.6629**	**.430** **NS**
FIG 6	**13.8182**	**3.7635**	

Noise			
Formula	**Mean**	**SD**	**t-value**
NAL-NLI	**12.8182**	**3.2502**	**.833** **NS**
DSL I/O	**12.3636**	**3.9818**	
DSL I/O	**12.3636**	**3.9818**	**.944** **NS**
FIG 6	**11.8182**	**4.1909**	
NAL-NLI	**12.8182**	**3.2502**	**2.141** **NS**
FIG 6	**11.8182**	**4.1909**	

Table IV : Mean, standard deviation and t-value for SIS in moderately severe hearing loss patient under quiet and noisy conditions.

The analysis of t-scores indicates that there is no significant difference in the SIS using the three formulae both under quiet and noisy conditions.

Severe

Quiet			
Formula	**Mean**	**S.D.**	**t-value**
NAL-NLI	**13.6250**	**2.3867**	**4.583****
DSL I/O	**12.8750**	**2.2321**	
DSL I/O	**12.8750**	**2.2321**	**.00**
FIG 6	**12.8750**	**2.9490**	**NS**
NAL-NLI	**13.6250**	**2.3867**	**1.821**
FIG 6	**12.8750**	**2.9490**	**NS**

**P<0.01

Noise			
Formula	**Mean**	**SD**	**t-value**
NAL-NLI	**12.2500**	**2.2520**	**2.393***
DSL I/O	**11.500**	**2.1381**	
DSL I/O	**11.500**	**2.1381**	**.552**
FIG 6	**11.2500**	**2.9155**	**NS**
NAL-NLI	**12.2500**	**2.2520**	**2.646***
FIG 6	**11.2500**	**2.9155**	

*P<0.05

Table V: Mean, standard deviation and t-value for SIS for severe hearing loss patients in quiet and noisy conditions

The analysis of scores using t-test indicate that - there is a significant difference between SIS of NAL-NLI and DSL I/O at 0.01 level under quiet conditions and NAL-NLI was seen to be better. No significant difference was obtained in the SIS using NAL-NLI and FIG and between DSL I/O and FIG 6 under quiet conditions.

Under noisy condition, a significant difference at 0.05 level is obtained between NAL-NLI and DSL I/O and also between NAL-NLI and FIG 6. Both cases, NAL-NLI gave a better score. No significant difference was obtained between SIS using DSL I/O and FIG 6.

The above result shows that NAL-NL1 gives the maximum score under quiet condition. This may be due to the fact that NAL-NL1 considers level distortion and hearing loss desensitization effects on speech intelligibility of people with different degrees of hearing losses.

Under noisy condition again NAL-NL1 gave the maximum score due to low frequency cutoff that reduces the noise.

Flat

Quiet			
	Mean	**S.D.**	**t-value**
NAL-NL1	**14.889**	**3.3936**	**2.122***
DSLI/O	**14.500**	**3.6822**	
DSL I/O	**14.500**	**3.6822**	**1.966 NS**
FIG 6	**13.9444**	**3.9775**	
NAL-NL1	**14.8889**	**3.3936**	**2.464* NS**
FIG 6	**13.9444**	**3.9775**	

•PO.05

Noise			
	Mean	**SD**	**t-value**
NAL-NL1	**13.5556**	**3.5846**	**.946 NS**
DSL I/O	**13.2222**	**4.0809**	
DSL I/O	**13.2222**	**4.0809**	**2.117***
FIG 6	**12.5000**	**4.2737**	
NAL-NL1	**13.5556**	**3.5846**	**3.124****
FIG 6	**12.5000**	**4.2737**	

*P<0.05

**P<0.01

Table VI: Mean, Standard deviation and t-value for SIS in people with flat audiometric configuration in quiet and noisy condition.

The t scores indicated that a significant difference in SIS is obtained between NAL-NL1 and DSL I/O and also between NAL-NL1 and FIG 6 at 0.05 level where NAL-NL1 was better under quiet condition. No significant difference between DSL I/O and FIG 6 in SIS under this condition.

Under noisy condition a significant difference at 0.05 level is obtained between DSL I/O and FIG 6, where DSL I/O was better and a difference at 0.01 LOS is obtained between NAL-NL1 and FIG 6, where NAL-NL1 was better. No significant difference is obtained between NAL-NL1 and DSL I/O.

The above results indicate that NAL-NL1 gives the best score out of the three formulae under quiet condition as it maximizes speech intelligibility. The DSL I/O and FIG 6 methods are designed for compression hearing aids but the stimulus level used was at 50 dB HL, which is at a low level for the compression to take place.

Under noisy condition, again NAL-NL1 gave a superior performance owing to the low cut energy of noise.

Gradually sloping

Gradually sloping quiet

	Mean	S.D.	**t-value**
NAL-NL1	15.8235	2.1282	-.356 NS
DSL I/O	15.9412	2.1351	
DSL I/O	15.9412	2.1351	-.545 NS
FIG 6	16.1176	1.7636	
NAL-NL1	15.8235	2.1282	-.704
FIG 6	16.1176	1.7636	NS

Noise

	Mean	SD	**t-value**
NAL-NL1	14.1765	2.2977	.814 NS
DSLI/O	13.8824	2.6665	
DSL I/O	13.8824	2.6665	-.566
FIG 6	14.1176	2.4465	NS
NAL-NL1	14.1765	2..2977	.194 NS
FIG 6	14.1176	2.4465	

Table VII: Mean, Standard deviation and t value for SIS using three formulae in people with gradually sloping audiometric configuration. The t-scores indicate that there is no significant difference obtained in SIS for all the formulae under quiet and noisy conditions.

The above results show that there is no superiority in the performance score using NAL-NLI. This may be because of the reason that NAL-NLI prescribes less gain than the other procedures in the region of greatest hearing loss.

Sharply sloping

Quiet			
Formula	**Mean**	**S.D.**	**t-value**
NAL-NL1	**14.11 II**	**1.9650**	**-1.206 NS**
DSL I/O	**14.7778**	**2.5874**	
DSL I/O	**14.7778**	**2.5874**	**1.333 NS**
FIG 6	**14.1111**	**2.3688**	
NAL-NI.I	**14.1111**	**1.9650**	**.00 NS**
FIG 6	**14.1111**	**2.3688**	

Noise			
Formula	**Mean**	**SD**	**t-value**
NAL-NL1	**12.5556**	**2.1279**	**.880 NS**
DSLI/O	**11.4444**	**3.1269**	
DSL I/O	**11.4444**	**3.1269**	**-.661 NS**
FIG 6	**12.2222**	**2.3333**	
NAL-NL1	**12.5556**	**2.1279**	**.894 NS**
FIG 6	**12.2222**	**2.3333**	

Table VIII: Mean, Standard deviation and t-value of SIS using the three formulae for patients with sharply sloping audiometric configuration.

The t-scores indicate that, both under quiet and noisy condition no significant difference between SIS is obtained across the three formulae.

The above results also indicate no superiority of one formula. This is again because of the fact that NAL-NL1, which has the aim of maximizing speech intelligibility, prescribes less gain than other procedures in the region of greatest hearing loss.

Other procedures like DSL I/O and FIG 6 are meant for compression hearing aids but the compression is not in play as the level of input stimulus is low.

BTE Users

Quiet			
	Mean	S.D.	t-value
NAL-NL1	14.2727	3.1013	1.456 NS
DSL I/O	13.8182	3.4876	
DSL I/O	13.8182	3.4876	-1.077 NS
FIG 6	14.1818	3.6005	
NAL-NL1	14.2727	3.1013	.232 NS
FIG 6	14.1818	3.6005	

Noise			
	Mean	SD	t-value
NAL-NLI	13.1818	3.3412	3.614**
DSLI/O	12.3636	3.6952	
DSL I/O	12.3635	3.6952	-.820 NS
FIG 6	12.6364	3.8019	
NAL-NLI	13.1818	3.3412	2.206*S
FIG 6	12.6364	3.8019	

*P<0.05
**P<0.01

Table IX: Mean, Standard deviation and t-value for existing BTE users in quiet and noisy conditions.

The analysis of the t-scores indicate that

- There is no significant difference in the SIS obtained using the three prescriptive formulae in quiet condition.
- Under noisy condition. There is significant difference between the scores obtained using NAL-NLI and DSL I/O at 0.01 LOS and a significant difference at 0.05 level between NAL-NLI and FIG 6. Both cases NAL-NLI gave a better score. No significant difference was found between DSL I/O and FIG 6 under this condition.

The above results indicate that NAL-NLI is preferred in noisy conditions due to low cut off energy of noise whereas DSL I/O and FIG 6 which are designed for compression hearing aids do not use any low frequency cut off.

Naive users

Naive users quiet				Noise			
	Mean	S.D.	t-value		Mean	SD	t-value
NAL-NL1	15.6207	2.5553	-.797 NS	NAL-NL1	13.9655	2.7056	-.105 NS
DSLI/O	15.8276	2.6601		DSL I/O	14.00	3.1053	
DSL I/O	15.8276	2.6601	1.822 NS	DSL I/O	14.000	3.1053	1.656 NS
FIG 6	15.3793	2.9083		FIG 6	13.4828	3.2140	
NAL-NL1	15.6207	2.5553		NAL-NL1	13.9655	2.7056	1.678 NS
FIG 6	15.3793	2.9083	NS	FIG 6	13.4828	3.2140	

Table X: Mean, standard deviation and t - value for the naive users in quiet and noisy conditions.

Results of the t-test suggest that there is no statistically significant difference between the SIS across the three formulae both in quiet and noise conditions.

The results indicate that there is no difference in the performance using the three formulae, even in noisy condition. This may be due to the reason that naive users are not able to appreciate the difference in their amplification of hearing aids as they are exposed to amplification for the first time. Better results may be expected after an acclimatization period.

Thus, from the above results, it is seen that NAL-NL1 gives the best speech identification scores especially in noisy situations as it cuts off the low frequency energy of noise. Also the principle aim of NAL-NL1 is to maximize speech intelligibility. The other two formulae DSL I/O and FIG 6 are designed for compression hearing aids but the compression is not taking place, as the input level of the stimulus is low.

SUMMARY AND CONCLUSION

Amplification represent the single most important rehabilitation tool available to the hearing impaired population (Ross & Giolas 1978, Bess & McConnell, 1981). .A hearing aid is an amplification device capable of amplifying the sound reaching a person's ear. The hearing aid selection can be done using comparative or prescriptive procedures. The prescriptive procedure refers to the tailoring of frequency response curve of a hearing aid in conformance with the client's audiogram (Ross, 1978). Several studies have been done to compare different prescriptive formulae in terms of the gain provided. The present study was undertaken to compare three threshold based formulae used for non- linear hearing aids - NAL-NL1, DSL I/O and FIG 6 in terms of their speech identification score under quiet and noisy condition.

Forty-four subjects above 18 years of age with acquired sensory neural hearing loss ranging from mild to sever were selected. The patients were fitted with a hearing aid after programming it using a particular formula. After fine-tuning of the hearing aid, speech identification scores using phonetically balanced words in Kannadu was found out in both quiet and noisy conditions.

The data was then subjected to statistical analysis using paired t-test The data was further subdivided based on the degree of loss, audiometric configuration and hearing aid use.

The results revealed that NAL-NL1 gave a superior score especially in presence of noise and also in some quiet conditions. This may be attributed to the fact that the principle aim of NAL-NL1 is to maximize speech intelligibility and NAL-NL1 also cuts off the low frequency energy of noise. DSL I/O and FIG 6 are meant for compression hearing aids but compression is not into play as the level of the input stimulus was low.

For gradually and sharply sloping audiograms there was no significant difference between the three formulae. This is because NAL-NL1 prescribes less gain than other procedures in the region of greatest hearing loss. This finding is in concurrence with the study by Byrne, Dillon, Ching, Katsch and Keidser (2001).

Though, statistically a significant difference was seen, across formulae clinically there was not a considerable difference in the SIS using the three formulae but a superior performance with NAL-NL1 was generally seen.

REFERENCES

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

Beattie, R. (1989). Word recognition functions for the C1DW-22 test in multitalker noise for normally hearing and hearing impaired subjects. *Journal of Speech and Hearing Disorder, 54,* 20-32.

Bess, F., & McConnell, F.(1981). *Audiology, education and the hearing impaired child.* St. Louis : C.V. Mosby.

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

Carhart, R. (1945). Classifying audiograms : An improved method for classifying audiograms. *Laryngoscope, 55,* 640-662.

Carhart, R. (1965). Monaural and binaural discrimination against competing sentences. *International Audiology, 4,* 5-10.

Carhart, R., & Tillman, T.W., (1970). Interaction of competing speech signals with hearing losses. *Archives of Otolaryngology, 91,* 273-279.

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

Cornelisse, L.E., Seewald, R.C., & Jamieson, D.G. (1995). The input / output formula : A theoretical approach to the fitting of personal amplification devices. *Journal of Acoustic society of America, 97(3),* 1854-1864.

Davis, II., Hudgins, C, Marquis, R., Nicholas, R., Peterson, G., Ross, D., et al. (1946). The selection of hearing aids. *Laryngoscope, 56,* 85-163.

Dillon, H (1998). The NAL procedure for selecting the saturation sound pressure level of hearing aids. *Ear and Hearing, 19,* 255-266.

Dillon, H. (1983). The effect of test difficulty on the sensitivity of speech discrimination tests. *Journal of Acoustic society of America, 73,* 336-344.

Dirks, D.D., Morgan, D.E., & Dubno, J.R. (1982). A procedure for quantifying the effects of noise on speech recongition. *Journal of speech and Hearing Disorders, 47,* 114-123.

Dubno,T.F., Levitt, H. (1981). Predicting consonant confusions from acoustic anulysis. *Journal of Acoustic Society of America, 69,* 249-261.

Gabrielsson, A., Schenkman, B.N., & Hagerman, B.(1988). The effects of different frequency responses on sound quality judgements and speech intelligibility. *Journal of Speech and Hearing Research, 31,* 166-177.

Garrett, H.E., & Woodworth, R.S., (1979). *Statistics in Psychology and Education,* New York : David Mackay Company, Inc.

Gatehouse, S., & Haggard, M.P. (1987). The effects of air bone gap and presentation level on word identification. *Ear and Hearing, 8,* 140-146.

Green, R., Day, S. & Bamford, J. (1989). A comparative evaluation of four hearing aid selection procedures speech discrimination measures of benefit. *British Journal ofAudiology, 23 (3),* 185-191.

Humes, L., & Houghton, R. (1992). Beyond insertion gain. *Hearing Instruments, 43(3),* 32-35.

Jerger, J. & Hayes, D. (1976). Hearing aid evaluation : Clinical experience with a new Philosophy. *Archives of Otolaryngology, 102,* 214-225.

Kamp, M.W., Margolf-Hackl, S., & Keissling, J. (2001). Comparison of two digital hearing instrument fitting strategies. *Scandinavian Audiology, 52,* 73-75.

Katz, J. (1978). *Handbook of Clinical Audiology* (2nd ed.), Baltimore : Williams and Wilkins.

Katz, J. (1994). *Handbook of Clinical Audiology.* (4lh Ed.) Baltimore : Williams and Wilkins.

Keidser, G., & Grant, F. (2001). Comparing loudness normalization (IHAFF) with speech intelligibility maximization (NAL-NL1) when implemented in a two-channel device. *Ear and Hearing, 22,* 501-515.

Keidser, G., Brew, C, & Peck, A. (2003). Proprietary fitting algorithms compared with one another and with generic formulas. *The Hearing Journal, 56(3),* 28-38.

Killion, M., & Fikret - Pasa, S. (1993). The 3 types of sensorineural hearing loss : Loudness and intelligibility considerations. *Hearing Journal, 46,* 31-36.

Libby, H.R. (1988). Hearing aid selection strategies and probe microphone measures. *Hearing instrument, 39 (7),* 10-17.

Lloyd, L.L., & Kaplan, H. (1978). *Audiometric interpretation : A manual of basic audiometry.* Baltimore : University Park Press.

Loven, F.C. & Hawkins, D.B. (1983). Interlist equivalency of the CID W-22 word lists presented in quiet and in noise. *Ear and Hearing, 4,* 91-97.

Mayadevi. (1974). The development and standardization of a common speech discrimination test for Indians. *Unpublished dissertation.* University of Mysore, Mysore.

Moore, B. C.J., Alcantara, J.I., & Marriage, J. (2001). Comparison of three procedures for initial fitting of compression hearing aids. I. Experienced users, fitted bilaterally. *British Journal of Audiology, 35,* 339-353.

Moore, B.C.J., Lynch, C, & Stone, M.A. (1992). Effects of fitting parameters of a two-channel compression system on the intelligibility of speech in quiet and in noise. *British Journal of Audiology, 26,* 369-379.

Plomp, R. (1986). A signal to noise ratio model for the speech reception threshold of the hearing impaired. *Journal of Speech and Hearing Research, 29,* 146-154.

Ricketts, T.A., (1996). Fitting hearing aids to individual loudness - perception measures. *Ear and Hearing, 17(2),* 124-132.

Ross, M., & Giolas, T. (1978). *Auditory management of hearing impaired children : Principles and pre requisites for intervention.* Baltimore : University park press.

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(4),* 230-238.

Smeds, K., & Leijon, A. (2001). Threshold based fitting methods for non-linear (WDRC) hearing instruments comparison of acoustic characteristics. *Sandinavian Audiology, 30,* 213-222.

Sourza, P.E., & Bishop, R.D. (2000). Improving audibility with non-linear amplification for listeners with high frequency loss. *Journal of American Academy of Audiology, 11(4),* 214-223.

Stelmachowicz, P., & Lewis, D. (1988). Some theoretical considerations concerning the relation between functional gain and insertion gain. *Journal of Speech and Hearing Research, 31,* 491-496.

Stelmachowicz, P., Dalzell, S., Peterson, D., Kopun, J., Lewis, D. & Hoover, B. (1998). A comparison of threshold based fitting strategies for non linear hearing aids. *Ear and Hearing, 19,* 131-138.

Wilber, L.A. (1994). Calibration, Purertone, speech and noise signals. In J. Katz (Ed.). *Handbook of Clinical Audiology.* (pp. 73-97). Baltimore : Williams and Wilkins.

Yost, W. (1994). *Fundamentals of Hearing : An introduction,* (3rd ed.). Sandeigo: Academic Press, Inc.