Effect of preferred gain and prescribed gain on speech perception in noise - A validation of prescriptive formulae

Register no: A0490004

A dissertation submitted in part fulfillment for the degree of

Master of Science (Audiology)

University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH & HEARING

NAIMISHAM CAMPUS

MANSAGANGOTHRI, MYSORE-570006

MAY, 2006.

DEDICATED TO

MA & BABU

THE MOST BEAUTIFUL FEELING IS

…"BEING YOUR DAUGHTER"

Certificate

This is to certify that this dissertation entitled **"Effect of preferred gain and prescribed gain on speech perception in noise-A validation of prescriptive formulae"** is a bonafide work in part fulfillment for the degree of Master of science (Audiology) of the student Registration no: A0490004. This has been carried under the 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.

Mysore
May, 2006

Prof. M. Jayaram
Director
All India Institute of Speech & Hearing,
Naimisham Campus
Manasagangothri, Mysore-570006

Certificate

This is to certify that this dissertation entitled **"Effect of preferred gain and prescribed gain on speech perception in noise-A validation of prescriptive formulae"** has been prepared under my supervision & 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

May, 2006

Dr. K.Rajalaikshmi
Guide
Reader & HOD, Dept. of Audiology
All India Institute of Speech & Hearing
Naimisham Campus
Mansagangothri, Mysore-570006

Declaration

This dissertation entitled **"Effects of preferred and prescribed on speech perception in noise - a validation of prescriptive formulae"** is the result of my own study and has not been submitted earlier in any other university for the award of any Degree or Diploma.

Mysore **Reg.No.A0090004**

May 2006

ACKNOWLEDGEMENTS

Ma & Babu... This work is dedicated to you, without who my existence is meaningless.. .thanks a lot ma for giving meaning to my life...
Babu...thanks a lot for the immense support you have given me... for being the pillar of strength for me.. .a million thanks to both of you to help me reach here...

I express my heartfelt thanks to my guide, Dr. K. Rajalakshmi, Reader, Head of Dept., Audio logy, for her valuable guidance and immense support. Thank you ma'm for being there for guiding each step.

A dream come true was studying in AIISH, and learning so much, I would like to thank Prof. M. Jayaram, Director, AIISH, who permitted me to conduct this study.

There is a rare and special quality in the way some people live...
However busy they may be, they still have time to give....
Kindness just comes naturally to these rare and selfless few....
SPECIAL GIVING PEOPLES...my Teachers...
A sincere thanks to Vanaja ma'm, Manjula ma'm, Asha mam, Animesh Sir, Ajish Sir...

My sincere acknowledgements for Prof. Asha Yathiraj and Vijayalakshmi. C.S for allowing me to use the word list.

The staff of Dept. of Audiology has been there to help me during difficult times and have make things easier for me.... Special thanks to Rama ma'm and Mamtha ma'm...

Thanks to all the subjects who participated as subjects in this study...

Thanks to Srikanta sir, for his insightful and timely advises and help,
Sir without you the completion of this study would have been

Impossible...! owe you a lot....

Sandipan, Anando, Lopa, Swarnali, my treasured pals… thanks for being there in my life...

Thanks to all my juniors, ERCians and seniors in AIISH, Pratiksha and Prasitha. Thanks for your help in initial days of my audio postings...

Sandeep Sir, Vinay Sir, Ajith Sir, Vani… .thanks for all the helps you provided...

A special thanks to Devi, Sujitha, Hari, Amy, Sonia...for helping me with my presentations and dissertation...and answering my queries.. .it was nice you people...

Shiva, thanks is not enough to acknowledge the favours you lended... Heartfelt thanks for all your selfless & timely help

Sumita & Rima, thanks for giving me the feeling of a home away from Home.... thanks for all the fun filled moments we spent....

A special thanks Vasantha ma'm...Who has taken pains to help me with statistical analyses

Thanks a lot Shivappa and crew...for your in time printing and typing works

I thank all my classmates for giving me lovely moments of fun ... These two years were learning experiences...discovering each other...having fun together...studying together and not studying together...I am happy that I got so many wonderful friends...

Geetha thanks a lot for giving me the technical support and help in making corrections and alignments...I know I have bothered you to the fullest extent...but you were really great...

A special thanks to the angel in my life...you have been there for me always...I am happy that I met you.

LIST OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The minimal goals of any hearing aid fitting are to achieve the best possible audibility (ability to hear soft, moderate and loud sounds) while providing comfort and excellent sound quality. In addition the hearing aid must meet the expectations of the patient which usually include communicating in a variety of situations including communicating in noise. Many significant technical improvements in hearing instruments e.g. widespread introduction of dynamic range circuitry, flexible programmable active filters, directional microphones and dramatic miniaturizations, have been realized over the past several decades since the hearing amplification system was invented.

Additionally, societal changes (e.g. demographics, greater prosperity, activities among retirees, increased noise exposure for all ages) and changing consumer expectations for speed and capacity in electronic products have ramifications for future hearing instrument design and acceptance.

On a more global basis, at least four fundamental developmental trends of hearing instruments are commonly noted, including miniaturization, the improvement of electro acoustic transmission properties, the extension of selection and configuration possibilities, and increased convenience of operation.

To satisfy the technical and electro acoustical demands of each hearing instrument, there have been and advancements and improvements in fitting procedures at the same pace as well. The selection procedures can be grouped, as comparative and prescriptive procedures. Both comparative and prescriptive procedures are types of selective amplification approach to hearing aid fitting. Selective amplification refers to the belief that some unique combination of hearing aid performance characteristics provides for optimal listening for each individual's hearing loss.

PRESCRIPTIVE HEARING AID SELECTION PROCEDURES

These are based on the assumption that optimum or desired electro acoustic characteristics can be specified prior to actual hearing aid fitting based solely on measurements of the auditory system. These can be pure-tone thresholds, most comfortable loudness levels (MCL), uncomfortable loudness levels (UCL) etc.

Prescriptive procedures make the general assumption that, if average conversation speech is amplified to the listener's comfortable loudness level, the fitting will result in user satisfaction by providing acceptable sound quality, clarity of speech, and comfort.

In spite of the basic assumption, factors as comfort, naturalness and pleasantness are not addressed directly by the prescriptive formulae. This is because of the fact that existing fitting software; though highly flexible in configuration possibilities, generally do not directly receive systematic input from the listener / user.

The fitting of modern hearing aids is becoming increasingly complex. An important reason for this trend is the fact that modern hearing aids aim to compensate for more than the audibility loss. Techniques have been introduced that try to compensate for supra-threshold deficits, using non-linear approaches in multiple bands, and that either enhance the speech signal or reduce the amount of background noise.

Fitting rules for the techniques in this area are not available yet and fitting is guided by trial and error or by proprietary fitting rules for specific devices that are usually not evidence based and mostly not properly documented. Moreover, precisely matching a prescriptive target, whether in a 2- cc coupler or patient's real ear does not guarantee either optimum speech intelligibility in noise or optimum sound quality. Moreover, consumer complaints about hearing instrument performance remain relatively high (Schweitzer, 1997, cited in Haubold & Schweitzer, 2000; Kirkwood, 2000; Kochkin, 1999; Kochkin, 2000).

A frequently occurring dilemma for the audiologist is deciding whether or not to adjust the electro acoustic parameters of hearing aid in adult patients in response to their complaints. There is literature support for the view that the preferred gain settings differ from the settings recommended by fitting formula. (Arlinger, Lyregaard, Billermark, & Oberg 2000; Berger and Hagberg, 1982; Byrne & Cotton, 1988; Arlinger, S., Lyregaard, P.E., Billermark, E., & Oberg, M.; Marriage et al. 2004). These authors have also discussed the effect of hearing aid experience on the difference between prescribed and preferred gain.

However Bentler, Niebuhr, Getta, and Anderson, (1993), Walden, Schuchman, and Sedge, (1977) also have examined the issue of changes in gain preferences over time, but focused exclusively on new hearing aid users (Walden et al., 1977). Results revealed that there was no trend for new hearing aid users to increase or decrease their preferred volume control setting over time.

These studies have supported their research with various qualitative and quantitative measures such as sound quality judgements (Munro & Lutman 2004), and administering hearing aid benefit scale. Speech in noise measures have been used limitedly in quantifying difference preferred and prescribed gain, except for few reports (Cunningham and Goldsmith, 2002). Apart from subjective and qualitative evidences empirical evidences in favour of fine-tuning is also required which has direct implications in clinical practice.

Listener with impaired hearing experience most of their difficulties in understanding speech under noisy conditions. Individuals with sensorineural hearing loss are more sensitive to noise masking effects than the normal hearing individuals listening to speech processed through a hearing aid. Adding a background noise to test stimuli makes the test more representative of real life listening. (Jerger and Hayes, 1976; Kalikow, Stevens, and Elliot, 1977; Plomp, 1986; Schow and Gatehouse, 1990). Hence, even the fine-tunings done relative to prescriptive procedure need to be verified using speech in noise measures.

The focus needs to be changed on each prescriptive formula per se in a particular user. So along with the question "does his/her gain preferences change over time"? An addition query "Are there any gain preference with respect to a particular formula & how each of them effect speech perception" is required.

Denis Byrne (1999) in his own words ... "No method of hearing aid prescription is better than the empirical evidence it could gather, the search for empirical evidence should concern us no less than the immediate clinical solution". So, the need of the present study stems from the concept of individualized hearing aid fitting which is one of the most contemporary principles in hearing rehabilitation.

NEED OF THE STUDY

The benefits of fine-tuning of hearing aids, in terms of speech understanding in noise are little know as there is dearth of literature.

- It is necessary from both theoretical and clinical stand point to establish if the prescribed and preferred gains affect various aspects of hearing such as speech perception in noise.
- Comparison of the prescribed gain with individual preferred gain is one of the important ways to determine the efficacy of fitting formulas. Such a method through recommended in literature has not been extensively used to validate hearing aid prescriptions (Dillon, 2001).

- The continued need to verify which formula among (NAL-NLI and DSL (i/o) gives a close match with preferred settings will eventually also be addressed, as this study will use 2 frequently used prescriptive formula.

RESEARCH GOALS

The present study has the following aims.

1. To determine if there is a significant difference between prescribed gain and preferred gain for two non linear hearing aid fitting formulae.

2. To determine whether there is any difference in speech perception in noise due to prescribed and preferred settings.

3. Does the difference if any depend on the formula?

4. Does the difference also depend on configuration of hearing loss?

CHAPTER II

REVIEW OF LITERATURE

The introduction of digital technology and fully digitized amplifiers in hearing aids has vastly increased the possibilities for re-configuring sound for individuals who suffer from hearing impairment. In spite of these extensive technical advances, it does not appear that consumer satisfaction and market penetration have greatly improved (Haubold & Schweitzer, 2000). Evidence from surveys in the United States (Schweitzer, 1997, cited in Haubold & Schweitzer, 2000; Kirkwood, 2000; Kochkin, 1999; Kochkin, 2000) indicates that consumer complaints about hearing instrument performance remain relatively high.

Incorporation of features like multiple memories, multiple microphones, multiple channels, programmable aids and completely in the canal aids have resulted in levels of satisfaction approaching just 75%, the highest level of satisfaction ever observed by the hearing aid industry (Punch, 2001). This shows that it is not just the level and sophistication of technology that determines the performance and consequently the patient satisfaction levels, but there are several other factors affecting the performance.

Since the evidence suggests that manufacturers are designing and producing technically better hearing instrument systems, it seems questionable to lay the blame for continuing complaints on them. Rather, suspicion may instead fall on the available means and methods of configuring and fitting hearing instruments to individual user preference. It might be a case of hearing instruments becoming "more mature" in technical sense but remaining 'immature' in the less technical aspects of user satisfaction.

All the current programming systems use some rule or formulaic prescription, based on hearing thresholds to establish the initial pre-setting configuration of the hearing instrument. Current hearing aid prescriptions formulae (e.g. Byrne & Dillon, 1986; Byrne, Dillon, Ching, Katsch & Keidser, 2001; Cornelisse, Seewald & Jamieson, 1995) specify the gain and maximum output of the hearing aid at each audiometric frequency. These procedures assume that a frequency specific gain function (i.e., selective amplification) can be prescribed for each hearing-impaired individual on the basis of audiometric data. These gain algorithms can be subdivided into 2 classes:

i) Formula that make use of threshold audiometric data.

ii) Formula that also incorporates supra threshold audiometric data in deriving electro acoustic prescriptions for hearing impaired listeners.

All the prescriptive procedures derive recommended frequency gain characteristics for various input levels from the audiogram alone but have various theoretical rationales. The different underlying rationales are normalization (Cornelisse, Seewald & Jamieson, 1995) or equalization of loudness density (specific loudness) or speech intelligibility maximization (Bryne, Dillon, Ching, Katsch, & Keidser, 2001).

A) Loudness Normalization

The goal of loudness normalization is to apply an acoustic transform to the input signal so that the hearing impaired listener's perceived loudness of an input signal matches the perceived loudness of a normal hearing listener across frequencies. (Cornelisse, Seewald, &Jamieson, 1995)

B) Loudness Equalization

The goal of loudness equalization is to amplify speech to approximate MCL contour. That is to apply an acoustic transform to the input signal so that the hearing impaired listener's perceived loudness of speech is equal across frequency bands.

C) Speech Intelligibility Maximization

The goal of speech intelligibility maximization is to provide the gain frequency response that maximizes speech intelligibility while keeping overall loudness of speech at levels being not more than perceived by a normal hearing person listening to the same sound.

Among the commonly used prescriptive procedures, NAL-NL1 (Bryne, Dillon, Ching, Katsch & Keidser, 2001) and DLS [i/o] (Cornelisse, Seewald and Jamieson, 1995) have gained wide acceptance in clinical fitting of hearing instruments.

NAL-NL 1 prescriptive formula

NAL-NL1 stands for National Acoustics Laboratories, Non-linear Version 1, and was first described by Dillon in the year 1999. The underlying rationale of NAL-NL 1 is to provide the gain frequency response that maximizes speech intelligibility while keeping overall loudness of speech at a level being not more that perceived by a normal hearing person listening to the same sound. The main objective of developing NAL-NL 1 was to determine the gain for several input levels that would result in maximal effective audibility. It is neither based on loudness normalization nor loudness equalization. However in this procedure the loudness of the signal is varied to such an extent where speech intelligibility is maximized. (Bryne, Dillon, Ching, Katsch, & Keidser, 2001). The NAL-NL 1 procedure was derived by calculations that combined a loudness model (Moore and Glasberg, 1997) with a modification of the Speech Intelligibility Index (SII) (ANSI, 1993). The only information required by both models is hearing thresholds and speech spectrum levels' input to the ear after amplification. The modification of Speech Intelligibility Index was done to calculate speech intelligibility for hearing impaired people. These modifications allow for the reduced analyzing ability that people have when hearing threshold exceed about 40dBHL. Correlations of this type have been called hearing loss desensitization and were derived from 52 audiograms that covered a wide range of shapes and severity of hearing loss. The loudness and intelligibility programs were linked to a constrained numerical optimizer using a fast computer. In this, one audiogram was fed in and an overall speech level of 40dB SPL was chosen. The computer then semi-randomly altered the gain at each 1/3-octave frequency and computed the total loudness and Speech Intelligibility Index that resulted. Further, it kept altering the gain characteristics until it found the characteristic that maximized the calculated speech intelligibility without exceeding the normal loudness for 40dB SPL speech. The same procedure was repeated for five more speech levels from 50dB SPL to 90dB SPL and for rest of the 51 audiograms. The result of this long process was a set of 312 gain curves. A formula was given to express these insertion gains so that the calculation can be done for any new audiogram and speech level in a few seconds. To accurately match the gain of each frequency the formula need the values of:

- Hearing threshold at each frequency
- 3-frequency average hearing threshold (500Hz, 1 OOOHz and 2000Hz)
- Slope of audiogram from 500Hz to 2000Hz
- Overall level of the speech input signal.

The formula therefore prescribes insertion gain at each frequency, for each speech level. The gain at any frequency ended up depending on the hearing loss at several frequencies, rather than only the frequency in question.

DSL [i/o] prescriptive formula

The development of Desired Sensation Level started in 1982 with the original published description occurring in 1985 (Seewald, Ross and Shapiro, 1985). This formed the foundation for the DSL method with its goal to make speech sufficiently audible to allow speech perception, without discomfort, for all degrees of hearing loss. A computer-assisted implementation was first released in 1991 (DSL 3.1). DSL [i/o] was first introduced in 1994

(Cornelisse et al., 1995) followed by the most recent version, DSL v 4.1 for Windows, in April 1997 (Seewald, Cornelisse, Ramji, Sinclair, Moodie and Jamieson, 1997). The DSL [i/o] algorithm was designed for the purposes of fitting hearing instruments with advanced non-linear processing schemes (WDRC and digital devices). DSL [i/o] is best described as an acoustic mapping algorithm (DSL v4.1 Manual, p-21). That is, for a given frequency band, an acoustic input region is mapped onto an acoustic output region. The input dynamic range is generally defined as an extended normal auditory area from the normal hearing threshold of audibility to the hearing impaired individual's upper limit of discomfort. The output dynamic range is defined by the hearing loss (threshold to UCL). The compression is applied given that the input dynamic range is different than the output dynamic range as defined by the hearing loss. Independent of the target algorithm, what makes DSL unique is the approach that it takes to the definition of variables that must be considered in the hearing instrument fitting and verification process. Very early in the development of the DSL method the authors recognized that audibility of speech signal could be viewed as the most basic prerequisite to auditory linguistic growth and performance (Seewald and Ross, 1988). It is imperative that the amplified level of speech output in the ear canal be placed at a preferred listening level across the broadest frequency range possible, in a variety of different listening conditions, to achieve maximal performance on speech perception measures. That is, the speech signal must be audible, comfortable and undistorted across a range of listening conditions regardless of the amplification circuitry and prescriptive method used. Defining audibility of an amplified speech signal is difficult if the audiometric thresholds are referenced in dB HL and the hearing instrument performance is measured in dB SPL. The HL audiogram also infers an average adult ear canal. Consequently, prediction of actual threshold in dB SPL based on a standard HL scale is difficult given the individual variations in ear acoustics (Hawkins, Cooper and Thompson, 1990). In order to ensure that the relative audibility of an amplified signal can be determined, DSL refers all assessment data, hearing instrument targets and verification data to real ear SPL. The process emphasizes a very basic scientific principle, that if two measures are compared, then they have to be measured with the same scale (dB SPL) and referenced to the same point (ear canal). The DSL method converts the HL audiogram into an audiogram in SPLogram. Targets are provided based on the degree of hearing loss for various levels of inputs. Validation studies would support that, if applied appropriately, the DSL algorithm ensures comfort and acceptable speech perception abilities over a wide range of input levels. For their underlying rationale, discussed above the benefits the listener draws while using NAL-NL1 and DSL-i/o are great.

Studies comparing NAL-NL1 and DSL-i/o

Due to difference in underlying rationale, the frequency gain response of both the formulae differ .The difference also varies with the type of hearing loss configuration. Sehgal, (2005); Byrne et al (2001); & Keidser and Grant (2001) reported that for gradually sloping hearing loss cases the REIG at low and mid frequencies were almost equal for NAL-NL1 and DSL-i/o. However at higher frequencies NAL-NL1 prescribes less gain than DSL-[i/o]. Sehgal, (2005); Byrne et al (2001); & Keidser et al (2001) report that for steeply sloping hearing loss both the formula do not show mush variation in gain for low and mid frequencies. The difference in gain becomes larger after 3000 Hz for all the frequencies. NAL-NL1 prescribes lesser gain at higher frequency and gain drops as frequency increases.

PRESCRIBED VERSUS PREFERRED GAIN

The prescriptive formula, threshold based or suprathreshold based, gives the first estimate of gain requirements. They provide with the prescribed gain settings for a particular audiogram. Prescribed fitting parameters are assumed to be appropriate for the median patient, but it is expected that on a patient-to-patient basis, individual adjustment, away from the median prescribed values will need to take place. There may be inter subject differences in loudness growth and preferred sound quality even when two subjects have the same audiogram configuration. Therefore, there is a need to verify the prescribed settings with subjective impression. Fine-tuning is the correction for individual variation from the mean. Some patients for example simply, prefer, more or less high frequency gain than would be expected based on the audiogram, fine adjustments with respect to the prescribed settings are required to determine the preferred gain settings.

There are supports from literature for two views.

- There is significant difference between prescribed and preferred settings and there are significant effects of each on sound quality judgments or speech perception measures.
- The other view is there is no difference between prescribed and preferred settings and if it is, there are no significant effects of each on sound quality judgments or speech perception measures.

Following are literature review in support of the first view.

Practical clinical experiences with prescriptive methods (Lyregarard, 1986; Libby, 1986; Sullivan, Levitt, Hwang & Hennessey, 1988) show that the methods cannot eliminate the need for individual allowances and adjustments. This suggests subjects should be active in the fine-tuning process to find the best fitting for the individual.

Theoretical calculations (Leijon, 1989, cited in Lunner, Hellgren, Arlinger & Elberling, 1997) indicated that some persons, with identical audiometric hearing losses but different impairments of auditory frequency resolution, might need markedly different hearing aid frequency responses. This emphasizes that prescriptive rules based only on hearing threshold should be treated with caution.

Humes, Wilson, Barlow and Garner, 2002; Leijon, Lindkvist, Ringdahl and Israelsson, 1990,cited in Smeds, 2004, using linear amplification has indicated that subjects with sensorineural hearing losses prefer considerably less overall gain than prescribed by the most commonly used prescriptive methods for linear hearing aids, NAL-R (Bryne and Dillon, 1986). So there is a need to investigate the gain preferences with respect to prescribed gain for formulae suitable for non-linear aids for example NAL-NL 1 and DSL [i/o].

However, Smedes. K. (2001) (preliminary data, cited in Smeds, 2004) have indicated that, subjects without previous hearing aid experience provided with level dependent gain also preferred less overall gain than prescribed by some of the current threshold based prescriptive methods for wide dynamic range compression (WDRC) hearing aids (NAL-NL 1, CAMEQ, and DSL [i/o]). Both NAL-NL 1 and CAMEQ prescribe similar gain as NAL-R for a mid-level input, and both methods aim at giving normal calculated overall loudness for a range of input levels according to a loudness model by Moore and Glassberg (1997).

Dillon, (2003) investigated if clients prefer less overall gain than prescribed by NAL-NL 1 when wearing a commercial device in their everyday environments. 48 clients (86 ears) were fitted with a digital 2-memory, 2-channel WDRC hearing aid. These clients were originally invited to evaluate the multimemory feature of the device. All clients were fitted according to the NAL-NL 1 formula in program 1. The hearing aid was initially adjusted to simulated target curves in the fitting software and then verified by real-ear measurements against the NAL-RP target using a 65dB speech shaped noise as input. The NAL-RP target was used in the verification process because NAL-NL 1 target was not available in the analyzing equipment used. During fitting appointment, the focus was on the alternative program to ensure that the 2 programs were audibly different. At a review appointment scheduled about 4 weeks post-fitting, the 2 programs were fine-tuned, if needed, according to client's experience with the 2 programs in real-life environments. The audiologist adjusted the overall gain as well as the frequency response shape. Real-ear measurements were obtained of the final settings from which the preferred 3 frequency average gains (500, 1000, and 2000Hz), the preferred low-frequency average gain (250 and 500Hz) and the preferred high-frequency average gain (2000, 3000 and 4000Hz) were calculated. The preferred average gain settings were then compared with the average NAL-NL 1 prescription for a 65dB speech input, which for each individual was obtained from the NAL-NL 1 stand-alone software. Results show that clients preferred 0.70dB, O.53dB and 1.5dB less gain than prescribed overall, in the low frequencies and in the high frequencies, respectively. The results also suggest that a few subjects preferred substantially more high frequency gain than prescribed by NAL-NL1. In this study the effects of prescribed and preferred gain were not verified using any speech perception measures. According to the author the gain settings shown as preferred lower gain could be a result of preference or could be a result of some limitation in gain adjustments due to vented moulds or feed back. And the author concluded, overall data do not support the claim that the NAL-NL 1 prescribes too much of overall gain for a 65 dB SPL input.

Leijon, Erikson-Margold, and Bech-Karlson, (1984), investigated the insertion gain versus frequency, preferred by a group of moderately hearing impaired, elderly, untrained hearing aid users both in the everyday listening situations and in acoustically specified test situations in laboratory. The subjects used experimental binaural hearing aids with modified controls, which could be easily and accurately operated. They adjusted both gain and bass-cut while using the aids. In the everyday listening situation, the subjects were asked to adjust the aid to the best position. They were asked to use the aid daily atleast in one situation. At the laboratory session the subjects were supposed to listen & watch a video tape recording and at the same time a stereo recording of coffee room noise was played. The preferred insertion gain was compared with recommendations from 3 methods of prescriptive fittings. At the laboratory session all the three methods recommended higher insertion gain than that preferred by the subjects. These differences were all significant at 1 % level (Wilcoxon matched pairs test for the average between 1 and 2 kHz and between right and left). The

Spearman rank correlation between preferred insertion gain and MCL was 0.76, which is significant at the 1 % level. No significant correlation was found between preferred gain and puretone threshold. These methods significantly overestimated preferred gain by about lOdB. In one to one conversation, with or without background noise, the average hearing aid control position preferred in everyday situations was compared with the positions preferred at the laboratory situations. More gain was generally preferred at the laboratory with a median difference of 2 dB. Though the preferred gain with respect to prescribed gain were verified with insertion gain measurements, no speech perception tests were carried out in this study, to observe the effects of each gain on speech perception.

In a later study, Leijon, Lindkvist, Ringdahl, and Israelsson, (1990) involving mainly first-time users, but also some subjects with previous although rather limited experience of hearing aids, confirmed the fact that preferred gain was less than prescribed. All the subjects had moderate hearing loss. They were fitted with BTE, equipped with tone controls and saturation level controls and was programmed according to NAL recommendation. The preset gain controls were set so that the user's volume control could be adjusted for 12 to 15dB greater gain than recommended by NAL formula. After a training period of one month, the client was interviewed about the quality of sound and the benefit experienced in different listening situations. Some patients decidedly wanted the frequency response to be changed. In these cases ear mold vent & / or tone-control setting was changed and another trial period was given. After reported satisfaction with sound quality, the subjects were asked to use the aid in at least one listening situation daily. Though the volume was set according to NAL recommendation, the subjects were asked to try different settings and choose the best in each listening situation. The subjects were required to answer a questionnaire about the listening situation and they also had to mention the volume setting used by them. At a final session the insertion gain was measured with the volume control in the position most typically used in everyday listening. The results showed that most of the subjects used clearly less insertion gain than recommended by the NAL formula in the frequency range 1 to 2 kHz. The difference between recommended and preferred gain was statistically highly significant. They could not find any correlation between prescribed versus preferred gain differences and the amount of previous hearing aid use or the degree of subjective hearing problems. Though the preferred gain with respect to prescribed gain were verified with insertion gain measurements, no speech perception tests were carried out in this study, to observe the effects of each gain on speech perception.

Arlinger, Lyregaard, Billermark, and Oberg (2000) in their study assumed that a gradual return to a more sound-rich life might be easier to adjust to than that offered by a hearing aid whose gain and outputs characteristics are set according to results obtained on experienced users. The study was double blinded by using a programmable hearing aid, set to either the standard setting as prescribed by manufactures or to reduced gain and maximum output. The study was performed on a group of first time user with gradually sloping pure tone audiograms. Half of the subjects were fitted directly with a hearing aid at the settings prescribed by the manufacturer's fitting protocol, and the other half started with a fitting where both gain and output were reduced relative to this standard fitting protocol. After 3 days the subjects underwent a test schedule involving subjective assessment of perceived sound quality and communication abilities. Then the settings were changed. Giving the first subgroup the reduced settings and the second, the settings according to the standard fitting protocol. After another 3 days the same assessment scheme was reported. The subjects were also asked about their preference for the two fitting alternatives tested. The users were blinded to which setting was in use since the aid was a programmable type. No significant difference in APHAB, sound quality, estimated communication ability or perceived loudness scores were seen for the two settings. Moreover there was no correlation between preferences for either of settings and hearing thresholds, loudness discomfort levels, dynamic range, age, gender or monaural v/s binaural fittings. The authors rejected the hypothesis that new users prefer less gain and output than experienced users. The conclusion of this study is complicated and to be inferred with caution as there was use AGC in both the 'target' and reduced programs which resulted in a smaller than intended gain difference between the two settings. The actual difference as measured in a 2cc coupler with a 60dBSPL input was only 2dB at 1 kHz and 4dB at 4 kHz, which may have made it difficult for some subjects to distinguish the 2 settings apart.

Mueller, Bryant, Brown, and Budinger (1991), cited in (Convery, Keidser, & Dillon, 2005) reported that new users with high frequency hearing loss preferred higher gains relative to NAL-R prescriptions and the use gains reduced by l-3dB over the first 6 week of hearing aid use. The subjects in this study chose preferred gain in response to recorded speech in laboratory settings and during field trial preferred setting was chosen in subject's own listening situation. But the authors did not mention whether the change in gain preference was statistically significant or not. The preferred gain was not verified with any speech perception tasks.

Cunningham, Williams and Goldsmith (2001) carried out a pilot study to investigate "do post-fitting fine-tuning adjustments to the instruments' electro acoustic parameters produce outcomes that are different from those that are obtained when only supportive counseling is offered?" A group of adult first-time hearing aid users with moderate, high frequency sensorineural hearing loss was studied over a 5-month post-fitting period. Half of the group served as a control group and half constituted the treatment group. Treatment consisted of making as many post fitting electro acoustical manipulations as the participants required with respect to DSL 4.1 fitting. These adjustments were withheld from the control group individuals. Group performance differences were assessed using the Client Oriented Scale of Improvement; Dillon, James and Cynis, (1997) (COSI), two versions of the APHAB, a satisfaction scale, a sound quality tool and the speech in noise test. No statistically significant differences in both group's performances and perceived benefit were reported. These data suggested that there was no measurable advantage to be derived from making post fitting frequency-gain adjustments of 10dB or less to hearing with WDRC.

The studies in the preceding section either used linear hearing aids or had verification measures as sound quality judgment &/or questionnaire on communication ability in daily listening situation. These studies also used real ear insertion gain measurements to estimate the differences in preferred gain with respect to prescribed gain. There is a dearth of literature for investigating the effect of differences in prescribed and preferred gain settings on speech perception in noise tasks. Cunningham et al., (2001) also administered Speech in Noise (SIN) tests to each participant. Two complete lists of sentences were given at each of the three presentation levels: 70,40 and 55 dB HL (in that order). The signal to noise ratio for each group of five sentences in each list was presented in the same order: S/N 15, S/N 10, S/N 5 and S/N 0. In each of the five sentences, five key words were scored at each S/N ratio. Scores were reported in number of words correctly identified. SIN tests were administered on each of the five other sessions at 30-day intervals. The subjects were required to correctly say 5 words in each sentence, which would have been a redundant task. Moreover studies done with WDRC hearing aids were carried out only for one prescriptive formula, the results have not been compared with similar effects of other prescriptive formulae.

SPEECH PERCEPTION IN NOISE

If one can identify and simulate specific acoustic conditions, speech tests provide a clear assessment of how much the hearing aids change the person's ability to understand speech in this situation. (Dillon, 2001). Many problems with hearing aids and their selection would be dramatically reduced if they were only to be used in quiet situations. Listener with impaired hearing experience most of their difficulties in understanding speech under noisy conditions. Individuals with sensorineural hearing loss are more sensitive to noise masking effects than the normal hearing individuals listening to speech processed through a hearing aid.

Therefore it has been documented in literature, adding a background noise to test stimuli makes the test more representative of real life listening. (Jerger and Hayes, 1976; Kalikow, Stevens, and Elliot, 1977; Hagerman, 1984; Plomp, 1986; Schow and Gatehouse, 1990). All these authors are of the view that speech - in - noise tests may be used to identify and demonstrate communicative difficulties. Evaluating speech recognition in quiet may not provide a realistic index of communicative difficulties in everyday situations because they are often characterized by competing noise. (Jerger and Hayes, 1976; Dirks, Morgan, and Dubno, 1982; Plomp, 1986; Gatehouse and Haggard, 1987). Moreover, measuring speech recognition in quiet does not predict performance accurately in background noise. Performance on speech in noise tests may enable the clinician to provide hearing impaired individuals and family members with more realistic expectations of unaided or aided auditory performance in everyday situation. (Jerger and Hayes, 1976; Kalikow, Stevens, and Elliot, 1977).

Gatehouse and Haggard, 1987, stated: "In the event of only one measure being affordable, speech in noise may be the preferable one, as it better indicates the worst case of disability, when communication is not well managed and better indicates the rather limited benefit a hearing aid can provide for some individuals." Testing in quiet may not reveal differences between hearing aids. (Schwartz, SUIT, Montgomery, Prosek and Waldel, 1979).

Addition of noise to speech may change the structure of the test. (Loven and Hawkins, 1983). Speech recognition errors are differentially affected by the addition of background noise. (Dubno and Levitt, 1981). Masking of a particular stimulus is dependent on the intensity spectrum, presence, duration of acoustic windows and the meaningfulness of the competing noise (Kalikow, Stevens, and Elliot, 1977; Dillon, 1983, Duquesnoy, 1983). Pink noise and speech spectrum noise (Rupp and Phillips, 1969) are more disturbing than white noise. However speech babble can produce more masking than a speech noise, as babble produces false speech cues and increases the load on attention and memory processes (Kalikow et. al., 1977).

Turner and Cummings (1999), Skinner (1980), and Turner and Brus (2001) provided evidence that maximizing the amount of audible speech was not always the beneficial strategy for patients with SNHL. Ching, Dillon, and Byrne, (1998) and Turner and Brus (2001), demonstrated that for lower frequency regions of speech range, amplifying speech to audible levels consistently provided benefit to all patients. Turner & Henry (2002), showed that providing audibility in frequencies with more loss, high frequency regions, gives an advantage to speech recognition in presence of background noise. They suggested that there are some easier cues for manner and even place that can be perceived by listeners with even severe hearing losses in the high frequency region. In their study it was also shown that the improvements noted in recognition in response to additional high-frequency bands of speech were usually not large. However, Ching, Dillon and Byrne, (1997) have shown that for listeners with hearing losses greater than mild degree the amount of information that can be extracted from a speech signal is not proportional to the amount of audibility.

EFFECT OF EXPERIENCE ON PREFERRED GAIN

There is a widespread belief among audiologists that new users of hearing aid prefer lower gain levels at a time of first fit and gradually come to prefer higher gain levels over time. The belief appears to stem from observations that client's who are new to amplification often find that a match to the selected prescriptive target is too loud. This has been explained by the concept of acclimatization.

"Acclimatization" means adapting to a new environment (auditory). From an auditory standpoint Gatehouse, (1989), cited in Mueller and Powers (2001), was one of the first to use the term acclimatization, explaining the speech processing capabilities of a group of people aided monaurally. In later research, Gatehouse used the term acclimatization to describe an improvement in speech recognition overtime. *Acclimatization* refers to improvement in speech recognition performance overtime, presumably as a result of the introduction of amplification and the learned use of newly available speech cues.

Going back to the previous section, where studies showed whether there are any gain preferences with respect to a prescribed setting or not, it is essential to know whether these preferences change overtime or not. If auditory acclimatization is really taking place, the gain preferences should change overtime towards, the prescribed setting and should have an effect on speech perception tasks and outcome measures.

There is evidence that some subjects do not like the initial prescribed tonal quality. E.g. In case of high frequency amplification and describe it is 'shrill', 'tinny' or 'metallic'. It is often assumed that this is because the subject has not heard the high frequencies for many years. However it could be also be that the prescription targets are based on 'average' values and may not be ideal for the specific subject. It is not clear if the clinician should optimize high frequency amplification or other quality related complaints at the initial fitting or alternatively, if a gradual introduction of high frequency gain would be more appropriate.

In the following section there is a review of studies, which tried to investigate changes in gain preferences of users from the time of fitting up to a certain period of time. These studies have also tried to investigate the effect of preferred and prescribed gain settings on subjective measures and objective measures, or on perceived benefit.

In a study, Olsen, Rasmussen, Nielsen and Borgkvist (1999), cited in Con very, Keidser and Dillon (2005), investigated whether there were loudness perception differences between experienced users of hearing aids and non-users with matched levels of hearing loss. The only significant result was that for subjects with hearing losses in the 50-75dBHL ranges, the mean level rated as 'loud' on a seven point categorical loudness scale was 4.5dB higher for the experienced users than for the non-users. Among the experienced users, no significant correlations were found between loudness perception and the length of time that hearing aids had been worn. Results of this study have been quoted by other researchers to support the belief that new users of hearing aids initially prefer less gain than do their experienced counterparts and that new users will gradually learn to prefer more gain over time. However Olsen et al. (1999), cited in Convery et al, (2005) point out in their discussion that differences in performance on the loudness-scaling task do not necessarily translate into a preference for higher hearing aid output levels among experienced users.

In a study Gatehouse (1992) demonstrates that new users of hearing aids tend to prefer higher gain levels as they become accustomed to amplification. He charted hearing aid benefit over time in new users, of hearing aid. Over the course of 10 visits during the first 12 weeks of aid use, subjects were instructed to select their preferred overall gain level in response to running speech presented at 65dBSPL in the free field. The average insertion gain measurements for 3 repetitions of the procedure were recorded at each visit. There was an average increase of approximately 4dB in the preferred gain setting between week 0 (initial fitting) and week 5. The number of subjects was small and the insertion gain data were not referenced to a prescriptive fitting target or to a control group of experienced hearing aid user. More over the author had expected a change in gain and this affected the results of the study. The subjects were allowed to adjust the gain of their hearing aids prior to each test session; changes in use gain masked the extent to which any reported benefits were due to the process of acclimatization, or simply to an increase in the audibility of the speech frequencies.

Berger and Hagberg (1982) examined the effect of experience and age on hearing aid gain levels through a retrospective examination of client files. 344 patients with varying degrees of hearing aid experience served as subjects, measurements of functional gain were reported relative to the Berger target. Use gain was defined as the hearing aid setting chosen by clients when they returned for an aid recheck 2-5weeks after being fitted. Results revealed no significant effect of years of hearing aid experience on preferred gain levels. The user preferences differed from the prescribed setting irrespective of experience with hearing aid.

Byrne and Cotton (1988) evaluated the NAL-R formula for prescribing the gain and frequency response of the hearing aid. They reported 2cc coupler measurements of use gain of 29 new and 15 experienced users. The subjects chose preferred hearing aid use gain in response to own everyday listening situations. Results show that preferred gain levels were not affected by previous amplification experience.

Leijon et al (1990) determined the insertion gain preferred by new and experienced hearing aid users in every day listening situations with respect to levels prescribed by the NAL-R formula, 26 subjects with varying degree of experience served as subjects for the study. The subjects were instructed to experiment with the volume control to find the best setting to use for most purposes in their own every day listening situations. There was no significant correlation between preferred gain levels and hearing aid experience.

Similarly Muller, Bryant, Brown and Calkins-Budinger (1991) cited in Convery, Keidser and Dillon (2005) showed that individuals with high frequency hearing loss prefer significantly lower gains than are prescribed by the NAL-R fitting rationale. REIG measurements of use gain were reported. At initial fitting, subjects chose preferred gain in response to recorded speech and during field trial, preferred setting chosen in subject's own listening situations. There were no changes in preferred gain levels over first 6 weeks of aid use. Hence, the above studies do show that there are preferences with respect to prescribed settings, which are different and these preferences do not change significantly over time.

Munro and Lutman (2005) aimed to study the time course of changes in perceived sound quality after hearing instrument fitting. The subjects were given a trial for four sessions with two frequency responses. One was a standard frequency response according to Desired Sensation Level (DSL) targets (Seewald, Ramji, Sinclair, Moodie and Jamieson, 1993) and an alternative frequency response which provided a mean gain reduction of 3, 8, 13, and 16dB at 2000, 3000, 4000 and 6000HL respectively. Subjects compared the standard and the alternative responses for sound quality along dimensions of comfort, clarity and overall preference while listening to running speech presented in quiet, steady noise, and speech babble. At the time of fitting there was a small preference for the standard response when judging clarity, but the alternative response was preferred for comfort and preferred overall. Repeated-measures analysis of variance for each quality dimension did not reveal any statistically significant change over time. It was concluded that this pattern of preference is unaffected by acclimatization to amplification, at least over the initial 24 weeks of instrument use. However, Marriage, Moore & Alcantara (2004) reported than new user requires 3dB greater reduction in gain relative to the prescriptive target to achieve an acceptable fitting than do experienced users.

To summarize, all the studies reviewed in the above section showed that the gain preferences did not change significantly with respect to prescribed sittings over time except for Marriage et al (2004) study. The fine tuning of the hearing aid can then be justifiably done at the initial session, with this notion in mind the present study was carried out to observe the effects of preferred and prescribed gain settings on speech perception in noise.

The fine adjustments were done without giving any practice to the subjects with the hearing instrument.

CHAPTER III

METHOD

The aim of the study was to investigate the effects of preferred and prescribed gain on speech perception in noise

SUBJECTS

Twenty individuals (mean age: 41 years; range: 23 to 56 years) with bilateral sensorineural hearing loss served as subjects for this study. Ten subjects had gradual sloping and eleven had steeply sloping hearing loss configuration in the test ear. The mean puretone average of the gradual sloping and steeply sloping hearing loss subjects were 53 dB (SD=7) and 59dB (SD=7) respectively. They were new users of hearing aid

The aided speech identification scores of all the participants were 75 % or more in the test ear. They were native speakers of Kannada language. The mean audiograms of both groups are shown below.

Figure 1: Mean audiogram of subjects with gradually sloping hearing loss

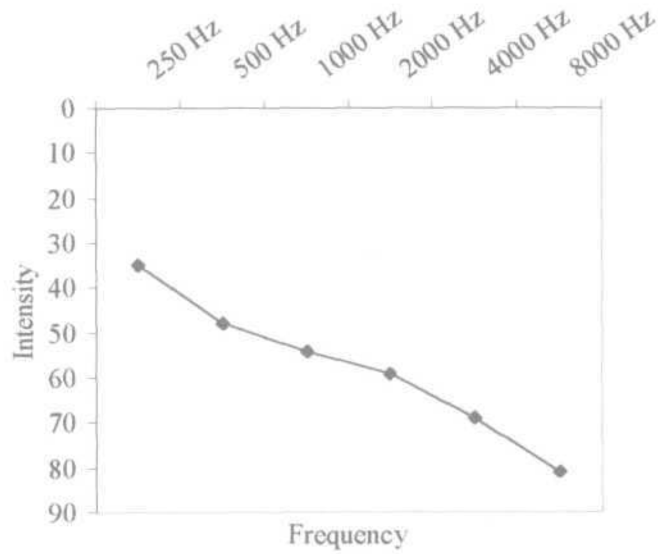
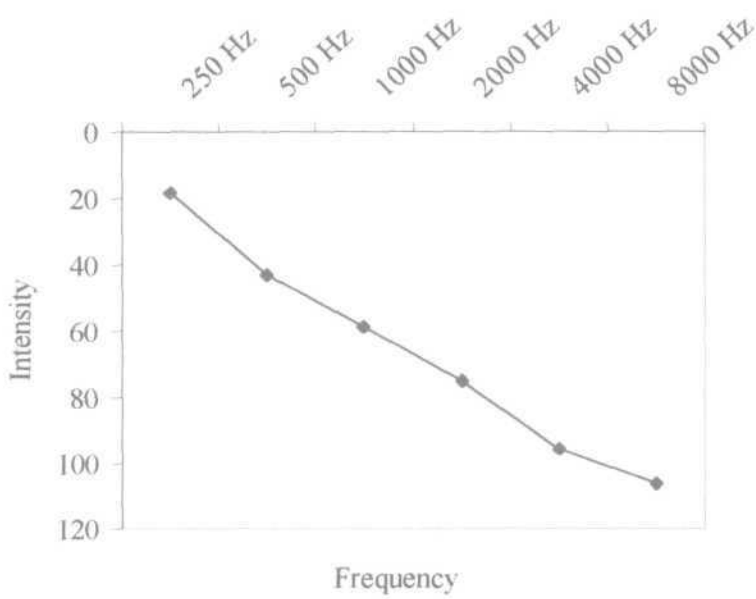


Figure 2: Mean audiogram of subjects with steeply sloping hearing loss



INSTRUMENTATION AND TEST SET UP

- A calibrated dual channel diagnostic audiometer (GSI 61) and a calibrated Immittance meter (GSI- TYMPSTAR) were used to recruit subjects.
- A calibrated dual channel audiometer (MAICO MA 53) with two hi-fi sound field speakers (MAICO) was used for hearing aid testing. The channel one of the audiometer, with input from a DVD player (Philips), was used to deliver recorded speech material. The channel two of the audiometer was used to deliver speech shaped noise from audiometer.
- A FP40D hearing aid analyzer was used to check the electroacoustic characteristics of the hearing aid and also for the Real Ear Insertion Gain measurements.
- All the testing, both for selecting subjects and for experimental purposes were conducted in an air conditioned, acoustically treated single or double room set up. The ambient noise levels inside the test room were within permissible limits (re: ANSI S3.1 1991, as cited in Wiber 1994).

HEARING AID FITTING

The Siemens Music Pro behind the ear hearing aid was used in this study. Music Pro is a fully digital multichannel instrument. This particular model was selected due to its availability in the stock and because it permitted prescription of independent fitting formula. It has two compression bands and the fitting range is mild to severe. The Music Pro has fine-tuning option, in which manufacturer's recommended solutions are available for complaints encompassing loudness of sound, loudness of speech, speech intelligibility and acoustic feedback. The hearing aid was programmed using NAL-NL1 and DSL [i/o] fitting formula using the Connexx software version v 5.0 through NOAH 3.0 version and Hi-Pro.

TEST MATERIAL

The phonetically balanced list in Kannada developed by Yathiraj & Vijaylakshmi (2005) was used in this study. The speech material consists of eight phonetically balanced word lists and each list has twenty-five words. All the eight lists were used for this study.

PROCEDURE

Routine audiological examination was carried out for each individual. The subjects fulfilling the stated criteria were included in the study.

PHASE 1: Programming the hearing instrument

The hearing aid was programmed using the Connexx software version v 5.0 through NOAH 3.0 version and Hi-Pro. The audiogram of the ear with better speech identification scores was fed into the fitting software. The hearing aid was fitted unilaterally to the ear with better speech identification scores. Prior to hearing aid fitting the electroacoustic performance of the aid was measured using FP 40 D hearing aid test system following standard audiological protocol.

i) Obtaining prescribed gain setting

For every new user the hearing aid was programmed with two independent prescriptive procedures: NAL-NL-1 and DSL [i/o]. No fine-tuning was allowed for the purposes of comparisons. The gain, frequency shaping and compression parameters were kept in records.

ii) Obtaining Preferred Gain Setting

The hearing aid fitting in new users were fine-tuned through frequency shaping option of the NOAH program (version 3.0) to determine the preferred gain settings. The hearing aid fine-tuning was performed following standard audiologic protocol. The fine-tuning parameters included audibility, intelligibility, comfort and sound quality, and were programmed using routine questionnaires. The questions were asked on one-to-one basis and with normal vocal effort at 4 ft to 5 ft distance. The low cut, high cut gains and the cut-off frequency values were then manipulated depending upon the subjects' response.

Subjects were first asked to judge the loudness of speech relative to the loudness that they would prefer in everyday listening situation. If it sounded much louder than their preferred loudness, the high-level gains in both bands were reduced, or (if the compression ratio was at its maximum value) all gains were reduced. If it sounded only slightly louder than their preferred loudness, the gains were left unchanged.

Complaints like "too soft", "too muffled" and "unclear" were considered as indication for increasing gain especially for the soft input levels. Adjustments were continued until the subjects judged the loudness to be acceptable. The subjects were then asked to concentrate on the "overall tone quality" of speech and to indicate whether it sounded "shrill" or "tinny" (associated with excessive high frequency gain) or "boomy" (associated with excessive low frequency gain), or whether the overall tone quality is acceptable. If the speech sounded "too shrill' or "tinny" the high- level gain in the high band was reduced. If the speech sounded "too boomy" the high level gain in the low band was reduced. Adjustments were continued until the overall quality of speech was judged to be acceptable. Finally the subjects were allowed one-to-one conversation for 15- 30 minutes. They were then asked to concentrate on speech sounds like /p/ and /k/ which are conveyed primarily by low-level information at high frequencies. If they could not hear these sounds clearly, the high frequency low-level gain was increased so that these sounds were just clearly heard. If the /p/ and *f\d* were judged to be very distinctly heard or to be loud, the high frequency low level gain was decreased slightly to the point where these sounds were less loud but still clearly audible. The frequency shaping parameters and compression parameters of preferred gain settings were stored in the hearing aid

PHASE 2:

i) Real ear insertion gain measurements

After programming the hearing aid according to each of the fitting formula real ear insertion gain (REIG) were measured at 65 dB SPL with digi-speech input signal using FP 40 D hearing aid analyzer. The values from 250 Hz to 6000 Hz were recorded.

ii) Speech to noise ratio threshold measurement

The minimum signal to noise ratio (SNR) that is needed to correctly identify and repeat the words presented in noise with a 50% criterion was measured. The SNR threshold measurements were performed at two levels 55 dB SPL (soft level) and 65 dB SPL (average level). The SNR threshold measurement for each subject was done at prescribed and preferred hearing aid settings for each prescriptive formula, NAL-NL1 and DSL- [i/o].

The phonetically balanced word list was played from the CD player and routed through the audiometer. The speech material was presented at 0° azimuth while speech shaped noise at was presented at either 45° or 315° azimuth depending on the test ear. The speakers were placed one meter away from the subjects (re: nose).

The SNR threshold was measured using an adaptive procedure. The speech was presented at a constant level of 55 dB SPL. The noise level was set at 15dB below the signal and varied systematically to measure SNR threshold, where individuals had to repeat correctly minimum 3 words in a set of 6 words. If the subject correctly repeated 3 or more words, the level of noise was increased in 4 dB steps and if not, the level of noise was decreased in 2 dB steps. Further if the subject repeated the word correctly the level of noise was increased by ldB and if not, the previous level was considered as SNR threshold. The same process was also carried out for SNR measurements at 65 dB SPL. Similarly SNR thresholds were measured in aided conditions for the other prescriptive formula at both levels. The procedure was further, repeated with preferred settings of two prescriptive formulae at each input level. Thus there were total of 8 SNR thresholds measured for each subject. The order of SNR measurements and word list presentations were randomized.

The procedure used can be summarized as follows:

1. Prescribed hearing aid settings were determined in each subject for both the prescriptive formula using NOAH (3.0) and Connex software v5.0

2. Preferred hearing aid settings were determined in each subject for both the formula as explained.

3. Real ear insertion gain was measured using digi-speech stimulus at preferred and prescribed settings for each prescriptive formula in each subject and the values were kept in record.

4. Speech to noise ratio thresholds for 50 % criterion were determined at preferred and prescribed hearing aid settings in each subject for each prescriptive formula at two levels: 55 dB SPL & 65 dB SPL using a adaptive procedure. Total 8 SNR thresholds were measured for each subject.

STATISTICAL ANALYSIS

A four-way ANOVA of repeated factors was administered to determine the main effects and interaction effects of all the variables in REIG measurement and SNR threshold measurement. To study the interaction effects separately, further paired t-tests were carried out.

CHAPTER IV

RESULTS AND DISCUSSIONS

The present study was designed to investigate effects of prescribed and preferred gain on speech perception in noise. Real ear insertion gain measurements and minimum speech to noise ratio for 50 % correct word recognition scores were estimated at the preferred and prescribed gain of both the prescriptive formula. All the measurements were carried out in two groups of subjects varying in hearing loss configuration - gradual sloping and steeply sloping and all were new users of hearing aid. The data was appropriately tabulated and statistically analyzed using SPSS (10.0 version). Four- way ANOVA (Analysis of Variance) for repeated factors was carried out in both REIG & SNR measurements.

1) REAL EAR INSERTION GAIN (REIG)

The following effects were analyzed for REIG measurements using four-way ANOVA.

a) The main effects of audiogram type (gradual sloping or steeply sloping), gain (preferred or prescribed), formula (NAL-NL1 or DSL-i/o), and frequency in REIG measurements.

b) Two factor interactions- there were total 6 two-factor interactions. These are: audiogram type and gain; audiogram type and formulae; gain and formulae; audiogram type and frequency; gain and frequency, & formulae and frequency.

c) Three factor interactions- there were total 4 three-factor interactions. These are: audiogram type, gain and formula; audiogram type, gain and frequency; audiogram type, formulae and frequency & gain, formulae and frequency.

d) Four factor interactions- there was one four-factor interaction. That is: audiogram type, gain, formulae and frequency.

The results are as follows:

a) Main Effects

TABLE 1: F- values for main effects

SOURCE	F	Sig
AUDIOGRAM TYPE	282.181	0.000***
GAIN	109.769	0.000***
FORMULA	3.656	0.05*
FREQUENCY	1547.947	0.000***

*** Significant at 0.001 levels.

* Significant at 0.05 levels

Table 1 shows that audiogram type, gain and frequency had significant main effect (P< 0.001).

b) Interaction Effects

TABLE 2: F-values for two-factor interaction effects

SOURCE	F-value	Sig.
AUDIOGRAM TYPE & GAIN	57.357	0.000***
AUDIOGRAM TYPE & FORMULAE	28.745	0.000***
GAIN & FORMULAE	60.290	0.000***
AUDIO TYPE & FREQUENCY	98.667	0.000***
GAIN & FREQUENCY	39.636	0.000***
FORMULAE & FREQUENCY	23.986	0.000***

******* Significant at 0.001 levels.

Table 2 shows two-factor interaction effects. It can interpreted from the table that all the three-factor interaction effects were significant (p< 0.001)

TABLE 3: F-values for three-factor interaction effects

SOURCE	F	Sig
AUDIO TYPE & GAIN & FORMULAE	71.582	0.000***.
AUDIO TYPE & GAIN & FREQUENCY	61.792	0.000***
AUDIO TYPE & FORMULAE & FREQUENCY	19.231	0.000***
GAIN & FORMULAE & FREQUENCY	11.909	0.000***

****** Significant at 0.001 levels***

Table 3 shows three-factor interaction effects. It can be interpreted from the Table that all the three-factor interaction effects were significant (p< 0.001)

TABLE 4: F-values for four-factor interaction effects

SOURCE	***F***	***Sig***
AUDIO TYPE & GAIN & FORMULAE* FREQUENCY	***17.610***	0.000***

****** Significant at 0.001 levels***

Table 4 shows four- factor interaction effects. It can be interpreted from the table that the four-factor interaction effect was significant (p< 0.001).

To study the above interactions, separate analysis was carried out for REIG measurements using paired t-tests.

The REIG measurements were carried out for all the subjects in both the groups for frequencies from 500 Hz to 6000 Hz. The REIG measurements were done both at preferred & prescribed gain of each prescriptive formula. Mean REIG measurements done at preferred gain & REIG done at prescribed gain for NAL-NL1 & DSL-i/o, in each hearing loss configuration were compared using paired t-tests. This analysis was carried out to address the first aim of investigating the difference between preferred & prescribed gain.

a) Mean REIG measurements done at preferred gain & REIG done at prescribed gain for NAL-NL1 & DSL-i/o

I) NAL-NL1 prescriptive formula

i) Gradually Sloping Hearing Loss

TABLE 5: Mean REIG at preferred versus REIG at prescribed gain for NAL-NL1

REIG at PF vs. PS	**T- value**	**Sig.**
500 Hz	0.175	0.864
1000 Hz	6.037	0.000***
2000 Hz	6.358	0.000***
3000Hz	1.406	0.190
4000 Hz	9.815	0.000***
6000 Hz	0.673	0.516

*** Significant at 0.001 levels

Tables 5 show there was significant difference between mean REIG at preferred and prescribed gain at 1 kHz, 2 kHz and 4 kHz.

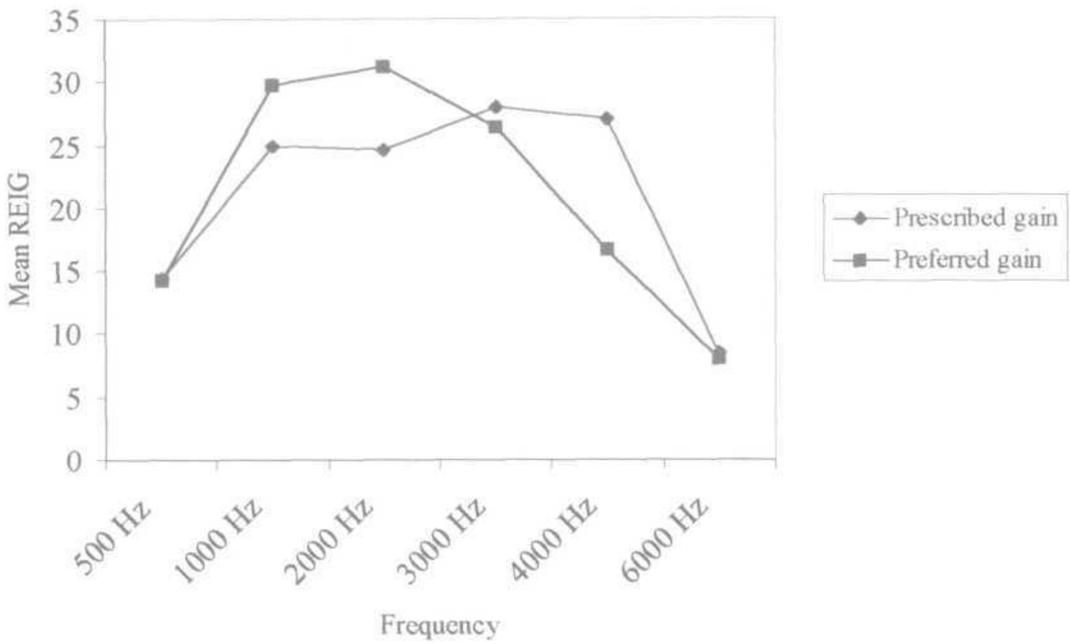


FIGURE 3: Comparison of REIG at preferred gain and prescribed gain in gradually sloping hearing loss subjects using NAL-NLl

Figure 3 shows the subjects in this group preferred greater gain at the mid frequencies i.e. 4 dB at 1 kHz & 7 dB at 2 kHz. However at 4 kHz, the subjects preferred lesser gain of around 10 dB than prescribed gain. There was no significant difference between gain prescribed at 500 Hz, 3000 & 6000 Hz and preferred gain.

The subjects prefer more gain in the mid frequency region, though NAL-NLl (Byrne Dillon, Ching, Katsch, & Kiedser, 2001) attempts to maximize speech intelligibility. As the listeners were new users, it is assumed that they might have preferred more gain for ease of listening. They might have given more preference to audibility than intelligibility while determination of their preferred gain. This is supported by a review done by Braida, Durlach, Lipman, Hicks, Rabinowitz & Reed, cited in Leijon, Eriksson-Mangold and Bench-Karlsen (1984) in which it was shown that prescriptive methods of fitting the frequency gain characteristics were usually designed and evaluated with the user's ability to understand speech as the sole criteria. However some users may primarily want to adjust the aid so that they can listen at a comfortable spectral balance, if there is a conflict between these goals.

At the high frequency (4000 kHz), lesser gain was preferred than prescribed to the subject. Though NAL-NLI acts on a desensitization factor that is it gives lower gains at frequencies with more severe losses compared to other frequencies to maximize speech intelligibility, even lower gains were preferred at 4KHz. There are evidence from previous research (Munro & Lutman, 2005) that some subjects do not like the initial tonal quality of high frequency amplification and describe it as "shrill", "tinny" or "metallic". It is often assumed that this is due to the fact that the subject has not heard the high frequencies for many years. It was also advocated that it could be due to the reason that prescription targets are based on average values and may not be ideal for a specific subject. There was no significant difference between gain prescribed at 500 Hz, 3000 & 6000 Hz and preferred gain. This shows that at these frequencies the prescription matched to listener preferences.

Findings of this study are in contradiction with earlier studies (Humes, Wilson, Barlow & Garner, cited in Smeds, 2004), which showed that the overall preferred gain by sensorineural hearing loss subjects was lower than prescribed. Other authors Leijon, Eriksson-Mangold and Bench-Karlsen (1984) and Leijon, Lindkvist, Ringdahl, & Israelsson,

(1990) have also demonstrated that new hearing aid users prefer less overall gain than prescribed gain. In the study by Leijon et al. (1990), it was demonstrated that users clearly used less insertion gain than recommended by NAL formula in the frequency range 1 and 2 kHz, and the difference was statistically significant. Dillon (2003), in his study showed that all the subjects preferred less gain than, prescribed overall, low frequency and high frequency gain. However, few subjects in his study preferred substantially more high frequency gain than prescribed by NAL-NLI.

Factors like subjects selected, the type of hearing aid, its electroacoustic features, and the procedure used to determine the preferred gain might have contributed to the difference in present study and previous studies. The results may vary largely, even if small differences in the above mentioned factors are present.

In the study by Humes et al. (2002) linear amplification was used for the subjects, which will give higher than normal loudness for a higher-level input for a person with loudness recruitment. But Smeds (2001) have indicated that subjects without previous hearing aid experience provided with level dependent gain also preferred less overall gain than prescribed by some of the current threshold based prescriptive methods for wide dynamic range compression hearing aids (NAL-NLI, CAMEQ & DSL-i/o).

In the study done by Leijon et al. (1990) the subjects were prescribed according to NAL recommendation in a linear hearing aid. The subjects were allowed to make volume control adjustments for about 12 dB to 15 dB above recommended value. They were given a trial period to judge the sound quality in their daily life listening situations and answer a questionnaire. However in the current study long trial periods were not given. This could not be a potential factor for the difference because in the previous study even experienced users showed similar preferences. Though the subjects in both the study had similar hearing loss configuration, the subjects in the previous study were elderly listeners, which might be one of the reason of preferring lesser gain, to avoid tolerance problems. In the previous study the gain at 250 Hz and 500 Hz were almost 0 dB due to direct leakage of the sound. Moreover in the previous study the measurement probe was inserted between the earmold and the skin. This might have cause additional ventilation and an underestimation of gain at 1 KHz and below. Only real ear insertion gain was measured in the previous study and no speech perception measures were used.

Moreover, in the previous study, the subjects were given several trial periods with the preferred settings, and the gains were adjusted on the basis of difficulties faced by the subject in daily listening tasks. In this study no such listening practice was given. So at the first perception, the clients might have preferred ease of listening compared to intelligibility.

According Dillon (2003) the gain settings shown as preferred lower gain in his study could be a result of preference or could be a result of some limitation in gain adjustments due to vented moulds or feedback in his study. The author also rejected the claim that the NAL-NLI prescribes too much of overall gain for 65 dB SPL input.

To summarize, it was observed that, the subjects with gradually sloping hearing loss preferred significantly more gain in the mid frequency (1KHz & 2KHz) region and significantly lesser gain at 4 KHz than the prescribed gain. However at 500, 3000 and 6000 Hz, the preferences were identical to prescribed settings.

ii) Steeply Sloping Hearing Loss

TABLE 6: Mean REIG at preferred versus REIG at prescribed gain for NAL-NLl

REIG PF vs. PS	**T-values**	**Sig.**
500 Hz	8.970	0.000***
lOOOHz	11.730	0.000***
2000Hz	26.902	0.000***
3000Hz	11.608	0.000***
4000Hz	30.576	0.000***
6000Hz	10.508	0.000***

•••Significant at 0.001 levels

Table 6 shows the results of paired t-tests. The results show that there was a significant difference between mean REIG measured at preferred and prescribed gain at all the frequencies from 500 Hz to 6000 Hz.

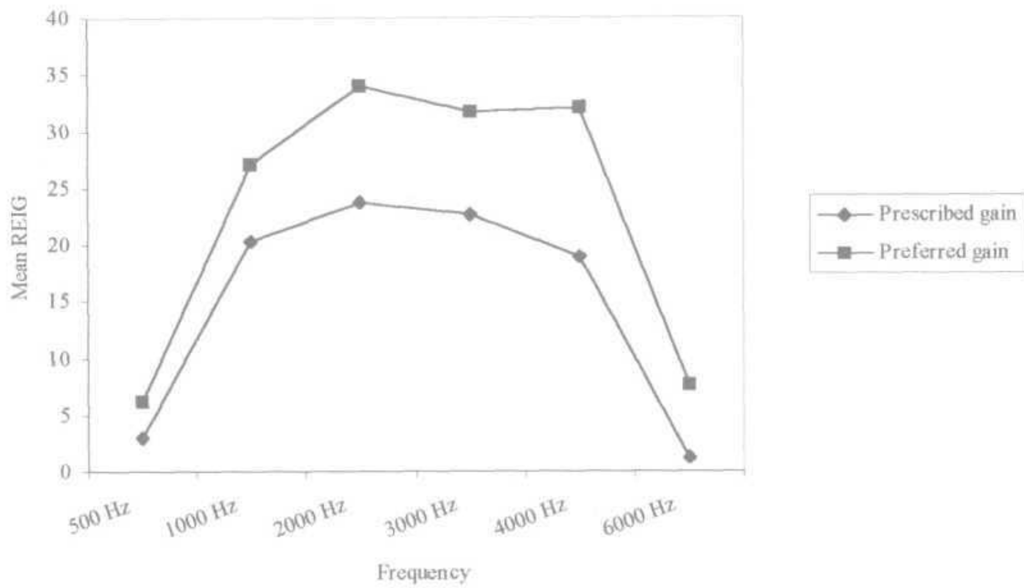


Figure 4: Comparison of REIG at preferred gain and prescribed gain in steeply sloping hearing loss subjects using NAL-NL1

The figure 4 shows that across all the frequencies the mean REIG at preferred gain were significantly greater compared to that at prescribed gain. In contrast to the gradually sloping hearing loss group, the subjects preferred higher gain at all the frequencies than the prescribed gain. The preference of more gain at low and mid frequencies can be accounted for more audibility and hence ease of listening. They also preferred more high frequency gain; this is in contrast with hearing loss desensitization factor, employed by NAL-NL1 where higher frequencies are given less emphasis, especially if the loss is more at high frequencies. It is because the high frequency does not contribute to speech intelligibility much. Most of the subjects of this group had severe to profound loss at high frequencies So it might be that as high frequencies were not heard at all they preferred more gain to hear those sounds again, whereas in gradual sloping subjects, the subjects did not enjoyed the high frequency sounds, and preferred lesser gain.

In the study done by Dillon (2003) few of his subjects preferred more high frequency gain than prescribed by NAL-NLI. And he has advocated that the notion that subjects prefer less overall gain compared to NAL-NLI targets is not true always.

II) DSL- i/o prescriptive formula

i) Gradually Sloping Hearing Loss

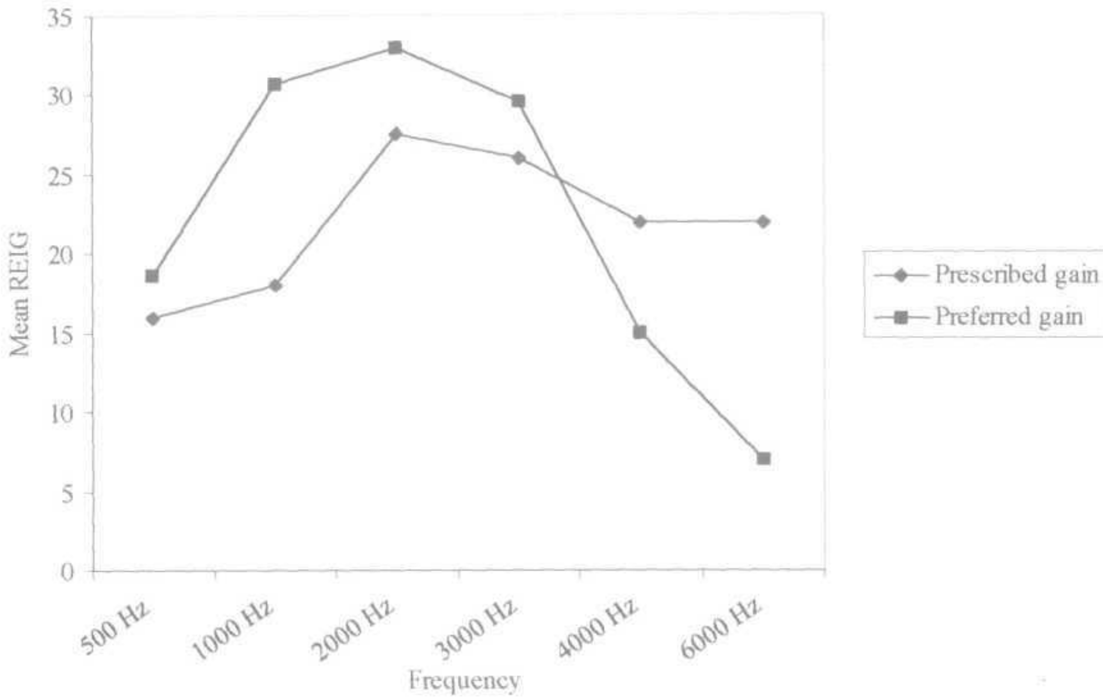
Table 7: Mean REIG at preferred versus REIG at prescribed gain for DSL-i/o

REIG PF vs. PS	**T-values**	**Sig.**
500 Hz	1.807	0.101
lOOOHz	15.201	.000***
2000Hz	7.488	0.000***
3000Hz	2.222	0.051*
4000Hz	16.010	0.000***
6000Hz	18.196	0.000***

***Significant at 0.001 levels

* Significant at 0.05 levels

Table 7 shows results of paired t-test. It shows that there is a significant difference between mean REIG measured at preferred and prescribed gains at frequencies 1000 Hz to 6000Hz. No significant difference was observed at 500 Hz.



Frequency

Figure 5: Comparison of REIG at prescribed and preferred gain in gradually sloping hearing loss subjects using DSL-i/o

The figure 5 shows mean REIG measured at preferred gain was significantly lower than REIG measured at prescribed gain for 4000 Hz and 6000 Hz. At 1000 Hz, 2000 Hz and 3000 Hz mean REIG measured at preferred gain were significantly greater than REIG measured at prescribed gain.

The greater preference of gain in mid-frequencies can be explained again with ease of listening explained in the previous section. All the subjects preferred to listen at a comfortable level and gave preference to audibility. Again the preference of lesser gain at high frequency can be explained by the fact that subjects might not have liked the high frequency amplification.

Moreover, it can be explained from underlying rationale of DSL-i/o (Cornelesse, *Seewald, & Jamieson,* 1995), which includes concept of extended dynamic range rather than normal dynamic range. This extended dynamic range is mapped on to the hearing impaired dynamic range, thus resulting in more gain frequency response than NAL-NLI for all hearing loss. Therefore subjects preferred lesser gain at the higher frequencies when DSL-i/o was used. This preference of less high frequency gain supports previous study by Munro & Lutman (2005) in which subjects were provided with less high frequency gain (16 dB reduction at 4000 Hz) in comparison to DSL, (prescribed gain). They preferred the reduced gain for overall comfort and this gain was preferred in overall conditions. However the authors also demonstrated that lesser gains were preferred at low and mid frequencies, which is in contradiction to the present study.

ii) Steeply Sloping Hearing Loss

TABLE 8: Mean REIG at preferred versus REIG at prescribed gain for DSL-I/O

REIG PF vs. **PS**	**T-VALUE**	**Sig.**
500Hz	11.947	0.000***
lOOOHz	7.129	0.000***
2000Hz	19.758	0.000***
3000Hz	8.820	0.000***
4000Hz	1.755	0.113
4000Hz	1.696	0.124

•••Significant at 0.001 levels

The Table 8 shows the results of paired t-tests. There was a significant difference between mean REIG measured at preferred and prescribed gain for frequencies 500 Hz to 3000 Hz. There was no significant difference at 4000 Hz and 6000 Hz

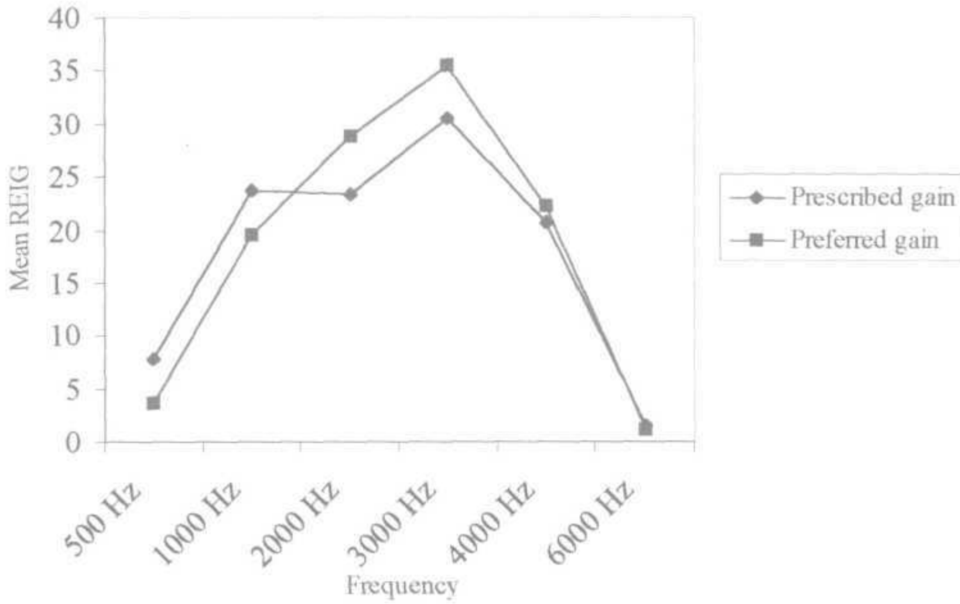


FIGURE 6: Comparison of REIG at prescribed gain and preferred gain in steeply sloping hearing loss subjects using DSLi/o

It can be observed from Figure 6 the mean REIG measured at preferred gain was significantly lower than that measured at prescribed gain for frequencies 500 Hz and 1000 Hz. At 2000 Hz and 3000 Hz the mean REIG measured at preferred gain was significantly greater than that measured at prescribed gain. The subjects preferred less gain at the low frequency where DSL-i/o prescribes a higher gain. At 500 Hz the low frequency gain were not essential for the subjects, as a higher gain would have masked the mid and high frequency information The lesser gain preference at 1000 Hz may be accounted to preference of the subjects. Again for ease of listening and comfortable hearing, the subjects preferred more gain at 2000 and 3000 Hz. There was no significant difference found at 4000 and

6000 Hz. Though the DSL-i/o is known to give more high frequency gain, compared to other formula (Sehgal, 2001, Byrne et al 2001; & Keidser & Grant, 2001), the listener's preferences were not more or less than the prescribed setting. They might have preferred the audibility in high frequency region where there was severe hearing loss.

b) Effect of formula on difference between REIG at prescribed and preferred gain

i) Gradually Sloping Hearing Loss

TABLE 9: Effect of formula on difference between REIG at prescribed and preferred gain in gradually sloping hearing loss subjects.

Formula effect on difference	T- value	Sig.
500 Hz	3.935	.003**
lOOOHz	5.624	.000***
2000Hz	1.438	.181
3000 Hz	1.063	.313
4000 Hz	2.326	.042*
6000Hz	38.582	.000***

* Significant at 0.05 levels
**Significant at 0.01 levels
***Significant at 0.001 levels

The Table 9 shows results of paired t-tests. There were significant differences between NAL-NL1 & DSL-i/o at 500 Hz, 1000 Hz 4000Hz & 6000 Hz.

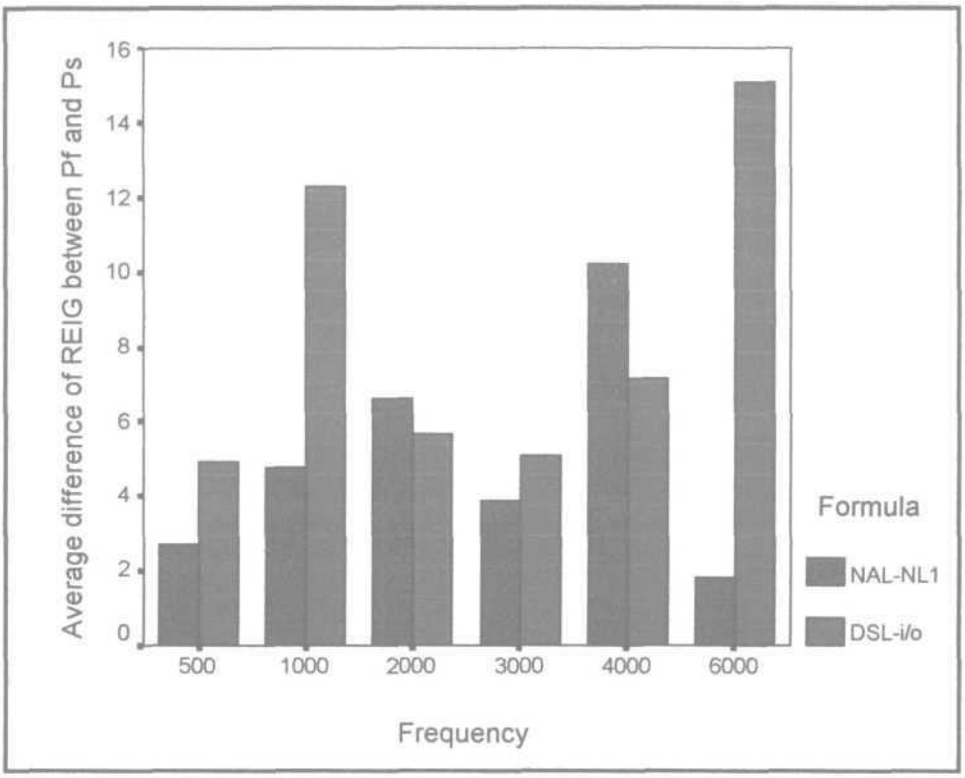


Figure 7: Effect of formula on mean difference between REIG at prescribed and preferred gain in gradual sloping hearing loss subjects

The mean difference in REIG between preferred and prescribed gain in case of NAL-NLI were significantly different than mean difference in DSL-i/o. The mean difference in REIG between preferred and prescribed gain was significantly higher in DSL-i/o than in NAL-NL1 at the frequencies 500 Hz, 1000 Hz and 6000 Hz. However at 4000 Hz the difference was more for NAL-NL1. The trend of difference in REIG was same for both the formula that is preferred gain was more than prescribed gain at 500 & 1 OOOHz. It was less at 4000 Hz & 6000 Hz. At 3000 Hz though not statistically significant the mean difference in REIG at preferred and prescribed gain was larger for DSL-i/o.

The type of frequency gain responses prescribed by each formula can explain this. The differences at 6000 Hz are explainable from frequency response characteristics of each formula. DSL-i/o prescribes almost same gain as NAL-NLI at low and mid frequencies but greater gain at and higher frequencies. Sehgal, (2005), Byrne et al (2001); & Keidser et al (2001) reported that for gradually sloping hearing loss cases the mean REIG at low and mid frequencies were almost equal for NAL-NLI and DSL-i/o. However at higher frequencies NAL-NLI prescribes less gain than DSL-i/o. So, though this explains the difference at 6000 Hz, but the difference at 500 Hz and 1000 Hz, remains unanswered. It might be accounted for the perceptual differences.

To summarize, it can be concluded that NAL-NLI prescribed gain gives a closer match to preferred gain setting.

ii) *Steeply Sloping Hearing Loss*

TABLE 10: Effect of formula on difference between REIG at prescribed and preferred gain in steeply sloping hearing loss subjects.

Formula effect on difference	T- value	Sig.
500 Hz	3.770	.004**
1000 Hz	2.957	.016**
2000 Hz	9.555	.000***
3000 Hz	3.262	.010**
4000 Hz	17.434	.000***
6000 Hz	12.172	.000***

* Significant at 0.05 levels

**Significant at 0.01 levels

***Significant at 0.001 levels

The Table 10 shows results of paired t-tests. There was significant difference between NAL-NLl & DSL-i/o at all the frequencies.

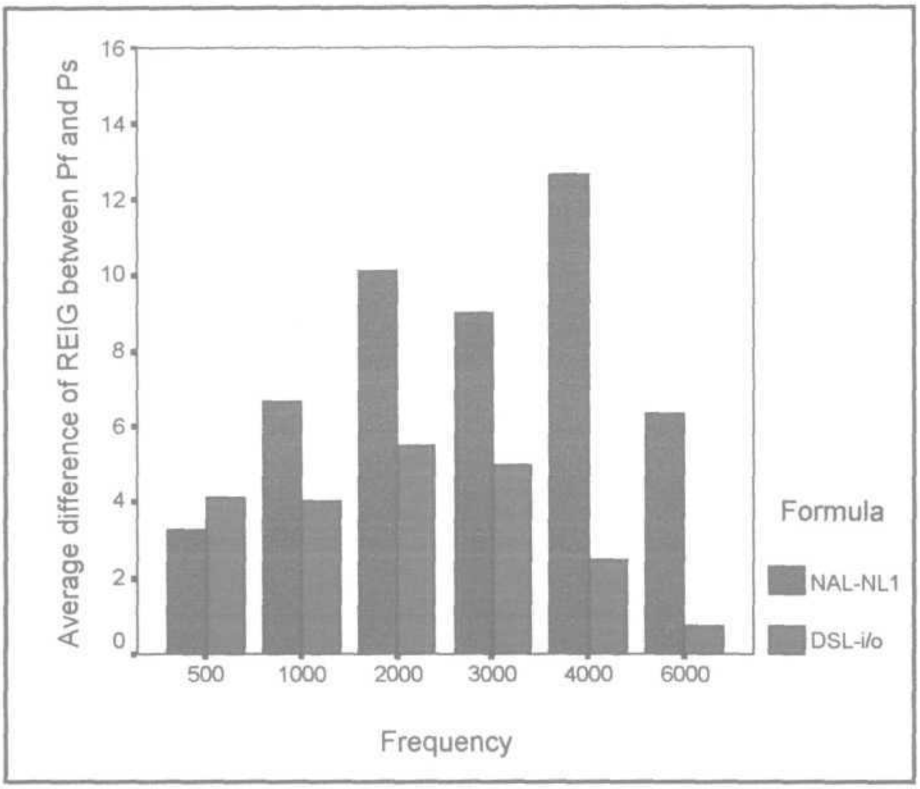


Figure 8: Effect of formula on mean difference between REIG at prescribed and preferred gain

The mean difference in REIG between preferred and prescribed gain was significantly higher in NAL-NL1 than the mean REIG difference in DSL-i/o at all the frequencies (figure 8). In this DSL-i/o prescribed gain gives a close match to the subject gain preferences. Moreover, the way and amount, by which the preferred gain differs from the prescribed one, are not identical for NAL-NL1 and DSL-i/o. There are some trends maintained by each.

In case of NAL-NLI, the preferred gain was significantly higher than prescribed gain at all the frequencies. Whereas in DSL-i/o the preferred gain was significantly lower at 500, 1000 and 6000 Hz than prescribed gain. And preferred gain was higher at 2, 3, and 4 kHz. Though the difference was not significant at 4 kHz and 6 kHz this can be explained partly by rationale of each formula. The NAL-NLI and DSL-i/o give identical frequency gain response in the mid frequency range and in both formulas more gain is preferred than prescribed whereas in case of lower frequencies, the NAL-NLI prescribes low gain, and DSL-i/o prescribed more gain than that. So users while listening with NAL-NLI, prefer more gain than prescribed and in case of DSL-i/o, the case is reverse. Sehgal, (2005), Byrne et al. (2001); & Keidser et al. (2001) report that for steeply sloping hearing loss both the formula do not show mush variation in gain for low and mid frequencies. The difference in gain becomes larger after 3000 Hz for all the frequencies. NAL-NLI prescribes lesser gain at higher frequency and gain drops as frequency increases.

To summarize the above results it can be concluded that in case of subjects with gradually sloping hearing loss, NAL-1 gives a closer correlation with the preferred gain settings. However for subjects with steeply sloping hearing loss, DSL-i/o gives a close correlation with the preferred gain settings. There is a dearth of literature for supporting this finding and future researches are to be carried out.

2) SPEECH TO NOISE RATIO MEASUREMENTS

The following between-subject effects were analyzed for SNR measurements

a) The main effects of audiogram type (gradual sloping or steeply sloping), gain (Preferred or prescribed), formula (NAL-NLl or DSL-[i/o]), and intensity (55dB SPL & 65 dB SPL) in SNR measurements.

b) Two factor interactions- there were total 6 two-factor interactions. These are: audiogram type and gain; audiogram type and formulae; gain and formulae; audiogram type and intensity; gain and intensity, & formulae and intensity.

c) Three factor interactions- there were total 4 three-factor interactions. These are: audiogram type, gain and formula; audiogram type, gain and intensity; audiogram type, formulae and intensity & gain, formulae and intensity.

d) Four factor interactions- there was one four-factor interaction. That is: audiogram type, gain, formulae and intensity.

The results are described below.

a) Main Effects

TABLE 11: F- values for main effects

SOURCE	*F*	*Sig*
AUDIOGRAM TYPE	5.694	.018*
GAIN	180.671	.000***
FORMULAE	.006	.939
INTENSITY	16.644	.000***

* Significant at 0.05 levels

**Significantat 0.01 levels

•••Significant at 0.001 levels

Table 11 shows audiogram type, gain and frequency had significant main effects (p< 0.001), but formula had a significant main effect only at p <0.1 levels.

b) Interaction Effects

TABLE 12: F-values for two-factor interaction effects

SOURCE	F	Sig
AUDIOGRAM TYPE & GAIN	5.977	.016*
AUDIOGRAM TYPE & FORMULAE	.644	.423
GAIN & FORMULAE	.357	.551
AUDIO TYPE & INTENSITY	14.729	0.000***
GAIN & INTENSITY	6.304	0.013*
FORMULAE & INTENSITY	1.889	.171

* Significant at 0.05 levels

**Significantat0.01 levels

•••Significant at 0.001 levels

Table 12 shows two-factor interaction effects. It can be interpreted from the Table that all the two-factor interaction effects were not significant except for audiogram type and gain; audio type & intensity; and gain & intensity.

TABLE 13: F-values for three-factor interaction effects

SOURCE	F	Sig
AUDIO TYPE & GAIN & FORMULAE	.203	.653
AUDIOTYPE & GAIN & INTENSITY	8.492	.004**
GAIN & FORMULAE& INTENSITY	.554	.458
AUDIO TYPE & FORMULAE & INTENSITY	.944	.333

** Significant at .01 levels.

Table 13 shows three-factor interaction effects. It can be interpreted from the table that all the two-factor interaction effects were not significant except for audiogram type and gain and intensity.

TABLE 14: F-values for four-factor interaction effects

SOURCE	F	Sig
AUDIO TYPE & GAIN & FORMULAE & INTENSITY	.093	.761

Table 14 shows four-factor interaction effects. It can be interpreted from the table that the four-factor interaction effect was not significant.

To study the above interactions, separate analysis was carried out for SNR measurements using paired t-tests.

The signal to noise ratio (SNR) threshold was measured at preferred & prescribed gain of each of the formula at two levels- 55dB SPL & 65 dB SPL. Paired t-tests were administered to investigate the following:

A) Gradually Sloping Hearing Loss

1) SNR measured at preferred gain vs. SNR measured at prescribed gain at 55 dB SPL and at 65 dB SPL in NAL-NL 1

TABLE 15: Mean SNR threshold measured at preferred vs. prescribed at two levels for NAL-NL 1 in gradually sloping hearing loss subjects

SNR at PF vs. PS	T-values	Sig. (2-tailed)
55dBSPL	0.377	0.714
65dBSPL	4.425	0.001***

*** Significant at .001 levels.

The Table 15 shows results of paired t-tests. There was no significant difference between mean SNR thresholds measured at preferred gain and mean SNR threshold measured at prescribed gain at 55dB SPL. But there was a significant difference between mean SNR measured in preferred gain and in prescribed gain at 65 dB SPL.

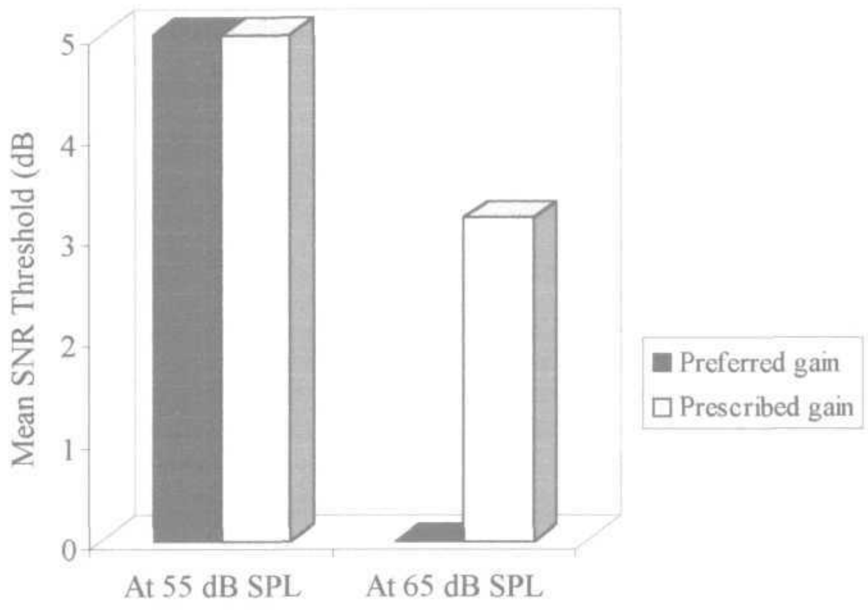


FIGURE 9 Comparison of SNR at prescribed and preferred in gradually sloping hearing loss subjects using NAL-NL1

2) Effect of level was evaluated on SNR threshold measured at preferred and prescribed gain in each formula:

TABLE 16: Mean SNR threshold measured at 55dBSPL vs. SNR measured at 65 dBSPL for preferred gain & prescribed in NAL-NL-1 in gradually sloping hearing loss subjects

SNR PFvs PF at two levels	T-Value	Sig
55 dB SPL vs 65 dB SPL	7.416	.000***
55 dB SPL vs 65 dB SPL	5.57	.000***

*** Significant at 0.001 levels

Table 16 shows results of paired t-tests. There was a significant difference between SNR measured at 55dBSPL and 65 dBSPL within each gain.

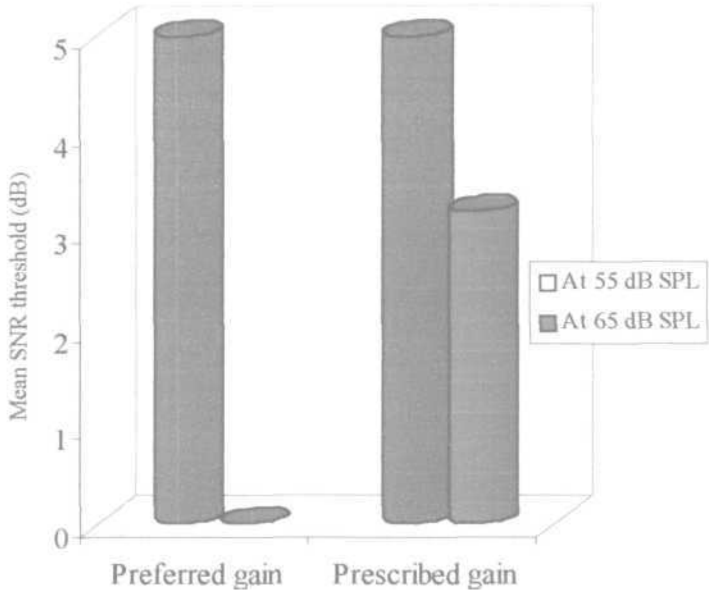


FIGURE 10: Effect of level on SNR in gradually sloping hearing loss subjects using NAL NL1 formula

The mean SNR thresholds did not change significantly when measured in two gains at 55 dB SPL, though there was differences in the mean insertion gain values at preferred and prescribed gain. It can be inferred that a greater audibility could not produce a significant change in speech perception. As explained in the previous section, the hearing impaired subject must have preferred greater audibility for ease of listening, but that was not sufficient to overcome masking effects of noise & improve intelligibility soft speech input levels.

Tillman, Carhart & Olsen (1970) reported that even though the speech is sufficiently amplified, the individuals with SNHL fail to understand speech. It has been shown by investigators that benefits of providing audible speech to listeners with SNHL have limitation. Turner and Cummings (1999), Skinner (1980) and Turner and Brus (2001) provided similar evidence that maximizing the amount of audible speech was not always the beneficial strategy for patients with SNHL.

But at 65 dB SPL a significant difference was found between mean SNR thresholds measured at preferred gain and prescribed gain. At the preferred gain subjects had approximately 5 dB lower mean SNR thresholds than at prescribed gain. So the increased mean insertion gain in preferred setting at 1 kHz & 2 kHz and reduced gain at 4 kHz were favorable to improve speech perception in noise at average speech input levels.

The results of the current study support findings of Ching et al. (1998) and Turner and Brus (2001), who demonstrated that for lower frequency regions of speech range, amplifying speech to audible levels consistently, provided benefit to all patients. The findings of the current study also support results obtained by Turner & Henry (2002), who showed that providing audibility in frequencies with more loss, high frequency regions, gives an advantage to speech recognition in presence of background noise. They suggested that there are some easier cues for manner and even place that can be perceived by listeners with even severe hearing losses in the high frequency region. In their study it was also shown that the improvements noted in recognition in response to additional high-frequency bands of speech were usually not large.

However, Ching, Dillon and Byrne, (1997) have shown that for listeners with hearing losses greater than mild degree the amount of information that can be extracted from a speech signal is not proportional to the amount of audibility.

Further, it can be observed from figure 10 that in both the gains the SNR thresholds were significantly lower at 65 dB SPL than at 55 dB SPL. This shows individuals with a SNHL are more sensitive to masking effects of noise when listening to speech processed through a hearing aid, and this is more marked at soft input speech levels, and supports findings of Sehgal, (2005), who reported similar findings when mean SNR thresholds were compared at two levels within the same formula (NAL-NL1 or DSL-i/o). So it can be concluded that at average levels when a greater gain was given, the subject's SNR thresholds improved and SNR thresholds were lower at 65 dB SPL in both the gain settings.

3) SNR measured at preferred gain vs. SNR measured at prescribed gain at 55 dB SPL and at 65 dB SPL in DSL-i/o:

TABLE 17: Mean SNR threshold measured at preferred and prescribed at two levels for DSL-i/o in gradually sloping hearing loss subjects

SNR PF vs. PS	T-value	Sig.
55 dBSPL	2.053	0.067
65 dBSPL	0.294	0.000***

******* Significant at 0.001 levels.

Table 17 shows results of paired t-tests. There was no significant difference between mean SNR threshold measured at preferred gain and at prescribed gain at 55 dB SPL. There was a significant difference between mean SNR threshold measured at preferred gain & at prescribed gain at 65 dB SPL

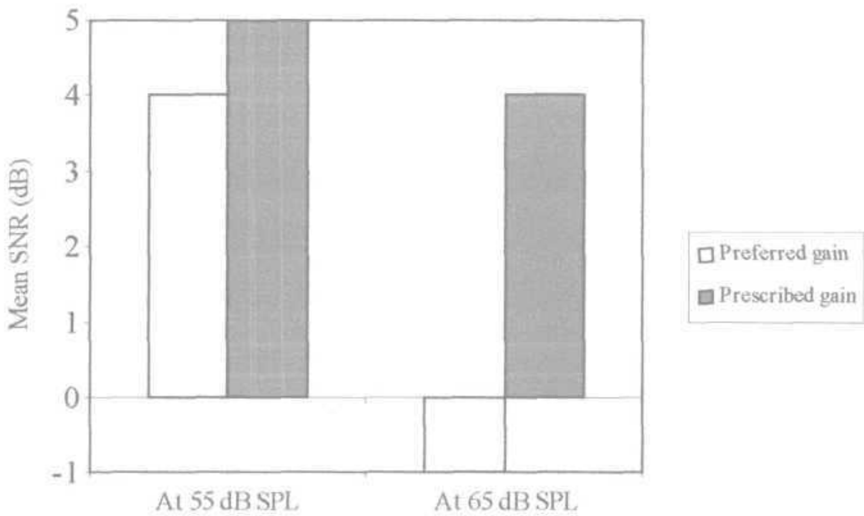


FIGURE: 11 Comparison of SNR at prescribed and preferred in gradual sloping hearing loss subjects using DSL i/o ***in gradually sloping hearing loss subjects***

4) Effect of level was evaluated on SNR threshold measured at preferred and prescribed gain in DSL-i/o

TABLE 18: Mean SNR threshold measured at 55dBSPL vs. SNR measured at 65 dBSPL for preferred gain in DSL-i/o in gradually sloping hearing loss subjects

SNR at two levels	T-value	Sig.
Preferred gain	5.39	0.000***
Prescribed gain	3.75	0.004**

*** Significant at 0.001 levels.

** Significant at 0.01 levels.

The Table 18 shows results of paired t-tests. There was a significant difference between mean SNR measured at 55 dB SPL and 65 dB SPL for preferred as well as prescribed gain.

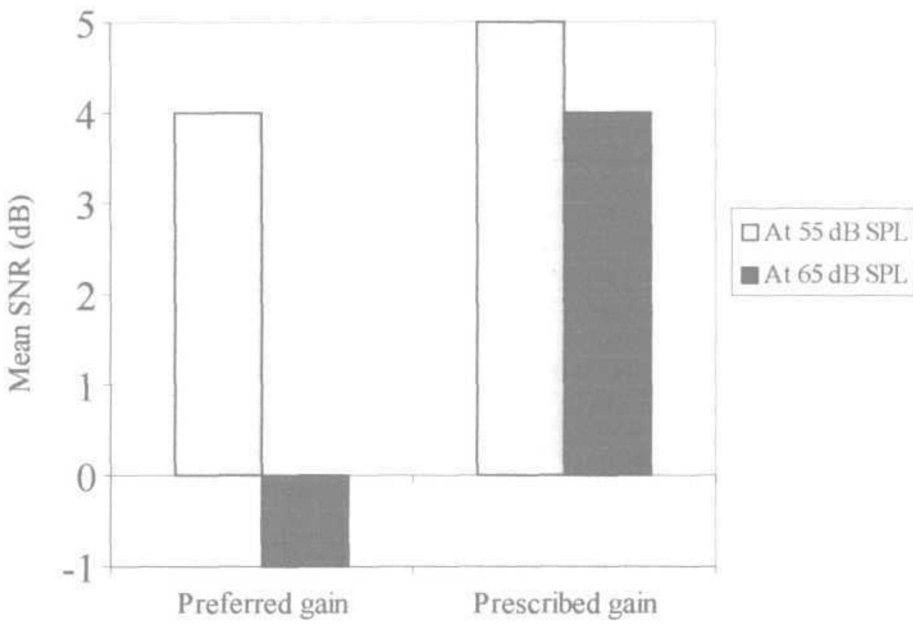


FIGURE 12: Effect of level on SNR in gradual sloping hearing loss subjects using DSLi/o formula in gradually sloping hearing loss subjects

Though the REIG at preferred gain was lesser than that at prescribed gain, it was not sufficient enough to produce a change in speech perception at 55 dBSPL. The mean SNR at preferred gain was 1 dB lesser than at prescribed gain in presence of background noises. The lower speech input levels are more affected than higher speech input levels when intelligibility is measured in presence of noise. In contrast to 55 dB SPL, the SNR thresholds at preferred gain were significantly lesser than at prescribed gain at 65 dB SPL. It was on the order of 4 dB, at preferred gain than prescribed gain. Moreover, within the same gain settings, both preferred and prescribed the mean SNR thresholds measured at 55 dB SPL were significantly more than that at 65 dB SPL. So the lower speech input levels are more adversely affected by presence of noise as compared to higher input levels.

So it can be concluded that for both the prescriptive formula, in gradual sloping hearing loss cases, the preferred gain settings were positively influencing the speech perception in noise at the average input level (65 dB SPL) i.e. the SNR required were less. So, the fine turning done was effectives for average input level. There is a need to expose subjects to more real life situation, to validate fine-tuning although

In the study by Cunningham, Williams & Goldsmith (2001), there were no differences on measures of aided hearing aid benefit (COSI; APHAB), speech perception in noise, sound quality, satisfaction or number of hours worn, between the control and treatment group. In the treatment group post fitting fine-tuning was done. The post fitting fine tuning was carried out in several periodic sessions, though there were subject driven changes in real ear insertion response in the range of 1 to 10 dB, over time, there were no significant changes in perceived benefit or speech in noise measures. The results cannot be directly compared with the results of current study as no trial session was given to the subjects in the present study.

B) Steeply Sloping Hearing Loss

1) SNR measured at preferred gain vs. SNR measured at prescribed gain at 55 dBSPL and at 65 dB SPL in NAL NL1

TABLE 19: Mean SNR threshold measured at preferred and prescribed gain at two levels for NAL-NL1 in steeply sloping hearing loss subjects

SNR PF vs. PS	T-Value	Sig.
55 dB SPL	1.177	0.269
65 dB SPL	0.542	0.601

Table 19 shows results of paired t-tests. There was no significant difference between SNR measured at preferred gain and prescribed gain for both the levels.

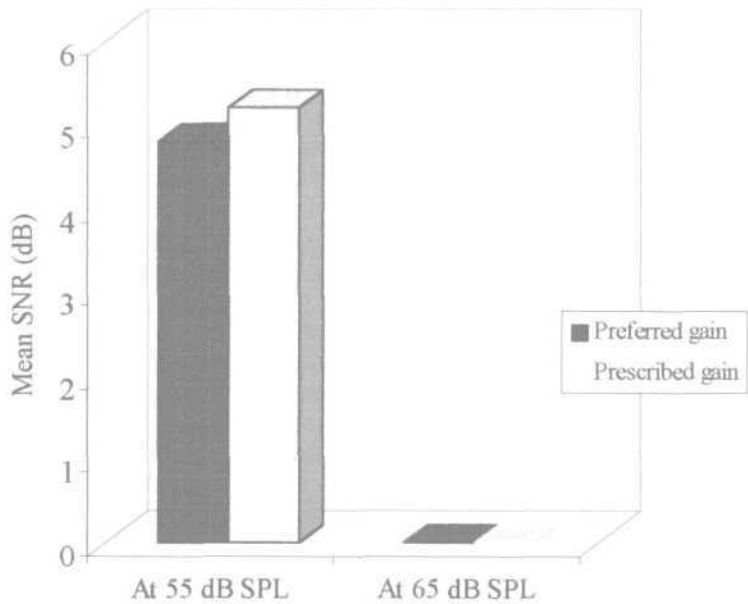


FIGURE 13:Comparison of SNR at prescribed and preferred in steeply sloping hearing loss subjects using NAL-NL1

2) Effect of level was evaluated on SNR threshold measured at preferred and prescribed gain in NAL NL1

TABLE 20: Mean SNR threshold measured at 55dBSPL vs. SNR measured at 65 dBSPL for preferred gain in NAL-NL-1 in steeply sloping hearing loss subjects

SNR PFvs PF at two levels	T-Value	Sig.
55 dBSPL vs.65 dBSPL	7.060	0.000***
55 dBSPL vs.65 dBSPL	7.220	0.000***

*** Significant at 0.001 levels.

The Table 20 shows results of paired t-tests. There was a significant difference between SNR measured at 55 dB SPL and 65 dB SPL for preferred as well as prescribed gain.

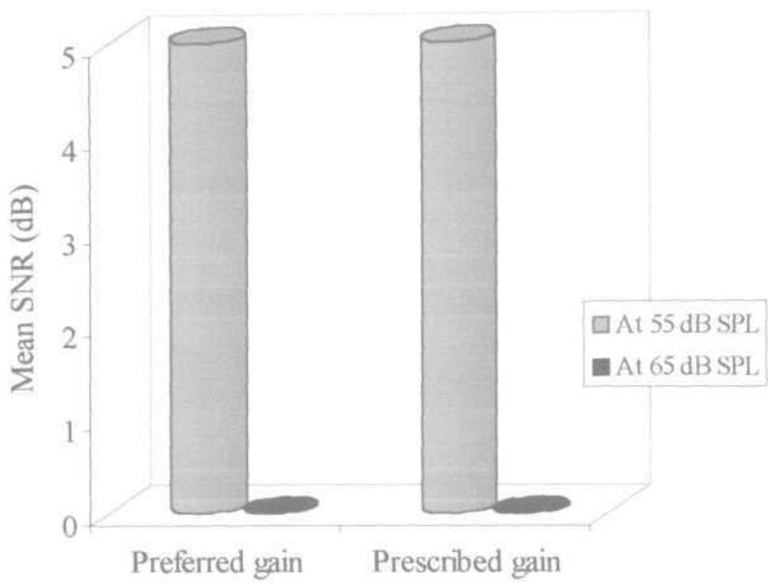


FIGURE 14: Effect of level on SNR in steeply sloping hearing loss subjects using NAL NL1 formula

The mean SNR thresholds at preferred gain was not significantly different from mean SNR threshold at prescribed gain. This shows the increase in REIG at preferred gain across all the frequencies, was not sufficient to improve or worsen the SNR thresholds. That is though a greater gain was provided after fine-tuning according to listener preference; it was not increasing or reducing the masking effects of noise. As past research has shown that providing high sensation levels at frequencies where the hearing loss was severe or profound did not always improve speech intelligibility (Murray & Byrne, 1986; Ching et al. 1998; Hogan & Turner, 1998), so it can be extrapolated that greater gain at the higher frequencies will not contribute much to speech intelligibility. Moreover some reports also suggest that providing amplification to individuals with SNHL, especially at the higher frequencies may deteriorate the speech perception in noise. (Ching, Dillon and Byrne, 1998; Hogan and Turner 1998; Turner and Cummings 1999; Skinner 1980; and Turner and Brus 2001). Further the hearing loss desensitization factor, employed by NAL-NL1 (Byrne et al, 2001), also suggests that increasing audibility especially at the high frequency does not maximizing speech intelligibility.

So it can be concluded that greater gain at the higher frequencies did not contribute much to speech intelligibility. There is reduced usefulness of audibility with increased hearing loss (hearing loss desensitization) and this is more marked at high frequencies than at lower frequencies. As compared to gradually sloping loss, wherein there was a significant difference between preferred and prescribed gain at 65 dB SPL, the same was not true in cases with steeply sloping hearing loss. If we look at the rationale of NAL-NL1 it provides less high frequency gain as these have minimal contribution to SII. In the present study though listeners with steeply sloping hearing loss preferred greater gain at low, mid and high frequency region, the speech intelligibility was not affected, neither it improved nor it deteriorated. This implies that fine-tuning at the first session can be carried out in response to subject complains without affecting the speech intelligibility. However, to validate the fine-tuning procedure sound quality judgment tasks should be included along with speech perception measures.

Even though the speech is sufficiently amplified the individuals with SNHL, fail to understand speech (Tillman, Carhart & Olsen, 1970). It has been shown by investigators that benefits of providing audible speech to listeners with SNHL have limitation.

Turner and Cummings (1999), Skinner (1980), and Turner and Brus (2001) provided similar evidence that maximizing the amount of audible speech was not always the beneficial strategy for patients with SNHL. Further the effect of level when analyzed gave similar results as in subjects with gradually sloping hearing loss.

In summary, the preferred settings significantly improved the SNR thresholds only in gradually sloping hearing loss subjects at 65 dB SPL. No change at 55 dB SPL was observed. However in case of steeply sloping hearing loss subjects the preferred settings did not affect the SNR thresholds at both the levels.

3) SNR measured at preferred gain compared to SNR measured at prescribed gain at within each level in DSL i/o

TABLE 21: Mean SNR threshold measured at preferred vs. prescribed at two levels for DSL-i/o in steeply sloping hearing loss subjects

SNR at PF vs. PS	T-value	Sig
55 dB SPL	0.000	1.000
65 dB SPL	0.294	0.775

Table 21 shows results of paired t-test. There was no significant difference between mean SNR measured at preferred gain and prescribed gain at both 55 dBSPL & 65 dBSPL

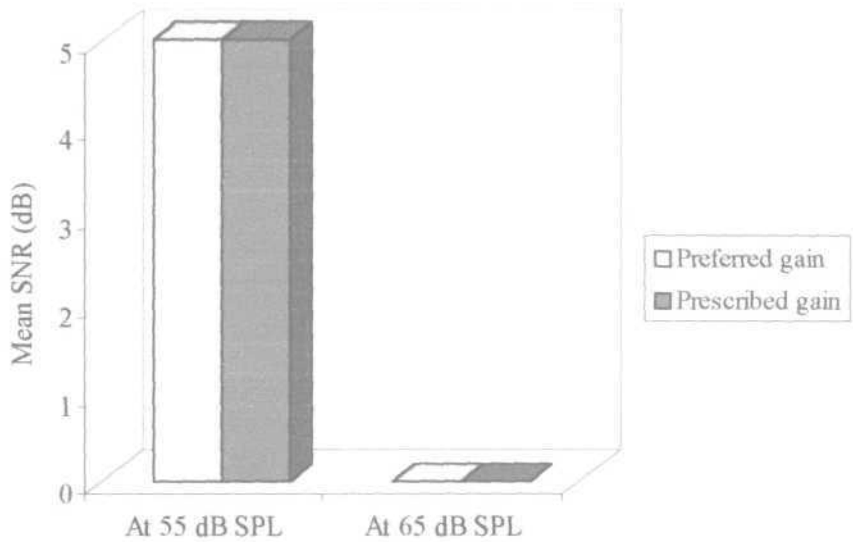


FIGURE 15: Comparison of SNR at prescribed and preferred in steeply sloping hearing loss subjects using DSL i/o

4) Effect of level was evaluated on SNR threshold measured at preferred and prescribed gain in DSL-i o

TABLE 22: Mean SNR threshold measured at 55dBSPL vs. SNR measured at 65 dBSPL for preferred gain in DSL-i/o in steeply sloping hearing loss subjects

SNR at 2 levels	T-value	DF	Sig.
Preferred gain	6.600	9	0.000***
Prescribed gain	6.128	9	0.000***

*** Significant at 0.001 levels.

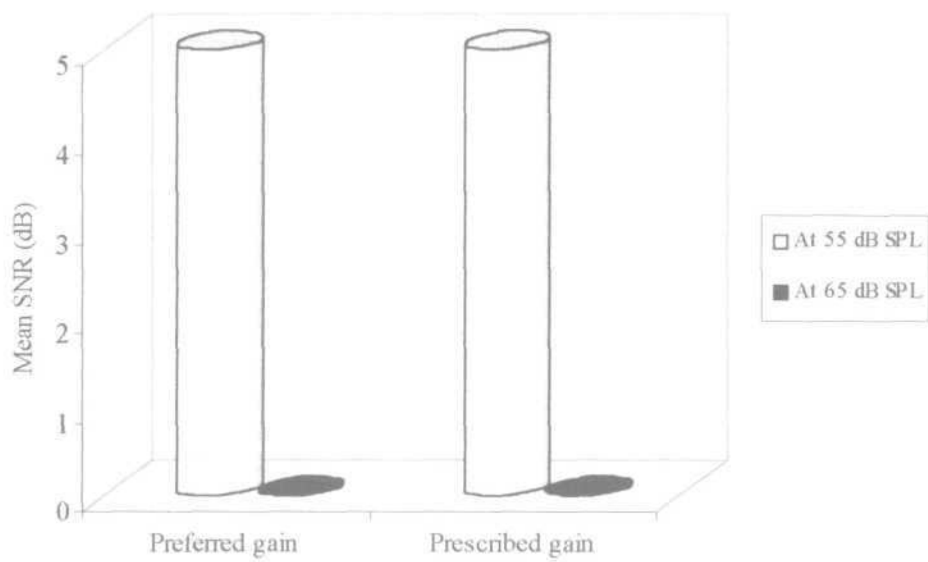


FIGURE 16: Effect of level on SNR in steeply sloping hearing loss subjects using DSL i/o formula

Table 22 shows results of paired t-test. There was a significant difference between mean SNR threshold measured at 55 dBSPL and 65 dBSPL for preferred as well as prescribed gain.

There was no significant difference between mean SNR threshold measured in prescribed gain and preferred gain at both levels. The differences in REIG were not sufficient enough to bring in changes in speech perception in noise. As observed in the REIG measurements, the subjects with steeply sloping hearing loss preferred more gain at mid frequencies and high frequencies. But this increased audibility did not improve or deteriorate the SNR thresholds. However it is reported by (Ching, Dillon and Byrne, 1998; Hogan and Turner 1998; Turner and Cummings 1999; Skinner 1980; and Turner and Brus 2001) previous authors increased high frequency audibility did not increased speech perception in noise, though few authors (Turner and Henry 2002), suggested improvements to be present. As the there were no significant changes in SNR thresholds, not even deterioration, it can be concluded that the amount of change done relative to DSL-i/o prescribed settings, does not brings about a change in speech perception in noise. So this amount of fine-tuning can be done in response to subject's complaints, without the fear incorrect amplification.

However there is a need to include sound quality judgment tasks, along with speech perception measures, in order to validate the process of fine-tuning.

Effect of Formula on SNR Measurements

i) Gradually Sloping Hearing Loss

TABLE 23: Mean SNR threshold at NAL-NLl vs. DSL-i/o in gradually sloping hearing loss subjects

SNRNALvs. DSL	T-values	Sig
55dB SPL	0.504	.625
65 dB SPL	1.869	.091

Table 23 shows results of paired t-test. There was no significant difference between mean SNR measured threshold for NAL-NLl and DSL-i/o when compared within same level and gain (preferred and prescribed).

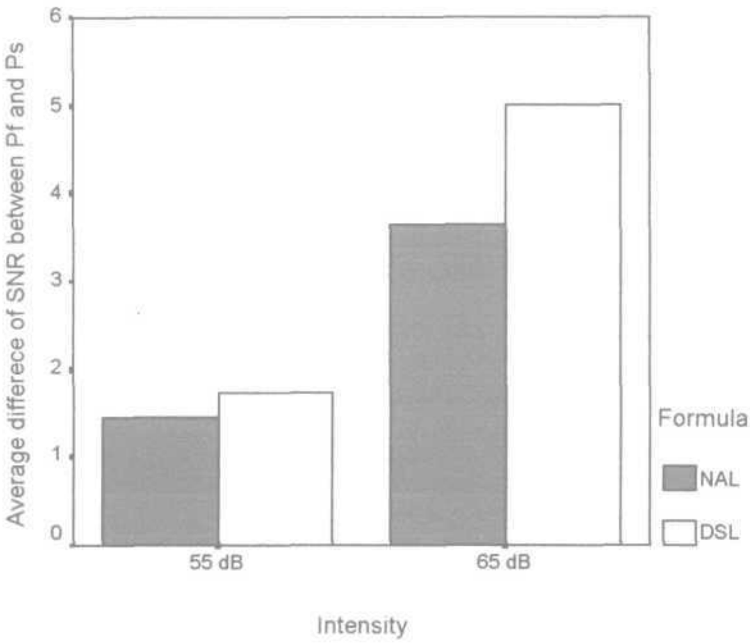


Figure 17: Effect of formula on difference between SNR at prescribed and preferred gain in gradually sloping hearing loss subjects

ii) Steeply Sloping Hearing Loss

TABLE 24: Mean SNR threshold at NAL-NLl vs DSL-i/o in steeply sloping hearing loss subjects

SNR NAL vs DSL	T-values	df	Sig
55	0	9	1.000
65	.843	9	.421

Table 24 shows results of paired t-test. There was no significant difference between SNR measured for NAL-NLl and DSL-i/o when compared within same level and gain (preferred and prescribed). The following table shows the results of paired t-test:

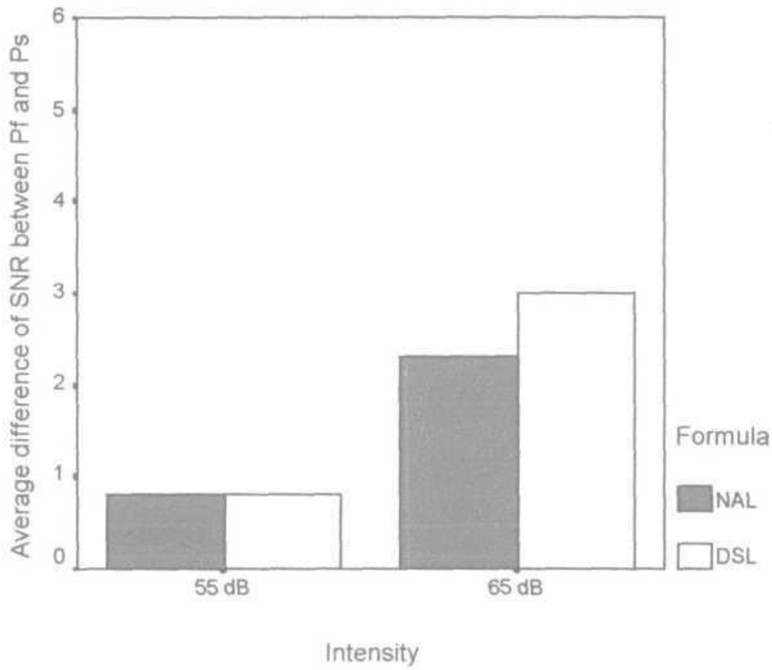


Figure 18: Effect of formula on difference between SNR at prescribed and preferred gain in steeply sloping hearing loss subjects

In case of SNR threshold measurements no significant difference was found between preferred and prescribed gain at 55dBSPL and 65 dBSPL. The perceptual preferences by the subject at low, mid and high frequencies were not sufficient to bring about changes in the SNR thresholds. Though the effect of both formula are significantly different in REIG measurements in both the configuration of hearing loss, the same is not true in case of SNR measurement. The trends of difference between prescribed and preferred gain in each formula are not reflected on SNR threshold measurement. It might be argued that as the adjustments were done in the same hearing aid with same signal processing, the differences in SNR threshold measurement were not evident across both the formula as well within each formula.

CHAPTER V

SUMMARY AND CONCLUSIONS

The present study aimed at investigating the effects of preferred and prescribed gain on speech perception in noise. Two widely used prescriptive formulae; NAL-NL1 and DSL-i/o were implemented in a commercial digital behind the ear hearing aid for the present study. Two groups of individuals with sensorineural hearing loss varying in hearing loss configuration served as subjects for this study.

The investigation was carried out to address the following research goals:

1. To determine if there was a significant difference between prescribed gain and preferred gain for two non linear hearing aid fitting formulae.
2. To determine whether there was any difference in speech perception in noise due to prescribed and preferred gain settings.
3. Did the difference, if any, depend on the formula?
4. Did the difference also depend on configuration of hearing loss?

Real Ear Insertion Gain measurements and Speech to Noise Ratio thresholds were established at preferred and prescribed gain settings of each formula in each group of subjects.

The procedure was carried out in two phases. In the first phase the hearing aid was programmed according to the recommendations of NAL-NL1 and DSL-i/o. The gain, frequency shaping and compression parameters were stored. Then fine-tuning was done using standard audiometric protocols and according to the software suggested (Connex version v5.0) options for both NAL-NL1 and DSL-i/o. The preferred settings were stored. In the second phase, REIG and SNR measurements were carried out. The REIG measurements were done using 65dBSPL digi-speech stimulus. It was carried out for each formula with the hearing aid programmed to its prescribed gain and then to the preferred gain. The values at frequencies from 500 to 6000 Hz were documented. Subsequently SNR thresholds were obtained using recorded phonetically balanced words and speech shaped noise. The words were presented at two levels; 55dBSPL and 65dBSPL .The speech level was kept constant whereas noise was adaptively varied. The SNR threshold was defined as the SNR at which 50% criteria was met in speech in noise test. SNR measurements were carried out for preferred and prescribed hearing aid settings for both the formulae. The data was statistically analyzed using four-way ANOVA to determine the main effects and interaction effects. It revealed significant main effects and interaction effects. Further paired t-tests were administered to study the significance of interaction effects.

The results obtained are given below:

- REIG measured at preferred and prescribed gain in NAL-NL1 as well as DSL-i/o were significantly different in most of the frequencies for both the groups. However the amount and direction of difference was frequency dependent. In some frequencies the difference between preferred and prescribed gain was not significant.

- The difference between REIG at preferred and prescribed gain in each formula was computed to investigate the effect of formula. It was found that each of the formula maintained a trend for each group. The NAL-NL1 prescribed settings were close to the preferred settings in case of gradually sloping hearing loss subjects. However for DSL-i/o the differences were large. In case of steeply sloping hearing loss, the trend was reversed; DSL-i/o gave a close match to the preferred settings.

Thus, it can be concluded that the listeners in both the groups showed deviant preferences from the prescribed settings when using each formula. In most of the cases, the listeners preferred higher gains at mid frequencies, showing that they enjoyed listening at a comfortable level whereas at high and low frequencies, the preferred gain was lower than the prescribed gain. However in steeply sloping hearing loss group there was a preference for higher gains than prescribed through out the frequency range when NAL-NL1 was used.

- In SNR threshold estimation, there were no significant differences between preferred and prescribed gain. The only exception was the gradually sloping hearing loss group, which revealed significant differences for both NAL-NL 1 and DSL-i/o at 65 dB SPL.

Hence, it can be concluded that, the trend of difference between prescribed and preferred gain in each formula observed in REIG measurement was not reflected on SNR threshold measurement. So the changes done in the overall gain and frequency shaping parameters in response to subjective impression, were not affecting the speech perception in noise in most cases, with the exception being gradually sloping hearing loss group at 65 dB SPL.

Hence the amount of fine-tuning done in this study for each subject, was favourable, but not harmful, because it improved sound quality, clarity, and pleasantness for all the subjects and even speech perception in noise in few subjects. But there should be further research including sound quality judgment tasks to validate the fine-tuning.

There were two more observations; the SNR thresholds at 55 dB SPL were higher than those at 65 dB SPL. The other observation was that the differences in SNR threshold measurement were not evident across both the formulae. However, the present study did not administer any quality judgment tasks, or hearing aid benefit scale to validate the preferred gains. The use of quality judgment tasks along with speech perception in noise measures could have shown some differences in both settings in each group. The future directions implicated by the present study are that, quality judgment tasks along with real ear and speech perception measures should be included for quantifying the difference between preferred and prescribed gain. Moreover the preferred gain was obtained in quiet situation. It is suggested that the protocol to determine preferred gain settings should also encompass listening in noisy situations with varying SNR and speech input levels. The validations should be carried out in varying listening situation, as the preferences can vary with circumstances and listening situations as well. Further research should be carried out using subjects with other configuration of hearing loss and an in larger population.

BIBLIOGRAPHY

American National Standards Institute (1993). American National Standards Methods for the Calculations of Speech Intelligibility Index. (ANSI S3.5-1993, draft v3.1). New York: ANSI.

Arlinger, S., Lyregaard, P.E., Billermark, E., & Oberg, M. (2000). Fitting hearing aids to first time users. *Scandavinian Audiology*, 29, 150-158.

Bentler, R.A., Niebuhr, D.P., Getta, J.P., & Anderson, C.V. (1993). Longitudinal study of hearing aid effectiveness. I: Objectives measures. *Journal of Speech and Hearing Research,* 36, 808-819.

Berger, K.W., & Hagberg, E.N. (1982). Gain usage based on hearing aid experience and subject age. *Ear and Hearing*, 3(4), 235-237.

Byrne, D., & Cotton, S. (1988). Evaluation of the National Acoustic Laboratories - New hearing aid selection procedure. *Journal of Speech and Hearing Research*, 31,178-186.

Byrne, D., & Dillon, H. (1986). The National Acoustic Laboratories (NAL) New procedure of selecting the gain and frequency response of a hearing aid. *Ear and Hearing*, 9 (4), 257-265.

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

Ching, T.Y.C., Dillon, H., & Byrne, D (1998). Speech recognition of hearing-impaired listeners: Predictions from audibility and the limited role of high frequency amplification. *Journal of the Acoustical Society of America*, 103 (2), 1128-1140.

Ching, T.Y.C., Dillon, H., Lockhart, F., Van Wanrooy, E., Brew, C, Lai, L., Newall, J., & Brannstrom, J. (2002-2003). Factors affecting speech intelligibility of hearing impaired people. National Acoustic Laboratories Report.

Convery, E., Keidser, G., & Dillon, H. (2005). A review and analysis: Does amplification experience have an effect on preferred gain over time? *The Australian and New Zealand Journal of Audiology*, 27(1), 18-32.

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 the Acoustical Society of America*, 97 (3), 1854-1864.

Cunningham, D.R., Williams, K.J., & Goldsmith, L.J. (2001). Effects of providing and withholding post fitting fine-tuning adjustments on outcome measures in novice hearing aid users: A pilot study. *American Journal of Audiology*, 10, 1-11.

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

Dillon, H. (1999). NAL-NLI: A new procedure for fitting non-linear hearing aids. *The Hearing Journal*, 52 (4), 10-14.

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

Dirks, D.D., Morgan, D.E., & Dubno, J.R. (1982). A procedure for quantifying the effects of noise on speech recognition. *Journal of Speech and Hearing Disorder*, 47, 112-123.

Dubno, J.F., & Levitt, H., (1981). Predicting consonant configurations from acoustic analysis. *Journal of the Acoustical Society of America,* 69,249-261.

Duquesnoy, A.J. (1983). Effect of a single interfering noise on speech source upon the binaural sentence intelligibility of aged persons. *Journal of the Acoustical Society of America,* 74,739.743.

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

Gatehouse, S. (1992). The time course and magnitude of perceptual acclimatization to frequency responses: Evidence from monoaural fitting of hearing aids. *Journal of the Acoustical Society of America,* 92 (3), 1258-1268.

Hagerman, B. (1984). Clinical measurements of speech reception threshold in noise. *Scandavinian Audiology,* 13,57-63

Haubold, J., & Schmeitzer, C. (2000). Fitting for an 'Auditory life'. *The Hearing Review,* 7 (9), 42-51.

Hawkins, D.B., Cooper, W.A., & Thomson, D.J. (1990). Comparison among SPLs in real ears, 2 cm and 3 cm^3 couplers: *Journal of the American Academy of Audiology,* 1, 154-161.

Hawkins. D.B., & Cook., J.A. (2003). Hearing aid software predictive gain values: How accurate are they? *The Hearing Journal,* 56 (7), 26-34.

Heike, H., & Kinkel, M. (2004). Acclimatization - a comparison of manufacturer fitting proposals with real fittings. Presented in IHCON 2004, August 25-29.

Hogan, C.A, & Turner, C.W. (1998). High frequency audibility: Benefits for hearing-impaired listeners, *Journal of the Acoustical Society of America,* 104 (1), and 432-441

Humes, L.E., Barlow, N.N., Gamer, C.B., & Wilson, D.L. (2000). Prescribed clinician-fit versus as worn coupler gain in a group of elderly hearing aid wearers. *Journal of Speech Language and Hearing Research,* 43 (4), 879-892.

Humes, L.E., Wilson, D.L., Barlow, N.N., & Garner, C. (2002). Changes in hearing aid benefit following 1 or 2 years of hearing aid use by older adults. *Journal of Speech, Language, and Hearing Research,* 45,772-782.

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

Kalikow, D.N., Stevens, K.N., & Elliott, L.L. (1977). Development of a test of speech intelligibility in noise using sentence materials with controlled word predictability. *Journal of the Acoustical Society of America,* 61,1337-1351

\ Keidser, G., & Grant, F. (2001). Comparing loudness normalization (IHAFF) with speech intelligibility maximization (NAL-NL1) when implemented in a two-channel device, *Ear & Hearing,* 22 (6), 501-515.

Keidser, G., Brew, C, Dillon, H., Grant, F., Lydia, S (2005). The preferred response slopes and two-channel compression ratios in twenty listening conditions by hearing-impaired and normal-hearing listeners and their relationship to the acoustic input. *International Journal ofAudiology,* 44, 656-670

Keidser, G., Convery, E., & Dillon, H. (2002-2003). Gain preference relative to the NAL-NL1 prescription. National Acoustic Laboratories Report.

Kirkwood, D. (2000). After a flat 1999,industry leaders suggest strategies to get the market growing again. *The Hearing Journal,* 53 (1), 21-36.

Kochkin, S. (2000). Marke Track V: "Why my hearing aids are in drawers". The consumers' perspective, *The Hearing Journal,* 53 (2): 34-42.

Kochkin, S. (2000). Marke Track V: Consumer satisfaction revisited. *Hearing Journal,* 53(1), 38-55.

Kochkin, S., (1999). Marke Track V: Baby boomers spur growth in potential market but penetration rate declines. *The Hearing Journal,* 52 (1), 33-48.

Kuk, F.K & Lau, C.C. (1996). Effect of hearing aid experience on preferred insertion gain selection. *Journal of American Academy ofAudiology,* 7 (4): 274-81.

Kuk, F.K., Harper, T., & Doublek, K. (1994). Preferred real-ear insertion gain on a commercial hearing aid at different speech and noise levels. *Journal of American Academy of Audiology,* 5 (2): 99-109.

Leijon, A., Eriksson-Mangold M., & Bench-Karl sen, A. (1984). Preferred hearing aid gain and bass-cut in relation to prescriptive fitting. *Scandavinian Audiology*,13:157'-161

Leijon, A., Lindkvist, A., Ringdsahl, A., & Israelsson, B. (1990). Preferred Hearing Aid Gain in Everyday use after prescriptive fitting. *Ear and Hearing,* 11 (4), 299-305.

Libby, E.R. (1986). Libby's response to Lyregaard (letter to the Editor). *Hearing Instruments;* 37 (11), 41-45.

Loven, F.C., and 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

Lunner, T., Hellgren, J., Arlinger, S., Elberling, C. (1997). A digital filter bank hearing aid - improving a prescriptive fitting with subjective adjustments. *Scandavinian Audiology,* 26,169-176.

Marriage, J., Moore, B.C.J., & Alcantara, J.I. (2004). Comparison of three procedures for initial fitting of compression hearing aids. III. Inexperienced versus experienced users. *International Journal of Audiology*, 43, 198-210.

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

Mueller, G., & Powers, T.A. (2001). Consideration of auditory acclimatization in the prescriptive fitting of hearing aids. *Seminars in Hearing*, 22 (2), 103-124.

Munro, K.J., & Lutman, M.E. (2005). Sound quality judgments of new hearing instrument users over a 24-week post fitting period. *International Journal of Audiology*, 44, 92-101.

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.

Punch, J.L. (2001). Technologic and functional features of hearing aids: What are their relative costs? *The Hearing Journal*, 54 (6), 32, 34, 36-38, 42, 44.

Rupp, R.R., and Phillips, D. (1969) The effect of noise background on speech discrimination function in normal hearing individuals. *Journal of Auditory Research*, 9,60-63.

Schow, R.L., & Gatehouse, S. (1990). Fundamental issues of self-assessment of hearing. *Ear and Hearing*, 11 (supplement): 6S-16S.

Schwartz, D.M., SUIT, R.K., Montgomery, A.A., Prosek, R.A and Waldel, B.E (1979). Performance of high frequency impaired listeners with conventional and extended high frequency amplification. *Audiology*, 18,157-174.

Seewald, R.C., & Ross, M. (1998). *Amplification for young hearing impaired children.* In M.C. Pollack (Eds.) (pp 212-271). Ornaldo, Florida: Grune & Stratton (3rd Ed.).

Seewald, R.C., Cornelisse, L.E., Ramji, K.V., Sinclair, ST., Moodie, K.S. & Jamieson, D.G. (1997). DSL 4.1 for windows: A software implementation of the desired sensation level (DSL [i/o]) method for fitting linear gain and wide dynamic range compression-hearing instruments.

Seewald, R.C., Ross, M., Shapiro, M.K. (1985). Selecting amplification characteristics for young hearing-impaired children. *Ear & Hearing,* 6 (1), 48-53.

Sehgal, A. (2005). *A comparative study of proprietive and generic prescriptive procedures for non-linear hearing aids.* Unpublished master's dissertation. Mysore: University of Mysore.

Skinner, M.W. (1980). "Speech intelligibility in noise-induced hearing loss: Effects of high-frequency compensation," *Journal of the Acoustical Society of America,* 67,307-317.

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

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

Tillman, T.W., Carhart, R., & Olsen, W.O. (1970). Hearing aid efficiency in a competing speech situation. *Journal of Speech and Hearing Research,* 13, 789-811.

Turner, C.W., & Brus, S. (2001). "Providing low- and mid- frequency speech information to listeners with sensorineural hearing loss. *Journal of the Acoustical Society of America,* 109,2999-3006

Turner, C.W., & Henry, B.A. (2002). Benefits of amplification for speech recognition in background noise. *Journal of the Acoustical Society of America,* 112 (4), 1675-1680

Turner, C.W., and Cummings, KJ. (1999). "Speech audibility for listeners with high-frequency hearing loss." *American Journal of Audiology*, 8, 47-56.

Turner, C.W., Humes. L.E., Bentler, R.A., & Cox, R.M. (1996). A review of past research on changes in hearing aid benefit over time. *Ear & Hearing,* 17 (3 Suppl): 14S-28S.

Walden, B.E., Schuchman, G.I., & Sedge, R.K. (1977). The reliability and validity of the comfort level method of setting hearing aid gain. *Journal of Speech and Hearing Disorders,* 42 (4), 455-461.

Wilber, LA. (1994). Calibration, pure tone, speech and noise signals. In J. Katz (Eds.). *Handbook of Clinical Audiology* (4^{th} Edn.) (Pp. 73-97). Baltimore: Williams and Wilkins.

Yathiraj.A, & Vijayalakshmi, C.S. (2005). *Private communication*