HEARING AID SELECTION THROUGH NAL-R AND FUNCTIONAL SPEECH MEASUREMENT : A COMPARISON

Reg. No. M 9608

AN INDEPENDENT PROJECT SUBMITTED IN PART FULFILLMENT FOR THE FIRST YEAR MASTER'S DEGREE IN SPEECH AND HEARING TO THE UNIVERSITY OF MYSORE

ALL INDIA INSTITUTE OF SPEECH AND HEARING
MYSORE - 570 006
INDIA
1997

DECLARATION

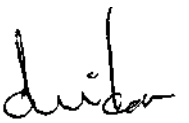
I hereby decalare that this independent project entitled "HEARING AID SELECTION THROUGH NAL-R AND FUNCTIONAL SPEECH MEASUREMENT : A COMPARISON" is the results of my own study under the guidance of Dr. (Mrs) Asha Yathiraj, Reader in Audiology. All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any University for any other Diploma or Degree.

Mysore

May 1997 Reg: No. M9608

CERTIFICATE

This is to certify that this Independent Project entitled **"HEARING AID SELECTION THROUGH NAL-R AND FUNCTIONAL SPEECH MEASUREMENT : A COMPARISON"** was done in part fulfillment for the first year of the Master's Degree in Speech and Hearing of the student with Reg. No. M 9608.



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CERTIFICATE

This is to certify that this Independent Project **"HEARING AID SELECTION THROUGH NAL-R AND FUNCTIONAL SPEECH MEASUREMENT : A COMPARISON"** has been prepared under my supervision and guidance.

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INTRODUCTION

Throughout the history of audiology, audiologist have been confronted with the problem of selecting the most appropriate aid for a patient from a set of commercialy available instruments. Since, the development of the wearable hearing aid, efforts have been made and procedures have been developed for the purpose of comparing performance of different hearing instruments.

Search for selection of an universal approach to hearing aid continues to this day and the solution to a certain extend continues to be ellusive. Earlier procedures by Carhart(l946), developed procedure for determining hearing aid candidacy and for hearing aid fitting. This was done in order to provide as much assurance as possible that the potential wearer could obtain a hearing aid that would be of substantial benefit.

Today 2cc coupler and real ear measurement provide a more objective measure of hearing aid function and in the latter case hearing aid function and in the latter case hearing aid functions in relation to clients ear canal resonance.

Various prescriptive procedures have been developed and by mid 80's more than ten such procedures were identified by Humes in 1986. The procedures take into consideration many acoustic and different factor in an effort to fit the

individual appropriately. It is also difficult to describe the development of routine clinical evalution procedures due to the lack of standardized terminology and procedures.

It is very difficult to compare the benefit of one fitting procedure over another, thus no one evalution method seems to be considered superior over any other method consistently. It was emphasized that it is necessary for the evaluation and fitter of the hearing aid to utilize a broad array of procedure and tailor the procedure to specific requirement of each potential hearing aid user.

Curran (1988), noted that no significant hearing aid procedure can be used for all hearing-impaired individuals because of the limitation of each method. The question arises as to which of the numerous methods available should one use to select the hearing aid for a patient.

MEED FOR THE STUDY:

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

AIM

To compare the NAL-R procedure with funtional speech measurement under three different conditions:

a) When the hearing aid output was "undershootting" the NAL-R target curve.

b) When the hearing aid output was "matching" the NAL-R target curve.

c) When the hearing aid output was "overshooting" the NAL-R target curve.

IMPLICATION

The results obtained would help us to decide, the use of prescriptive hearing aid selection with or without taking subjective measurements.

REVIEW

Numerous procedures have been advocated to accomplish the goal of prescribing an individual with hearing aids. These procedures are grossly divided into (Table 1).

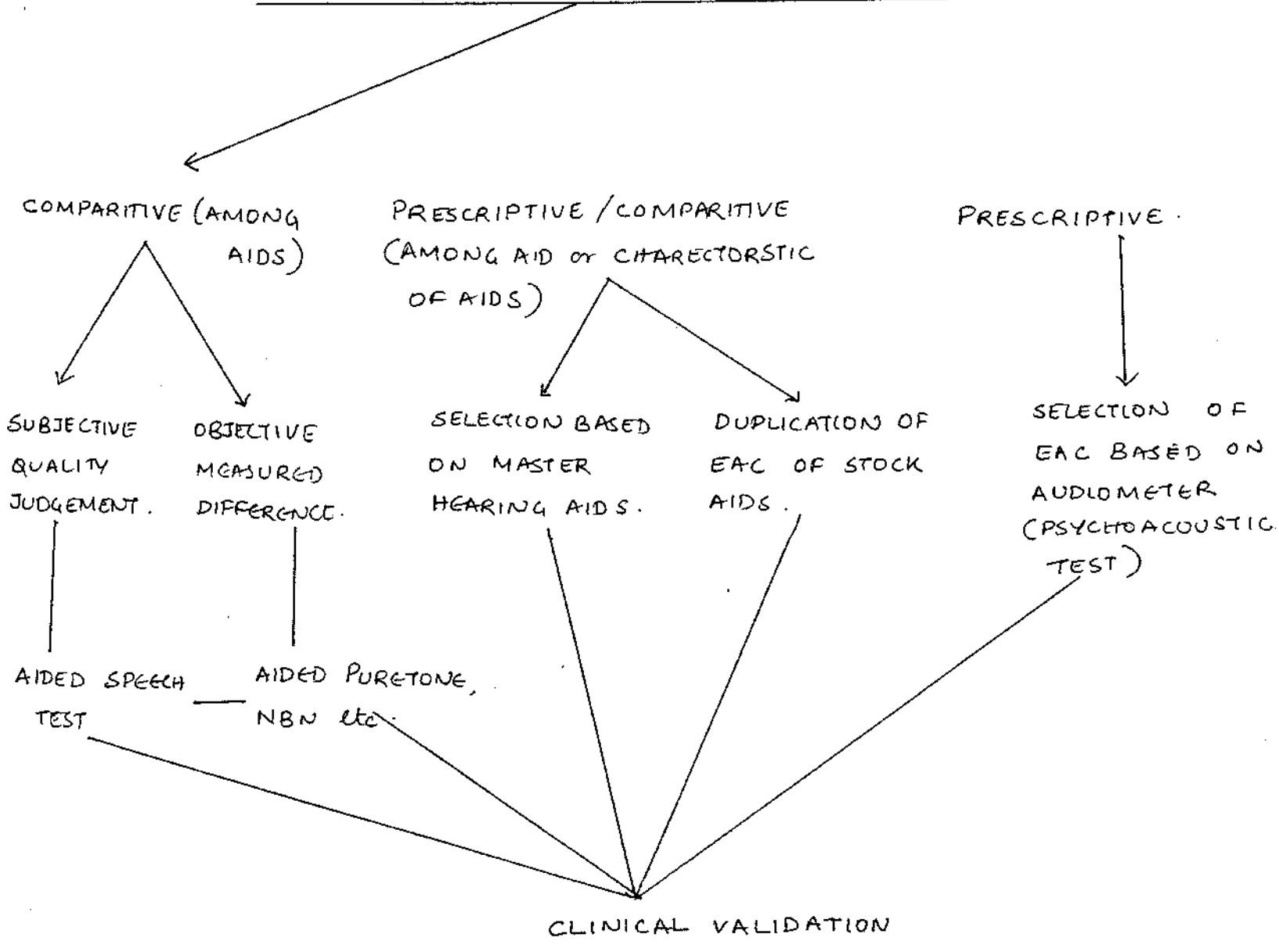
1) Comparative Procedure

a. Subjective
b. Speech Test
c. Real ear methods - it includes function gain measurement CFG) and Insertion gain (IG).

2) Prescriptive Procedure

3) Comparative - Prescriptive procedure

TABLE I : HEARING AID SELECTION PROCEDURES.



COMPARATIVE PROCEDURE

The fitting recommended by carhart (l946), typifies the comparative method. Here various stock aids are selected for an individual hearing aid trial, based upon known characteristic or upon experience of the clinician. The performance of the hearing impaired with the hearing aids are compared, and the one selected would be the device with the lowest aided threshold and highest on speech discrimination score. Selection can be solely based on subjective response or difference in sound clarity or guality among various aids. The subjective criterion would be the basis for selection of a specific hearing aid. Punch (l98l), gave advantages and disadvantages for this method ;-

Advantages :

a) It is capable of making functional judgement differentiation among various aids.

b) Procedure is reliable and varies minimally with stimulus type, type of listener (normal/hearing impaired, from individual to individual).

Drawbacks:

a) It is time consuming.

b) Small difference cannot be differentiated unless comparison of condition, setting or aids made with little or no time interval.

c) Quality judgement of the aids are highly subjective.
d) It requires the use of linguistic or speech material.
e) Electro acoustic characteristic (EAC) that influence the performance cannot be determined.
f) Differences in function can be measured, but the reason for these difference cannot be ascertained definitely.

1) SUBJECTIVE METHOD :

In this approach the listner makes some form of preference judgement based on perception of either sound quality or relative intelligibility of the hearing aid processed speech. This method is also known as the paired comparison method.

Advantages:

a) Instruction are relatively simple to explain and comprehend.
b) This method is reliable
c) Response is a simple binary decision as to which hearing aid in a gives fair produces the best quality or the most intelligible speech.
d) It varies minimally with stimulus type and type of listeners.

2) SPEECH BASED MEASUREMENT:

Interest in the development of an effective method of selecting an optimal amplification dates back to nearly fifty

years ago, when wearable hearing aids were being used. The search for an universally accepted approach to hearing aid selection continuous to be elusive. The optimum choice of frequency gain characteristic is likely to depend on interaction between the sound source, the transmission channel, the details of hearing loss and preferred listening level.

In the search for an effective hearing aid selection procedure, Carhart (1946) proposed what is essentialy a trial and error procedure using speech as the test signal. This approach was logical and simple that it rapidly became the procedure of choice. Speech discrimination tests used for hearing aid evaluation have changed little since the part world war II. Unfortunately speech reception threshold and speech discrimination score based test methods caused hearing aids with the greatest gain to appear best. These method resulted in overfitting of a hearing impaired individual.

McCandless and Lyregaard in 1983, gave the following factors to be considered while evaluating:

a) Speech intelligibility is not the only relevant property, sound quality may lead to the rejection of a hearing aid.

b) The statistical spread in the speech intelligibility score is fairly large. Hence, only large differences between hearing aids can be reliably assessed.

c) Speech tests are particularly time consuming if several hearing aid and adjustment were to be tested.

d) Although speech tests may indicate that the particular aid is not adequate, they are unable to indicate what modifications are required to improve the intelligibility.

e) Test variability is dependent upon the subjects true performance level as well as the test sample size. Test, retest variability for individual patient are to be obtained.

Bryne and Dillon (1986), used unfiltered speech (ie., prescribed response) and later compared it with each of four filtered condition (ie., response variation being low cut, low boost, high cut, high boost). The client response was to judge relative intelligibility. The aim of the study was to determine whether any of the comparison response were better than that of paired response. Results indicated that though 20% of the times they judged comparative procedure to be better, but the mean performance did not vary across various methods.

In a study done by Schwartz and Walden (1980), eight patients were evaluated with the same set of three hearing aids for a successive five days period. They reported that the day to day variability in word recognition score in noise was shown to fluctuate by as much as 30% in some patients.

While speech testing may indicate gross difference in hearing aids, the method is too insensitive to identify which electroacoustic characteristic are necessary to improve the results. Many studies have failed to demonstrate that a hearing aid can be chosen reliably or validly in clinical environment in a reasonable period of time using speech test results.

Hence from speech test alone one cannot modify the characteristic to improve the intelligibility of speech. Despite the lack of reliability it is still a widely used procedure, though search continues for an improved understanding of and control over the operating acoustic factor.

3) REAL EAR MEASUREMENT:

Real ear gain describes the change in hearing condition for the patient while wearing the hearing aid. This can be done by two methods: a) Functional gain (FG)

b) Insertion gain (IG) (Cole, 1975).

a) Functional gain:

This method was devised to assess the real ear frequency response directly. The condition was first described by Ramanov in 1942 and was later popularized by Pascoe in 1975. This method represents the actual amplification provided by a hearing aid compared to an unaided condition. In the unaided condition, all the head and body diffraction effects are

present, concha and ear canal are open and resonating. In aided condition, the head and body diffraction are seen.

Haskell 1987, described various advantages, disadvantages and limitation of the use of FG measurements:

Advantages:

a) It provides a frequency specific measure of hearing aid gain.

b) It has simple instrumentation.

c) It makes use of a wide range of stimuli.

d) It measures the behaviour threshold, and reflects what an individual actually hears.

e) It accounts for all the individual variables that can affect the real ear gain.

Disadvantages:

a) It is sensitive to artifacts from the noise floor of the test environment and internal noise from hearing aid itself.

b) It requires active subject participation which can be time consuming and can increase the variability.

c) Frequency specificity is often limited by stimulus available on standard audiometric equipment and time constraint with individual testing.

Limitations:

a) It provides information only at octaves or at best half octave interval.

b) It does not provide information about the hearing aid performance such as distortion, saturated sound pressure level (SSPL).

c) It can sometime provide an unrealistic estimate of the real ear gain of a hearing aid.

d) Masking is required for an individual with unilateral and asymmetrical hearing loss.

e) An invalid unaided/aided sound field threshold can result producing accurate FG.

The use of probe microphone has increased dramatically in recent years. It offers potential for listening to a wide range of frequencies while eliminating the variability of the human response in measuring the hearing aid performance.

Shift towards insertion gain using computerized probe microphone (CPM) measurement:

Hearing aid measures have undergone a great upheaval since Ramanov introduced the 2cc coupler in 1942. The 2cc coupler proved to be an accurate and reproducible device for comparing hearing aid performance. The results obtained with it can be processed to estimate insertion gain (IG) for a

typical average situation. It is not useful for measuring the effects of earmold venting because it lacks acoustic damping. The limitations was that the last 18mm had a 3mm bore which showed a greater performance in high frequency than the usual 2mm bore, Zwislocki (l97l), introduced the coupler for measuring insert earphone. Burkhard and Sachs in 1975, modified the Zwislocki coupler.

In an independent study done by Knowles in 1972, Burkhard and Sachs in 1975, recognised the limitation of the couplers and hence introduced KEMAR (Knowles Electronic Manikin for Acoustic Research). It represents an average adult and brought reality closer but did not provide reality itself.

Frye (1982), successfully combined digital technology with the 2cc coupler to provide valuable instrumentation. In recent years, greater use of wide band transducer and increased capability of earmold acoustic systems developed by Killion (1980), Libby (1982, 1984, 1985) have lead to the need for measurement of actual ear canal of the patient's. With the advent of CPM measurements, the frequency response of a hearing aid can be measured in the ear canal within a few seconds.

Ringdahl and Leijion (1984), reported that standard deviation of IG measurement using CPM measures were 4 dB less upto 4 KHz, which was considered acceptable for hearing aid fitting. They speculated that CPM has brought us to a step

closer to reality. This technique appeared to offer significant objective information on the effects of earcanal resonance, diffraction, body baffle effect, earmold occlusion, head shadow, and microphone placement in the earcanal of the hearing impaired persons.

Jerger (1986), stated that real ear gain measurement has advanced the course of hearing aid selection by revealing what is happening in the earcanal rather than in 2cc coupler. He demonstrated the effect of frequency response when characteristic of the hearing aid is changed. He however, added that a rational scheme for hearing aid selection would be to preselect from real ear measure and validate it by speech audiometry.

Mueller (1986), pointed that this technique is not a substitute for speech testing but rather a reliable alternative for functional gain testing. He felt that the equipment is an excellent educational tool in demonstrating both visually and aurally, the interaction of the hearing aid and hearing auditory mechanism.

Hence, one finds that though CPM measures are less time consuming, economical and easier to obtain frequency measures in few seconds, studies have indicated that CPM measure alone cannot give a proper hearing aid fitting to an individual. It has to be validated by speech audiometry. CPM can be used as a reliable alternative for functional testing.

There are generally two types of instrumentation and methods used for making ear canal probe measures:

a) Lauridson and Guentherson (l98l), used a method where a microphone is placed in the ear canal. This microphone has wide dynamic range, flat frequency response, and it fits easily into the ear canal of most adults.

b) Lauridson and Guntherson in 1981, modified the Weiner and Reiss 1946 method. They used a silicon probe tube that is placed in the ear canal. The tube is coupled to a measuring microphone which remains outside the ear. The probe tube occupies considerably less space within the ear canal than the probe microphone.

VARIABLES THAT AFFECT PROBE MEASUREMENT:

Though probe measures have increased dramatically in recent years, several investigators have described variables that might influence earcanal probe measures: (Tecca,Woodford 1987; Walden 1981; Tecca, Woodford, Kee 1987).

a) Unintentional venting that occurred upon repeated placement of the earmold and probe microphone can cause a short term deviation in the low frequency region, ranging from about 2.5 to 4 dB.

b) There is a difficulty in placing probe microphone for a subject having narrow or torturous ear canal.

c) A slight microphone or tube movement between unaided and aided condition increase the opportunity for such variables.

d) An alteration of earmold characteristic, presence of soft probe mic in the earcanal can affect the measurements.

e) Free field transfer function (external ear effect) should match the receiver and tube resonance for accurate insertion gain measurement (Teeca and Kee, 1987).

Tecca, Woodford and Kee (1987) reported measures of the differences served on repeated measures of insertion gain were exceedingly small, never exceeding 1 dB. The variability can be reduced by making multiple measures under each condition of a test session. This would allow easy identification of an error made on a given measure due to factors such as probe position or subject movement.

Hawkins and Mueller (1986) gave the following advantages and disadvantages of probe measurement.

Advantages:

a) It is an objective method.

b) The reliability is good on repeated testing.

c) It is a means of rapidly obtaining accurate results when assessing the performance in difficult to test patients.

d) All peaks and valleys are revealed because a sweep frequency tracing is possible.

e) They are not influenced by slope of an audiogram.

f) They are not contaminated by internal hearing aid noise.

g) It allows easy assessment of amplification on the poorer ear of the individual with unilateral or asymmetrical hearing loss. Need for masking the nontest ear is ruled out since both ear can be tested separately.

h) They do not require a use of audiometric room to obtain valid results.

i) They are more time efficient than behaviour methods.

j) They allow direct measurements of wearers frequency response.

k) It is an accurate method of determining whether over amplification is occurring or not.

1) It can detect effect of minimal hearing aid tone adjustment and ear mold modification.

n) Transfer formula as in coupler measurement are unnecessary.

These advantages are compelling only when the measurement obtained are an accurate reflection of real hearing aid performance.

Disadvantages:

a) There is no standardized instrument for measurement.

b) There is a likelihood of obtaining unreliable result and frequency response above 5 KHz.

c) In children, the mic or probe cannot be accommodated owing to small canal.

d) It is contradicted when a significant accumulation of cerumen is present in the ear canal.

e) The placement of probe tube in narrow and unusually curved ear canal can be difficult and time consuming.

f) The placement of the probe tube between the earmold and earcanal wall introduce a vent, which may significantly alter the low frequency results when occluding earmold or small vent are used (Pederson, 1984).

g) This vent can also cause acoustic feedback even before the described volume setting is reached.

h) A slight change in probe tube insertion depth can cause a large difference in the test results.

i) The passive cooperation of patient is required.

j) Profound hearing loss unaided threshold may be vibrotactile, hence the results may be misleading.

k) They do not measure hearing. They use little valve without valid hearing test result.

PROCEDURE FOR PROBE MICROPHONE MEASUREMENTS:

1) Stimulus type
2) Clinical consideration
   a) Prescription data
   b) Choice of test type
      i) Insitu gain
      ii) Insertion gain
   c) Choice of test method
      i) Substitution
      ii) Comparison
      iii) Pressure
      iv) Ipsi comparison method.

STIMULUS TYPE:

The test may be performed in the range of 125-8 KHz Usually 500 - 4 KHz is preferred. The test is administered in a free field conditions. Frequency modulated or narrow band noise is used instead of sinusoidal composite signals during the measurement. This signal consist of 80 frequencies presented all at once. This signal is shaped so that the spectrum level decrease at a rate of -6dB per octave, with a 3 dB down point of 900 Hz.

PRESCRIPTION DATA:

Audiological evaluation should be done initially in order to find the degree and type of hearing loss. Then using any one of the prescriptive procedures like Berger et al. (1980), NAL-R (Bryne and Dillon), POGO (Lyregaard, (1983) and Libby (1986) hearing aids are prescribed.

CHOICE OF TEST TYPE:

Real ear measurements can be classified into two main categories.

a) INSITU GAIN:

It refers to the hearing measurement performed on live ears or on KEMAR. This term describes hearing aid measurement in the natural or in use condition. The need for these measurement arises from the importance of including major acoustical variations of diffraction and ear canal resonances created by the human presence and the partial or total occlusion by the earmold. The diffraction of the body and head of a hearing aid wearer on incident sound can change the input sound pressure to a hearing aid microphone. The frequency response obtained with a hearing aid are distinguished by whether the unaided frequency response is included in the total response (insitu response) or substracted from the aided frequency response (insertion gain). Insertive mesurers are used to assess the sound

pressure developed by a hearing aid for a given free field input pressure.

Insitu gain measures the differences between the SPL of an hearing aid output at the ear drum of a patient and the SPL that exist at a defined external point. It is used in order to compare various types of hearing aids iasitu as a patient or on a KEMAR.

b) Insertion gain:

In order to express the performance of a hearing aid qualitatively, it is necesary to specify the reference condition to which the performance of any hearing aid may be compared and to specify the method for making such comparison.

The concept was introduced by AYERS in 1943 who stated that the measurement of hearing aid can be expressed as the amplification which it introduces in the air path to the listeners ear. Dalasgard and Dyrlundjunson 1976 stated that IG is the ratio of the sound pressure at a specified point in the ear canal of a treated ear to the sound pressure at the same point in the ear canal of the untreated ear.

The procedure measures sound with either a microphone placed in the ear canal or with a tube in canal which route the signal to the external microphone. Any of the prescriptive procedure like NAL-R, POGO or combination can be used to measure the actual insertion gain.

Uses of IG: [Teeca, Woodford, Kee (1987)]

The IG can be used to determine:

a) The gain of the hearing aid

b) To find the frequency response of hearing aid

c) To find the quality of frequency response

d) To find real ear SSPL 90

e) To find the acoustic modification effects

f) To find the difference between users gain and full on gain

g) To find the performance and comparison among aids

h) To find the electro acoustical adjustment.

Precaution for IG Measurement:

(Ringdahl and Leijion, 1984) gave the precaution for IG measurement

a) Prior to testing, the probe tube is checked for holes/blockage by wax. Ear canal are to be tested for wave or any kind of blockage.

b) Care should be taken while inserting the probe tube in the ear canal during unaided condition so as not to cause damage to the tympanic membrane.

c) During aided measurement, the ear mold should be fitted snuggly in the concha, so that low frequency leakage are minimized.

d) The case should be seated closly to the speaker, so that reflection and reverberation are minimized.

e) Head movements on the part of patient should be avoided.

f) Validity can be ensured by rechecking the measurement.

CHOICE OF TEST METHOD:

The test type use a reference point which differs for different application. IEC - 118 - 0 publication describes various position of the reference point [Madsen (1986)].

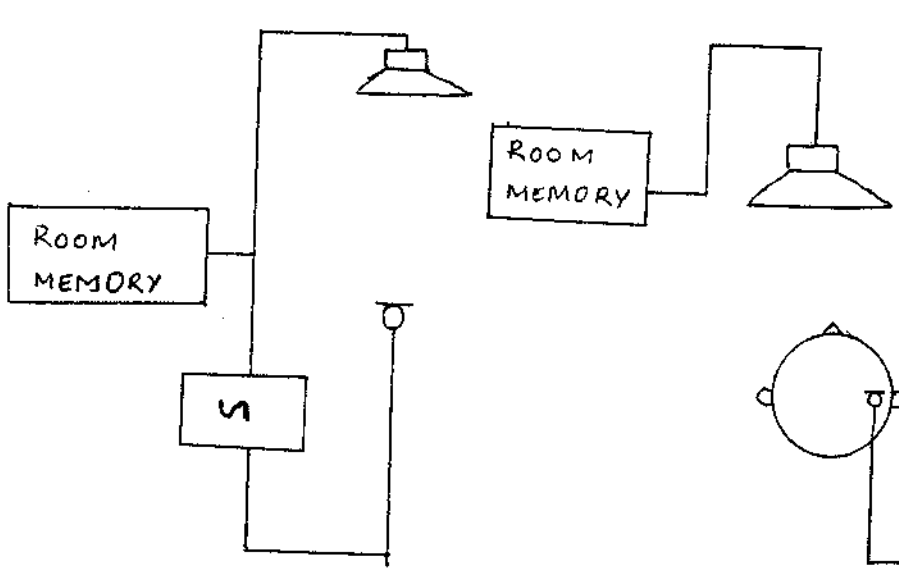
There are four type of test method;

a) Substitution
b) Comparison
c) Pressure method
d) Ipsilateral comparison method.

a) Substitution Method:

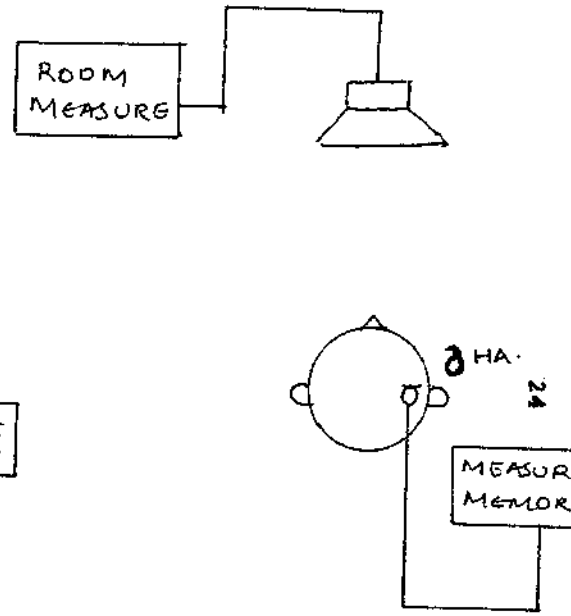
It is a method of measurement in which the test microphone and reference microphone employed to measure the free field sound pressure, are placed alternatively at the same point in the sound Field (Fig. a).

FIGURE a: SUBSTITUTION METHOD



(i) Room calibration without patient.

(ii) Unoccluded ear.



(iii) Occluded ear.

The limitation of the method are as follows:

a) It requires a memory medium for storage of room calibration and the unoccluded and occluded test results.

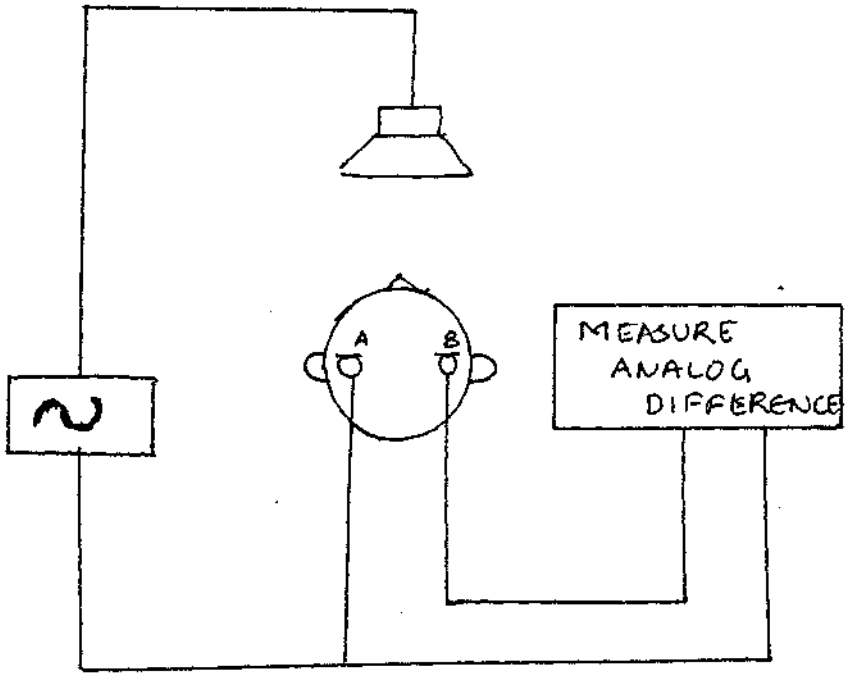
b) Ambient noise and patient movement will result in measurement error.

c) Methods required indentical measuring conditions during calibration and during testing measurements.

d) It does not exclude the extreme diffraction effects of patients body, head and of the hearing aid.

b) Comparison method:

It is a method of measurement in which the test microphone and reference microphone employed to measure the free field sound pressure, are placed simultaneously at two acoustically equivalent points in the sound field that is, in each of the two ear canals (Fig. b).



Advantages:

a) It is an online measuring method which continuously compensates for variation in ambient condition.

b) It excludes extreme diffraction effects of the body and head of the patient.

Disadvantages:

a) It requires completely symmetrically body and head shape and identical ear canal.

b) Head movement has considerable influence in producing measurement error.

c) Both reference and test ear has to be treated with probe tube.

d) It is inapplicable for insitu measurement because the reference point is in the ear canal.

PRESSURE METHOD:

It includes a constant input sound pressure level (SPL) which is controlled at the point of entry of ear canal in which the test microphone is situated. The constant controlled input SPL includes a calibrated reference microphone, thus eliminating distraction effects (Fig.C).

At one time it was suggested that the pressure method is more appropriately suffered to as the modified compression

method. It differs from the substitution and modified pressure method in the following ways:

a) There is no specification conducted with the patient absent.
b) A second regulating microphone is used to control the signal delivered from the speaker and to maintain the signal at constant level.

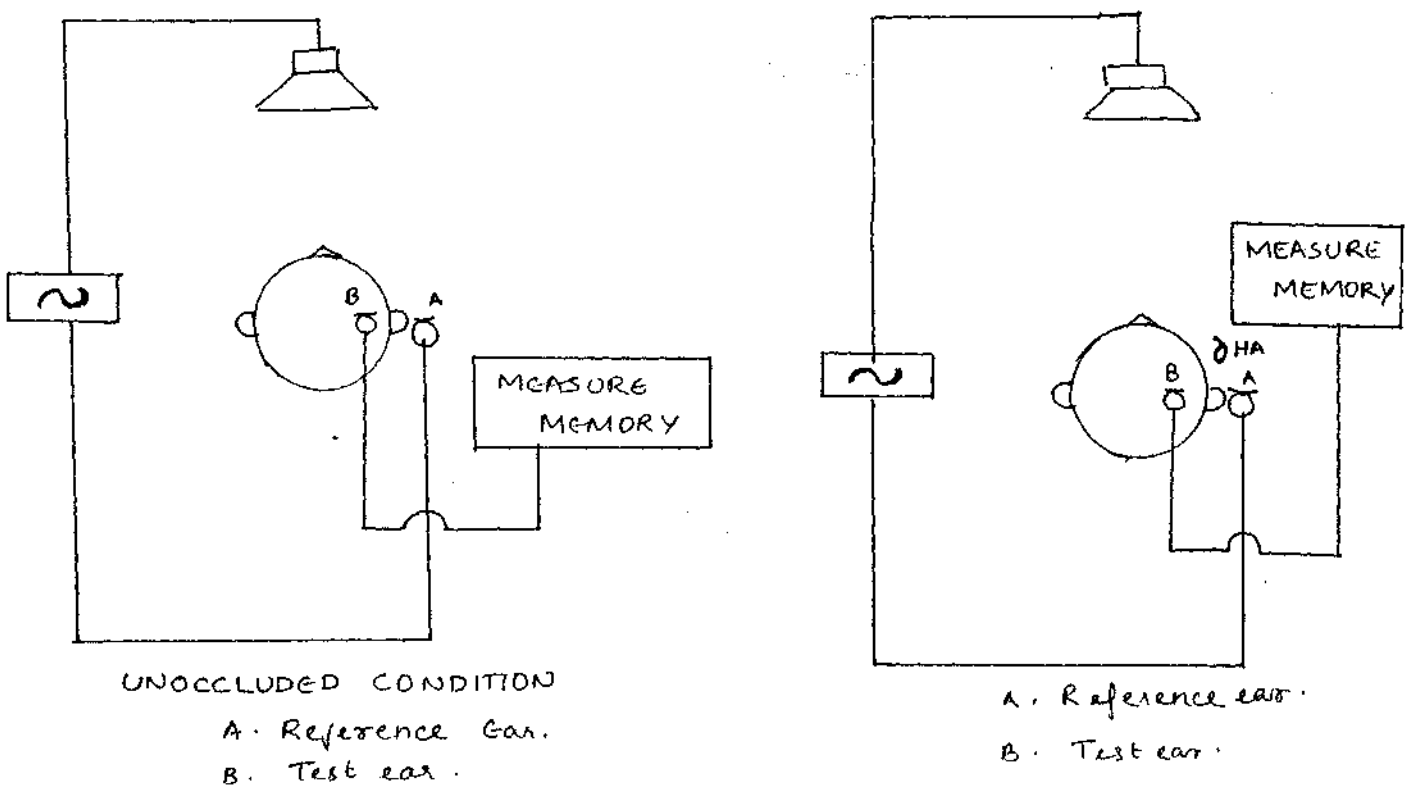
Advantages.

a) It eliminates the diffraction effect of the hearing aid, patients body and head.
b) It compemates for ambient noise and patients movements.

Disadvantage.

a) It require a memory medium to store the results.

FIG.C



UNOCCLUDED CONDITION
A. Reference Ear.
B. Test ear.

A. Reference ear.
B. Test ear.

IPSILATERAL COMPARISION METHOD:

It is a non standardized variation of comparison method. They are very similar except that in the IPSI-comparison method the test microphone and a fictive reference mic are placed simultaneously at the same acoustical paint in the sound field, that is at the same ear (Fig.D). This method avoids the fallacy that the two ears on a given subjects are identical.

Advantages:

a) It does not require completely symmetrical body, head shape and identical canal.

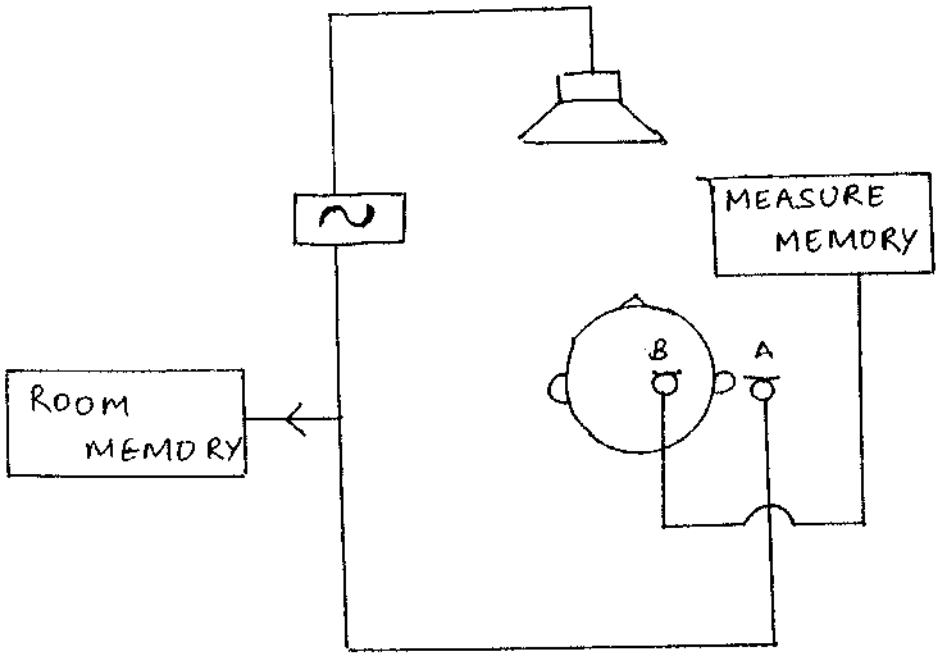
b) Head movement have only half the influence on the measurements error.

c) Only the test car has to be treated with a probetube.

d) It excludes extreme diffraction effect of the body and head of the patient.

All the measurements done would give the same IG results if the test condition (hearing aid, earmold, ambience that is sound transmission and the room) are completely linear which may not always be the care.

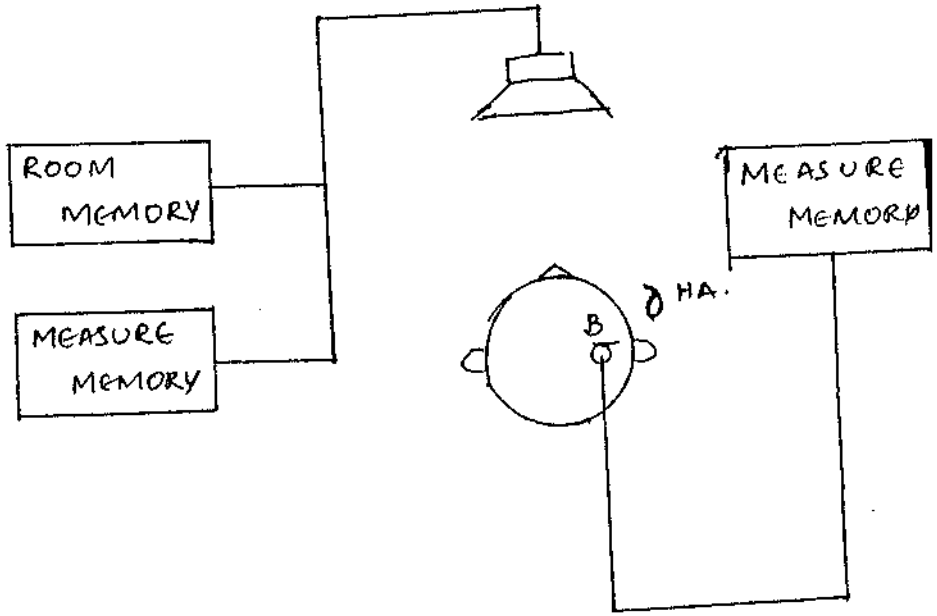
FIG: D



(i) Room Calibration and Unoccluded ear.

a) . Reference ear.

b) Test ear.



(ii) . Occluded ear.

A) Reference ear

B) Test ear.

STUDIES COMPARING FUNCTIONAL GAIN AND INSERTION GAIR:

Many studies have been conducted over past years to find a relationship between Functional Gain (FG) and Insertion Gain (IG) measurements. Some studies reveal that both IG and FG yield similar result, some indicate IG being better than FG and vice versa.

Studies conducted independently by various researchers Harford (1981), Mason and Popelka (1986), Dillon and Murray (1987), revealed that both IG and FG yield similar results and small difference were attributed due to difference in measuring methods.

Mason and Popelka in 1986, studied twelve subjects with sensory neural hearing loss for comparison of FG various IG. Results indicated that variability was reduced at 250 Hz, 500 Hz, 3 k and 4 kHz. At 6 kHz variability of probe tube contributed significantly. They concluded that probe tube measure (IG) and FG are resonable measure of real car gain and atleast one of them is necessary for accurate hearing aid measure.

Tecca and Woodford (1987), in their study on comparison of FG versus IG stated that under optional condition these methods should provide similar methods, as they are influence by earcanal sound presser level.

Zemplenyns, Dirk and Gilman (1985), who determined gain from coupler and FG measurement on fifteen subjects with

moderate sensory neural hearing loss. Results indicated that gain as measured with probe system agreed with FG measurement throughout 4 kHz. At a frequencies 5-6KHz, the probe measure under estimated gain particularly when compared to measurements conducted with earmold stimulates Other comparison was made between gain measured in a HA-2 coupler and FG. The average difference between these measurements of gain agree with previous investigation, but individual variation around the average difference was smaller than precisely separated.

Though various studies done support the use of both FG and IG, for hearing aid evaluations. Studies done by Tecca and Woodford in 1987, stated that many of the potential acoustic or behavioral problem of FG can be avoided by replacing it with electroacoustic methods.

Bryne and Dillon in 1986, stated that reliability of IG or SPL measured is better than that reported for FG measurement based on repeated sound field threshold that use Bekesy tracing procedure.

Tecca and Woodford in 1987, stated that though FG has a high level of face validity, it is believed that many of the potential acoustic behaviors problem of FG are avoided by replacing that psychoacoustic method with electroacoutic method.

Hence, studies done on the comparison of both the procedure yield almost same results except at few frequencies. It is now confirmed that for hearing aid evaluation both FG and IG or any one method in necessary, but if only coupler measurements is done, it should be often validated by functional measurement as it takes individual differences into consideration.

PRESCRIPTIVE PROCEDURE:

It involves a process of specifying optimum electroacoustic characteristic (EAC) prior to actual fitting, based solely an audiometric/psychoacoustic data. In this procedure it is assumed that the requirements for acoustic compensation of hearing loss can be correctly derived from measurements of the auditory system. Translation of these test results into required gain, saturated sound pressure level (SSPL), EAC is then made. If accurate and significant audiometric measures are obtained, high speech reception scares and patient satisfaction will results.

Advantage:

a) It holds promise as a method of choice in hearing aid evaluation, as specific auditory deficit can be quantified by test and measurable EAC can be calculated.

Limitations:

a) Lack of clear rationale for specifying optimum or 'best' gain and SSPL for specific hearing loss.

b) Absence of technique for accurately translating desired EAC into wearable hearing aid.

c) Lack of objective clinical criteria to validate the prescriptive fitting with real ear measures.

THE CHOICE OF PRESCRIPTIVE PROCEDURES AVAILABLE ARE:

1) MIRRORING OF THE AUDIOGRAM:

West(l93o), gave this approach which was based on having the frequency gain characteristic of a hearing aid mirror the hearing loss as indicated on a puretone audiogram. This procedure, works well with conductive hearing loss. However, a person with recruitment senosory neural (SN) loss will not require the overall gain as indicated by the loss.

2) EQUAL LOUDNESS CONTOUR PROCEDURE:

Watson and Kundsen in 1940 proposed that optimum hearing aid performance could be obtained by amplifying the average level of speech to the most comfortable level (MCL) for a 1000 Hz tone for a hearing impaired subject. A loudness matching technique was used for determining the MCL at other specific significant frequencies (250Hz, 500Hz, 2Hz, 4KHz), thus obtaining the MCL contour with the 1KHz tone as a reference. The gain of the hearing aid was then determined by finding the difference between a subjects equal loundness contour and the normal auditory threshold.

3) BISECTION OF DYNAMIC RANGE

Wallenfels in 1967, gave this approach. In this approach the dynamic range is equal to the threshold of discomfort minus the speech reception threshold (SRT) or it is defined

as the threshold of discomfort at a specific frequency minus pure tone air-condition threshold at the same frequency.

At frequencies below 1KHz, the hearing level curve depended on the bisection line between 1KHz and 4KHz. If that slope of bisection was sleep, then the hearing level curve continued downwards with the same slope. If the slope was less than 8dB/octave, then the downward slope below 1KHz was fixed at 8 dB to 10 dB/octave. The limited gain suggested for frequencies below 1KHz, was to present upward spread of masking, in which the amplified low frequency component of speech or background noise could mask the high frequency component of speech i.e consonats for speech intelligibility.

4) SELECTION METHOD FOR SKISLOPE LOSS CASES:

For severe (ski-slope) high frequency loss, skinner 1976 suggested a frequency response in which there is no gain below 500Hz. Between 500 to 1.6KHz the average functional gain should mirror the audiogram and an average of 23 dB gain above 1.6KHz. He used 1/3 octave bands of noise for determining functional gain.

5) ZELNICK FORMULA:

In 1982, Zelnick suggested the following prescriptive formula :

(i) Average HAIC gain - MCL + 20dB - 65 dB + 10 dB.

(ii) Average HF gain = MCL + 20dB - 55 dB + 10 dB.

(iii) Reference test gain (RTG) = MCL + 20 dB + 55 dB.

The 20 dB was a correction factor to convert the MCL measured with the audiometer from dBHL to dBSPL.

The average intensity level of speech is 65 dB SPL (however some researcher consider the average level of speech as 60dB SPL). The average HAIC gain was based on measurement made at 500, 1K, 2KHz. The 10dB was added in the above formula so that the aid was not worn at full on gain, when the aid was adjusted to the preferred listening level (PLL) by the user.

The average high frequency gain (HF gain) and RTG were based on measurements made at 1KHz, 1.6KHz and 2.5KHz. The 10 dB was added to the average HF gain formula, so that the aid was not worn at the maximum setting of the volume control. In everyday use, the client can determine the gain setting of the aid in keeping with his/her needs and comfort. He recommended that the appropriate amplification selected should reflects the clients audiogram for frequencies from 250 Hz to 6KHz as the primary concern for selective amplification was to provide good audibility for speech sound. Amplification prescribed by half gain or one third gain rule fall short of providing adequate high frequency amplification for the high frequency consonant necessary for speech intelligibility.

6) LIBBY'S METHOD:

This method was given by Libby in 1985, who rejected the functional gain (FG) measurement. He stated that FG cannot be used effectively in patients who are unable to respond intelligently such as cases who are mentally retarded, aphasic and those with severe articulation disorders.

According to Libby, subjects with mild to moderate hearing loss, prefer a listening level close to one third of their hearing level. A correction of 5dB is made for 250 to 6KHz and 3dB for 500Hz. (Table 2)

Table 2: Formula by Libby (1985).

Frequency	Formula
250 Hz	1/3 HL-5
800 Hz	1/3 HL-3
1K Hz	1/3 HL
2K Hz	1/3 HL
3K Hz	1/3 HL
4K Hz	1/3 HL
6K Hz	1/3 HL-5

For individuals with a severe to profound hearing loss, one half to one third gain is used to reach the PLL of the subject. Like POGO, it is based on three paradigms i.e., preselection, implementation and verification and is measured

using probe tube microphone measure. After the person adapts, more gain is recommended.

7) SHAPIRO (1976):

This procedure utilizes MCL to determine the required hearing aid gain. Initially a persons pure tone thresholds were obtained. Following this MCL for narrow band noise (NBN) at 500 Hz, 1K, 2K, 3K and 4KHz, were measured. The desired user gain is calculated by subtracting 60dB from the MCL curve at each frequency, except at 500Hz, where the gain is 10 dB less than 1KHz. To each of these, a constant is added to find gain calculation.

Shapiro added 10 dB to ideal gain for each frequency to specify the maximum gain for the hearing aid. He also determined the UCL for NBN and specified that the SPL should not exceed the average UCL in sound pressure for NBN. No particular rule was described for 250Hz.

8) LYBARGER (1963):

This formula for 'operating gain' was based on the idea that average intensity of conversational speech was 65dBSPL at a one meter distance. Hearing aid gain was felt to be sufficient when the user's threshold was brought up to the speech range. This procedure was not only based on the speech spectrum, but also on his extensive experience in testing and manufacturing of hearing aids. With slight modification this procedure yields desired gain

characteristic very close to those designed for current hearing aid gain,

gain = Hearing level by AC/2.

The gain was calculated only at 500Hz, 1K, 2KHz. The average operating gain was obtained by obtaining 'mean' for these frequencies. A correction factor of -l0dB was done for binaural fitting. It was also given for conductive hearing loss.

Berger, Hafberg and Rane 1980 gave a modification for Lybarger one half gain formula. They recommended an increase in the operating gain especially at 1KHz and 2KHz. For the maximum gain, a±10 dB of reserve gain was necessary, depending on the microphone location.

9) BRAGG (1977):

His interest was to supply sufficient gain to an average speech signal to bring it within a subjects desired listering level.

The steps for calculation were:-

a) obtain a pure tone threshold for an individual; later obtain the MCL for 250Hz to 4KHz.

b) calculate the gain as a difference between the average speech spectrum and the MCL

The speech spectrum in dBSPL for different frequencies were:-

250Hz = 50dB	2KHz = 54dB
1KHz = 58dB	4KHz = 46dB

Since, the MCL is close to the intersetting line between pure tone and UCL, gain can be calculated by inferring MCL. The desired gain can be derived by obtaining the values one third above the pure tone threshold for frequencies below 1KHz and one half of those for frequencies above 1KHz.

10) BERGER, HAGBERG and RANE (1980):

They described a prescriptive scheme that multiplied the threshold at all the five test frequencies from 250 Hz through 4 KHz by each of the following values ie., 0.45, 0.5, 0.625 and 0.5 respectively. Different rules were generated by using loudness discomfort level (LDL) in order to limit the maximum gain.

They specified all the values in dBSPL and indicated that the maximum SPL at 250 Hz should be less than 6 dB at 500 Hz. There is a 20 dB reduction in upper limit at 250 Hz relative to 500 Hz because all the analysis had been done at dBHL rather than dBSPL. Hence, 14 dB difference in SPL is needed for audiometric zero at 250 Hz and 500 Hz.

11) CID:

Pascoe (1975), gave this method where the real ear gain requirement are derived by measuring the pure tone threshold

were predicted with the following equations as described in Table 3.

Table 3: Cox MSU procedure formula (1983).

Frequency	Formula	Correction
250 Hz	0.37 (HL in dBSPL) + 85	- 1.0
500 Hz	0.25 (HL in dBSPL) + 83	- 1.0
800 Hz	0.45 (HL in dBSPL) + 73	- 1.5
1 KHz	0.44 (HL in dBSPL) + 71	- 1.0
1.6 KHz	0.41 (HL in dBSPL) + 69	- 1.0
2.5 KHz	0.37 (HL in dBSPL) + 69	- 4.5
4 KHz	0.39 (HL in dBSPL) + 68	- 6.0
6 KHz	0.39 (HL in dBSPL) + 68	- 3.0

The goal of the frequency/gain specification was to place the amplified speech spectrum in the middle of a clients long term listening range from 250 to 4 KHz. The long term listening range was conceptualized as the range of intensity level which are comfortable to hear (though not necessarily loud enough to understand) for an extended period of time.

Cox (1988), created a target Real Ear Aided Response (REAR) with a speech spectrum as an input and the hearing aid was adjusted until it matched the target value (long term listening range).

and the range of comfortable loudness and discomfort levels. Functional gain is determined by finding the amount of gain necessary to amplify the speech spectrum into MCL.

The objective of this method was to amplify speech to level just below the MCL. Ju3t below MCL was defined as MCL minus 3 dB. They also recommended the prescribed gain at 250 Hz so as to amplify speech in that frequency region to a level midway between threshold and MCL.

12) COX (1983):

Cox (1983) advocated a procedure that had a goal of positioning the aided speech signal midway between the listners hearing threshold and UCL. The maximum level of aided speech signal were determined in this procedure by adding 12 dB to upper limit of the loudness comfortable level (ULCL). This procedure was called as the memphis emphasis state university (MSU) procedure.

He suggested that the term ULCL be changed to Highest Comfortable Level (HCL) to avoid confusion with UCL. In the Original MSU, it was necessary to obtain puretone and HCL to define long term listening range. In MSU 3 (1988), it was possible to have HCL predicted based on audiometric threshold. In both cases auditory thresholds were expressed in dBSPL rather than dBHL. If HCL values could not be obtained on a person due to his/her inability to make a reliable suprathreshold loudness judgement, then the values

13) DESIRED SENSATION LEVEL APPROACH (DSL):

Seewald (1992), described a different approach for selecting characteristic of hearing aid. In this procedure the amplified speech spectrum was determined at each frequency for all degree of SN hearing loss.

The hearing aid gain characteristic was chosen in such a way that the long term spectrum of speech was amplified to the DSL. With the speech spectrum output, the hearing aid setting is adjusted to match best with the target value.

This procedure can be implemented totally with probe microphone measurement and has appeared as a tool in fitting children with hearing impairment. Although, it is not an insertion gain approach, Seewald (1992), have calculated the Real Ear Insertion Gain (REIG) necessary for different hearing threshold to accomplish the goal. This procedure is easily computerized and as with Cox's (MSU) procedure, this approach can also be easily implemented.

14) POGO (PRESCRIPTION OF GAIN OUTPUT):

This procedure was developed by McCandless and Lyregaard (1983). This procedure was based on the philosophy that gain or frequency response and output limiting are the current essential characteristic to be specified in prescription of a hearing aid. Characteristics recommended should produce an amplitude pattern that is subjectively pleasant and that yield high speech intelligibility.

Many of the techniques of hearing aid fitting prior to the development of POGO were based on speech intelligibility and aided 3peech threshold comparison. But such a comparison was not feasible due to many reasons:

a) Sound quality and not just the speech intelligibility is an important property.

b) Those methods are based on speech threshold comparison, only large difference between the hearing aids can be reliably assessed.

c) Speech tests take a long time especially when there are several hearing aids and adjustments to be tested.

d) Though speech tests may adequately reject a hearing aid, they are unable to identify which electroacoustic characteristic may contribute to poor or good discrimination.

POGO is predominantly individualized to SN loss or sensory loss with recruitment. Additional gain is require for those with conductive hearing loss which is not yet provided for in the basic procedure.

POGO can be carried in three major steps:

Step 1: Based on the audiometric information the required characteristic gain and maximum power output (MPO) can be calculated by using the formula (Table 4).

Table 4: POGO REIG formula (McCandless and Lyregaard, 1983).

Frequency	a) Insertion gain
250 Hz	1/2 HTL - 10
500 Hz	1/2 HTL - 5
1 KHz	1/2 HTL
2 KHz	1/2 HTL
3 KHz	1/2 HTL
4 KHz	1/2 HTL

b) For maximum power output

$$MPO = \frac{UCL_{500} + UCL_{1000} + UCL_{2000}}{3}$$

a) For insertion gain:

Step 2: Implementation of the gain and MPO. This involves the selection and adjustment among the hearing aids available to the dispenser. The selection of the best hearing aid can be done in the following ways:

a) The required MPO, calculated using the formula, should be within the adjustment range of the individual.

b) Similarly, maximum insertion gain required in the region of 500 Hz and 2 KHz is determined and checked if it lies within the adjustment range of individual with permissible range of $\pm$10 dB reserve gain.

c) The required insertion frequency response is compared with the frequency response available for each aid.

The present available frequency response of hearing aids predominantly lies in the frequency range of 250 Hz - 2 KHz.

Step 3: This includes verification and acoustical performance. In this, the extent to which the required characteristic have been achieved, as the ear, is to be verified. This is utmost important, since the same hearing aid will have different characteristics on different ears due to anatomical variation. Thus, using a probe tube microphones, the insertion gain and MPO should be checked on every hearing impaired individual. Now with increasing importance being given to insertion gain measurements, the probe tube microphone should be made use of, rather than functional gain measurements. In case functional gain measurements are made, it should be compared with the insertion gain required. A deviation of $\pm$ 5 to 10 dB gain is permissible.

Schwartz, Lyregaard and Lundh (1988), modified P060 I to make the procedure applicable to severe hearing losses. The formula was altered to change gain when the hearing loss was greater than 65 dB. This procedure was called POGO II (Table 5).

Table:5 POGO II REIG formula Schwargch, Lyregaard and Lundh (1988).

Frequency	Insertion gain
250 Kz	1/2 HL + 1/2 (HL - 65) - 10
500 Kz	1/2 HL + 1/2 (HL - 65) - 5
1 KHz	1/2 HL + 1/2 (HL - 65)
2 KHz	1/2 HL + 1/2 (HL - 65)
3 KHz	1/2 HL + 1/2 (HL - 65)
4 KHz	1/2 HL + 1/2 (HL - 65)

The modification increases the gain by one half the amount, when the hearing loss exceeds 65 dBHL. To convert the POGO II values to full on 2 cm^3 coupler gain, correction values can be added (Table 6).

Table 6: POGO full on 2cc gain formula.

Frequency	Formula	ITE	BTE	Body
250 Hz	1/2 HL - 10	+ 7	7	3
500 Hz	1/2 HL - 5	+ 9	9	3
1K Hz	1/2 HL	+ 8	10	0
2K Hz	1/2 HL	+ 16	12	21
3K Hz	1/2 HL	+ 16	21	23
4K Hz	1/2 HL	+ 15	19	23

15) NATIONAL ACOUSTIC LABORATORY (NAL) PROCEDURE:

In 1976, Bryne and Tonnisson introduced the first version of the procedure developed at National Acoustic Laboratory (NAL) in Australia. It is a pure tone based procedure which does not require suprathreshold loudness judgements. The rationale behind the procedure was to amplify the long term spectrum of speech so that it is comfortably and equally loud across frequencies. The speech signal is shaped so that each frequency band contributes equally to its loudness.

In order to determine the desired gain, they examined the Preferred Sensation Level (PSL) data, as represented by MCL value minus threshold. They found that, for each 10 dB increase in loss, the PSL decreased by 5.6 dB. To compensate for overall 5.4 dB decrease of Sensation Level (SL) (ie., 10-5.6) for each 10 dB increase in hearing loss, the gain in their formula is increased by 4-6 dB. Thus producing a value quite close to 1/2 gain rule. Two sets of correction are then made, one for loudness difference across frequency and one for the shape of the long term speech spectrum.

The revised NAL formula for desired real ear insertion gain (REIG) at each of nine frequencies are shown in Table 7.

Table 7: NAL REIG formula for BTE and ITE.

Frequency	Formula [x = .05 (HL.5k + HLIK + HL_{2k})]
250 H2	x + .31 HL_{250} - 17
500	x + .31 HL_{500} - 8
750	x + .31 HL_{750} - 3
1k	x + .31 HL_{1K} + 1
1.5k	x + .31 $HL_{1.5K}$ + 1
2 k	x + .31 HL_{2K} - 1
3k	x + .31 HL_{3K} - 2
4k	x + .31 HL_{4K} - 2
6k	x + .31 HL_{5K} - 2

These formula yield the target insertion gain value for probe microphone measurements. Bryne and Dillon in 1986, gave a new procedure for selecting the gain and the frequency response of a hearing aid from pure tone thresholds. This procedure was developed as the earlier procedure (Bryne and Tonnison, 1976) did not meet the aim of amplifying all frequency bands of speech to equal loudness. The gain prescribed at the low frequency band was insufficient, relative to gain prescribed for both band to reach MCL with the same overall gain setting. This procedure also prescribe too much variation in frequency response for various slopes of audiogram. Hence in 1986, Bryne and Dillon gave a revised version of NAL.

NAL procedure also yield the predicted full on 2 cm^3 coupler gain that should produce the described REIG for the average person when 15 dB of reserve gain is left. (Table 8).

Table 8: NAL full on 2cc gain formula.

Frequency	Formula	BTE	ITL
250	$X + .31\ HL_{250}$	+ 1	- 1
500	$X + .31\ HL_{500}$	+ 9	+ 9
750	$X + .31\ HL_{750}$	+ 12	+ 13
1k	$X + .31\ HL_{1K}$	+ 16	+ 14
1.5k	$X + .31\ HL_{1.5K}$	+ 13	+ 14
2 k	$X + .31\ HL_{2K}$	+ 15	+ 14
3k	$X + .31\ HL_{3K}$	+ 22	+ 15
4k	$X + .31\ HL_{4K}$	+ 15	+ 13
6k	$X + .31\ HL_{5K}$	+ 12	+ 4

$$[x = .05(HL._{5K} + HL_{1K} + HL_{2K})]$$

The desired REIG is same for BTE and ITE but different 2 cm^3 coupler value are needed to produce the same REIG.

The NAL procedure is a careful approach with some validation data. Bryne and Cotton 1988, compared the NAL procedure to variety of frequency response that represented deviation from the desired responses. In nearly all cases, individuals with impaired hearing preferred NAL response in terms of speech intelligibility and pleastness of sound quality.

Bryne, Parkinsons and Newall (1990), recommended that the formula can be used for SN loss (severe cases). Two specific modification to the original NAL was suggested.

a) The X factor in the equation is increased if the three frequency average exceeds 60 dB. The following is added to the "X" portion of the NAL equation when the sum of the threshold at 500 Hz, 1KHz and 2KHz exceeds 180 dB.

$$0.116\ (X - 180)$$

X = combined total of HL at 500 Hz, 1KHz, 2 KHz

b) Change in gain at low and high frequencies if the degree of hearing loss at 2 KHz exceeds 90 dBHL (Table 9).

Table 9 : NAL - R REIG formula.

HL (dBHL) at 2 KHz	.25	.5	.75	1	1.5	2	3	4	6
				(Frequency in Hz)					
95	4	3	1	0	-1	-2	-2	-2	-2
100	6	4	2	0	-2	-3	-3	-3	-3
105	8	5	2	0	-3	-5	-5	-5	-5
110	11	7	3	0	-3	-6	-6	-6	-6
115	13	8	4	0	-4	-8	-8	-8	-8
125	15	9	4	0	-5	-9	-9	-9	-9

Limitation of NAL:

1) It is used only for severe SN hearing loss. It could not be used for mixed or profound loss.

A study done by Bryne and Tonnisson 1986, showed that subjects prefer a listening level closer to 1⁄3 hearing threshold (HTL level) using NAL which is significantly less than the 1⁄2 gain rule recommended by most prescriptive procedure. Severe to profound hearing loss cases may require a gain close to 1⁄2 HTL.

COMPARISON OF NAL WITH OTHER PROCEDURES:

In a study conducted by Brooks and Chetty, 1985, two different approaches of hearing aid selection were evaluated ie., NAL (Bryne and Tonnisson, 1976), and frequency response selection developed by Siemens (1985). Initially target hearing aid frequency response was derived on theoretical basis. After a period of 6 months, listening comfort was assessed by Siemes procedure. Results indicated that there was a good agreement between theoretical prescription (NAL) and the users judgement of best response. Hence, they concluded that as the two procedure concur so closely as to shape the frequency curve, it result in good use and high level satisfaction. The authors suggested that the Bryne and Tonnison formula is clinically practicable and satisfactory method of determining the amplification characteristic for the first time hearing aid candidate.

Rankovic (1991) applied the Articulation Index (AI) model to the fitting of linear amplification in twelve subjects with sensory neural hearing loss, HE compared the amplification characteristic specified by NAL-R (Bryne and

Dillon (1986) and POGO (McCandless and Lyregaard, 1983) prescription, as well as a procedure that attempted to maximize the AI. Results indicated that POGO prescription made the average speech spectrum more audible than the NAL-R prescription for all, subjects. Further, they also reported that the frequency gain characteristic that maximized the audibility of the speech spectra required more gain than neither the NAL and POGO prescription.

Sullivan et al.(l988),examined the performance difference among various prescriptive hearing aid selection methods. The 4 prescriptive method used were: a) Lybayer's half gain rule (1963), b) NAL (Bryne and Tonnisson 1976), c) Skinners et al, CID, MCL based method (1982), d) Levit's et al adaptive protocol (1987). He concluded that the response prescribed by the original NAL method resulted in a score that was significantly better than there obtained with other three methods.

Humes and Hackett (l990),compared the speech reception results from 12 listeners wearing hearing aids. The hearing aids were adjusted to optimize to match between measured IG and that prescribed by NAL-R, POGO II, MSU - R method. They found a significant difference among the prescribed frequency response, but not in obtained frequency response. The greatest disparity observed was at 4 KHz for most of the cases. It was not observed for listeners with steep sloping hearing loss. For the case with steep sloping hearing loss,

the obtained gain was less than the prescribed gain. Similar findings were reported by Cox and Alexander in 1990.

Mueller (1990), compared various prescriptive procedure and stated that:

a) The (Berger, et al., 1986) procedure recommends excessive gain at 2 KHz relative to 500 Hz.

b) The (Pascoe, 1975) procedure may prescribe slightly too much gain, at 500 Hz and the overall gain needed to be reduced.

c) The POGO (McCandless and Lyregaard, 1983) procedure prescribed an excessive gain at 2 KHz compared to 500 Hz for steeply sloping hearing loss.

d) The NAL procedure (Bryne and Tonnisson, 1976) has less low frequency gain than Pascoe and Cox procedure due to the different speech pattern that were used.

e) The (Cox, 1983) procedure may prescribe inadequate gain in order to make speech spectrum comfortably loud across frequency.

f) The (Libby, 1985) procedure prescribed the least amount of gain and gain varied as a function of audiogram slope less than the other procedures.

He concluded that the gain prescribed by and of the current prescriptive procedures may need to be altered for a given hearing impaired individual.

Bratt and Sameth (1991) selected 35 sensory neural loss cases to display the relationship among 2 cm^3 coupler gain, the REIG and the NAL prescriptive target. They found that too much gain was provided in the low and mid frequencies and too little gain was present and high frequencies. When NAL was compared to REIG, greater deviation from the target occurred at 3 KHz and above. They also compared this with other prescriptive procedures such as the POGO and MSU. The fitting error was similar for all the three methods in the low and mid frequencies, however at 3 KHz and 4 KHz the fitting error for the POGO method was higher (5 dB) than that obtained by NAL. This suggests that the POGO targets are higher than the NAL target at 3 KHz and 4 KHz when a downward and sloping hearing loss is present.

They concluded that although these deviations from the target are greater, the target values are only a starting point and may need to be altered based on speech testing and subjective response from the hearing aid user.

Green, Day and Bamford (1989) studied 49 subjects who met the following criteria of loss: a) the hearing loss was either mild, moderate, severe loss, b) the configuration of loss was flat, sloping or irregular and c) young and old subjects. The aim of this study was to examine the efficacy

of a number of commonly used hearing aid selection procedure. The 4 procedures compared were: i) NAL, (Bryne and Tonnisson,1976) ii) Bergers method (1986), iii) a fixed method of selection in which all patient receive an aid with a +6 dB/octave frequency, response scope and iv) fixed method of selection in which an aid is selected based on assessment and interview by an experienced clinician.

The results indicated that the prescriptive procedure was better prescriptive than the fixed or intutive method. The effect of selection procedure on benefit was little influenced by degree of hearing loss but considerably influences by configuration of loss. For patient with gently to steep sloping hearing loss, the prescriptive method by selection were shown to provide more benefit than the others.

A study conducted by the same authors in 1989, on quality judgement by hearing aid wearers were used to compare hearing aid frequency response selected by 4 different hearing aid selection procedure. Results indicated that quality judgement did not appear significantly to be influenced by the fitting procedure. The only factor that influenced the results was the order in which the patient listened to the aids. The second aid was always preferred.

By looking into the various studies done, we can say that the original NAL (Bryne and Tonnison) method seems to be superior method as it takes subjective response too.

In general, it had been noted that prescriptive methods tends to produce superior result as compared to alternative methods for a given subject and listening condition. This agrees as the prescriptive measures tends to be more objective than other measures of hearing aid selection.

According to Green (1988), selection of hearing aid though initially be based on prescriptive procedure, it should be confirmed subsequently be functional measurement, as the prescriptive procedure do not take individual difference into account.

COMPARATIVE PRESCRIPTIVE PROCEDURE:

It is currently practised technique. In this process, the hearing aid models are recommended based on comparative test (speech are used to elicit a subjective response). A second prescriptive step is to specify a set of optimum EAC which are to be integrated in the patients with the help of master hearing aid setting.

METHODOLOGY

SUBJECTS:

Eleven subjects including ten males and one female were selected for the study. The subjects fulfilled the following criteria.

a) All the subjects had sensory neural hearing loss with the degree varying from moderate to moderately severe.

b) All the subjects had speech identification scores above sixty five percent.

c) The imitance audiometry revealed no middle ear pathology.

d) All the subjects underwent an ENT check up to further rule out the presence of any external or middle ear problem.

e) All the subjects were Kannada speakers.

f) All the patients were required to have custom made earmolds.

INSTRUMENTATION:

The following instruments were used for the study:

a) The FONIX 6500-C, hearing aid test system was used to perform the real ear measurement. The instrument was calibrated as per the instruction given in the operation manual (Appendix-I).

b) The clinical audiometer Madsen 0B822 with matching speakers was used for performing speech audiometry. The instrument was calibrated as per ANSI S3-6 1989 standards (Appendix-Ill).

c) A moderate gain hearing aid (Elkon BM-79) is used for the study. The electro acoustic properties of the hearing aid which were measured using FONIX 6500-C in accordance with the IS standards (ISO 84).

TEST ENVIRONMENT:

Both the probe measurements and the speech audiometry were carried out in sound treated room, where the ambient noise level were 18 dB and 38 dB respectively for Madsen OB822 and IGO rooms. These noise were within permissible limits (ISO 91).

TEST SIGNAL:

For the probe measurements a composite signal were presented through the loudspeaker at an intensity of 70 dBSPL.

TEST MATERIAL FOR SPEECH:

Everyday sentences and paired words in Kannada, which were developed in the department of Audiology, All India Institute of Speech and Hearing, were used for the audiometric Speech Test. There were five lists in the test

material. Each of the lists had five everyday sentenses and five paired words (Appendix-IV).

TEST PROCEDURE:

I For real ear measurements:

Premeasurement procedure:

i) The leveling of the instrument FONIX 6500-C was carried out prior to the measurement (Appendix II).

ii) The audiometric data was fed and the target gain was obtained using the NAL-R formula given by Bryne and Dillion (1986) (Appendix-V).

iii) The subjects were seated twelve inches from the loudspeakers. The loudspeakers were placed at a 45°C azimuth relative to the patients. The head band was secured above the ears and the ear hanger was placed around the ear to be tested. The reference microphone was placed firmly over the head band.

iv) The probe tube was placed in the ear of the subject such that it extends 5mm beyond the ear canal portion of their earmold.

v) The patient was instructed to look straight and not to move or talk until the test was complete.

Probe Measurements: The following steps were carried out to obtain the real ear probe measurements.

i) Initially, the Real Ear Unaided Response (REUR) was measured. This response gave the information regarding the ear canal resonances.

ii) The ear mold was then placed along with the probe tube and the hearing aid was switched on, and Real Ear Aided Response (REAR) was obtained.

iii) The Real Ear Insertion Gain (REIG) was determined automatically by the instrument.

iv) The tone and the volume control of the hearing aid were adjusted such that:

a) The Insertion Gain (IG) curve matched the target gain curve in the speech frequencies.
b) The IG curve was undershooting the target gain curve by about 5-10dB in the speech frequencies.
c) The IG curve was overshooting the target gain curve by about 5-10 dB in the speech frequencies.

The setting of the tone and volume controls were noted in the above conditions.

Precautions taken while carrying out the probe tube measurements:

a) Head movements on the part of the patient were avoided as these might affect the measurement.

b) A constant insertion depth of the probe tube was maintained throughout the measurement for each case.

c) Care was taken to ensure that the loudspeakers azimuth was maintained at 45°.

d) During the REUR measurement, negative values were obtained whenever the probe tip was directly against the wall of the earcanal. Reinsertion or removal of the crimp was done to solve this problem.

e) During the REAR, it was ensured that the earmold fitted snugly in the concha, so that the low frequency leakage was minimized.

II) PROCEDURE FOR SPEECH AUDIOMETRY:

The subjects was seated one meter away from the loudspeaker, which was placed at a 45° azimuth. The speech material (every day sentenses and paired words) in Kannada were presented through the loudspeaker in the freefield condition using the clinical audiometer Madsen OB822. The speech signal were presented at 40-45 dBHL. The subject were instructed to answer the questions asked and repeat the paired words. The item was presented once to the subjects. If they answer wrongly the test item was repeated. The aided performance was assured at the different volume and tone settings obtained through various probe measurements and the scores were noted. For each correct response a score of two as assigned and score of one when the questions and the paired words were repeated.

RESULTS AND DISCUSSION

The aim of the study conducted was to compare the prescriptive procedure NAL-R (Bryne and Dillon 1986) with functional gain speech test. For the aim to be verified, the data was statistically analyzed using the nonparameteric t-test (Garret 1966).

The results obtained are indicated in the tables given be1ow:

Table 10: Mean standard deviation (SD) and range for sentences at different hearing aid volume setting.

Hearing aid volume setting	Mean (Maximum Score=10)	SD	Range
undershooting target curves	4.909	2.862	0 - 8
Matching target curve	8.818	1.740	4 - 10
Overshooting target curve	9.636	0.881	7 - 10

Table 11: Mean standard deviation (SD) and range for period wards at different hearing aid volume setting.

Hearing aid volume setting	Mean (Maximum score=10)	SB	Range
undershooting target curves	4.363	2.77	0 - 9
Matching target curve	7.327	2.03	4 - 10
Overshooting target curve	8.818	1.69	5 - 10

Table 12: Significant of difference between means for different volume control setting

Hearing aid volume setting	Sentence	Paired word
undershooting with matching curves	* - 3.70	* - 3.11
Undershooting with overshooting curve	* - 4.13	* - 4.95
Overshooting with matching curve	3.08	1.63

* Statistically significant at 0.01 level.

Results of 't' test suggested that:

a) There was a statistically significant difference between the scares obtained when the output of the hearing aid was undershooting and when matched the NAL-R target curve for both sentence and paired words.

b) There was a statistically significant difference between the scores obtained when the output of the hearing aid was undershooting and when overshooting the NAL-R target curve for both sentences and paired words.

c) There is no statistically significant difference between the scores obtained when the output of the hearing aid is matched and overshooting NAL-R target curve for both sentence and paired words.

Hence, the above data can be interpreted that if a hearing aid gain is undershooting the target curve NAL-R then

speech scores obtained were poor. However, 100% scores curve not obtained even when the aid was matched with target gain. seven out of the eleven subjects had a score above six. When the aid was overshooting the target curve, the scores obtained were better than these obtained for matched target gain.

The results obtained in the study were in accordance with a study by Rankovic (1991). NAL required lesser gain from the heairng by aids than the POGO procedure. The frequency gain characteristic that maximized audibility of speech spectrum requires more gain. It was also found in the present study that with increase in gain the subjects performance on the Speech test improved though not significantly.

Therefore, the present study done using the Indian language also suggest that there is a need for higher gain than that prescribed by NAL for better performance of speech.

SUMMARY AND CONCLUSION

An experimental study was conducted in order to compare the NAL-R (Bryne and Dillon, 1986) with functional speech tests. The speech-tests used were every day sentences and paired words in Kannada. These were done on eleven adults who had bilateral moderate to moderately severe sensory neural hearing loss. Their speech intelligibility scores were above 65%.

The functional speech measures were done under the following conditions:

a) When the hearing aid output was "undershooting" the NAL-R target curve.

b) When the hearing aid output was "matching" the NAL-R target curve.

c) When the hearing aid output was "overshooting" the NAL-R target curve.

The data was subjected to statistical analysis, using the non-parametric -t-test (Garrett 1966) it was concluded that:

a) There was a significant difference in the speech performance of the subjects when the gain of the hearing aid was undershooting and when the gain was matched with the target gain.

b) There is no significant difference in the speech performance of the subjects, when the gain of the hearing aid was matched and when the gain was overshooting the prescribed target gain.

Therefore, the present study suggests that there is a need for higher gain than that prescribed by NAL for better performance of speech. This finding is in concurrence with the finding of Rankovic (1991).

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APPENDIX - I

CALIBRATION OF THE QUICK PROBE II OF THE FONIX 6500-C HEARING AID TEST SYSTEM.

The calibration was carried out as per the procedure described below.

Instruments required : Sound level calibrator (Quest CA-12), 14mm to 1 inch adaptor, probe microphone calibrator adaptor and the calibration clip.

Procedure:

The sound level calibrator's battery was initially checked. Following this, a 14mm - to 1 inch adaptor was put into the calibrator and the reference microphone was inserted into it. To calibrate the reference microphone, the measured microphone amplitude was compared to the intensity of signal picked up by the reference microphone. If the intensity of the reference microphone was not within 1dB of the calibration value, (110 for quest CA-12) the gain of the reference microphone was adjusted with a small screwdriver using the control marked 'REFERENCE' on the bottom of the quick-probe module.

To calibrate the probe microphone, the reference microphone was removed from the calibrator and the probe microphone adaptor was inserted. The probe tube was fully inserted into the calibrator adaptor. It was checked to make

certain that nothing was clogging the probe tube, and that it was properly connected to the body of the probe microphone The measured microphone amplitude was compared with the intensity of the calibrator level. If the value of the probe amplitude was significantly below the calibration level (110 for quest CA-12), it was checked to see that the probe tube has gone all the way into the adaptor. This was done by taking the probe calibrator adaptor out to check. If necessary, the gain of the probe microphone was adjusted with a small screw driver using the control marked "PROBE" on the bottom of the remote module. Using the above procedure, calibration was done for the reference and probe microphones of the Fonix 6500C.

Calibrating the sound field loudspeaker of FONIX-6500C:

The subject wearing the headband was seated in the proper position near the loud speaker.

The reference microphone and the probe microphone were combined with the calibration clip. The tip of the probe was kept at the centre of the grid of the reference microphone. Both microphones were positioned on the headband just above the ear nearest to the loudspeaker. The test signal was turned on. The RMS source SPL was compared to the RMS OUTSPL.If the level were with in 3dB of each other,the calibration was correct. When the difference was greater than 3dB, the adjustment for the loudspeaker on the back

panel of the main module was adjusted, until the RMS source and RMS OUT level were within 3dB of each other.

Appendix-II

Leveling (Automatic Adjustment of the loudspeaker Response) was done as per the instructions given below.

With the speaker, the reference microphone & probe tube in position, the 'level' button on the remote control was operated.

A composite tone at 69 dBSPL was presented from the speaker. Depending on the instrument location and the ambient noise, one of following three different leveling conditions resulted.

a) If leveling was achieved within 2dB in the frequencies between 600 & 5000 Hz, the word 'leveled' appeared on the screen. The measured response curve appeared in the lower graph. Probe testing was continued if the displayed curve was within the acceptable limits.

b) If the RMS amplitude of the reference microphone was not within 6 dB of the target, the screen showed the word unleveled.

Following this, it was checked to see if

i) The speaker was too close or too far away from the reference microphone.
ii) The microphones were unplugged and
iii) The calibration of the sound field speaker and the microphones were checked.

If still unsuccessful, the sound field environment was changed before trying the level again.

c) If leveling was attempted and neither 'leveled[1] nor 'unleveled' appeared in the message area, it meant that the present leveling compensation was some where between the conditions described in (a) and (b) above. The sound field conditions and the position of the reference microphone, were checked once again before leveling.

Appendix III

SPEECH AUDIOMETRY CALIBRATION

Loudspeaker output level calibration procedure:

The controls on the audiometer were set to the free field testing operation. The SPL meter (B&K 2209) was placed one meter away from the loudspeaker at a position where the subject's head is likely to be during the test situation. The speech noise was presented through the loudspeaker at 80 dBHL (ANSI-S3-26, 1989). The output from the audiometer to loudspeaker was monitored to zero on the VU meter. The SL meter was set to 'Linear scale' and the readings were taken. The internal calibration was carried out if the output of the loudspeaker did not match the recommended value as per ANSI-S3-26 (1989) standards.

Speech Output Level Calibration:

The controls on the audiometer were set for speech audiometry and intensity dial to 80dBHL. A l000Hz tone (calibrating tone) was introduced through the Microphone continuously. The input intensity level was adjusted until the VU meter was monitored to 'zero'. The output level from the SL meter with 'Linear setting' were noted and compared with the standards. If the discrepancy was more than + 2.5 dB between the observed values and recommended values, the internal calibration was done.

Linearity Check:

The intensity dial of the audiometer was set at the maximum level and the attenuator on the SLM was set at a level corresponding to the maximum level on the audiometer. The attenuator setting on the audiometer was decreased in 5 dB steps and the corresponding reading on the SLM was noted. For every decrease in the attenuator setting, the SLM indicated a corresponding reduction.

VU Meter Calibration Procedure:

A puretone was fed from the oscillator through the electronic switch to the input of the audiometer. The VU meter was monitored. A rapidly interrupted signal was produced by activating the electronic switch. The VU meter was again monitored to confirm whether there is any overshoot or undershoot with reference to the steady state signal.

Appendix IV

Test Items Used For Hearing Aid Selection

SET A

Every day questions

1. nimma ṭandeja hesaru e:nu?
2. ni:vu illige basalli baṇdra:?
3. ni:vu ra:ṭri eʃṭu gaṇṭege maluguṭira:?
4. nimma u:ru ja:vaḍu?
5. ni:vu beḷage e:nuṭiṇḍi ṭiṇḍri?

Paired words

1. be:ḷe-ka:lu
2. gaṇṭu-mu:ṭe
3. aṭṭa:-iṭṭa:
4. suṭṭa:-muṭṭa:
5. hola:-gaḍe

SET B

Every day questions

1. nimage eʃṭu varʃa?
2. nimma hesaru e:nu?
3. nimage ja:va kivijalli tʃanna:gi ke:lusuṭe?
4. ni:vu e:nu kelsa ma:ḍuṭira?
5. nimage ja:va ja:va baːʃe baruṭe:?

Paired words

1. kaʃta-suka
2. ta:ji-tande
3. anda-tʃanda
4. hotte-batte
5. nade-nudi

SET C

Every day questions

1. nimage eʃtu dzana akka tangijaru ida:re
2. i:ga gante eʃtu?
3. manejalli ja:va baːʃe ma:tanaduti:ra?
4. ni:vu e:nu o:didi:ra?
5. nimma manejalli eʃtu jana ida:re?

Paired words

1. ati-a:se
2. kappe-tʃippu
3. mane-mata
4. namma-nimma
5. guru-ʃiʃya

SET D

Every day questions

1. ni:vu belage e tu gantege eluti:ra?
2. nimage eʃtu dzana anna tammandiru ida:re?
3. ni:vu manege basalli ho:guti:ra, oto:dalli ho:guti:ra?
4. nimma mane ellide?
5. nimma dzote ja:ru bandidare:?

Paired words

1. tindi-ti:rta
2. alli-illi
3. sanna-putta
4. kanasu-nanasu
5. kallu-mannu

SET E

Every day questions

1. nimma ta:jina hesaru e:nu?
2. ivatu ja:vu va:ra?
3. ni:vu kofi atava ti: kuditi:ra?
4. ni:vu illige eʃtu gantege bandri?
5. nimage ja:va:galinda kivi ke:lusuta:illa:?

Paired words

1. mi:na-me:ʃa
2. betta-gudda
3. atta-itta
4. hetʃu-kammi
5. tʃinna-belli

APPENDIX - V

Table 7: NAL REIG formula for BTE and ITE.

Frequency	Formula [x = .05 ($HL_{.5K}$ + HL_{1K} + HL_{2K})]
250 H2	x + .31 HL_{250} - 17
500	x + .31 HL_{500} - 8
750	x + .31 HL_{750} - 3
1k	x + .31 HL_{1K} + 1
1.5k	x + .31 $HL_{1.5K}$ + 1
2 k	x + .31 HL_{2K} - 1
3k	x + .31 HL_{3K} – 2
4k	x + .31 HL_{4K} - 2
6k	x + .31 HL_{5K} - 2

Table 8: NAL full on 2cc gain formula.

Frequency	Formula	BTE	ITL
250	$X + .31\ HL_{250}$	+ 1	- 1
500	$X + .31\ HL_{500}$	+ 9	+ 9
750	$X + .31\ HL_{750}$	+ 12	+ 13
1k	$X + .31\ HL_{1K}$	+ 16	+ 14
1.5k	$X + .31\ HL_{1.5K}$	+ 13	+ 14
2 k	$X + .31\ HL_{2K}$	+ 15	+ 14
3k	$X + .31\ HL_{3K}$	+ 22	+ 15
4k	$X + .31\ HL_{4K}$	+ 15	+ 13
6k	$X + .31\ HL_{6K}$	+ 12	+ 4

$[x = .05(HL._{5K} + HL_{1K} + HL_{2K})]$

Table 9 : NAL - R REIG formula.

HL (dBHL) at 2 KHz	.25	.5	.75	1	1.5	2	3	4	6
				(Frequency in Hz)					
95	4	3	1	0	-1	-2	-2	-2	-2
100	6	4	2	0	-2	−3	-3	-3	-3
105	8	5	2	0	-3	-5	-5	-5	-5
110	11	7	3	0	-3	-6	-6	-6	-6
115	13	8	4	0	-4	-8	-8	-8	-8
125	15	9	4	0	-5	-9	-9	-9	-9