VERIFICATION OF HEARING AID SELECTION USING VISIBLE SPEECH AND SPEECH INTELLIGIBILTY INDEX

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Dedicated to
My Beloved AAI-
BABA
AND Marvellous
DADA

CERTIFICATE

This is to certify that this dissertation entitled ***"Verification of hearing aid selection using visible speech and speech intelligibility index"*** is the bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student with registration no. 07AUD006. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled ***"Verification of hearing aid selection using visible speech and speech intelligibility index"*** is the result of my own study under the guidance of Dr. P. Manjula., Reader, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other University for the award of any Diploma or Degree.

Mysore

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Chapter 1

INTRODUCTION

There are several components that typically are included in a comprehensive protocol for the selection and fitting of hearing aids. In hearing aid fitting, the major steps such as hearing assessment, pre-selection of hearing aid, fitting, verification, orientation or counselling, and real-world validation are often included (Mueller, 2005). Each step plays an important role in assuring a successful audiological treatment and rehabilitation process. One of the major steps is verification which is a common component of most protocols in medicine and technology. It has been defined by Mueller (2005) as 'substantiating or determining the truth or accuracy'.

In order to verify the performance of the hearing aid, one must have a pre-determined set of data, target data, or at the least, general fitting goals (Mueller & Hornsby, 2002). Historically, verification method has considered functional gain measurements as a valuable verification procedure. In this, warble tones and speech material were utilized to verify hearing aid selection. Such verification methods paralleled the fitting goals, with the goal of maximizing speech intelligibility being a primary one. It is not surprising, therefore, that there is a long history of using speech audiometry to assess hearing aid performance.

From the 1950s through the 1970s, the primary verification tool was aided monosyllabic word recognition; a procedure used by 80 to 90% of audiologists (Burney

1972; Smaldino & Hoene, 1981). In the late 1970s, around the same time that the reliability of speech testing as a verification procedure was being questioned, prescriptive fitting approaches were gaining more popularity (Valente, 2002).

Most would agree that a "good" hearing aid fitting must be a combination of optimizing audibility, optimizing intelligibility, matching preferred loudness levels, avoiding loudness discomfort, and providing good sound quality (Humes, 1996). These goals have led to the development of several prescriptive methods over the past several years. These prescriptive methods provided fitting targets expressed in dB gain or output values – something that indeed could be verified.

Audiologists have at least two fitting procedures that provide us with validated prescriptive targets. The audiologist's task, therefore, is then to verify that these targets have been met at the time of the fitting of the hearing aids. The reasonable method to accomplish this is to use real ear measurements (REM) or probe tube microphone measures (Dillon & Keidser 2003). Real-ear probe-microphone measures are important because they represent the only objective way of analysis of sound between the hearing aid and the tympanic membrane.

However, most audiologists choose not to use this method. Surveys conducted over the past several years suggested for fitting hearing aid to adults, the routine use of probe-microphone measures for verification in the United States (US) was probably no higher than 30 to 35% (Mueller, 2005) and there are some data to suggest that the actual use rate is even lower than that suggested by typical survey (Mueller, 1998).

The resistance of the audiologists to conduct real-ear measurements is partially based on the lack of a clear and consistent relationship between REMs and successful

hearing aid fitting outcomes (Beck & Duffy, 2007). Perhaps another reason is the lack of an appreciable increase in patient understanding or comprehension of aided benefit, secondary to traditional REM (Beck & Duffy, 2007). A third reason could be the confusing multiplicity of acronyms related to real ear measurements such as REIG, REAR, REIR, and RESR (Mueller & Hornsby, 2002).

Moreover, traditional REM uses composite noise as stimulus which is not a real world stimulus. The audiologist does not know how a hearing aid is going to perform in real world situations. The gains actually achieved for real-life signals such as speech and music may differ considerably from the gains measured with steady signals, such as tones and noise. The difference depends on the number of channels in the hearing aid, the speed of the compressors, and the compression thresholds (Stone & Moore, 1992; Verschuure, Maas, Stikvoort, de Jong, Goedegebure, & Dreschler, 1996; Souza, 2002; Henning & Bentler, 2005; Jenstad & Souza, 2005). This can be the case even when features such as noise reduction or feedback cancellation are not present or are not activated (Lindley, 2007). It seems apparent that utilizing a real speech signal, as it occurs in real life could add benefit when making program changes to improve hearing ability through amplification (Lindley, 2007).

Like REM, Speech Intelligibility Index (SII) has been used as a verification tool for hearing aid selection (Cox, Alexander, & Rivera, 1991). The SII is calculated from the speech spectrum, the noise spectrum, and the listener's hearing threshold. The SII is determined by accumulation of the audibility across the different frequency bands, weighted by the band importance function. The resulting SII is a number between zero and unity. The SII can be seen as the proportion of the total speech information available

to the listener. An SII of zero indicates that no speech information is available to the listener; an SII of unity indicates that all speech information is available. However, a SII of one does not necessarily mean that the individual understands 100% of the information. It only suggests that 100% of the speech cues are audible and usable in a given setting (Hornsby, 2004). The SII calculates the intelligibility of speech which is the signal of maximum importance. In real life situations, it is the speech signal which is important for being processed through hearing aids.

Speech is an interesting and familiar stimulus for all of us. It is the signal that the hearing instrument is required to process. Audiologists have longed for the ability to use actual speech in REM. Researchers have been successful in using speech signals as a stimulus for REM. The visible speech measure can be used to accomplish this during real ear measurements (Ross & Smith, 2005). 'Visible Speech' also known as 'Live Speech Mapping' (LSM) is fitting processes that uses probe microphones and live / recorded real-time speech to allow the client and their family members to immediately see and understand the benefits of hearing aids and fitting adjustments**.** The visible speech utilizes "real-time speech", that of a family member, friend, or familiar third party, for real-ear measurements. One key difference between this technology and other verification tools is that it allows the client and family to clearly understand the results and realize an immediate and positive impact on their hearing as the programming of their hearing aid is changed.

Visible Speech allows the professional to record and demonstrate the appropriateness of the hearing aid fitting while reviewing, demonstrating, and explaining the process in terms the patient understands-based on human speech and the Speech

Intelligibility Index. Hence, visible speech along with SII would be of great value to audiologists in determining the performance of a client in real-life situations. It would add to the objectivity and better understanding of the hearing aid benefit by the client.

Need for the Study:

The major shortcomings of functional gain measurement are

a. The FG does not assist in making frequency gain adjustments, when speech is used as the stimulus. It only tells whether a set of hearing aid parameters are resulting in better or poorer scores.
b. It does not reflect which electroacoustic characteristics would contribute to better or poorer aided performance.
c. It is a subjective test and is affected by various biases/factors.

It is necessary to incorporate a more objective measurement along with the functional gain measurements for verification of during hearing aid selection.

Problems with routine REM

Measurements are often made with either tonal or noise stimuli rather than the actual speech. A pure-tone sweep or composite signal is routinely used to obtain real ear measurements. The non-linear digital hearing aids do not faithfully produce the actual output when such test signals are being used. Also, clients find it difficult to relate the data shown on insertion gain and the audibility of actual speech. The whole procedure of

insertion gain and its outcome is a confusing step for clients during hearing aid selection and verification (Poe & Ross, 2005). The clients showed inability to grasp the importance or outcomes of insertion gain measurements.

To overcome this disadvantage of REM, the REM is carried out using the actual speech that may aid in hearing aid selection. As actual speech is more meaningful and acceptable to clients, it would satisfy them with better understanding of their hearing aids. In addition, the SII has been documented as one of the techniques for hearing aid selection (Pavlovic, 1989). Hence, if the visible speech is used along with the SII routinely to verify the hearing aid selection, it would boost the objectivity in hearing aid verification.

Aims:

The aim of the present study is to investigate the usefulness of visible speech during real ear measurements for selection of hearing aid by

1. Comparing the verification of hearing aid selection done by visible speech with that of real ear aided gain measurements.

2. Comparing the verification of hearing aid selection done by visible speech with that of speech identification scores.

3. Comparing the verification of hearing aid selection done by visible speech with that of speech intelligibility index.

Chapter 2

REVIEW OF LITERATURE

"Old order changeth, yield place to new ..."

- Lord Alfred Tennyson.

The advancement, miniaturization and quality improvement in the field of hearing aids has not only led to more satisfaction on the part of clients but also more contentment on the part of clinician. Many hearing aid companies have incorporated recent advances in signal processing strategies and other components of hearing aids. Yet, the clinician faces a lot of problem while making selection and verification of hearing aids to best suit the individual's needs.

There are several components that typically are included in a comprehensive protocol for the selection and fitting of hearing aids. Areas such as hearing assessment, hearing aid selection, fitting, verification, orientation or counselling, and real-world validation are often included. Each step plays an important role in assuring a successful audiologic treatment and rehabilitation process. The process begins with the assessment of the auditory system and detailed diagnosis of the problem. The selection of hearing aid is based on various auditory and non-auditory factors. Both the clinician and patient have to be actively participating in the selection and fitting process.

Verification is a common component of most protocols in medicine and technology and is defined as "substantiating or determining the truth or accuracy"

(Mueller, 2006). To appropriately fit the hearing aid, verification of appropriate gain, output and other features must be completed first (Valente, 2002). The fitting and verification procedure is viewed as a process rather than an event, which culminates in the optimal fitting for the individual patient. Verification procedures also serve as a benchmark against which future hearing aid changes can be compared (Mueller, 2006). Verification procedures are based on validated fitting rationales. The hearing aid fitting and verification procedures are expected to yield a comfortable fit of a hearing aid, including all desired features.

Historically, verification methods have paralleled the fitting goals, with the goal of maximizing speech intelligibility being a primary one. It is not surprising, therefore, that there is a long history of using speech audiometry to assess hearing aid performance. From the 1950s through the 1970s, the primary verification tool was aided monosyllabic word recognition; a procedure used by 80–90% of audiologists (Burney, 1972; Smaldino & Hoene, 1981). This verification process, sometimes referred to as the comparative or "Carhart fitting approach", usually consisted of aided sound field speech testing of two or three different hearing aids. Following this testing, the client was then fitted with the aid, which provided the highest percent of correct response. Many questioned, however, if the approach was verification of the fitting because of the variability associated with the test procedure (Studebaker, 1982; Mueller & Grimes, 1983; Schwartz & Walden, 1983). In the late 1970s, the reliability of speech testing as a verification procedure was being questioned and prescriptive procedure was gaining favour. A "good" hearing aid fitting must be some combination of optimizing audibility, optimizing intelligibility, matching preferred loudness levels, avoiding loudness discomfort, and providing good sound

quality (Valente, 2002). These goals have led to the development of several prescriptive methods over the past several years. These prescriptive methods provided fitting targets expressed in dB gain or output values, something that indeed could be verified.

In the recent days, NAL-NL1, which is a prescriptive method, has gained widespread acceptance in fitting of hearing aids. NAL-NL1 has evolved as a compression-based method for non-linear hearing aids in 1998. The method presents with some interesting features, which are based in part, on the original underlying philosophy of whole NAL 'family' of fitting methods. This includes *equalization* rather than *normalization* of loudness relationships among the speech frequencies. The reason the NAL-NL1 method deviates from the approach of preserving the unaided loudness relationship among the different frequency elements of speech is because the preserving approach has not been shown to improve speech intelligibility (Dillon, Katsch, Byrne, Ching, Keidser, & Brewer, 1998).

Like all compression based fitting methods, the NAL-NL1 has more than one target; as the hearing aid compression offers different amount of gain at different input levels. The main aim of developing NAL-NL1 was to determine the gain for several input levels that would result in maximal effective audibility. According to Keidser and Dillon (2006), the NAL-NL1 aims to maximize speech intelligibility for any input level above the compression threshold, while keeping the overall loudness at or below normal. It is derived from an optimization procedure combining SII formula and a loudness model of Moore and Glasberg (1997). Keidser and Dillon (2006) also stated that NAL-NL1 produces a gain-frequency response that makes loudness of speech bands approximately constant across frequencies.

The initial fitting of hearing aids for adults is often based on a NAL-NL1 target, usually derived from the audiometric thresholds. Atleast, some of these targets are based upon the empirical measurements showing that fitting according to the target leads to the greater speech intelligibility both in quiet and in noise; and/or better subjective quality than fittings that deviate significantly from the target (Byrne, 1986; Byrne & Cotton, 1988; Moore, Alcantara, & Marriage, 2001). Also, fitting according to a target can optimize the audibility of speech for a given overall loudness (Moore & Glasberg, 1998). Hence, it is desirable to meet the target as closely as possible.

The clinician task, therefore, is to verify that these targets have been met at the time of fitting of hearing aids. Measurement of real ear measurement (REM) is a reliable and accurate method for determining how well a hearing aid is adjusted to match a prescriptive target and for adjusting a hearing aid so as to improve the match (Seewald, Moodie, Sinclair, & Scollie, 1999). Thus, the preferred method for verification of gain and output includes measurement of hearing aid output characteristics from within the ear canal using miniature probe microphones to obtain a representation of 'real ear' as against the 2 cc coupler gain.

In the present study, use of visible speech method for verification is being investigated. In this connection, the review of literature is being organized under the following topics:

2.1. Traditional Real Ear Measurements

2.1.1. Principle of Real Ear Measurements

2.1.2. Studies on Traditional Real Ear Measurements

2.1.3. Types of input signal for Traditional Real Ear Measurements

2.2. Visible Speech measurement

2.2.1. Introduction

2.2.2. Essential concepts

2.2.3. Visible Speech stimuli

2.2.4. Speech spectrum analysis and the Speech Intelligibility Index (SII)

2.2.5. Target speech spectrum

2.2.6. Why Visible Speech as a verification tool?

2.1. Traditional Real Ear Measurements

In 1942, Romanow wrote in his seminal paper "Methods for Measuring the Performance of Hearing Aids":

> A hearing aid can be considered as a sound transmission system which is interposed in the path between source of the sound and listener's ear. As such, its performance can be judged by comparing the sound that reaches the ear first through air path and then through hearing aid.

Romanow's concept was that if the listener could perceive sounds without and with hearing aids, then the fitter could get an idea of the efficacy of the chosen instrument. Today, clinicians use probe-tube microphone measurements of sounds in the ear canal to obtain quantitative, objective observations of the unamplified versus the amplified sound that "reaches the ear". The probe microphone real ear technique is very much clinically oriented. It is practical and designed to be used with clients of all ages. The equipment is useful for difficult-to-test patients such as mentally challenged and

stroke patients. It can also be used with young children in whom hearing aid selection, otherwise, would have become difficult. It is an objective measure and can save time.

2.1.1 Principle of Real Ear Measurements

The three principles of REM according to Libby (1986) include -

1. The ideal hearing instrument response can not be really achieved. It is just an approximation.
2. For a particular hearing loss, insertion gain predictions remain same. This is because insertion gain is based on the formulae from which it was derived.
3. For fitting hearing aids, insertion gain and in-situ measurements must be made and considered.

The term real ear measurement is used by audiologists to cover a range of different measurements of the real-ear acoustical characteristics of hearing aids. In clinical audiology, the purpose of the real ear measurement is to compare and verify the real ear acoustical characteristics of a hearing aid with prescription target. Real ear measurements are used to ensure that the initial adjustment of the hearing aid is an adequate match to a target set of gain-frequency responses. For atleast the past decade, doing real ear measurements has been considered good practice for verifying hearing aid performance.

2.1.2 Studies on Traditional Real Ear Measurements

Aahz and Moore (2007) investigated whether routine real ear insertion gain measurement is necessary in fitting digital hearing aids. They also assessed the extent to which modifying the frequency-gain response of aid could lead to better match to the target in cases where the target was not initially matched. The target formula used was NAL-NL1. Real ear insertion gain (REIG) measurements on 42 ears showed that 64% of the cases failed to come within ±10 dB of the target. After adjusting the frequency gain response of the aid, about 83% of the cases came within ±10 dB of the target.

Leijon, Lindkvist, Ringdahl, and Israelsson (1990) investigated the insertion gain preferred in everyday listening situation by a group of 26 elderly participated with moderate hearing impairment. The fitting of the hearing aid was checked with one or more follow-up sessions. The subjects were strictly instructed to try the recommended volume control setting before reporting which setting they preferred. The prescription significantly overestimated preferred gain by about 7 dB.

Ringdahl, Leijon, Liden, and Backelin (1984) investigated whether old fitting of the 25 aided subjects could be improved by using more precise prescription rules and a real ear measuring technique. The application of these rules resulted in improved high frequency gain and better speech discrimination for consonant in noise.

Mathur (2008) evaluated the efficacy of NAL-NL1 with which it prescribes the hearing aid parameters for persons with varying types and degrees of hearing loss. The study also aimed at finding out the changes observed in the preferred amplification parameters by the hearing aid users after the first 6 to 8 weeks of hearing aid fitment, and how much they deviate from the target curve prescribed by NAL-NL1. The findings

proved that ‘fine tune program’ of the hearing aid provided better results when compared to NAL-NL1. Re-programming according to individual’s listening needs can enhance the benefit that one obtains from the hearing aid. Hence, follow-up for fine tuning of hearing aid should be considered as an integral part of hearing aid prescription procedure for greater user satisfaction and continued hearing aid use.

Hawkins, Morrison, Halligan, and Cooper (1989) reported that performance of the aid can be evaluated in terms of how well the hearing aid amplifies and packages the long-term average speech spectrum into the user’s residual dynamic range through insertion gain. The probe tube microphone approach, combined with careful setting of the real ear maximum output, provides the audiologist with a clear visualization of what the hearing aid is capable of acoustically providing the client.

Mueller (2001) reported that probe microphone measurements can be successfully used to verify the selection of digital hearing aids. Digital hearing aids have various features which need to be validated before fitting an individual. In his opinion, probe microphone measurements are reliable and valid tool for the verification of digital hearing aids.

Hellstrom and Axellson (1993) reported a good test-retest reliability of probe tube microphone measures. Hawkins, Montogomery, Prosek, and Walden (1987) reported that the reliability of insertion gain decreases as a function of frequency. However, in general, the reliability of insertion gain measurements is better than that reported for the functional gain measurements.

The use of REIG rather than the real ear aided gain (REAG) or real ear aided response (REAR) is the most popular method of verifying hearing aid performance today.

There is a gradual shift, however, towards greater use of the aided response in the fitting process. As prescriptive methods, probe microphone equipment and hearing aid selection procedures evolve in the next few years, it is probable that the REAR will surface as the method of choice for determination of the quality of the hearing aid fitting (Mueller, Hawkins, & Northern, 2001).

There are several clinical applications of the REARs documented by Mueller, Hawkins, and Northern (2001) even for audiologist who solely rely on the insertion gain measures. It is sometimes useful to display family of curves obtained at different input levels. This is especially useful if inter-modulation distortion is suspected. The REAR is usually preferred over insertion gain when measuring certain special hearing aid features, such as directional microphones, compression or signal processing circuitry. On such occasions, the REAR is useful in trouble shooting user complaints about the hearing aid performance. Sharp peaks in the frequency response, which might cause incipient feedback or unpleasant sound quality, are identified more readily in the REAR than in the insertion gain measures. An important use of REAR is to measure the maximum output of the hearing aid in the real ear, when it is in saturation.

Also, unusual shapes and sizes of the ear canal may especially result in large discrepancies between the target and measured REIG values (Sanborn, 1998). It is debatable whether attention should be focused on achieving the correct REIG. Most prescriptive fitting procedures have as their goal for a given hearing loss a specific target spectrum for speech, as measured at the ear drum and characterized by the REAR measured with speech-shaped noise or real speech (Aazh & Moore, 2007). Moore, Glasberg, and Stone (1999) stated that “to get the appropriate gains for a specific

individual ear, it is preferable to perform real ear measurements using a probe microphone system and to express the target gains as gains at the eardrum". In other words, the REAR is more relevant than the REIG. The REMs are needed to achieve the appropriate REAR values.

Aarts and Caffee (2005) examined how well one manufacturer's software was able to predict REARs for a DSP behind-the ear product in 41 adults (N = 79 ears). The results showed that for all ears tested, the measured REAR values were significantly different from the predicted values for most of the audiometric frequencies, for all the test conditions. The discrepancies between predicted and measured REAR values suggest that reliance on manufacturer estimated REAR values is clinically inappropriate. These results were consistent with recommendations appearing in the literature that audiologists use evidence-based 'best practices' (including real-ear measures) when verifying hearing aid fittings rather than rely on manufacturer software predictions (Hawkins & Cook, 2003; Mueller, 2003; Van Vliet, 2006).

Keidser, Convery, and Dillon (2002) investigated if clients preferred less overall gain than prescribed by NAL-NL1 when wearing a commercial device in their everyday environment. All the clients were fitted according to NAL-NL1 formula. 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 65 dB speech shaped noise as input.

On an average, the clients preferred 0.70 dB, 0.53 dB and 1.54 dB less gain than prescribed overall, in the low frequency and in the high frequency respectively. The data suggested that a few subjects preferred substantially more high frequency gain than that

prescribed by NAL-NL1. Overall, these data do not support the claim that NAL-NL1 prescribes too much overall gain for a 65 dBSPL input.

Groth (2001) reported that non-speech signals will tend to underestimate gain for real speech when hearing aids are operating in a non-linear fashion, with the greatest discrepancies occurring for the swept pure tones. Hence, the real ear measurements must be carried out using a broad-band signal in order to achieve appropriate values of real ear amplification.

Preves, Beck, Burnett, and Teder (1989) found lower output levels with swept pure tones than with broadband noise. They asserted that frequency response curves obtained using broadband noise inputs would be more representative of how "real world" sounds are processed by the hearing aid.

Stelmachowicz, Kopun, Mace, and Lewis (1996) used hearing aid gain for continuous discourse as the basis for comparison with different input signal types. Like Preves and his colleagues (1989), they found lower hearing aid gain for swept pure tones than for broadband signals, particularly when the hearing aids were set to provide non-linear amplification. Compared to hearing aid gain for real speech, the gain observed for swept pure tones varied by up to 14 dB.

Thus, real ear measurements are powerful tools of hearing aid selection and it helps in ferreting out the problems in responses obtained by the hearing aid devices to determine malfunction or inappropriateness of the hearing aid selected to meet the acoustic needs.

2.1.3. Types of input signal for Traditional Real Ear Measurements

The type of input signal used also is an important consideration in real ear measurements. At one time, it was common to use swept tones for probe microphone assessment. But today, because nearly all products use multiple channels, compression, digital noise reduction (DNR), and other overlapping algorithms, broad-band input signals are preferred (Mueller, 2005). Many of these signals have been designed to have modulations similar to speech, so that testing can be conducted with DNR active. Of late, most equipment have facility for using real speech as an input signal.

Testing non-linear, adaptive hearing aids can be challenging because the measured response varies greatly depending on the test signals selected. In addition, a spectrum analysis mode on the hearing aid analyzer allows the tester to use any type of input signal, such as music or white noise, to determine how the hearing aid circuit classifies and processes each one. It has been shown experimentally that modern noise reduction algorithms generally identify speech correctly and pass those signals without attenuation; however, the non-speech sounds such as white noise and sometimes music are attenuated to varying degrees depending on design philosophy. For example, some hearing aid algorithms attenuate music by as much as 20 dB, whereas, others do not attenuate it at all (Bentler & Chiou, 2006).

Scollie and Seewald (2002), Henning and Bentler (2005) and others have shown that because of the interactions with compression and multiple channels, hearing aid output can vary significantly based on the input signal used. This of course would then influence the verification process and tweaking of the hearing aid at the time of the fitting. In addition to the spectral content, the shape of the available broad-band signals

also may be quite different, which again easily could influence the match to target. Care should be taken to use an input signal that is broad-band, but that also is most similar to the signal that was used to develop the prescriptive method that is being verified. The availability of real speech and speech-like signals improves the reliability of the measurements of multi-channel digital devices (Henning & Bentler, 2005).

Recent evidence points to a resurgence in real ear measurements (REMs) as the premier verification tool in the hearing instrument fitting process. Real-ear probe-microphone measures are important because they represent the only objective analysis of sound between the hearing aid and the tympanic membrane.

However, Mueller (2005) reported that only about 1 in 3 hearing care professionals regularly obtained real-ear measures. Additionally, Strom (2006) reported that, although 57% of hearing care offices have real-ear equipment, REM tests on adults are routinely performed only 23% of the time.

The study by Van Vliet (2006) indicated that, although 67% of all dispensing offices report having REM testing equipment, only 26% routinely performed REMs during hearing instrument fittings. Similarly, Hearing Journal/AO survey reported that 21.5% of practices “always or nearly always” conduct real-ear probe-mic measurements, while another 12.2% say they conduct the test “most of the time” (Margolis, 2004). This suggests that, although there is ample evidence that clinicians should be performing REM on all their patients, the test is not universally viewed as a vital part of the verification / fitting process, or is not being conducted due to time constraints and/or the amount of

information that can be drawn from the test results. Therefore, it can be argued that traditional REMs are used only in a minority of hearing aid fittings.

Traditional REMs have not gained widespread clinical acceptance. Although the exact reasons are not clear, perhaps dispensing professionals' resistance to conducting real-ear measurements is partially based on the lack of a clear and consistent relationship between REMs and successful hearing aid fitting outcomes. Perhaps another reason is the lack of an appreciable increase in patient understanding or comprehension of aided benefit and a third reason has been the sometimes confusing multiplicity of acronyms related to "REM" such as REIG, REAR, REIR, and RESR.

2.2. Visible Speech Measurement

2.2.1. Introduction

The primary reason for individual's purchase of hearing aids is to hear and understand speech. Thus, speech signals always have been a logical input signal to use for real ear measurement verification (Ross & Smith, 2005). Clinicians have always been interested in verifying their hearing instrument fittings, and most were trained in the use of Real-Ear Measurement (REM), sound field assessment, electroacoustic analysis, various types of speech-based tests, and "diary-type" assessment tools (Ross & Smith, 2005).

Ironically, over recent years, researchers have attempted to provide hearing care professionals with electronic "speech-like" signals designed to simulate actual speech, with all of its fluctuating amplitudes and changing spectral characteristics, as a target

signal for real ear measurements (Mueller, 2006). It seems apparent that utilizing a real speech signal, as it occurs in real life could add benefit when making program changes to improve hearing ability through amplification. Since speech is so dynamic, and the residual hearing range of an individual with hearing impairment is so reduced, it is important that as many frequencies as possible in the appropriate range of human speech can reach audibility without "over-driving" the ear.

All of the traditional real ear measurement procedures were appropriate for use with traditional analog technology. While meaningful to the clinician, most of these tests ultimately had little impact on the patient's acceptance or use of amplification, and the "targets" defined in REMs were often not acceptable to the patient (Moore, 2006). Additionally, these procedures were time consuming and, if one considers the real return-for-credit rate in the hearing industry, may have had limited impact on the quality of treatment (Ruskin, 2008).

Acceptance and understanding of amplification by clients can be elusive. These remain among the biggest challenges that the professionals face when recommending amplification. Clearly, one of the fundamental communication needs of the individuals with hearing impairment is to hear and understand human speech. Recent innovations in technology now provide professionals with a patient-centric system that fully engages both the patient and third parties in the counselling and the fitting process. One such innovation is Visible Speech (VS).

'Visible Speech' synonymously known as 'Live Speech Mapping' is a fitting process that uses probe microphones and real-time speech to allow the patient and their

family members to immediately see and understand the benefits of hearing aids and fitting adjustments (Beck & Duffy, 2007)**.** Visible speech (VS) utilizes "live/recorded real-time speech" that of a family member, friend, or familiar third party for real-ear measurements in contrast to electronic speech-like stimuli (Ross & Smith, 2005). Visible Speech allows the professional to record and demonstrate the appropriateness of the hearing aid fitting while reviewing, demonstrating and explaining the process in terms the patient understands-based on human speech and the Speech Intelligibility Index.

2.2.2. Visible Speech: Essential Concepts

Beck and Duffy (2007) reported that the VS concept is simple and is based on three straight-forward concepts:

1) Speech is the single most important sound we listen to. For hearing aid fittings to be successful, speech must be appropriately amplified with respect to loudness, clarity, and comfort. Soft speech should be perceived as soft, medium speech sounds should be perceived as medium, and loud speech sounds should not exceed the patient's loudness discomfort levels despite reduced dynamic ranges for people with sensorineural hearing loss (Schum & Beck, 2005).

2) It is difficult for patients to relate their hearing loss to their audiogram. Pure-tones, decibels, and Hertz are difficult concepts for the average person. Although the audiogram is the common currency of hearing loss among dispensing professionals, it is considerably less meaningful and more difficult to understand for the patient.

3) Visual images facilitate counseling. Representing the patient's ability to perceive human speech in aided and unaided conditions provides a powerful message which is easily recalled by the patient.

According to Beck and Duffy (2007), Visible Speech (VS) is built on a logical, scientific foundation, and offers many of the benefits of traditional REM. However, information obtained and displayed based on visible speech stimuli is more intuitive and pragmatic because:

1) VS is based on human speech. It is more engaging and meaningful to the patient than pure-tones, warble-tones, or other artificial sound stimuli.

2) VS represents a tool for explaining hearing loss to patients. It provides the dispensing professional, patient, and significant other(s) an excellent counseling and aural rehabilitation tool which simultaneously measures, verifies, and demonstrates aided benefit, based on human speech.

3) VS is intuitive for patients. It presents information in an easy-to-understand model based on the speech intelligibility index, allowing greater understanding and retention of the information via a multimedia presentation.

2.2.3. Visible Speech Stimuli

The acoustic stimulus for VS recordings is human speech. Speech can be generated using a live microphone input from the patient, their significant other, the audiologist, or speech samples can be digitally imported from other sources into the VS

software. Digitized speech samples are available within the pre-packaged software, including adult-male and adult-female speech samples. To acquire VS measures and recordings, the in-situ headset has a probe microphone assembly which allows VS recordings.

2.2.4. Speech spectrum analysis and the Speech Intelligibility Index (SII)

The concept of presenting a "picture of spoken words" is not new to audiology, nor is the idea of "picturing" aided versus unaided speech. There have been many useful and creative speech intelligibility, audibility, and articulation index formulae.

Mueller and Killion (1990) noted calculations of the articulation index (AI) have been used for more than 55 years. The AI is basically a percentage of speech audible to a given patient based on their hearing thresholds. AI is a simple, easy-to-understand representation of "heard" compared to "not heard" speech sounds. Of course, the fact that a sound is heard does not mean the sound was perceived or is useful to the patient. However, in general, AI is an excellent teaching and counseling tool. The general concept of the AI is carried forward in the Visible Speech module via the Speech Intelligibility Index.

The SII within the module has been calculated in accordance with the ANSI S3.5-1997 standard, presuming: 1) There is no external noise signal; 2) there is no self-speech masking, and 3) the speech signal corresponds to the standardized speech spectrum level for normal vocal effort. Within the Visible Speech module, unaided thresholds and UCL measures are shown on the VS-audiogram in dB SPL as measured at the eardrum. The

data are presented at one-third octave center frequencies from 125 Hz to 8,000 Hz with consideration for the speech signal, a masking noise, and the hearing loss parameters.

2.2.5. Target Speech Spectrum

The target speech spectrum for non-linear hearing aids is difficult to estimate and depends on many factors (e.g. number of compression channels, bandwidth of compression channels, non-linear gain characteristics, time constants, fitting rationale, etc). A "target" speech spectrum is calculated as the standard speech spectrum amplified in accordance with a well-known linear fitting rationale (NAL) (Beck & Duffy, 2007). Theoretically, if the patient were to perceive all the sounds within the target range, they would obtain the best possible SII score, presumably similar to their word recognition score at MCL.

2.2.6. Why Visible Speech as a 'Verification' tool?

Margolis (2004) determined that one-half of all information transmitted from professionals to patients is retained, and perhaps as much as two-thirds are instantly forgotten. He suggested that, to increase the patient's retention and recall, visual materials (photographs, charts, illustrations) should be offered as demonstration tools and given to the patient as take-home items.

Beck and McGuire (2006) noted a reasonably high probability that the spoken message from professional to patient is often not perceived correctly. They reported that using high quality, easy-to-use and easy-to-understand multimedia tools increases the

probability of the correct transfer of information. Visual images are powerful, emotional, and they initiate additional cognitive processes.

Beck and McGuire (2006) suggested that combined auditory and visual presentations are synergistic and provide the most powerful transmission and retention of information. It seems reasonable that a patient-based multimedia presentation, which is based on live, recorded, or familiar speech, would help to educate and counsel patients regarding their hearing, hearing loss, and hearing aids. Thereby, it would likely facilitate more significant information transfer and retention than traditional clinical tools.

One of the primary advantages of using visible speech as part of a clinical protocol is that it can be used to involve the patient directly in the fitting, adjustment, and purchase process (Crumley, 2007). New patients who already wear amplification can have an accurate look at what their hearing aid is or is not doing for them. The clinician can display graphics on the performance of the patient's aid, presenting a professional image and reinforcing their recommendations for further or alternative treatment. For patients buying new hearing instruments, visible speech allows the patient and family to visualize the results of the hearing aid fitting. In short, visible speech provides visible reinforcement of auditory results, yielding greater patient confidence in the clinician and their prescribed treatment.

The introduction and development of digital technology has created a demand for a newer type of verification process that is meaningful to both the clinician and the patient. Visible speech should be considered a fitting process since it is much more than a

simple test. According to Poe and Ross (2005), the criterion upon which this technology is based on is as follows:

1. The protocol is easy to use.
2. It requires limited time to administer and interpret.
3. It is capable of measuring and displaying any type of auditory stimulus (i.e. live speech, recorded sounds, music, etc) in real time.
4. It is capable of measuring any type of hearing instrument without turning off any features.
5. It is capable of providing interaction between the patient and the displayed results.

One key difference between this technology and other verification tools is that it allows the patient and family to clearly understand the results and realize an immediate and positive impact on their hearing as the programming of their hearing aid is changed.

Chapter 3

METHOD

The present study evaluated the verification of the hearing aid selection by comparing the use of visible speech with speech identification scores, real ear aided gain for ANSI-digi speech signal and speech intelligibility index (SII).

Participants

30 individuals with hearing loss in the age range from 18 years to 75 years (mean age of 52.6 years).

Inclusion Criteria:

a. Hearing loss of post-lingual onset.

b. Flat sensori-neural type of hearing loss with pure-tone average (PTA) ranging from 41 to 90 dB HL. In the present study, flat type of configuration was operationally defined as the configuration in which the maximum threshold difference between any of the frequencies on the audiogram being not more than 20 dB HL (Pittman & Stelmachowicz, 2003).

c. The participants were divided into three groups based on their degree of hearing loss, as given in Table 3.1.

Table 3.1: Criteria based on pure-tone average for Groups 1, 2 and 3.

Groups	*Criteria*
1. Group 1 (N = 10)	Participants with pure-tone average between 41 and 55 dB HL.
2. Group 2 (N = 10)	Participants with pure-tone average between 56 and 70 dB HL.
3. Group 3 (N = 10)	Participants with pure-tone average between 71 and 90 dB HL.

d. Speech identification scores of ≥70%.

e. No indication of middle ear pathology as shown by tymapanometry.

f. Native speakers of Kannada and had adequate speech-language skills.

g. Naive hearing aid users.

Exclusion criteria:

1. Indication of retro-cochlear involvement or central auditory processing disorder.
2. Indication of associated problems like cognitive deficits.

Instrumentation

1. A calibrated sound field audiometer. The loudspeakers of the audiometer were located at 45 degrees Azimuth on either side of the participant at a distance of 1 meter.
2. Two commercially available digital BTE hearing aids. The hearing aids were fully digital hearing aids with a fitting range for moderate to severe degree of hearing loss. Hearing aids 1 and 2 had two and six channels respectively. Stock earmolds were used to couple the hearing aid to each participant.
3. Two personal computers, one connected to the auxiliary input of the audiometer for presentation of speech material which was recorded on a CD. The other

personal computer, with NOAH (version 3.1.2) and hearing aid specific softwares connected to the HI-PRO, was used to programme the digital hearing aids. In addition, this latter personal computer with WinCHAP software was used to perform the real ear measurements in all the participants.

4. A calibrated Fonix 7000 hearing aid testing system for performing the real ear measurements through WinCHAP. The personal computer (PC) with WinCHAP software was connected to Fonix 7000 hearing aid testing system through auxiliary input of PC. WinCHAP can be used to select various signals at different intensities for carrying out traditional real ear measurements. It can also be used to save the data of the participants.

Test Material

a. The phonemically balanced (PB) word lists in Kannada developed by Yathiraj and Vijayalakshmi (2005) was used in the study. The speech material consisted of four phonemically balanced word lists and each list had 25 words. The speech material was digitally recorded using Adobe Audition - 2 software in an acoustically treated room, on a data acquisition system using 44.1 kHz sampling frequency and 16 bit analog to digital converter. The word lists were spoken with normal vocal effort by a native female speaker of Kannada. The word list was presented to ten individuals with normal hearing to check the intelligibility of recorded test material. The participants were instructed to write down responses on a sheet of paper. The words which were incorrectly identified by individuals with normal hearing were re-recorded again using the same method as mentioned above.

b. A standardized Kannada story (Sairam, 2002) with all the speech sounds of the language was used as the stimulus for the measurement of visible speech and speech intelligibility index. The standardized Kannada story was digitally recorded in the same manner as that of word lists.

Test Environment

The testing was carried out in an air-conditioned single or double room sound treated environment.

Procedure

The experiment was carried out in the three stages for each of the two hearing aids, for each participant.

Stage 1. Hearing aid programming to first fit for NAL-NL1

Stage 2. Optimization of hearing aid using

2.1. Traditional real ear measurement protocol

2.2. Visible speech protocol

Stage 3. Verification using speech identification scores

3.1. Speech identification scores: Hearing aid optimized for traditional real ear measurement protocol

3.2. Speech identification scores: Hearing aid optimized for visible speech protocol

Stage 1: Hearing Aid Programming to First Fit for NAL-NL1

The participant was fitted with programmable digital behind-the-ear (BTE) hearing aid. The hearing aid was connected to a personal computer through a HI-PRO interface unit. The NOAH software (version 3.1.2) along with hearing aid specific software (Electone connexx V6.1 & Aventa 2.6) were used to programme the hearing aid being worn by the participant. Initially, the hearing aid was programmed with NAL-NL1 using the first fit feature in the software. It should be noted that the fine-tuning of the hearing aid was not attempted at this stage.

Stage 2: Optimization of hearing aid

Hearing aid was optimized using the traditional real ear measurement protocol and the visible speech protocol.

2.1. Optimization of hearing aid using traditional real ear measurement protocol

In this particular stage, the hearing aid was optimized for NAL-NL1 targets using traditional real ear measurement protocol which utilizes ANSI-digi speech like stimulus as the input signal. The personal computer which was used for programming the hearing aid had the Win CHAP software installed in it. Step-wise procedure was carried out for real ear measurements through Fonix 7000.

1) The Fonix 7000 instrument was ‘switched’ on.

2) Levelling of the instrument was ensured before carrying out the real ear measurements.

3) The real ear navigation was accessed by pressing the F2 button of Fonix 7000; later F3 button was selected to enter into the insertion gain measurement function.

4) Placement of sound field speaker for REM: The sound field speaker was placed 12 inches from the participant's head. This sound field speaker was at an Azimuth angle of 45 ° (half-way between the participant's nose and ear) as shown in the Figure 3.1.

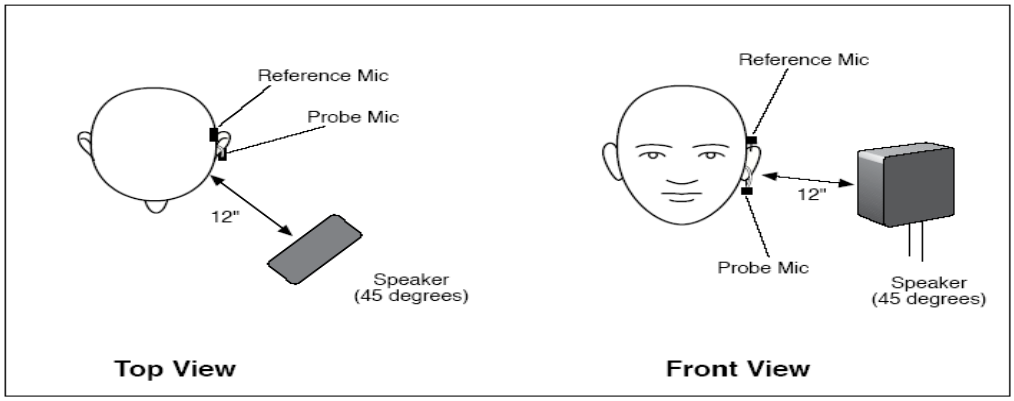

Fig. 3.1: Position of the participant and the loud speaker for real ear measurements

5) Marking the probe tube for real ear measurements.

- An unattached probe tube was placed on a flat surface along with the earmold.
- The earmold was held next to the probe tube, so that the tube rested along the bottom of the canal part of the earmold, with the tube extending at least 5 mm past the canal opening. This was done as shown in the Figure 3.2.
- The probe tube was marked where it met the outside surface of the earmold with a marking pen.
- The probe tube was attached to the body of the probe microphone.
- The probe tube was inserted into the participant's ear (without the earmold or aid) so that the mark was at the location where the bottom of the outer

surface of the ear mold was, once the ear mold was in place.

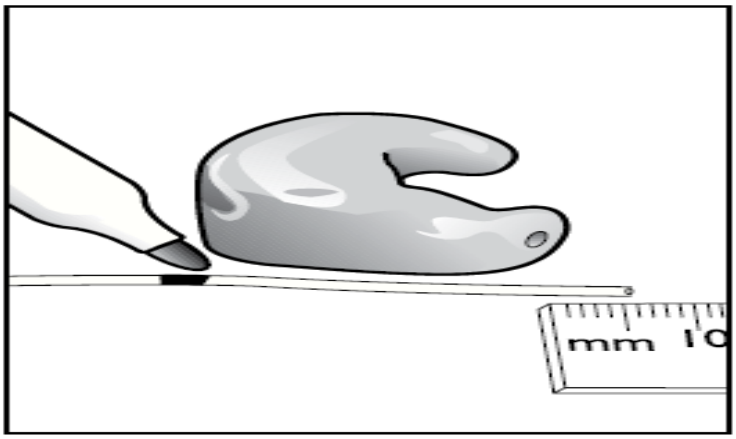

Fig. 3.2: Illustration of the measurement of probe tube length for REUG and REAG

6) Placement of ear hook, reference microphone, and probe microphone:

- The integrated probe microphone set was positioned on the participant's ear.
- The small reference microphone was secured on the ear hook above the ear.
- The ear hook slider was adjusted up or down for optional positioning of the probe tube into the ear as shown in Figure 3.3.

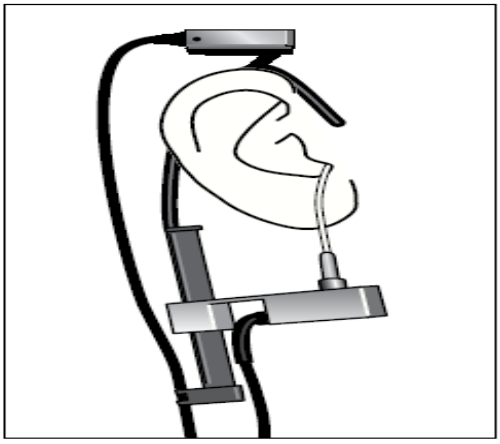

Fig. 3.3: Placement of reference microphone and probe microphone

After setting up the participant for real ear measurements, WinCHAP software was selected. This software enabled storing the participant's data as well as hearing aid data. This software also enabled storing the important measurements made with Fonix 7000 analyzer, eliminating the need for paper or pen. The following steps were followed:

a) After enabling WinCHAP measurement in the personal computer, the 'Data entry' icon was selected.
b) By clicking on 'Client's icon', the details of the client were stored.
c) The 'Hearing aid icon' was selected to store the details of the hearing aid used for testing.
d) Then from the WinCHAP main menu, 'Test menu' for a specific participant was accessed. After accessing the 'Test menu', specific participant's file was chosen.
e) In the 'Client's test' menu, the details of the audiogram (air conduction, bone conduction thresholds) were entered.
f) Then from the Win CHAP, DSL/NAL Test menu, 'NAL' testing was enabled.
g) From this screen, the NAL gain, Real ear and Real ear aided gain were selected.

h) On entering the NAL screen, the target gain for moderate levels was displayed at different frequencies from 125 Hz to 8000 Hz. This target gain curve was based on the NAL-NL1 prescriptive rule for the participant's hearing loss. It should be noted that the target gain curve was for the real ear aided gain measurement.

2.1.1 Measurement of Real Ear Unaided Gain (REUG)

Once the equipment was set-up, the traditional real ear measurement was carried out using Fonix 7000 and WinChap. The unaided measurement was carried out by selecting 'Unaided' from 'Real Ear Aided Gain' sub-menu. The unaided measurement for ANSI digi speech signal at 65 dB SPL was carried out.

Table 3.2: Protocol for REUG and REAG

Type of Stimulus:	Digi-Speech, ANSI
Level of stimulus :	65 dB SPL
Location of integrated probe microphone set :	Participant's pinna
Reference microphone :	Enabled, located over pinna
Prescriptive formula:	NAL-NL1
Output limiting:	125 dB SPL

The 65 dBSPL ANSI-digi speech signal that was presented through the loudspeaker of Fonix 7000 was picked up by the probe tube mic in the unaided ear canal. The Fonix 7000 measured this signal in the unoccluded ear canal. Data were tabulated

from ‘View curve data menu’. For the purpose of analysis, the following data was tabulated for each participant:

a. RMS REUG amplitude of signal in ear canal, in dB SPL

b. Amplitude level of REUG at 500 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz, in dB SPL

2.1.2. Measurement of Real Ear Aided Gain (REAG):

The hearing aid was fitted on the participant without disturbing the length of probe tube in the ear canal. The hearing aid was switched on. It was ensured that the earmold fitting was good and there was no feedback.

Protocol for REAG:

The same protocol as shown in Table 3.2 was followed for REAG measurement. The probe tube microphone in the aided ear canal picked up the sound from the ear canal for REAG measurement. During the measurement, it was ensured that the REAG matched the NAL-NL1 targets at most of the frequencies. This was done by optimizing the hearing aid parameters to meet NAL-NL1 the target at moderate level input. At the end of this stage, the following REAG data were tabulated for each participant for the purpose of analysis.

a. RMS amplitude of REAG in ear canal, in dB SPL

b. Amplitude level of the response at 500 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz

2.2. Optimization of Hearing Aid using Visible Speech Protocol

In this particular stage, the hearing aid was optimized for NAL-NL1 targets using visible speech protocol which utilizes actual speech as the input signal.

2.2.1. Visible Speech Screen

The Visible Speech feature is a special feature used for performing real-ear measurements with live/recorded speech or any other external source types. Visible Speech was designed to demonstrate the real-time response of the hearing aid to the speech signal. With this the average response of the aid over the time of the test and the minimum and maximum amplitudes of each frequency could be recorded.

On entering the Visible Speech screen (Figure 3.4), the following information is displayed:

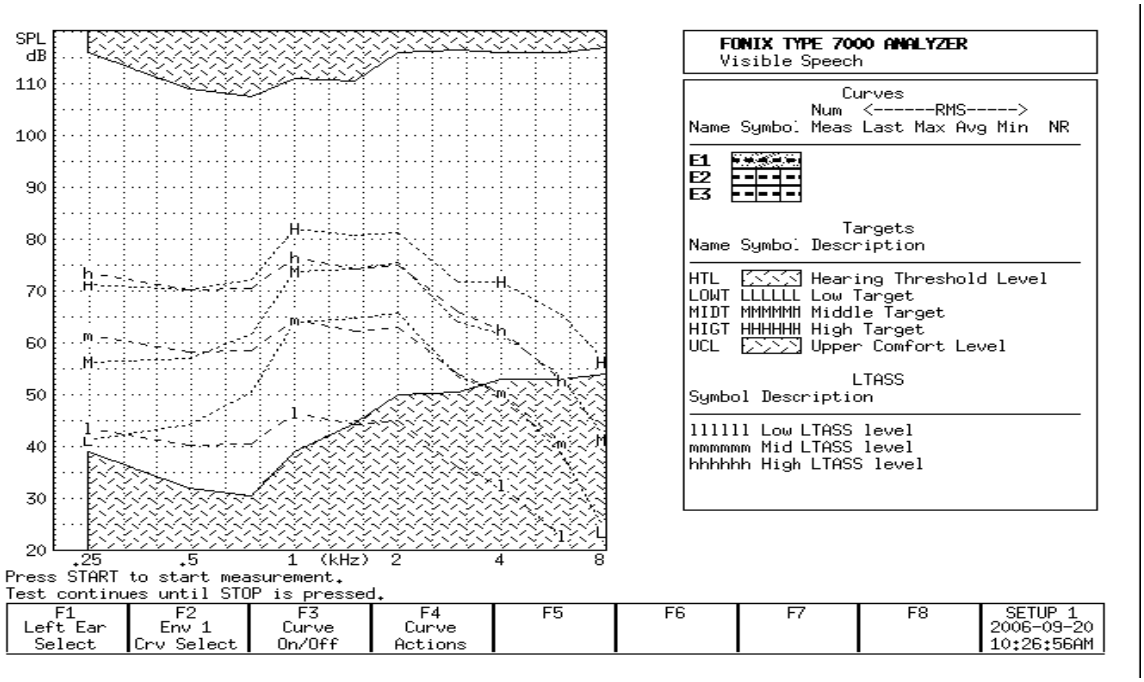

Fig. 3.4: Visible Speech screen before a measurement is taken. The shaded regions are below and above the participant's thresholds and uncomfortable levels. The L, M, and H lines represent the real-ear targets at 50, 65, and 80 dB SPL.

a. Shaded areas below and above represent the participant's threshold and uncomfortable values respectively. The non-shaded area in the centre of the graph represents that participant's dynamic range of hearing.

b. L, M, H dotted lines indicating the NAL-NL1 prescriptive targets at 50, 65, and 80 dB SPL.

c. l, m, h dotted lines indicating the region of average unamplified speech. These lines are called collectively the LTASS (long term average speech spectrum). They can be used as a comparison against the amplified speech response.

The above parameters were incorporated for the following purposes:

a. Participant's threshold – to check if the speech levels are above threshold.

b. Uncomfortable loudness levels – to check if the speech levels are below this.

c. Real ear NAL-NL1 targets – to check if the speech levels matched the required target.

2.2.2. Participant preparations

The testing was carried out in a double room situation. The participant was seated in the test room and the clinician operated the presentation of speech material through personal computer in the control room. The participants were seated in the calibrated position in the sound field with speech material (Standardised Kannada passage) being presented through the loud speaker of the audiometer positioned at 45^0 Azimuth and at a distance of 1 meter. Levelling of the Fonix 7000 hearing aid testing system was not

required for the measurement of visible speech as the signal was not presented through the Fonix 7000 loudspeaker.

To ensure the proper insertion of probe tube, the probe tube was placed in ear canal, so that the tube rested along the bottom of canal with tube extending atleast 5 mm past the canal opening. The hearing aid was fitted on the participant without disturbing the location of probe tube in the ear canal. The hearing aid was switched 'on'. It was again ensured that there was no feedback during the measurement.

The recorded Kannada passage was played through windows media player in personal computer and was routed through auxiliary input of the audiometer to the loudspeaker. The VU meter deviation was monitored to ensure that it did not exceed an average deflection of 0 dB on the scale.

2.2.3. Protocol for visible speech and SII:

The Table 3.3 shows the parameters settings for the measurement of visible speech and SII.

Table 3.3: Protocol for visible speech and SII

Type of Stimulus:	Recorded paragraph in Kannada
Level of stimulus:	65 dB SPL
Location of integrated probe microphone set:	Participant's pinna
Reference microphone:	Enabled, over the pinna
Prescriptive formula:	NAL-NL1
Output limiting:	125 dB SPL

2.2.4. Performing Visible Speech Measurements

1. The participant's audiogram was entered into the analyzer on selecting 'audiogram' displayed on the main menu. Both the air conduction and bone conduction thresholds were entered to generate the real ear target based on NAL-NL1 rule.
2. Once the audiogram was entered, real-ear measurement was accessed.
3. The Visible Speech screen was later selected.
4. The external signal, a Kannada story passage was played through windows media player in the computer. This was routed through an audiometer. The output from audiometer was given to the loudspeaker. This signal was picked up by the hearing aid worn by the participant.
5. The Visible Speech measurement on the Fonix 7000 analyzer was initiated.

2.2.5. Viewing the Real-time Visible Speech Display

The VS measurement provided both the real-time response of the hearing aid and information about its response over the time of the test. The visible speech measurement was stopped when the average response curve was stabilized which took 60 seconds of time. On completion of the visible speech measurement, the following curves were displayed on the visible speech screen as shown in Figure 3.5

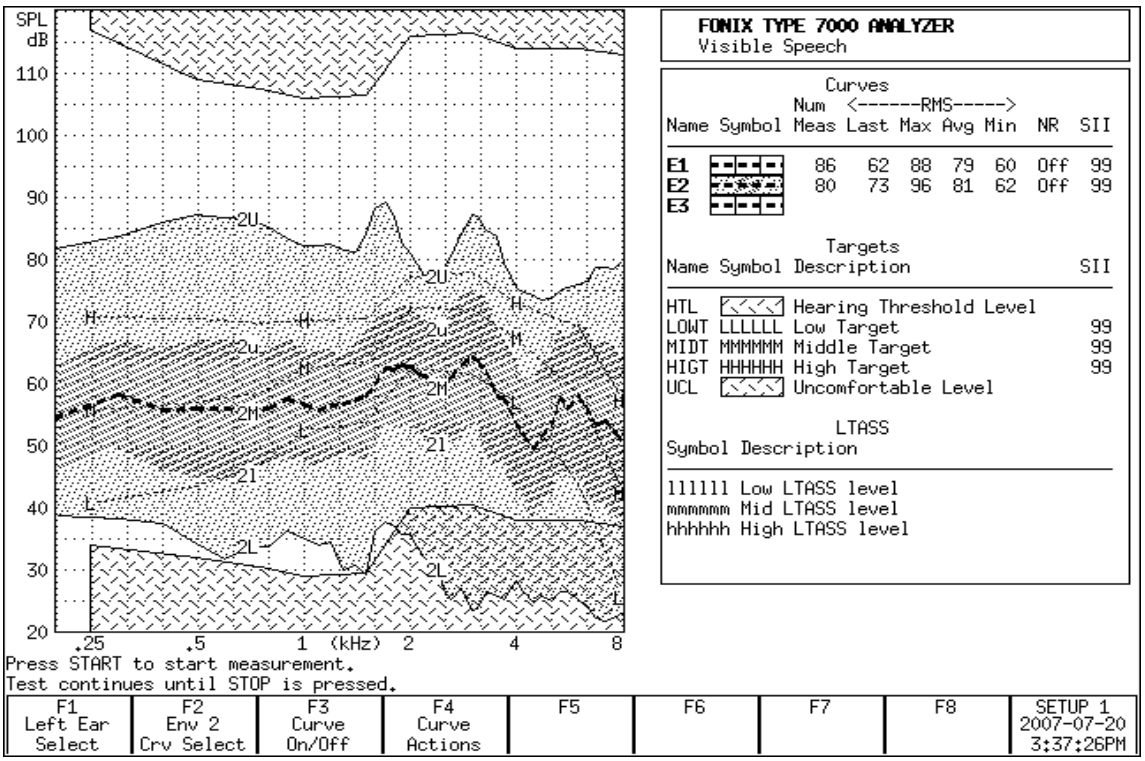

Fig. 3.5: Displayed curves on the completion of the visible speech measurement.

1. 2U - Represents the maximum response per frequency over the time of the test.
2. 2u - Represents the upper boundary of the standard deviation around the average frequency response.
3. 2M - Represents the average frequency response of the test.
4. 2l - Represents the lower boundary of the standard deviation around the average frequency response.
5. 2L - Represents the minimum response per frequency over the time of the test.

If the output of the hearing aid did not match the desired target level, then the hearing aid was further optimized. The hearing aid was optimized to match the visible speech targets based on the visible speech procedure. Once the hearing aid output

matched the real ear NAL-NL1 targets at most of the frequencies then the following data were tabulated for each participant for the purpose of analysis.

1. RMS amplitude of the response of visible speech spectrum, in dB SPL.
2. Response amplitude of visible speech spectrum at 250 Hz, 500 Hz, 750 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz and 4 kHz, in dB SPL.
3. Speech Intelligibility Index, SII (re: ANSI S3.5 - 1997).

Stage 3: Verification of Hearing Aid using Speech Identification Scores

Speech identification scores were obtained with the hearing aid being optimized with traditional REAG with ANSI-digi speech as well as with visible speech measure.

3.1. Speech identification scores: Hearing aid optimized using traditional real ear measurement protocol

Speech identification scores (SIS) were obtained in aided conditions when hearing aid was optimized using traditional real ear measurement protocol. The aided speech identification scores were obtained once the hearing aid real ear aided gain matched the NAL-NL1 targets, using traditional real ear measurement protocol.

3.1.1. Participant preparation

The testing was carried out in a double room sound treated suite. The participant was comfortably seated in the test room at a distance of 1 meter and 45^0 Azimuth from

the loudspeaker of the audiometer on the side of the aided ear. The tester controlled the presentation of speech material from the control room.

3.1.2. Procedure

The recorded word list was played through windows media player in a personal computer and was routed through auxiliary input of the audiometer in the control room to the loudspeaker of the audiometer in the test room. The VU meter deflection was monitored using calibration tone to ensure that it did not exceed an average deflection of 0 on the scale. The presentation level was kept constant at 45 dB HL as this level corresponded to average speech levels from a distance of 1 meter during conversation. Further, it was ensured that this level was within the uncomfortable loudness level of the participants. The participant was instructed to repeat the words being presented through the loudspeaker. The responses were scored on a response sheet as the number of words correctly identified. The maximum score was 25 as each list consisted of 25 words. Each correct response was given a score of 1 and each incorrect response was given a score of 0.

The steps 3.1.1. and 3.1.2. were repeated for all the participants and the SIS in the aided condition was tabulated for each participant for further analysis.

3.2. Speech identification scores: Hearing aid optimized using visible speech protocol

Speech identification scores were obtained in aided condition when hearing aid was optimized using visible speech protocol. The aided speech identification scores were obtained once the hearing aid output matched NAL-NL1 targets using speech as the input

signal. The same procedure as described in 3.1.1. and 3.1.2. was followed to obtain SIS in this stage.

All the three major stages described above were followed for another hearing aid (HA 2) also. Hence, the following data were tabulated, for two different hearing aids, for each participant.

Conditions	Frequencies								
	250 Hz	500 Hz	1 kHz	1.5 kHz	2 kHz	3 kHz	4 kHz	RMS amplitude	
Traditional REAG									SII
Visible Speech									

In addition, the speech identification scores (SIS) were tabulated for each participant, for each hearing aid (HA 1 and HA 2), in two conditions. The two conditions being hearing aid optimized using traditional REAG protocol and hearing aid optimized using Visible Speech protocol. These data were analyzed using appropriate statistics.

Chapter 4

RESULTS & DISCUSSION

The aim of the present study was to investigate the efficacy of visible speech measure and speech intelligibility index in verification of hearing aid fitting. To evaluate the objectives of the study, data were collected using both subjective tests and objective tests. These data were collected with the two different hearing aids (HA 1 & HA2) from the participants who were grouped into three major categories based on their degree of the hearing loss (groups with moderate HL, moderately-severe HL &severe HL).

The data from the subjective test included the unaided and aided speech identification scores. The data from the objective test included real ear measurements using WinChap software and Fonix 7000 hearing aid analyzer. The latter included the traditional real ear aided gain measurement with ANSI-digi speech signal, visible speech measurement and speech intelligibility index.

Statistical Package for Social Sciences, SPSS (version 16 for windows) was used for analyses of the data. To compare the REAG for ANSI-digi speech signal, visible speech measure, speech intelligibility index and speech identification scores, the correlation analysis was done both collectively on all the participants and independently on each group.

The results of the objective tests are discussed under the following headings:

4.1. Real Ear Aided Gain using ANSI-digi speech signal

4.2. Visible speech measures

4.3. Speech intelligibility index

The results of the subjective tests are discussed under the following headings:

4.4. Speech Identification Scores

4.5. Comparison of different test measures within each group between:

4.5.1. REAG and Visible speech at 250 Hz, 500 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz, 4 kHz.

4.5.1.1. Group with moderate hearing loss

4.5.1.2. Group with moderately severe hearing loss

4.5.1.3. Group with severe hearing loss

4.5.2. RMS amplitude of REAG and visible speech

4.5.3. Speech identification scores, Speech intelligibility index, RMS amplitude of visible speech.

4.1. Real Ear Aided Gain using ANSI-Digi Speech Signal

The mean and standard deviation (SD) of the REAG for ANSI-digi speech signal for the three groups of participants with two hearing aids (HA1 & HA2) is given in Table 4.1. It can be inferred from the Table 4.1 that the target gain as per NAL-NL1 is least in the group with moderate hearing loss (HL). As the hearing loss increased, target gain was increased and the group with severe HL showed highest target gain values. The measured real ear aided gain showed the similar trend as that of the target gain. The real ear aided gain was least in group with moderate HL and highest in the group with severe HL.

Table 4.1: Mean and Standard Deviation (SD) of target gain and REAG with two hearing aids, HA 1 & HA 2, for the three groups of participants

Freq. (Hz)	*HA*	*Groups based on severity of hearing loss*								
		Group I (N= 10)			*Group II (N= 10)*			*Group III (N= 10)*		
		Target Gain (dB)	*REAG (dB)*		*Target Gain (dB)*	*REAG (dB)*		*Target Gain (dB)*	*REAG (dB)*	
			Mean	*S.D.*		*Mean*	*S.D.*		*Mean*	*S.D.*
250	HA1	7.52	7.01	2.87	17.53	14.26	7.04	22.23	22.29	6.12
	HA2		6.85	3.51		12.72	3.99		17.63	3.67
500	HA1	15.06	17.34	3.09	23.54 23.54	23.55	5.31	32.71	34.64	3.18
	HA2		15.48	5.56		22.99	3.92		30.59	3.60
1000	HA1	27.97	31.24	3.05	37.30 37.30	37.47	4.25	45.31	47.71	3.39
	HA2		30.86	2.52		36.56	2.38		44.28	3.61
1500	HA1	33.27	36.26	2.70	44.07 44.07	44.49	3.45	51.13	53.42	3.01
	HA2		37.15	2.67		44.22	2.96		50.07	3.80
2000	HA1	38.5	39.65	3.01	50.25 50.25	48.76	4.10	56.36	57.49	3.45
	HA2		40.85	3.22		48.44	3.16		54.82	3.25
3000	HA1	37.56	36.89	2.40	45.11 45.11	44.24	3.92	52.50	52.42	2.80
	HA2		36.20	2.72		44.67	3.89		50.26	2.88
4000	HA1	36.04	35.62	3.19	41.21 41.21	39.48	5.42	48.39	46.47	4.77
	HA2		32.96	3.62		40.17	2.56		46.80	3.12

The mean target gain and REAG values for the group with moderate HL (Group I) is shown in the Figure. 4.1. It can be seen that the target gain and measured real ear aided gain was lower at low frequencies. That is, the mid and higher frequencies had higher gain values in both target and REAG than compared to the low frequencies. It can

also be observed that the measured REAG were matched to the target gain values at all the frequencies for both the hearing aids.

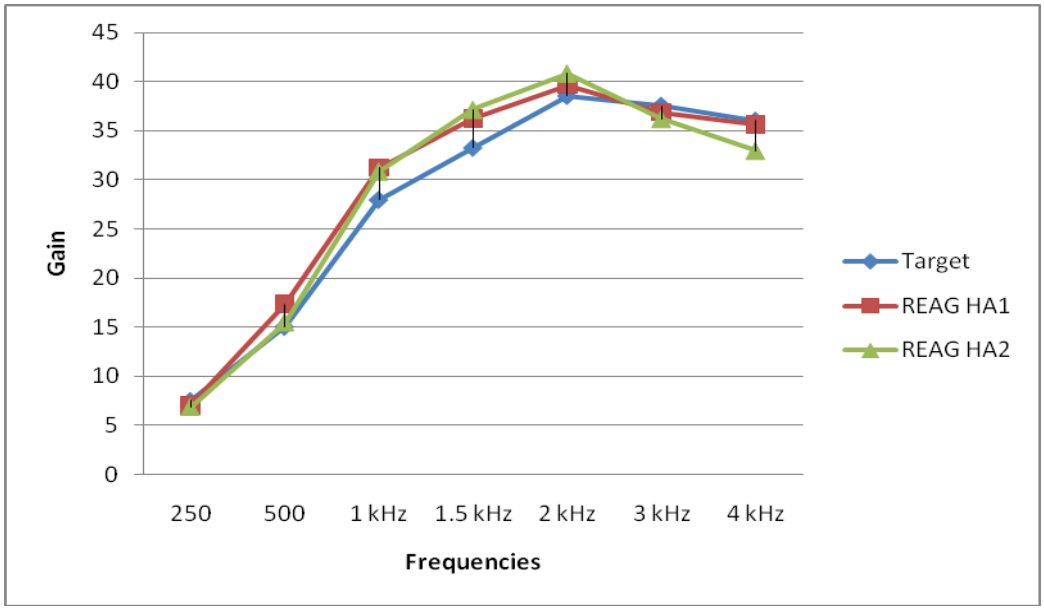

Fig 4.1: Mean target gain and REAG values for Group I.

The mean target gain and REAG values for the group with moderate-severe HL (Group II) are shown in the Figure. 4.2. Similar results as in Group I were obtained in Group II.

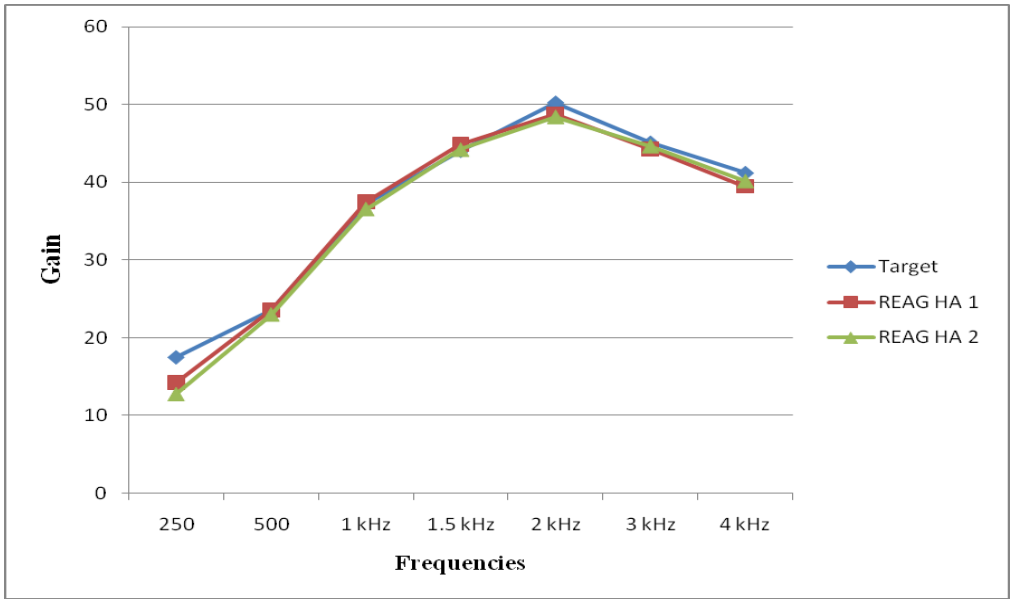

Fig 4.2: Mean target gain and mean REAG values for Group II.

The mean target gain and REAG values for the group with severe HL loss (Group III) are shown in the Figure. 4.3. Similar results as in Group I were obtained in this group also.

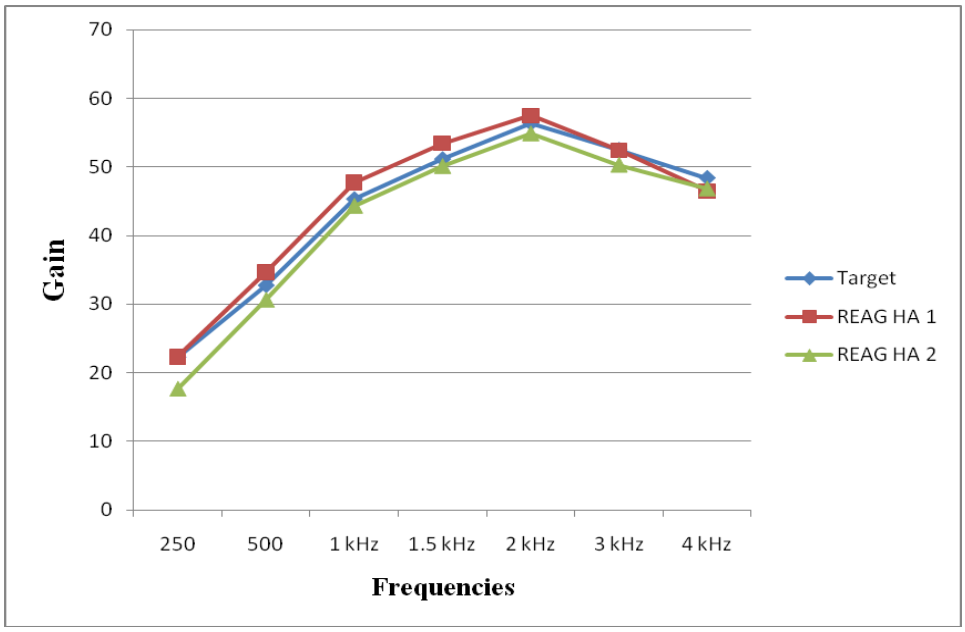

Fig 4.3: Mean target gain and mean REAG values for Group III.

Bryne and Dillon (1986) performed real ear measurements recommended by NAL fitting method. In their opinion, the fitting was considered acceptable if the difference between the target and the measured values is within ±10 dB. In another study by Aahz and Moore (2007), the frequency-gain response of the hearing aid was modified to better match the NAL-NL1 target. Authors had used ±10 dB criteria to consider that the target gain and measured REAG were matched. In the present study too, the difference between the mean target gain and mean measured REAG values for the two hearing aids was within ±10 dB at all the frequencies. Hence, it can be inferred that the REAG matched the NAL-NL1 target at all the frequencies in Group I. Similar results were obtained in the other two groups of participants (Groups II & III).

The difference between the mean target gain and the measured REAG was also calculated. It should be noted that as mentioned in the previous chapter, the target gain curve was for the real ear aided gain (REAG). The absolute difference between the mean target gain and the measured REAG was within ± 4dB at all the frequencies for both the hearing aids as shown in Figure 4.4. This further confirms the notion that the target was being matched appropriately using the traditional REAG measure, in both the hearing aids.

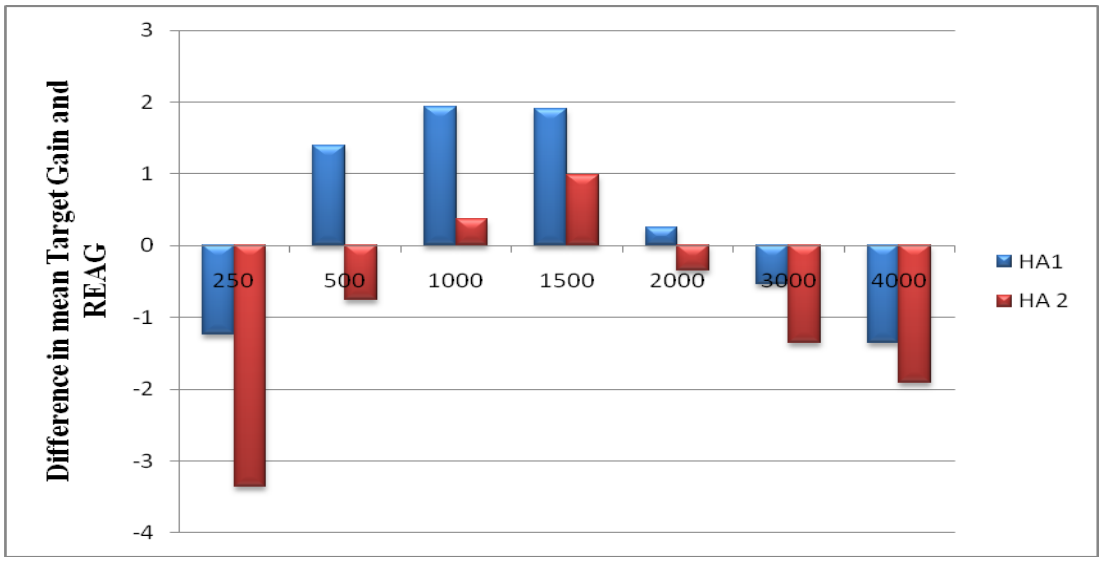

Fig. 4.4: Difference between the mean target gain and the measured REAG.

4.2. Visible Speech

The mean and standard deviation (SD) of the Visible Speech amplitude is shown in Table 4.2. It can be observed from the Table 4.2 that the target values as per NAL-NL1 were least in group with moderate HL. As the hearing loss increased, the target values increased, and the target values were highest in the group with severe HL. The

visible speech measure showed the similar trend as that of the target curve. The visible speech measure was least in the group with moderate HL and highest in the group with severe HL. This finding is similar to that noted for the traditional REAG.

Table 4.2: Mean and Standard Deviation (SD) of target and aided VS response with two hearing aids, HA1 & HA2, for three groups of participants

Freq. (Hz)	*HAs*	*Groups based on severity of hearing loss*								
		Group I (N= 10)			*Group II (N= 10)*			*Group III (N= 10)*		
		Target	*Mean*	*S.D.*	*Target*	*Mean*	*S.D.*	*Target*	*Mean*	*S.D.*
250	HA1	58.60	62.5	2.22	65.00	68.50	3.40	73.80	76.0	2.70
	HA2		60.40	2.79		66.30	3.16		75.30	2.16
500	HA1	65.40	69.2	1.39	72.60	75.70	3.02	83.90	85.10	3.69
	HA2		66.0	2.16		73.10	2.33		83.50	2.63
1000	HA1	74.90	75.9	3.47	85.00	85.00	2.94	92.20	90.7	2.45
	HA2		74.80	2.82		83.90	2.68		89.90	1.85
1500	HA1	78.50	81.7	4.02	88.30	89.30	3.09	95.20	91.50	1.58
	HA2		80.0	3.71		88.00	2.16		89.10	1.52
2000	HA1	83.00	83.1	3.66	91.70	89.00	2.44	96.30	88.30	1.76
	HA2		82.10	3.17		87.70	1.70		84.80	2.65
3000	HA1	78.70	79.0	3.09	85.70	83.80	3.04	89.50	83.8	2.69
	HA2		77.70	2.75		82.70	1.82		81.20	1.31
4000	HA1	75.70	74.0	2.66	81.30	78.40	1.95	87.20	79.40	3.23
	HA2		73.20	2.85		75.90	2.18		76.80	2.20

The mean NAL-NL1 target curve and visible speech response for the group with moderate HL (Group I) is shown in the Figure 4.5. The graph shows that the target curve and measured visible speech amplitude increased as the frequencies were increased. That

is, higher frequencies had higher amplitude values in both target and visible speech compared to the low frequencies. It can also be observed that the visible speech measure matched the target curve values at all the frequencies, for both the hearing aids.

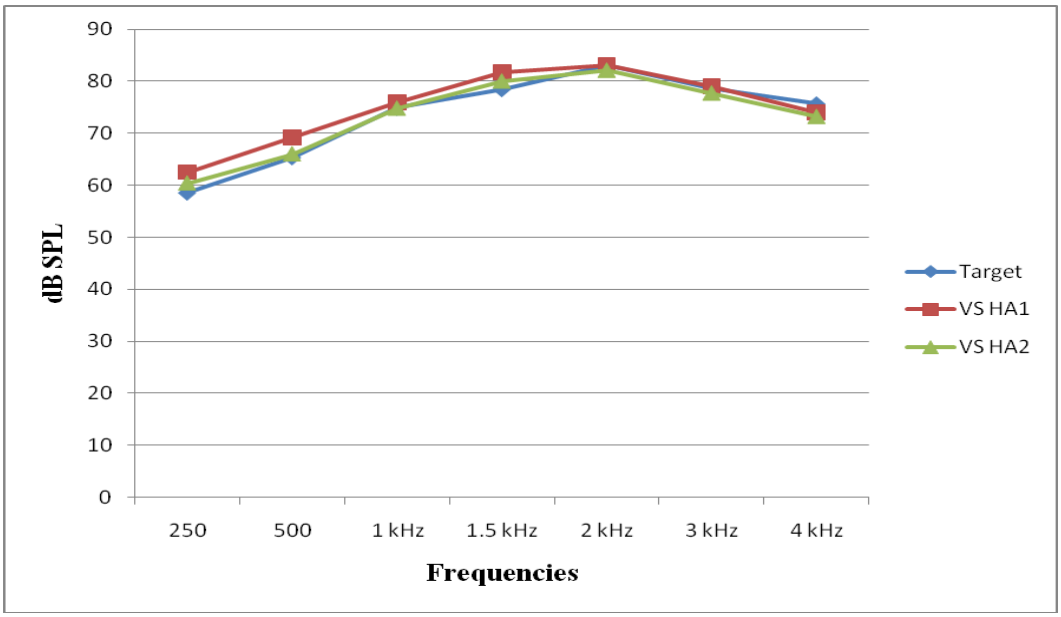

Fig. 4.5: Mean target curve and mean amplitude for visible speech for Group I

The mean NAL-NL1 target curve and visible speech amplitude values for the group with moderately-severe HL (Group II) are shown in the Fig. 4.6. Similar results as in group with moderate HL were obtained for the group with moderately-severe HL, with both the hearing aids.

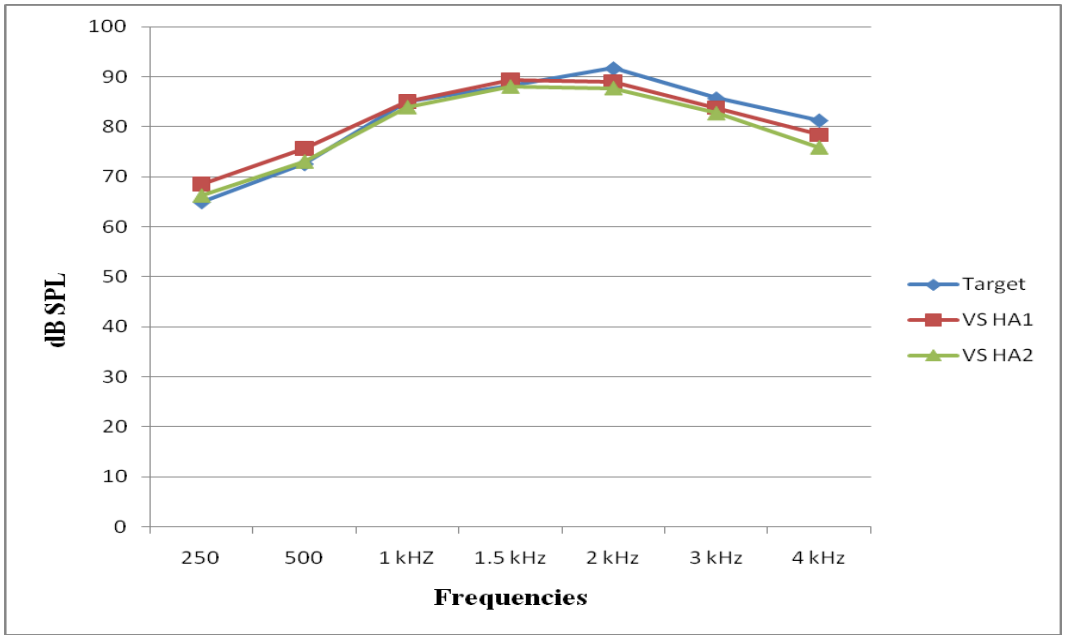

Fig 4.6: Mean target curve and mean amplitude for visible speech for Group II.

The mean NAL-NL1 target curve and visible speech amplitude values for the group with severe HL (Group III) are shown in the Figure 4.7. In severe group, the visible speech response values were matched with the real ear targets in low frequency regions. However, the mean visible speech measures values slightly deviated from the mean target curve, especially at 2 kHz and 4 kHz where the difference was greater than 10 dB. The hearing aid 2 was poorly matched with the targets in high frequencies than the hearing aid 1. This could be attributed to reduced high frequency amplification capacity of HA 2 compared to the HA 1.

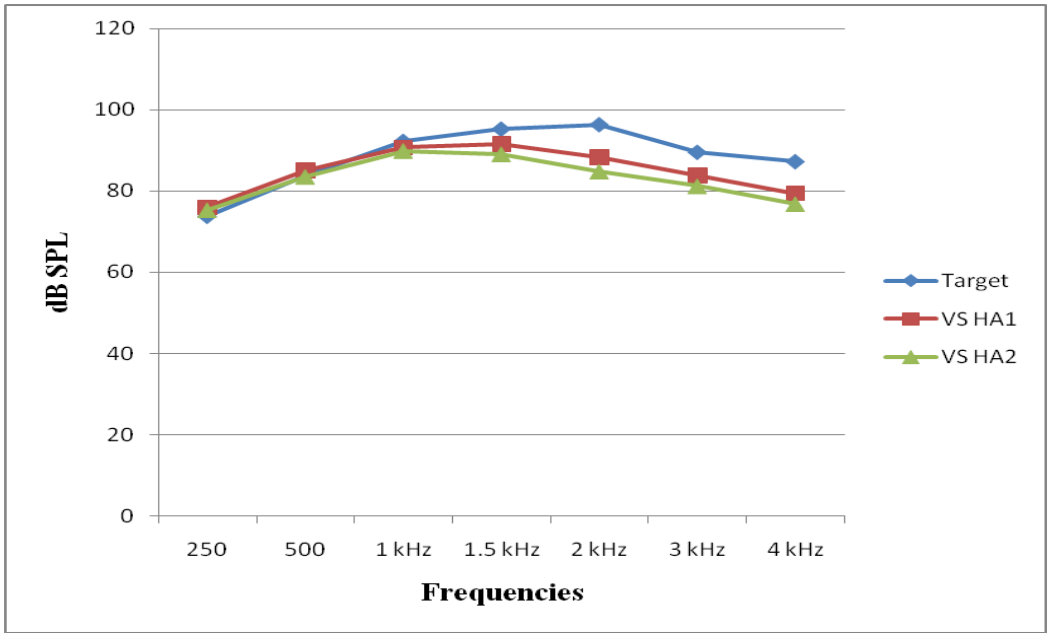

Fig 4.7: Mean target curve and mean amplitude for visible speech for Group III

Authors in the past have used ±10 dB criteria to determine if the targets are matched by the measured real ear measures (Bryne & Dillon, 1986; Aahz & Moore, 2007). In the present study, the difference between the target and measured visible speech measures was within ±10 dB except at 2 kHz for hearing aid 1 and at 4 kHz for both the hearing aids, in the group with severe HL. Visible speech measures requires more amplification in high frequencies than the traditional real ear aided gain. In groups with moderate and moderately-severe HL, further increase in high frequency gain was possible in both the hearing aids which helped in matching the target curve at high freqeuncies also. In contrary to that, hearing aid gain could not be further increased in group with severe HL to match 2 kHz and 4 kHz targets as the maximum gain limit in these frequecy regions was reached.

The difference between the mean target response and the visible speech response is plotted in graphical form as shown in Figure 4.8. It can be seen from the Figure 4.8 that the difference was more than ±5 dB in 2 kHz and 4 kHz regions. However, the difference was still within 10 dB, the criteria suggested by Byrne and Dillon (1986) and Aahz and Moore (2007).

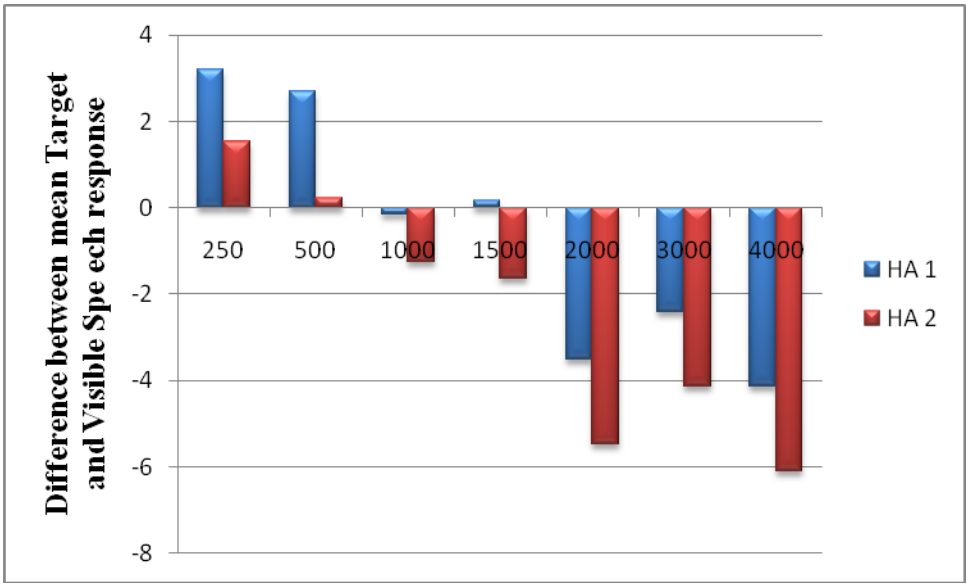

Fig. 4.8: Difference between the target response and the amplitude of visible speech measures.

4.3. Speech Intelligibility Index

Speech intelligibility index (SII) was tabulated from the visible speech display screen for all the participants. The speech intelligibility index showed variability across different groups in mean and standard deviation (SD), as shown in Table 4.3. As expected, the SII was maximum in the group with moderate HL followed by groups with moderately-severe and severe HL, for both the hearing aids.

Table 4.3: Mean and Standard Deviation (SD) of Speech Intelligibility Index with two hearing aids, HA1 & HA2, for three groups of participants

Measure	*Hearing Aids*	*Groups based on severity of Hearing Loss*					
		Group I		*Group II*		*Group III*	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
SII	HA 1	84.40	1.77	74.60	1.64	65.30	3.30
	HA 2	81.30	2.71	74.10	2.28	64.60	4.76

The SII reflected the amount of acoustic cues available to the participants, with hearing loss, in the aided condition. Thus, the speech intelligibility index decreased as the amount of hearing loss increased. The SII is also based on the audibility of the signal presented to the individual with hearing loss (Cox, Alexander & Rivera, 1995). In participants with moderate HL, more acoustic cues were available compared to those with higher degree of HL. Hence, individuals with moderate degree of HL obtained a higher SII compared to the other two groups.

SII procedure is highly useful while testing individuals speaking different languages across the country. It has been observed by Ramakrishna, Nair, Atal, & Subramaniam (1962) that several of the Indian languages have common sounds. It is an unachievable task to develop a standard speech test in each language or mother-tongue. Hence, the use of SII for hearing aid selection would prove to be more appropriate.

SII has many clinical advantages over the other routine tests for hearing aid verification. According to Pavlovic (1989), SII enables an audiologist to decide how the gain of the hearing aid should be changed to increase intelligibility. This is because AI

gives an indication on audiogram regarding the effect of a given hearing aid and the threshold on spectrum. SII has also been used to demonstrate the reasons for selecting a particular amplification device. Further, it has been used to explain to clients the reasons for poor performance with amplification (Zelnick, 1992). This would substantiate the information that is provided while counselling an individual regarding the expectation from a hearing aid.

4.4. Speech Identification Scores

Speech identification scores were measured in two different conditions, i.e., when the hearing aid was optimized using REAG for ANSI-digi signal and later when the hearing was optimized using visible speech measurement. Mean and standard deviation (SD) of the aided speech identification scores revealed variations in the aided speech identification scores across the groups and conditions as shown in Table 4.4.

Table 4.4: Mean and standard deviation (SD) of the aided speech identification scores (SIS).

Condition	*Hearing Aids*	*Aided SIS (Max = 25)*					
		Group I		*Group II*		*Group III*	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
HA optimized using REAG	HA 1	18.9	1.37	17.8	1.81	14.4	1.89
	HA2	17.8	1.54	17.7	1.63	13.3	1.15
HA optimized using Visible Speech	HA 1	21	1.41	19.4	1.89	14.9	1.37
	HA 2	19.8	1.87	19.3	1.56	13.6	1.24

The mean SIS with the hearing aid optimized using visible speech condition was slightly greater than that when the hearing aid was optimized using REAG for ANSI-digi

speech signal condition. This suggests that the hearing aid optimized using visible speech yielded a higher SIS than compared to hearing aid optimized using ANSI-digi speech signal. In group III, the difference in SIS was the least when the hearing aid was optimized with REAG using ANSI-digi speech signal and when optimized using visible speech. This reflected the fact that the available gain or audibility was not sufficient to improve the SIS for group with severe HL. This agrees with difference in mean target and visible speech response for the group with severe HL (Figure 4.7).

The paired t-test was performed to determine the significant difference between the two experimental conditions. The paired t-test was performed on each group separately. There was a significant difference between SIS obtained when HA was optimized using ANSI-digi speech signal and SIS obtained when HA was optimized using visible speech protocol in the groups with moderate HL and moderately-severe HL ($p<0.001$).

The speech identification scores obtained when hearing aid was optimized using visible speech, showed an increase in mean scores of SIS in moderate and moderately-severe groups of participants as against hearing aid optimized using ANSI-digi speech signal. The increase in SIS could be attributed to increased audibility in high frequencies when hearing aid is programmed using visible speech. There was no statistically significant increase in SIS for group with severe HL. This finding can be attributed to the inability to further increase hearing aid gain in high frequencies as compared to REAG condition in the Group III. Overall, there was an improvement in speech identification of individuals with hearing loss when hearing aid was optimized using visible speech.

Lindley (2007) compared speech mapping data with insertion gain data. The study reported the apparent advantages of speech mapping. According to him, with the insertion gain graph, it was marginally evident that additional high frequency gain would be required to meet the target. However, the author did not have any indication of how much audibility was provided nor any information related to the patient's dynamic range. Speech mapping (i.e., Visible Speech) results provided the same advantage (i.e., increased high frequency gain) with an easy-to-understand visualisation of the audibility and how much room is available for more gain to be desired.

From the findings in the present study, it can not only be inferred that the visible speech protocol can be a substitute to the traditional REAG protocol, but also the speech identification improves when the VS protocol is used to optimize hearing aid settings.

4.5. Comparison of different test measures

4.5.1. Correlation between traditional REAG and Visible speech measures

The real ear aided gain for ANSI-digi speech signal obtained separately at each frequency (250 Hz, 500 Hz, 1 kHz, 1.5 kHz, 2 kHz, 3 kHz & 4 kHz) were correlated with the visible speech measure for the same frequencies. Pearson's correlation was administered between the REAG values and VS values for both the hearing aid conditions. A significant positive correlation was obtained between REAG and visible speech measures when the analysis was carried out on all the 30 participants ($p<0.01$). Further, analysis was also carried out on each of groups separately.

4.5.1.1. Correlation between REAG and visible speech measures for the group with moderate hearing loss

There was no significant correlation between real ear aided gain and visible speech aided condition at all the frequencies for hearing aid 1 ($p > 0.05$). Also, there was no significant correlation between real ear aided gain and visible speech aided condition at all the frequencies ($p > 0.05$), except at frequency of 500 Hz for hearing aid 2.

4.5.1.2. Correlation between REAG and Visible speech for group with moderately severe hearing loss

Pearson's correlation demonstrated no significant correlation between real ear aided gain and visible speech aided condition at all the tested frequencies except at 500 Hz for both hearing aid 1 and hearing aid 2 ($p > 0.05$).

4.5.1.3. Correlation between REAG and Visible speech for group with severe hearing loss

Analysis revealed no significant correlation between real ear aided gain and visible speech response condition at all the tested frequencies in hearing aid 1 ($p > 0.05$). A significant correlation was obtained between real ear aided gain and visible speech measure at 1500 Hz in the hearing aid 2. However, the other frequencies did not show significant correlation between real ear aided gain and visible speech measures ($p > 0.05$).

An overall positive correlation between the real ear aided gain and visible speech measures at all the frequencies suggest that the visible speech can be used in routine hearing aid verification of hearing aid as visible speech measure has several benefits over the routine traditional real ear aided gain measurements. The hearing aid can be fine-

tuned for all the frequencies using visible speech measure which uses actual speech, either live or recorded, for real ear measurement.

4.5.2. Correlation between RMS amplitude of REAG and visible speech measure

RMS amplitude was measured for both the types of real ear measurements, i.e., REAG and visible speech. Mean and Standard deviation (SD) of RMS amplitude for REAG and VS are given in Table 4.5.

Table 4.5: Mean and Standard deviation (SD) for RMS amplitude for REAG and visible speech measures

Measure	*Hearing Aids*	*RMS amplitude (dB SPL)*					
		Group 1		*Group 1I*		*Group III*	
		Mean	*S.D.*	*Mean*	*S.D.*	*Mean*	*S.D.*
REAG	HA 1	95.98	2.60	106.02	3.19	114.13	2.58
	HA2	94.03	2.78	104.33	3.33	112.52	2.35
Visible Speech	HA 1	93.70	3.61	103.50	1.84	110.80	2.34
	HA 2	93.00	1.82	100.90	2.33	107.1	1.91

The mean RMS amplitude of REAG and Visible Speech varied across the three groups of participants. The RMS amplitude of both the measures was highest in the group with severe HL and least in the group with moderate HL. In other words, as the degree of hearing loss increased, the RMS amplitude of both the REAG and Visible Speech measures increased.

Pearson's correlation was performed on the RMS amplitude of REAG and RMS amplitude of visible speech. A significant correlation was obtained between RMS average amplitude of REAG and visible speech when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$). This suggests that the RMS amplitude of visible speech and REAG measure can be interchangeably used in verification of hearing aid fitting. Further, Pearson's correlation was carried out separately for each of the groups. Pearson's correlation demonstrated no significant correlation between RMS average amplitude of REAG and visible speech in each of the three groups ($p >0.05$). The scatter plot showing correlation between RMS amplitude of traditional REAG and visible speech is given in Figure 4.9. It can be seen from scatter plot that the direction of both the measures is similar, i.e., as the RMS amplitude of traditional REAG increases, amplitude level of visible speech also increases.

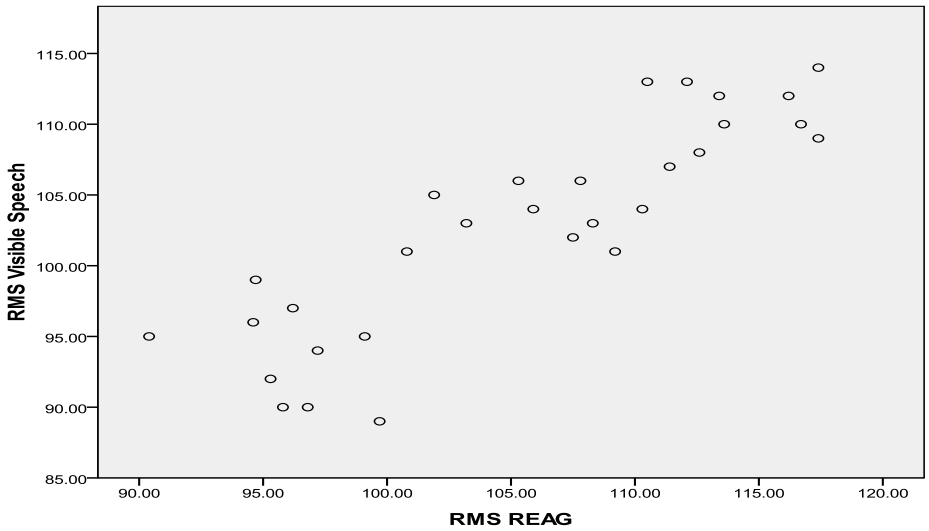

Fig. 4.9: Scatter plot showing correlation between RMS amplitude of REAG and Visible Speech.

An overall positive Pearson's correlation between the RMS amplitude of REAG and RMS amplitude of visible speech demonstrated that the two measures can be used

interchangeably in the clinic. Traditional real ear aided gain measurement is a well documented verification tool for hearing aid fitting but has several disadvantages compared to visible speech as reported in literature (Poe and Ross, 2005).

Traditional REAG utilizes composite noise as the test signal which does not provide information on real life performance of hearing aid. Moreover, clients are unable to perceive the importance of tonal stimuli while testing. It is not a great counselling tool as the terminologies involved in traditional real ear measurements are often confusing. The results of the present study implied the use of visible speech measure instead of traditional real ear measurement protocol for more effective verification of hearing aid selection.

4.5.3. Correlation between Speech identification scores, Speech intelligibility index and RMS amplitude of visible speech.

Pearson's correlation was administered between speech identification scores, speech intelligibility index, RMS amplitude of visible speech for both hearing aids. Following results were found

a. A significant correlation between RMS amplitude of visible speech and speech identification scores was also revealed when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$).

b. A significant positive correlation was obtained between speech identification scores and speech intelligibility index when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$).

c. A significant correlation between speech intelligibility index and RMS amplitude of visible speech was also obtained when the analysis was carried out on all the 30 individuals with hearing loss ($p<0.01$).

Later, analysis was carried out on each of the groups separately. There was no significant correlation between speech identification scores, speech intelligibility index and RMS amplitude of visible speech in each of the three groups ($p >0.05$). The scatter plot showing correlation between SIS obtained when hearing aid was optimized using visible speech and Speech intelligibility index is given in Figure 4.10. It can be seen from scatter plot that as the SII is increased there is an increase in SIS also.

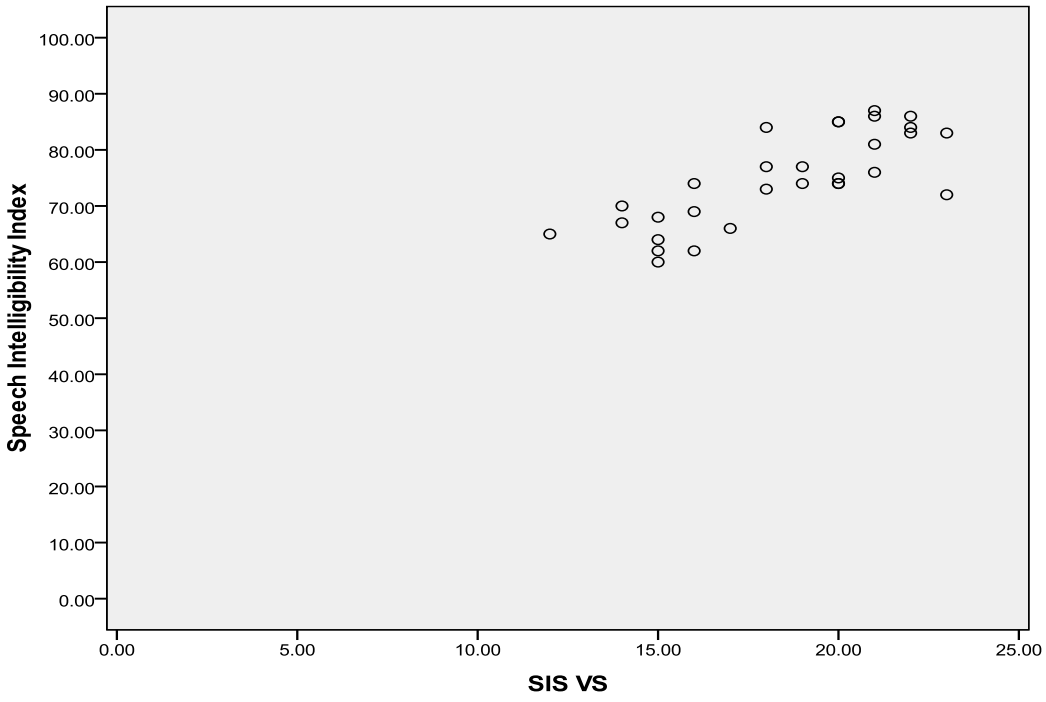

Fig. 4.10. Scatter plot showing correlation between SIS obtained when hearing aid was optimized using visible speech and Speech intelligibility index.

A significant correlation between SIS and SII has been reported in literature. Pavlovic (1984) reported good predictions of speech recognition for normal hearing and

subjects with less hearing impairment but not for those with greater impairment. The monotonic relation of SII with SIS was found to hold good not only for individuals with normal hearing but also for individuals with hearing impairment (Aniansson, 1974; Pavlovic, 1984) and for individuals with hearing impairment who wore hearing aids (Magusson, Karlsson, & Leijon, 2001). According to Ching, Dillon, and Byrne (1998), the monotonic relationship between the SRS and SII may not be true for individuals with severe hearing loss.

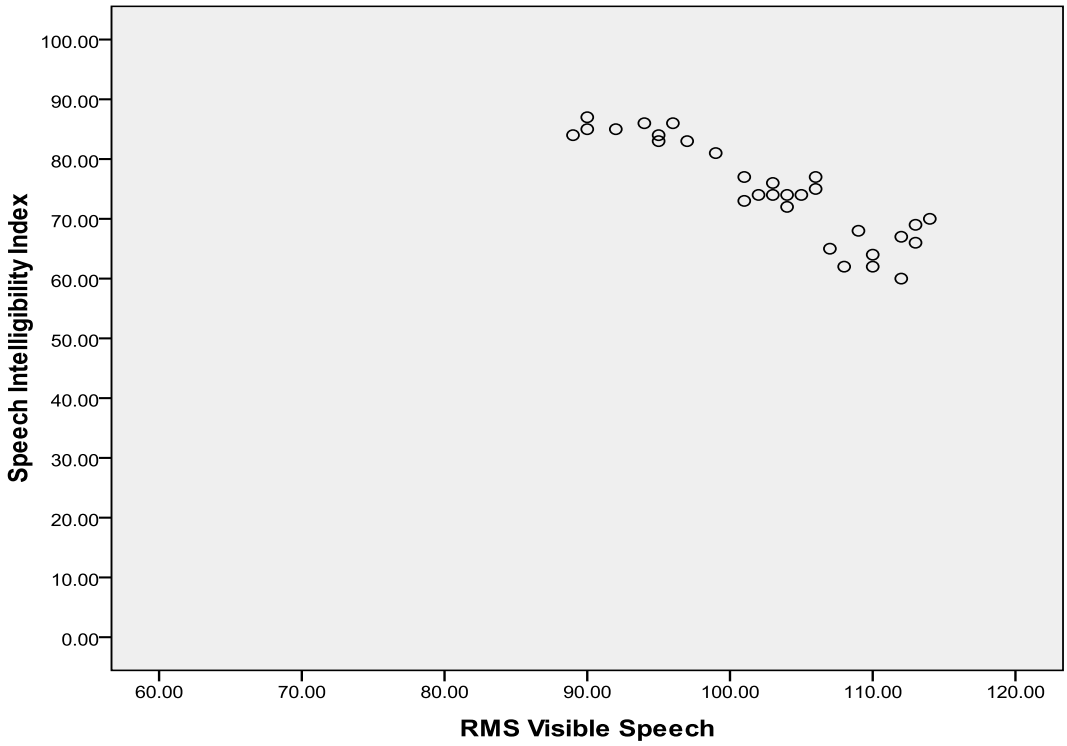

Fig. 4.11. Scatter plot showing correlation between RMS amplitude of Visible Speech and SII.

The scatter plot showing correlation between RMS amplitude of VS and Speech intelligibility index is given in Figure 4.11. It can be seen from scatter plot that, the low

RMS amplitude had higher SII because the low RMS amplitude is depicting the group with moderate loss. As the degree of hearing loss less, more number of acoustic cues was available which resulted in higher SII.

It can be inferred from the above observations, that the visible speech can be used as a verification tool in hearing aid selection, as there was a positive overall correlation between the visible speech measure and speech identification scores. Also, a positive Pearson's correlation was also obtained between speech intelligibility index and visible speech. Speech intelligibility index has been proven to be a good verification method in selection of hearing aids. Visible speech is an objective measure and has many advantages over the speech identification scores as reported in literature.

The visible speech measures would be beneficial to verify hearing aids as it would provide both electroacoustic performance of the hearing aid as well as the speech understanding abilities of the individual through SII. Speech intelligibility index which is being displayed on the visible speech screen would provide necessary information about the amount of audible cues present to the hearing aid user. In the present study, visible speech along with speech intelligibility index has been proved to be a strong verification tool in the hearing aid selection.

Moreover, traditional real ear measurements have been clinically adopted for the verification of hearing aids (Hawkins & Cook, 2003; Mueller, 2003, Van Vliet, 2003). But, the major disadvantage of traditional real ear measurements (e.g. REAG) is the use of composite noise signals as an input signal to hearing aids (Moore, 2006). These are the signals which are of lowest concerns when hearing aid has to perform in real-life situations. The most common signal one is exposed to is the speech stimuli. Hence,

verifying hearing aid fitting with composite signal would not give an indication of the performance of a hearing aid in real-life situations.

Visible speech may be the solution to this problem. According to Moore (2006), using visible speech, effective amplification provided by the hearing aid can be assessed using realistic signals such as speech or music and with the aid in its normal mode of operation (with features such as feedback cancellation and noise reduction enabled). Thus, the influence of factors such as number and bandwidth of channels, compression speed, etc., is automatically taken into account. The gains actually achieved for real-life signals such as, speech and music, may differ considerably from the gains measured with steady signals, such as tones and noise (Moore, 2006). The difference depends on the number of channels in the hearing aid, the speed of the compressors, and the compression thresholds. This is the case even when features such as noise reduction or feedback cancellation are not present or are not activated.

When a hearing aid incorporates feedback cancellation, pure-tone test signals may be interpreted by the aid as feedback, and a pure-tone test signal is then partially or completely cancelled. The gains measured when this happens may be totally unrepresentative of the gains achieved in everyday life (Mueller, 2006). In some hearing aids, it is possible to disable the feedback cancellation system, but this may change the effective frequency response of the aid and may also limit the gain that can be achieved.

Many hearing aids incorporate some form of noise reduction. If any particular spectral region appears to be dominated by noise (or by any steady sound), then the gain of the hearing aid in that frequency region is reduced (Mueller, 2006). If the test signal used to assess the gain of the hearing aid is a steady noise or a tone, the gain that is

measured may be much less than actually achieved for everyday sounds such as speech and music (Moore, 2006). In some hearing aids, it is possible to disable the noise reduction system, but this may change the effective frequency response of the aid, and the gain applied by the aid may differ from that obtained when the noise reduction is active. The sounds that are used to make the measurements have no relevance to the sounds that the hearing aid user experiences in everyday life, for example the voice of a spouse or parent.

To summarize, the major advantages of visible speech approach is that the effective amplification provided by the hearing aid can be assessed using realistic signals such as speech or music and with the aid in its normal mode of operation (with features such as feedback cancellation, multichannel compression and noise reduction enabled). Thus, the influence of factors such as number and bandwidth of channels, compression speed, and many more are automatically taken into account. Furthermore, any effects of feedback cancellation or noise reduction on the performance of the aid are automatically included in the display of visible speech.

Cunningham, Laó-Dávila, Eisenmenger, and Lazich (2002) reported a longitudinal study on live-speech mapping. Live Speech Mapping reduced the number of post-fitting follow-up visits. It was reported that a 48% reduction in total number of follow-up visits and a 36% reduction in mean number of visits per patient when Live Speech Mapping was used.

Patient satisfaction is the ultimate goal of hearing care professionals. It leads to fewer returns and fewer follow-up visits, thus saving both time and money. Engaging the patient in an interactive fitting process with a technologically-advanced approach like the

Visible Speech can make great strides toward achieving that patient satisfaction. The involvement of family members as part of the fitting process provides support for both the patient and the clinician. From a counselling standpoint, most clients find output-based data easier to understand and more meaningful than insertion gain curves (Lindley, 2007). The signal used for testing makes sense for these clients. Prescriptive targets have been derived assuming that a speech stimulus can be employed as benchmarks regarding the appropriateness of the hearing aid settings. Hence, visible speech has many advantages over routine real ear measurements. Now, it is also found that visible speech measure yields better speech recognition except in group with severe HL. This is not because the VS measure is not a good measure, but because the hearing aid was unable of providing the required amount of gain for matching the NAL-NL1 target in the group with severe HL.

To summarize the results, visible speech measure obtained a good correlation with the traditional REAG and SII. Also, there was a positive correlation between SIS and SII. The speech recognition scores improved when hearing aid was optimized using visible speech protocol than compared to traditional real ear measurement protocol. Hence, visible speech along with SII proves to be a better verification tool for the selection of hearing aid.

Chapter 5

SUMMARY AND CONCLUSIONS

Verification of hearing aid selection is a major step in the hearing aid fitting process. There are various methods for the verification of hearing aid selection described in the literature which have been used for decades. The traditional real ear measurements have been considered as one of the most valid tools in the verification of hearing aid selection. With the advent of digital technology, selection of stimulus for verification through real ear measurements is a big concern. The traditional REM utilizes composite noise signals which are not encountered routinely in real life situations and hence inappropriate for testing high end digital hearing aids. The response output for such stimuli through digital hearing aids is inappropriate and underestimates the performance of hearing aids.

Hence, the present study was taken up to verify the selection of hearing aids using actual speech. Visible speech measure along with speech intelligibility index was utilized for verification of hearing aid selection.

The participant group comprised of 30 naïve hearing aid users, with post-lingual onset of hearing loss. Individuals with hearing impairment were divided into three groups based on degree of hearing loss. The three groups of participants were participants with moderate HL, moderately-severe HL and severe HL. Two digital BTE hearing aids were optimized using traditional protocol of real ear measurements and the visible speech protocol. Fonix 7000 hearing aid analyzer was used for the traditional real ear

measurement protocol which utilizes ANSI-digi speech as stimulus while the visible speech protocol used actual recorded speech. Speech intelligibility index was also tabulated from the visible speech display screen. Speech identification scores were obtained in two different conditions, i.e., when the hearing aid was optimized using traditional real ear aided gain, using ANSI-digi speech signal, and other condition was when the hearing aid was optimized using visible speech measure. The following results were obtained.

1. The measured mean REAG for ANSI-digi speech signal matched the mean target gain at all the frequencies for the moderate level of input signal (65 dB SPL) for both the hearing aids.

2. The mean real ear response for visible speech measure matched the mean target curve at all the frequencies except at 2 kHz and 4 kHz in the group with severe HL for the moderate level of input signal, with hearing aid 2.

3. The mean REAG for ANSI-digi speech signal and mean real ear response for visible speech measure varied across the three groups of participants. The mean value for REAG for ANSI-digi speech signal and mean real ear response for visible speech was higher in group with severe HL followed by groups with moderately-severe and moderate HL.

4. The aided speech intelligibility index varied across different groups. The Group with moderate HL obtained highest SII score followed by groups with moderately-severe and severe HL. The SII was least in group with severe HL as participants had reduced audibility of speech signal even in the aided condition.

5. The speech identification scores were highest in group with moderate HL followed by groups with moderately-severe and severe HL. There was an increase in speech identification scores when hearing aid was optimized using visible speech protocol compared to when the hearing aid was optimized using the traditional real ear measurement protocol (ANSI-digi speech stimulus).

6. The Pearson's correlation showed a significant correlation between measured REAG and visible speech measure at all the frequencies when data from all the 30 participants were combined for analysis. However, there was no significant correlation when each group of participants were analyzed separately.

7. There was a positive correlation between the speech identification scores, speech intelligibility index and visible speech measure when all the 30 participants were together analyzed. On the contrary, there was no significant correlation between the speech identification scores, speech intelligibility index and visible speech measure in each group of participants.

These findings prove that verification of hearing aid using visible speech protocol is leading to higher speech identification scores. Also, there was a positive correlation between speech identification scores and speech intelligibility index. Hence, verification of hearing aid selection using visible speech protocol and speech intelligibility index yielded a better performance in individuals with varying degree of hearing loss.

The visible speech measure proves to be a valuable tool for audiologists. It allows markedly improved accuracy in the verification and fitting of hearing aids. It also provides an immediate indication of the audibility of important everyday signal such as

speech, including the speech of family members or relatives. Visible speech measure makes it possible to adjust the parameters of hearing aids to optimize the audibility of speech while avoiding loudness discomfort. It involves the client and their relatives in the fitting process, leading to greater understanding and satisfaction, and it is likely to reduce the number of post-fitting visits, saving time and money.

Clinical Implications

The findings of the present study have important clinical implications:

1. The visible speech protocol is an effective verification tool for the selection of hearing aids.

2. The implementation of visible speech protocol for verification of hearing aid selection withdraws guesswork of an audiologist about the performance of a hearing aid in the real-life situations.

3. The speech intelligibility index provides an indication of speech intelligibility of a hearing aid user. The SII is also displayed on the visible speech measurement screen. Hence, the visible speech along with SII proves to be a valid objective tool for the verification of hearing aid selection.

References

American National Standard Institute. (1997). *American National Standard Methods for the Calculation of the Speech Intelligibility Index.* ANSI S3.5-1997. New York: American National Standard Institute.

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

Aarts, N.L., & Caffee C.S. (2005). Manufacturer predicted and measured REAR values in adult hearing aid fitting: Accuracy and clinical usefulness. *International Journal Audiology, 44,* 293-301.

Aniansson, G. (1974). Speech discrimination predicted from tone audiometry and articulation index. *Acta Otolaryngologica Supplement, 32,* 36-48.

Beck, D., & Duffy, J. (2007). Visible Speech: A patient-centered clinical tool. *The Hearing Review, 16*(1). Retrived January 21, 2009, from, http://www.hearingreview.com/issues/2007-01.asp

Bentler, R., & Chiou, L. K. (2006). Digital noise reduction: An overview. *Trends in Amplification, 10*(2), 61–82.

Beck, D. L., & McGuire, R. (2006). Multimedia: Better tools facilitate a better process. *The Hearing Review, 13*(5). Retrived January 21, 2009 from http://www.hearingreview.com/issues/2006-05.asp

Byrne, D. (1986). Effects of frequency response characteristics on speech discrimination and perceived intelligibility and pleasantness of speech for hearing impaired listeners. *Journal of the Acoustical Society of America, 80,* 494-504.

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 for selecting the gain and frequency response of a hearing aid. *Ear & Hearing, 7,* 257-265.

Burney, P. (1972). A survey of hearing aid evaluation procedures. *American Speech Hearing Association, 14*, 439–444.

Cox, R. M., Alexander, G. C., & Rivera, I. M. (1991). Comparison of objective and subjective measures of speech intelligibility in elderly hearing impaired listeners. *Journal of Speech and Hearing Research, 34*, 904-915.

Cunningham, D.R., Laó-Dávila, R.G., Eisenmenger, B.A., & Lazich R.W. (2002). Study finds use of Live Speech Mapping reduces follow-up visits and saves money. *The Hearing Journal, 55*, 43-46.

Crumley, W. (2007). Science-based Fittings: Cross-checking the Hearing Loss and Verifying the Fitting. *The Hearing Review, 14*(1). Retrieved January21, 2009, from http://www.hearingreview.com/issues/2007-01.asp

Dillon, H., Katsch, R., Byrne, D., Ching, T., Keidser, G., & Brewer, S. (1998). The NAL-NL1 prescription procedure for non-linear hearing aids. *National Acoustics Laboratories Research and Development, Chatswood, NSW, Australia Annual Report, 1997/98*, 4-7.

Dillon, H., and Keidser, G. (2003). Is probe-mic measurement of HA gain-frequency response best practice? *The Hearing Journal, 56*(10), 28–30.

Groth, J. (2001). Influence of advanced hearing aid technology on choice of signal for probe microphone measures. *Trends in Amplification, 5*(2), 69–72.

Hawkins, D. B., Montogomery, A. A., Prosek, R. A., & Walden, B. E. (1987). Examination of two issues concerning functional gain measurements. *Journal of Speech & Hearing Disorders, 52*, 56-63.

Hawkins, D.B., & Cook, J.A. (2003). Hearing aid software predictive gain values: How accurate are they? *The Hearing Journal, 56*(11), 26-34.

Hawkins, D, B., Morrison, T. M., Halligan, P. L. W., & Cooper, W. A. (1989). Use of probe-tube microphone measurements in hearing aid selection for children: Some initial clinical experiences. *Ear & Hearing, 10*(5), 281-287.

Hellstrom, P.A., & Axellson. A. (1993). Miniature microphone probe tube measurements in the external auditory canal. *Journal of the Acoustical Society of America, 93*, 907-919.

Henning, R. W., & Bentler, R. (2005). Compression-dependent differences in hearing aid gain between speech and nonspeech input signals. *Ear & Hearing, 26*, 409-422.

Hornsby, B. (2004). The Speech Intelligibility Index: What is it and what's it good for? *The Hearing Journal, 57*(10), 10-17.

Humes, L. (1996). Evolution of prescriptive fitting approaches. *American Journal of Audiology, 5*, 19-23.

Jenstad, L. M., & Souza, P. E. (2005). Quantifying the effect of compression hearing aid release time on speech acoustics and intelligibility. *Journal of Speech Language & Hearing Research, 48*, 651-667.

Keidser, G. & Dillon, H. (2006). NAL Research and Development, *Annual Report, 2005-06*. Retrieved March 2, 2009, from http://www.nal.gov.au/Publications/NAL_AnnualReport05-06.pdf

Keidser, G., Convery, E., & Dillon, H. (2002). Gain preference relative to the NAL-NL1 prescription. NAL Research and Development, *Annual Report, 2002-03*, 44-46.

Leijon, A., Lindkvist, A., Ringdahl, A., & Israelsson, B. (1990). Preffered hearing aid gain in everyday use after prescriptive fitting. *Ear & Hearing, 11*(4), 229-305.

Libby, R. E. (1986). The shift towards real ear measurements. *Hearing Instruments*, 37, 6-7.

Lindley, G. (2007). From insertion gain to speech mapping: Benefits of an output-based approach. *Oticon Clinical Update No 1*. Retrieved on February 2009 from http://www.oticonusa.com/eprise/main/SiteGen/Uploads/Public/Downloads_Oticon/Oticon_Clinical_Updates/Insertion_Gain_OCU_2.pdf

Magusson, L., Karlsson, M., & Leijon, A. (2001). Predicted and measured speech recognition performance in noise with linear amplification. *Ear and Hearing, 22*, 46-57.

Margolis, R. H. (2004). In one ear and out the other: What patients remember. Retrieved March 29, 2009, from www.audiologyonline.com.

Mathur, A. (2008). *Efficacy of NAL-NL1 prescription for the first-time hearing aid users: A follow-up study*. Unpublished dissertation submitted to University of Mysore, in part fulfilment of Masters degree in Speech and Hearing.

Moore, B. C. J. (2006). Speech mapping is a valuable tool for fitting and counseling patients. *The Hearing Journal, 59*(8), 26-30.

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

Moore, B. C. J., Glasberg, B. R., and Stone, M. A. (1999). Use of a loudness model for hearing aid fitting. III. A general method for deriving initial fittings for hearing aids with multi-channel compression, *British Journal of Audiology, 33*, 241-258.

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

Moore, B. C. J., & Glasberg, B. R. (1998). Use of loudness model for hearing aid fitting. I. Linear hearing aids. *British Journal of Audiology, 32*, 317-335.

Mueller, H. G. (1998). Probe-microphone measurements: Yesterday, today and tomorrow. *The Hearing Journal, 51*(4), 17–22.

Mueller, H. G. (2001). Probe-microphone measurements: Twenty years of progress. *Trends in Amplification, 5*(2), 35–68.

Mueller, H. G. (2003). Fitting test protocols are "more honored in the breach than the observance". *The Hearing Journal, 56*(10), 19–26.

Mueller, H. G. (2005). Probe-mic measures: Hearing aid fittings most neglected element. *The Hearing Journal, 58*(10), 21-30.

Mueller, H. G. (2006). Probe-Mic Verification: Getting Better But Still Mostly Ignored. *Hearing Care for Adults 2006: Proceedings of the First International Adult Conference.* Chicago, USA: Phonak AG.

Mueller, H. G., & Grimes, A. (1983). Speech audiometry for hearing aid selection. *Seminars in Hearing, 4*(3), 255–286.

Mueller, H. G., & Hornsby, B. (2002). Selection, verification and validation of maximum output. In M. Valente (Eds.), *Strategies for selecting and verifying hearing aid fittings* (pp. 23–66). New York: Thieme Medical Publishers.

Mueller, H. G., & Killion, M. C. (1990). An easy method for calculating the articulation index. *The Hearing Journal*, *43*(9), 1-4.

Mueller, H. G., Hawkins, D. B., & Northern, J. L. (2001). *Probe microphone measurements. Hearing aid selection and assessment*. San Diego, California: Singular Publications Group Inc.

Pavlovic, C. V. (1984). Use of arituculation index for assessing residual auditory function in listeners with sensorineural hearing impairment. *Journal of the Acoustical Society of America, 75,* 1253-1258.

Pavlovic, C. V. (1989). Speech spectrum consideration and speech intelligibility predictions in hearing aid evaluation. *Journal of Speech and Hearing Disorders, 54*, 3-8.

Pittman, A. L., & Stelmachowicz, P. G. (2003). Hearing loss in children and adults: Audiometric Configuration, Asymmetry, and Progression. *Ear and Hearing, 24, 198-205.*

Poe, H., & Ross, T. (2005). A "Small" Change in Verification: A Compact Live Speech REM System. *The Hearing Review*, *12*(12). Retrieved February 24, 2009 from http://www.hearingreview.com/issues/2005-12.asp

Preves, D., Beck, L., Burnett, E., & Teder, H. (1989). Input stimuli for obtaining frequency response of automatic gain control hearing aids. *Journal of Speech and hearing Research, 32*, 189-194.

Ramakrishna, B. S., Nair, K. K., Chiplunkar, V. N., Atal, S. S., Ramachandran, V., & Subramanian, R. (1962). Some aspects of relative efficiencies of Indian languages- A study from information theory point of view. Ranchi: Catholic press.

Ringdahl, A., Leijon, A., Liden, G., & Backelin, L. (1984). Hearing aid prescription rules using insertion gain measurements. *Scandivian Audiology, 13,* 211-218.

Romanow, F. F. (1942). Cited in Libby, R. E. (1986). The shift towards real ear measurements. *Hearing Instruments, 37*, 6-7.

Ruskin, A. (2008). Live Speech Mapping: Charting a New Course. *The Hearing Review, 15*(3). Retrieved February 24, 2009, from http://www.hearingreview.com/issues/HPR_2004-03.asp

Ross. T., & Smith, K. E. (2005). How to use live speech as part of a hearing instrument fitting and verification process. *The Hearing Review, 12*(6), 40-46.

Sairam, V. V. S. (2002). *Long-term average speech spectrum in Kannada.* Unpublished independent project submitted to University of Mysore, in part fulfilment of Masters degree in Speech and Hearing.

Sanborn. P. E. (1998). Predicting hearing aid response in real ears. *Journal of the Acoustical Society of America, 18*, 665-674.

Schum, D. J., & Beck, D. L. (2005). Modern applications of multi-channel non-linear amplification. *News From Oticon*. Retrieved January 7, 2009, from *www.oticonusa.com/eprise/main/SiteGen/Uploads/Public/Downloads_Oticon/News_from_Oticon/NFO_Nov_05.pdf*

Schwartz, D., & Walden, B. (1983). Speech audiometry and hearing aid assessment: A reappraisal of an old philosophy. In D. Konkle, and W. Rintelmann (Eds.), Principles of speech audiometry (pp.56–78). Baltimore: University Park Press.

Scollie, S., & Seewald, R. (2002). Evaluation of electroacoustic test signals I: Comparison with amplified speech. *Ear and Hearing, 23*(5), 477–487.

Seewald. R. C., Moodie, S. K., Sinclair, S. T., & Scollie, S. D. (1999). Predictive validity of the procedure for the paediatric hearing aid procedure. *American Journal of Audiology, 8*, 143-152.

Smaldino, J., & Hoene, D. (1981). A view of the state of hearing aid fitting practices. *Hearing Instruments, 32*(1), 14-15.

Souza, P. E. (2002). Effects of compression on speech acoustics, intelligibility, and sound quality. *Trends in Amplification, 6*, 131-165.

Stelmachowicz, P. G., Kopun, J., Mace, A.L., & Lewis, D.E. (1996). Measures of hearing aid gain for real speech. *Ear & Hearing, 17*(6), 520–527.

Stone, M. A., & Moore. B. C. J. (1992). Syllabic compression: Effective compression ratios for signals modulated at different rates. *British Journal of Audiology, 26,* 351-361.

Strom, K. E. (2006). The *HR* 2006 dispenser survey. *The Hearing Review, 13*(6), 16-39.

Studebaker, G. (1982). Hearing aid selection: An overview. In G. Studebaker, and F. Bess (Eds.), *The Vanderbilt hearing aid report* (pp. 147–156). Upper Darby Pa: Monographs in Contemporary Audiology.

Valente, M. (2002). *Hearing aids: Standards, options and limitations (2nd Ed.).* New York: Thieme Medical Publishers.

Van Vliet, D. (2006). When it comes to audibility, don't assume. Measure! *The Hearing Journal, 59*(1), 86.

Verschuure, J., Maas, A. J. J., Stikvoort, E., de Jong, R. M., Goedegebure, A., & Dreschler, W. (1996). Compression and its effect on the speech signal. *Ear & Hearing, 17,* 162-175.

Yathiraj, A., & Vijaylakshmi, C. S. (2005). *Phonemically Balanced Word List in Kannada*. Developed in Department of Audiology, AIISH, Mysore.

Zelnick, E. (1992). The use of Articulation Index simplified, Part II. *Audecibel, Winter,* 22-26.