INSERTION GAIN MEASURMENT FOR HEARING AID SELECTION
AN AUDIO VISUAL PROGRAM FOR THE "CURIOUS"

Reg.NO.M9015

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"All the well wishers" especially

... to my parents, and

... to my guide

. . . who have - encouraged

me at every stage

CERTIFICATE

This is to certify that the Independent Project entitled: Insertion gain Measurement For Hearing Aid Selection-An Audio Visual Program For the "Curious" is the bonaf ide work in part fulfilment for M.sc., in Speech and Hearing, of the student with Reg. No.M9015.

Mysore

1991

Director -
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CERTIFICATE

This is to certify that the Independent Project entitled: Insertion Gain Measurement For Hearing Aid Selection-An Audio Visual Program For the "Curious" has been prepared under my supervision and guidance.

Mysore
1991

Dr.(Miss) S.Nikam.
Prof, and Head
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DECLARATION

This Independent Project entitled: Insertion Gain Measurement For Hearing Aid Selection-An Audio Visual Program for the "Curious" is the result of my own study undertaken under the guidance of Dr. (Miss) S.Nikam, Prof, and Head of the Department of 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.

1991. RegNo.M9015

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TABLE OF CONTENT

Chapters **Page No.**

INTRODUCTION

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

Lord Alfred Tennysen.

The advancement of hearing aids,miniaturisation end quality improvment in the field of hearing aids has not only led to more satisfaction on the part of the clinicians bat also more contentment on the part of the clinicians. Many hearing aid Manufacturing companies have coma up manufacturing different types of hearing aids of mild. modo-rate or strong categories. These hearing aids do not vary such from each other. yet the clinician faces lot of problems while making a selection of hearing aid which would best suit the person' s needs. For this purpose many prescriptive and comparative procedures have been put-forth by many technologists. Even after making use of these formulae for prescribing a wall fittig Nearing aid, when asked, a client would still Show some amount of dissatisfaction. Hence, many clinicians have started using the term prefered listening level(PLL) to conform the hearing aid to the user's satis-faction.

Lybarger(1944) was the first to recommend a prescrip-tive procedure which is commonly known as half gain rule. which brought in some amount of satisfaction to both the

clients and clinicians. Gradually lot of changes have taken place and many clinicians have recommended various formulae based on half gaia rule.

Thus these older and more crude methods were slowly and gradually modified to yield new, more advanced and more objective methods of selecting a hearing aid.

In the part, more stress was given to making 2cc coupler or Knowles electronics Manikin Acoustics Research (KEMAR) measurement but nOW importance has been given to only real ear measurements that is,making measurements of gain and sound pressure level on the individual' s ear. Real ear measurement involves calculating the real ear gain, either insertion gain or insitu gain using the various prescriptive formulae.

Formulating gain in this manner helps in selecting a hearing aid for an individual which is in accordance with his or her preferred listening level. As the above stated quotation goes 'old order changeth, yielding place to new...' all these old methods have gradually boon modified into newer and quicker means of selecting and fitting hearing aids.

The real ear measurements or probe tube microphone measurements has advanced into more objective computerised methods so that real ear probe tube microphone measurements for selecting the best hearing aid for an individual can be performed in a matter of few minutes, that too objectively.

Many computer manufacturing companies like Fonix, Madsen, Rastronics and others have come into being and they manufacture computerised systems with the best technology available to meet the evergrowing problems in the field of hearing aid selection. These computers have been bestowed with the capacity to make real ear measurement, insertion gain as well as insitu gain measurements, select the appropriate aid for a person based on prescriptive procedures.

PURPOSE:

The purpose of doing a study on the literature available regarding insertion gain measurements is to make the "curious" especially the students, aware of what real ear measurements are ,its advantage over coupler or manikin measurements and also throw light on insertion gain measurements and its merits over other types of testprocedures.

This will help the students, to perform real ear measurements on patients who have to be prescribed with a hearing

aid, more confidently and with grater accuracy within a short period of time. This project also attempts to give a clear picture about what the external ear effects are, how they influence the real ear mesurements and also about what happens when there are external ear deformities.

EXTERNAL EAR

AN INTRODUCTION:

When a sound source is located at a great distance from us and is also not parsimonious to the direction in which we ara standing, most of us have had the experience of capping hands behind the pinna - only to direct sounds into the ear canal. This mechanism of "cupping" allows greater range of intense hearing.

To be precise, the external ear cannot be overlooked with respect to its contribution to better hearing.

Only mammals have pinnae, and yet there are lot of modifications across various manuals. In all the inverte-brates and most vertebrates the pinna is completely absent or often it is reduced to a small hole as in birds and reptiles.

In lower mammals, the flange may be mobile. Most often, it has been investigated that only animals with relatively low frequency hearing may have mobile pinnae. In human beings, mobility is restricted because of the absence of any useful muscles. These immobile pinnae help in localising high frequency sounds and channelising the sounds towards the external auditory meatus.

Moreover, the size and shape of pinna is related to the wavelength of sounds that human beings can hear. Not only that, the sounds and noises originating in front can be distinguished from the sounds arising at the back-solely due to the pinna. Familiar voices could be discriminated from unfamiliar voices. Without damaging our ears, we are able to hear a very very intense sound as also a very faint sound.

A PEEP INTO THE ANATOMY AND PHYSIOLOGY OF THE EXTERNAL EAR

The external ear is composed of auricle or pinna or flange and external auditory meatus or canal.

AURICILE_ is a flap like cartilagenous structure with is externally visible and atteched to the side of the head at an angle of 30^{o}. It is through the auricle that the sound vibrations in the air are picked up, directed and conveyed through the external meatus to strike the membranous drum head - the tymplanic membrane.

The surface of the auricle is formed of many elevations and depression.

CONCHA is the deepest depression and lies some what in the centre of the auricle. It is surrounded by a less elevated area called scapha.

HELIX (Snail shaped) is the carved rim of the entire auricle. The anterior portion of the helix descends obliquely into the concha dividing it into an upper cymba or skiff and a larger lower, the cavitas or cave. The cavitas continues inward as external auditory canal.

On the posterior portion of the helix a small thickening, the Darwin's tubercle is present. This varies in size and shape from species to species.

Parallel to the helix is a semicircular ridge called anti-helix. It circles concha from behind and on its upper portion divides it into two limbs upper and lower crus. The portion between the two limbs is the triangular fossa and the furrow like depression beteen helix and antihelix is called the scaphoid fossa.

Tragus is the small ridge like boundary for the concha anteriorly. Just oppesited from each other by an intra-tragal incisura.

Lobule is the inferior most part of the auricle with is soft.

EXTERNAL AUDITORY MEATUS: This is a tube like passage or Channel through which the sound waves traverse to reach the eardrum.

This passage or tube is approximately, one inch or 25 mm long and ¼ th of an inch or 6-7 mm wide.

The external ? rd of the meatus has cartilaginous support whereas internal ? rd is formed by bony support. The direction varies in different contour. The shape of the meatus also varies. The diameter reduces from its external orifice to the junction of bony and certilagfnous

section, expands again and than decreases once more at the isthmus where it is attached to the tympanic membrane. The inner surface lining of the meattts is akin which contains ceruminous glands and hair follicles on cartilag fnous portion.

PHYSIOLOGY:

Auricle is a sound collector. It guards deeper parts of auditory apparatus, Mammalian auricles play a role in auditory orientation. Human beings have emall auricles as compared to animals like bats, cows etc.

A large auricle is often an advantage since it can collect "physiologically" more effective segment of sound waves.

Localisation of sounds with respect to space is based upon the intensity of stimulus and phase of sound waves coming from a single source and received by two ears. The sounds are also diffracted around the corner and there is a partial loss of energy and reduced intensity accomplished by a lag of time of arrival into the ear.

The ear canal acts as a sound pressure detector. It also acts as a tube open at one end and closed at the other thus creating resonances at different frequencies. On the whole the auditory function of the external ear canal is efficient sound transmission, from the envirenment to the tympanic membrane.

There are other physiological non-auditory functions of the external ear. The auricle and the auditory canal are basically protective ia nature because of their anatomical shape. They prevent any direct injury to the tympanic membrane and to other underlying structures.

The canal also has a self cleansing action preventing any accumulation of debris. The external canal has ceruminous glands which secretes wax. In addition it has hairs.. Both these assist in preventing any foreign body from entering the canal.

They also play an importent role in Migration of debris to the entrance of the ear canal.

Thus the external ear has a role not only ia auditory functions as localisations and resonance but also in non-auditory functions as protection and self cleansing action.

EXTERNAL EAR EFFECTS - UNOCCLUDED AND OCCLUDED EARS

External ear is not a very good sound collector below 2 KHz but above this, it is an efficient sound collector with remark able directionality and it gives us perceptions of acoustic space. In reality externalear is an intruding filter of complex characteristics.

Head, torso, pinna flange, concha and ear canal act as an integrated system. Head, torso, and pinna act as diffracting bodies; and ear canal and concha serva as acoustic resonators, and ear drum provides an acoustic termination.

Now we shall see the external ear effects and how the transformation takes place from free field to eardrum.

TRANSFORMATION OF SOUND ER ESSURE FROM THE FREE FIELD TO .THE HUMAN EARDRUM :

We shall study different structures which contribute to the transformation.

Head and Torso:

The head is a spherical object and hence it act: hard stationary obstacle, and external ear aets as pressure detector (Reyleign. 1876, 1945). some others, give

inter-aural time differences at all frequencies and inter-aural phase and pressure amplitude upto around 1 KHz.

It is seen that inter-aural time differences is virtually independent of frequency and relatively insensitive to head shape. Even inter-aural phase difference is almost independent of the distance provided the sourceis at least 1 metre away from the head. When the source approaches the head, generally speaking, the gain at the ear nearer the source is increased and that at the remote ear decreased. Torso effects the response by reducing it between 1 and 2 KHz.

Pinna flange, concha and ear canal:

The entire human external ear can be represented by a cylindrical cavity in the side of the head roughly 2.5 cm. in length and 0.7 *cm* in diameter open at one end and closed at the other (Von Bekesy, 1932, 1960; Weiner and Ross, 1940)

The primary resonance of the external ear occurs at 2.7 KHz and rapidly increases in response on the low frequency side of the resenance.With frontal incidence -0^{o} azimuth, this resonance produces a pressure gain of 17 dB. At 45^{o} azimuth, the pressure gain increases even further to 21 dB.

As we pass this peak, the resonance in the concha sustains the response for almost 1 octave, concha contributes to around 10 dB gain at 4-5 KHz (when ear canal is closed with no pinna) - (yamaguchi and Sushi, 1956; shaw and Teranishi, 1968). The addition of pinna flang enhances the pressure gain slightly by a few decibels in the range of 3-6 Khz.

The addition of earcanal, a few more peaks are observed in the response curve. It is found that the greatest overall acoustic pressure gain for human subjects in the azimuthal plane occurs at 45^{o} asimuth for requencies between 2-5 KHz. Ear canal and concha of the human ear are complementary to one another, together providing substantial acoustic pressure gain from 1.5 Khz- 9 KHz.

The gain produced by pinna is only 3 dB at 4KHz The effect of the pinna varies considerably at the angle of incidence of sound. The gainproduced by concha is around 10 dB at 4-5 KHz but there is a loss of around 5 dB at 10 KHz. Above 16 KHz there is no uniform wave at the tympanic membrane, but the sound pressure varies by as much as10-15 dB for small lateral distances.

When concha, ear canal and tympanic membrane complement each other, they broaden the gain between 2-5 KHz, which is important for speech perception. The total gain from combining all components is approximately 20 dB at 2.5 KHz. There is a broadened maximum between 2-5 KHz.

Blocked meatus response:

Most of the external ear functions have been gained through experiments on real ears and replicas under carefully controlled conditions (shaw, 1972; 1975a, Shaw sad Teranishi, 1968).

It is advantageous that the ear canl proper is only 7-8 mm in diameter because the wave Motion in the canal, (except at the entrance) is plane upto around 18 KHz.

Many careful measurements on simple models have shown that the addition of ear canal makes hardly any difference to the directionality of the ear upto high frequencies (10-15 KHz). Thus the interest in learning about the directionality of real ears under blocked meatus conditions.

To make such measurements the ear is excited with a special source designed to produce clean, progressive waves at grazing incidence. It is placed close to the ear to avoid

head diffraction effects and without effecting the free field characteristics of the ear. The response is measured with a probe microphone placed at the centre of the plug or mold, closing the canal entrance (Shew, 1972).

The results for a human ear done at 8 angles of incidence (-15° to 90° are as follows: As sound waves approaches from front, the response falls rapidly above 5 KHz passing through a deep minima between 6-11 KHz. Between 11 and 16 KHz the response increases again. When sound approaches from above, the situation is reversed. Excitation is More between 6 and 11 KHz but weak between 11 KHz W 16 KHz.

The diffuse field response of the ear may well determine the spectral quality of sound perceived in enclosed spaces, since in most cases, the energy density in such spaces is predominantly reverberant. For hearing aid user, it is a face to face communication that is normally of primary importance end in such cases a flat frequency response of the open earis seen. Thus a hearing aid normally can be said to have a flat frequency response when it transforms sound pressure level from the free field to the ear drum.

open mold and no mold condition:

When the hearing aids are operated in the no mold or open mold conditions, the radiation impedance of the open or

Partially open ear reduces the output. While calibrating any system, this aiditional parameter must be matched accurately over a wide frequency range (at the resonant frequency of the external ear). Thus we should make use of simulators to take into account the variations in size and shape of ear canal and concha (Berland, 1975).

CONCLUSION:

We know that tha human extarnal ear possesses remarkable directionality at the higher fraquancies. In a normal human ear, we observe three major kinds of responses.

1. a large reduction in response in the 4-5 KHz region as the direction of the source is changed from 45^{o} to $135^{o.}$
2. as increase in response between 7-10 KHz as the source elevation is changed from 0^{o} to 75^{o}.
3. at the same time, a decrease in response between 12 and 15 KHz range with same source elevation as before.

Thus we can conclude that the spectrum of the sound will systematically vary with the direction of the source. this variation is related to our ability to perceive acoustic stimuli and hence to discriminate between sound sources (Butler, 1969, 1970).

whether to try and simulate natural directionality of the human acoustic antenna system, if we are to restore the hearing ability in high frequencies by amplification. In a sensori-neural hearing loss, the neural receptors are lost, or do not function normally. There is also a reduction in filter capacity and this does not additional problem to analyze complex signals such as speech in an environment of noise. The problem is more of a loss of signal to noise ratio which is comparable to the amount of hearing loss the person has. Thus our aim should be to improve the signal to noise ratio. This is possible only by increasing the forward direction which would in turn increase the signal to noise ratio for the hearing aid user, and hence help in effective communication in noisy places.

Thus for maximizing the information content of the sound that reaches the inner ear, a hearing aid should be adjusted with frequency response, directionality and other like - parameters from moment to moment.

EXTERNAL EAR EFFECTS IN EXTERNAL EAR ABNORMALITIES

So far our interest in the external ear effects was restricted to the normal external ears. However, it becomes very important, for us, to consider the resonance and the gain effects in cases of external ear pathologies.

All of us know that the sound gathering capability or localisation in man is minimized to a great extent in the advancement of evolution. But, the patency of external ear including the canal is essential for proper transmission of air conducted sound waves to the middle ear. Thus, varying the dimensions of external ear canal would lead to an alteration of maximum resonance frequency characteristics. Thus the external ear disorders, leading to improper sound transmission manifest themselves as conductive hearing loss. Any part of external ear - pinna, concha or ear canal may be involved.

PINNA :

The pinna may be placed lower on the face (low set ears) because of arrest ia the development of the mandible. In same cases mandible may completely fail to develop, in such cases, the pianae may actually be fused below a small mouth called synotia.

In such cases, neither localisation i. possible nor the resonant frequency be high in amplitude. In other words frequency response in the range of 3-6 KHz may be reduced and additional gain due to the pinna flange is, to a great extent, reduced.

The pinna may also be totally absent or may assume various. shapes and sizes.The pinna may also be protruding lop ears. In such cases, probably, the localisation ability may abnormally increase. Microtia of the pinna may also be possible. IN Such cases, contribution of concha and other convolutions may be reduced. In other words effects of frequency response in the range 4-5 KHz and additional pressure gain provided may be reduced.

In cases of cauliflower ears - there is a psoriasis of auricles, lumen of the ear canal is reduced. In these cases, mild to moderate bilateral sloping high frequency sensori-neural hearing loss may be seen, which is of course, super-imposed with conductive component. In these cases vertical localization may be reduced and directional response may be affected.

EXTERNAL AUDITORY MEATUS:

Aural atresia-(Closure of auditory canal): This may be unilateral or bilateral. Failure of external auditory meatus.

to canalise will give rise to significant conductive hearing loss, Canal atresia may involve either the cartilaginous or the bony portions of the canal or both.so long as any quantity of tissue totally obstructs the passage of air transmitted sound pressure waves, hearing loss will persist. Conductive hearing loss in the range of 500 - 2000 Hz with flat audiograms will be seen.

In addition, acoustic pressure gaia may be reduced in the range of 2-5 KHz.

Collapsed canal effect - A collapses anterior displaced conchal fold and cartilage may be responsible for blockade of the external auditory meatus producing fluctuating conductive hearing loss. In the old aged population, it is often seen that excessive earphone pressure on the plan a can cause the soft cartilaginous portion of the external auditory meatus to collapse. This prevents complete transmission of air conducted sound through out the auditory system. This collapsed canal effect is known as Reger effect. This an artificial conductive hearing loss is found predominantly in the high frequency and also throughout the frequency range (sometimes).

In such cases, we should not hold the earphones close to the canal/pinna. In this case, the sound pressure gain

In the region of 2-5 KHz will be temporarily reduced.

Foreign bodies in the canal -

Cerumen or wax - Cerumen normally has a lubricant function. If there are variations in amount and character of cerumen produced by individuals, it results in a copius amount of thick secretions and produces a mass which may occasionally obstruct. The external auditory canal. It may produce fullness. When occlusion is total, a hearing loss may be produced. The resonant frequency may or may not be affected depending on the occlusion.

Foreign bodies - These may be large enough to occlude the cana1 and produce tinnitus and hearing loss. A big foreign body may cause reduction in fundamental resonance peak and reduces sound pressure gain too at its characteristic frequency range.

Tumors - Tumors also alter the sound conducting characteristic of external auditory meatus. by occlusion or erosion. Conductive hearing loss is present. High frequency tinnitus is also attributed to external auditory neoplasms. Growths result in reduction of canal volume thus increasing the frequency at which the resonance will occur.

Trauma . Trauma external ear can create special diagnostic difficulties for the audiologist.We can have surgical

and

post surgical trauma. When external or middle ear surgery is being performed, damage can occur to the external ear. Alterations in external ear produce their acoustical effects primarily in the higher speech frequency above 1500 Hz alternating the SPL at the tympanic membrane by approx-
mately 20 dB. Hearing loss may occur because of pre-exist

ing complications and in addition conductive hearing loss due to trauma created by surgically altered acoustic proper-
ties of the external ear.

Hearing effects resulting from malformation of the external ear vary in extent from very mild to a moderately severe degree depending on the amount of closure. Altera-
tions in the size and configuration of the pinna influence auditory receptive behaviour. We know that the auricle is not an efficient sound collector in human beings Even when it is entirely missing only a 3 - 6 dB decrease in spectral energy from 3000 Hz - 6000 Hz is measured at the tympanic membrane.

The pinna has a role of sound localisation and if it is missing or malformed, the individual may not be able to easily localise the sounds in the median plane. The concha contributes more to the sound reception. It functions

acoustically as a resonating cavity by producing an increase in SPL of. approximately 10 dB between 4-5 KHz. The normal exteral ear produce a 12 dB gain in SPL between, 3400 Hz and 3900 Hz at the tympanic membrane (Durrant and Hovrinic, 1977,Good, Friedrich and Falk, 1977).

Deformities of external ear produce variations is the sound spectrum which reach the tympanic membrane and this altered spectral information produces a significantly changed auditory spectrum.

HEARING AID SELECTION : A PREVIEW

When a hearing impaired individual approaches an audiologist, the foremost task of the audiologist is to assess and evaluate the hearing acuity of the individual. But, is it all that an audiologist does? The answer to this query is obviously, a "No 2.

The audiologist also lays his hands in rehabilitating the hearing impaired individual. A 'suitable' amplification device, most often a hearing aid is given. Now what does the term suitable amplification device imply?

All hearing aids do not fit all individuals and neither do all of them provide adequate amplification. Hence, we have to perform a detailed hearing aid evaluation for each individual, search for the appropriate hearing aid that would best suit the individual' s needs of hearing both at and outside home.

However, a major question that arises is 'how do we evaluate and select a hearing aid for an individual?'. This, of course is not an easy procedure. It involves lot of patience and skill on the part of the clinician. A number of different commercial hearing aids can be prescribed to the

hearing impaired individual with acceptable sound quality, good speech inte1ligibility and maximum sound output which is not too loud. The clinician preselects one or many hearing aids for each individual. This is necessary for an appropriate and accurate hearing aid evaluation.

Two predominant approaches, to hearing aid selections have come into picture. The comparative and the prescriptive procedures.

The comparative procedure compares hearing aids with each other as the basis of selection. The prescriptive procedure focusses on the determination of appropriate electro-acoustic characteristics for a hearing aid and frequency - gain function which is necessary for an individual.

Different procedures, and not the same procedure are applied for every individual. In the early 20th century, especially during World War II period, only comparative procedures were used. Later on, prescriptive procedures based on threshold or loudness data came into being. At present, the procedure that is being used is the prescriptive procedure followed by the comparative procedure.

COMPARATIVE PROCEDURE:

This procedure was first reported by Carhart (1946a) and hence this procedure oftea bears his name. This procedure aimed at finding a hearing aid which was of utmost use in everyday listening and in adjusting to the hearing aid. The procedure was as follows -

- Audiological and otological examinations were made.

- Custom earmoldswere made by taking ear impressions.
- Based on certain preselection hearing aids, a number of hearing aids were selected and a practice was given.
- Finally 3-4 hearing aids were selected for clinical evaluations.

The clinical evaluation procedure is as follows:

1. A detailed audiological evaluation is done. Unaided thresholds of puretone (air conduction and bone conduction) and also of sound field speech reception thresholds, discrimination scores and tolerance limits are measured
2. The patient is then made to wear each hearing aid. Gain control is adjusted so that a normal speech signal level at around 40-60 dB HTL is at the most comfortable level (MCL).
3. With each hearing aid, aided gain for speech thresholds and tolerance limits are measured.

At the same time performance and discrimination tests in noise and in quiet are made. Thus based on these, by comparing the test results of different hearing aids and patient' s choice, a hearing aid is prescribed to the patient. Comparative procedures are thorough and intensive. They are also advantageous in that, they allow patients to make a decision regarding the hearing aid. Prior to the selection procedure a training on use of hearing aid is given.

However, the major disadvantage is that it is time consuming and expensive. Hence, the classic procedure is often shortened. This procedure also assumes an interaction between hearing aids and hearing impaired. It is believed that audiological tests are sensitive to this interaction and can differentiate the performance of hearing aids. However, as the hearing aids are becoming morerefined in their quality, it is becoming more and more difficult to establish difference by clinical tests. Thus hearing aid consultation rather than comparative hearing aid tests is used frequently.

Jerger and Hayes (1945) considered the evaluation procedure as a part of total rehabilitation procedure. According to them, the evaluation procedure aimed at

1. differentiating among hearing aids.

2. achieving face validity by using materials which resembled conversational speech rather than phonetically balanced lists of words.
3. a procedure which was simple to administer with standard clinical instrumentation.

Thus they used synthetic sentences in competition consisting of continuous speech from a single talker. The sentences were delivered at 60 dB SPL while the competition message intensity was varied. The message to competition ratio was varied from +20 to -20^0 Unaided, aided and again unaided results were obtained. This had maximum user satisfaction.

Hearing aid consultation - Resnick and Becker (1963) state that comparative procedures should be replaced by the term hearing aid consultation. It consists of the following:

- Audiological assessment including puretone air conduction and bone conduction thresholds, speech reception thresholds and speech discrimination scores.
- The patient is counselled regarding the nature of the hearing loss and the use of hearing aid is explained.
- Then the patient is referred to the hearing aid dispenser.

PRESCRIPTIVE PROCEDURES:

Hearing aid gain prescriptions often incorporate an adjustment to compensate for the fact that normal speech

contains more low frequency energy than high frequency energy.These prescription generally provide for less low frequency gain and greater high frequency gain. There are many procedures which have been devised for selecting the frequency responses and gain of hearing aids for hearing impaired individuals. one of them is the procedure using thresholds and the other is using loudness level or uncomfortable loudness level. Thus whereas the 1st type derives the prescription for gain and saturated sound pressure level,the 2nd type derives the prescription of measurement of the patient' s loudness perception.

The 'threshold based procedures' have the advantage that they are applicable to almost all patient since they require only the ability to detect the presence of a sound. However, the hearing impaired cannot perform well at threshold levels and hence listen to amplified sound at supra threshold levels. Moreover, the loudness growth varies considerably across hearing impaired individuals. Thus measurement of gain and saturated sound pressure level based on threshold procedure would yield an inaccurate prescription.

The 'loudness based procedures' on the other hand, have the apparent advantage of providing more genuine information about a patient's auditory functioning. Loudness

based procedure gives more satisfactory results than threshold based gain and frequency prescriptions. But the major disadvantage of this procedure is that not all patients can make loudness judgements. Test-retest-reliability is better with threshold procedures. A main format approach is used and based on this, any of many combinations of procedures for deriving threshold based prescriptions, loudness based prescription comparative speech tests and comparisons of aided behavioural thresholds are used. After all this, an inter aid comparison (Comparative procedure) is made.

So this procedure involves measurement of unaided sound field threshold for the ear to be amplified. Then, deriving prescription and expressing it in HA-1, and HA-2 coupler level. One of several different signal delivery systems is used for the preselection tests. These tests yield the data Which are used to derive the preselection.

LOUDNESS BASED PROCEDURE:

At the outset, the clinician should check whether the patient can make loudness judgements. This decision is made on the basis of patient's functioning. Most of the adults can make a loudness judgement. However, some loudness tests are more easily comprehended than others, In the loudness procedure, a measure of upper limit of comfortable loudness can be made.

This procedure involves, threshold measurement of the patient and upper limit of comfortable loudness (ULCL) in seven frequency regions. Usually, the stimuli (warble tone) are calibrated in SPL. However, one third octave noise bands may also be used especially for flat frequency loss configurations.

These data are utilized to derive a frequency gain function which amplifies speech with an input of 70 dB SPL to a point in the middle of the range between the SPHL (Hearing thresholds in SPL) and ULCL contours. (At each frequency SSPL 90 (saturated sound pressure level 90) is specified constantly 12 dB above the ULCL.)

THRESHOLD BASED PRESCRIPTION:

If the patient is unable to make loudness judgements, the threshold based prescriptive procedure is entered. In this procedure,(initially assessment of hearing loss for pure tone is made. If thresholds at frequency above 1000 Hz are all poorer than 90 dB HTL, it is assumed that this patient will not probably benefit greatly from speech cues available in this frequency region. Hence gain in the frequency range of 250 - 1000 Hz is more emphasised as compared to the shaping the frequency response curve.) Thus a

general, simple prescription rule, a 4/10 rule can be obtained from the above data Which specifies that the gain desired at any frequency is 0.4 times the hearing loss at that frequency. It is observed that preferred listening level typically increases at the rate of 3-5 dB for each 10 dB of hearing loss. Hence quite often the prescription rale is based on patient's preferred listening levels. The entire speech spectrum can be amplified to the patient' s preferred listening levels.

A threshold based prescription can also be made using formulae given by various researchers as Lybarger (1946) Fletcher (1952), Byrne and Tonnisson (1976, 1978). Most of the procedures are derived or modified from Lybarger' s half gain rule. In Lybarger' s (1946) half gain rule, the frequency response and gain is so adjusted that most comfortable level is obtained. According to this rule, an individual's audiometric threshold (dBHL) obtained under earphones are multiplied by 0.5 between 1000-4000 Hz to give the prescribed real ear gain. It is mainly used for sensori-neuralhearlng loss cases.

Another frequently used procedure is prescription of gain output as devised by McCandless and Lyregaard in 1983 This is a modification of Lybarger' s half gain rule. Here

the gain at 250 Hz and 500 Hz reduced by 10 dB and 5 dB respectively. This procedure is appropriate for sensori-neural hearing loss, especially sensory loss with thresholds more than 80 dB HTL.

(Berger et al (1984) recommend that at 500 Hz, 4000 Hz and 6000 Hz, half gain rule can be used and more gain (.59 - 0.67) between l000 Hz and 3000 Hz. This is called the prescribed operating gain. This gain provided will cause the amplified speech energy to he equally loud between 500 Hz and 2000 Hz. At higher frequencies, less gain is recommended as further damage to the cochlea does not take place and neither is the intelligibility reduced.

Byrne and Tonnisson (1978) also derived real ear gain from preferred listening levels of speech.

Recently National Acoustic Laboratories (1986) have come up with a hearing aid selection procedure in which pure-tone thresholds are utilized to prescribe both real ear frequency response and overall gain. Frequency response is more critical of these two. It is similar to the (formulae) procedure used by Byrne and Tonnisson (1978), NAL aims to make all parts of the frequency spectrum of speech, equally loud.

When a hearing instrument is worn at preferred listening level. The main aim of tills procedure is have a wide range of frequencies of speech spectrum. Here the gain can be calculated by multiplying hearing threshold level (HTL) with •31 and adding it to a frequency dependent constant (K) and also X which is 5% of sum of hearing threshold levels at 0.5,1 and 2 KHz. ie gain= X + 0.31 HTL + K.

Thus these are some of the prescriptive procedures common used. There are many other prescriptive procedures which shall be dealt under following chapter.

Now, is it enough if we calculate the gain, using the prescriptive formulae and procedure? How do we know which is the most suitable hearing aid for an individual?

So, once the prescriptive stage is complete, the audiologist must decide whether or not to compare different hearing aids, all of which aatisfy the prescription. In most of the instances, comparison of hearing aids is taken up because -

1. We cannot always ahieve a perfect matching of frequency gain prescription. Thus different hearing aids which nominally fulfil a prescription which have different frequency gain function are chosen.

2. Even though several hearing aids may have the same frequency gain function, they may differ in other important features like the amplifier, compression circuits etc.
3. Different manufacturing companies manufacture different hearing aids with different circuit designs and components which may lead to an overall difference as reported be the individual wearer.

Thus, Comparisons may be taken up either to reject or select a hearing aid. (When hearing aid comparison is not suitable for the evaluation, a hearing aid is selected and its gain and $SSPL_{90}$ are configured to match the prescription. The configured hearing aid is then put on the patient and aided sound field thresholds are obtained. Matching of aided sound field thresholds to that required can be improved by adjusting the tone or volume control of the hearing aid.

The most important step is an individual's decision about the hearing aid. They can accept or reject the hearing aid on whatever dimensions they like and feel are important patients should hence, be trained well prior to the selection procedures, so that a suitable hearing aid can be recommended. If hearing aid (inter aid) comparisons can be made, the clinician chooses 3 or 4 hearing aids and configures all of

them to match the prescription gain derived from the formulae. Then inter aid comparisons are made and based on their performance on the individual a suitable hearing aid is chosen.

AIDED SOUND FIELD THRESHOLD COMPARISONS:

The criteria for good speech intelligibility is that maided sound field thresholds are 20 dB or more below the speech spectrum at least in the low frequencies (250 Hz - 1000 Hz In such a case, inter aid comparisons are made on the basis of aided sound field thresholds than speech intelligibility. If we amplify only high frequencies on the basis of speech intelligibility test, we may come across similar hearing aids which differ in the gain or amplification, they provide above 2500 Hz. Above this frequency, speech intelligibility tests are not sensitive to small difference in amplification or gain provided by different hearing aids.

Hence, using aided sound field thresholds we can recommend a hearing aid which approximates the goals or prerequisites.

SPEECH INTELLIGIBILITY TESTS:

Sometimes patients with average language skills are asked to rate the speech intelligibility through different

hearing aids. This is done when the speech spectrum is greater than 20 dB.above the unaided sound field thresholds at 250 Hz to 1000 Hz. Based on this, inter-aid comparisons are made and the patient is prescribed the best suited hearing aid.

For hearing aid selection, the clinician should make his or her own decision in carrying out the prescriptive and comparative selection procedures. Thus whereas selecting the appropriate procedures is at clinician's discretion, choosing from among the preselected hearing aids is the individual' s decision.

Hence we can say that clinician and the patient both play an equally important role in hearing aid selection which will best suit the needs of the patient. The clinician should learn to display his scientific knowledge in an artistic way to tailor according to the individual client's needs.

HISTORICAL PERSPECTIVE OF PROBE TUBE MICROPHONE MEASURES

Interestingly, the ear canal probe measures has increased in recent years. Probe measures are capable of rapid testing of a wide range of frequencies. At the same time they eliminate the variability of the human response in measuring hearing aid performance. The idea of ear canal probe measurements is not new, and is as aid as 1940s, though it was not brought into clinical use till late 1980s over the past 6 years computerized probe tube microphone measurements has increased. Moreover, the development of miniaturized transducers and micro processor controlled test modules and better understanding of acoustics, has led to clinical use of the instrumentation.

There are two general types of instrumentation - the probe microphone and the probe tube microphone measures. In the probe microphone, the microphone is placed in the canal. It has a wide dynamic range and a flat frequency response and it fits easily into the ear canals of most adults. The SPL output of the control microphone is a part of the feedback system. It produces a puretone stimulus through a loudspeaker at a constant SPL at the entrance of the microphone.

The control microphone is either placed on the superior helix of the test ear or in the non-test ear. Since these are large they may not fit in children' s ear canal. Probe tube microphone uses a soft silicone probe tube which is placed in the ear canal. The probe tube is thin, flexible tube attached to the probe microphone. since the thin probe tube itself can be placed in the ear canal instead of microphone, it is advantageous over probe microphones.

The major advantage of probe tube microphone systems is that they not only measure electroacoustic characteristics of hearing aids but also the real ear gain for a particular prescriptive procedure. Thus by measuring the sound pressure level with aad without an hearing aid, we can calculate the real ear gain, needed for a person with hearing loss.

Though the probe tube measurements were present even in early 20th century, it has been implemented only recently. We have shifted dramatically from an age of 2cc coupler, KEMAR to real ear computerized measurements. The 2cc coupler has been continuously in use since its development in 1942 by Romanow. 2cc coupler measurements are relatively easy, simple and provides fairly accurate and repeatable results. It has been widely used for various purposes other than

hearing aid selection. Example - Calibration, quality control measures. Romanov (1942) stated that 2 cc coupler was not a real ear simulator but was very convenient.

The major and the most important disadvantage with 2cc coupler is that it yields an artificial resonance in the frequency response curve because of the hard walled cavity which occurs at a lower level in ears of patients wearing a hearing aid. Thus slowly the trend changed from the use of 2 cc coupler to a KEMAR which was introduced in 1972. This is a better representation of an adult head and torso and it closely simulates the real adult ear. Yet KEMAR measurements did not yield very accurate results as they did not take into account the head movements, the flexibility of the real ears and so on.

Thus gradually the increased use of earmold acoustic systems has changed the trends to making measurements of the actual ear canal of a person. Many researchers like Harford (1930); Schwartz (1980); Proves (1934); McCandless (1933) demonstrated the clinical potential of miniature measures in the ear canal. But clinicians did not recommend it because the assembly was not available and it neaded an

anechoic chamber. The development of computerized probe microphone assemblies brought ia a safe comfortable, soft invasic silicone tube to measure SPL in the external auditory meatus.

The greatest advantage with the computerized probe microphone (CPM) is that it is designed to be used without anechoic chamber. CPM offers significint objective information oa the effects of ear canal resonance, diffraction earmold occlusion/ body baffle, head shadow effects and microphone placement in the individual ear canal of the hearing impaired person.

Sullivan (1986) compares computerized probe tube microphone to impedance audiometry saying computer probe tube measurements holds the same relation with hearing fittings as impedance to diagnostic audiology. According to him, both of them perform insitu acoustic measurements. Computerized probe tube measurements allows the clinician to see in reality what physically occurs in the ear canal of the patient. Schwartz (1980) remarks that ironically it has taken almost half a century to realise that Romanow's original ideas of real ear measurement reflect more accurately the output speech spectrum of a hearing aid delivered to the plane of the tympanic membrane.

(Mueller (1980) states that this technique is a reliable alternative for functional gain testing . Functional gain may under-estimate the actual gain in regions where hearing is at or near normal Probe microphone insertion gain overcomes this problem. Functional gain is also difficult where hearing threshold level is greater than the output of loud speaker. These demerits are overcome when computer probe tube microphone is utilized.

Gerald Popelka (1980) noted that all hearing aidfitting schemes can be improved if the acoustic characteristics of hearing aid at the tympanic membrane are known. with probe tube microphone measures it is now possible to measure unaided hearing, aided hearing and hearing aid with same reference, thresholds most comfortable level, loudness discomfort level.

Thus hearing aid fittings and selection procedures, research in this field, have improved significantly and thus made the clinical work easier, quicker and more reliable.

REAL EAR MEASUREMENTS

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 helpful with difficult-to-test patients as the mentally disabled, stroke patients or mutiple handicapped individuals with low communication abilities, It can also be used with young children in which hearing aid selection, otherwise would have become difficult. It is objective and can/save time.

Degree of hearing loss - Real ear hearing aid measurements are useful with all degrees of hearing loss ranging from mild to profound impairment sometimes in severe-profound hearing loss, the insertion of silicone probe microphone under the earmold creates feedback which interferes with real ear measurement. In such a ease the probe is inserted into the canal through a 1.5 mm vent in the earmold thus making real ear measurement.while the probe tube is not in use, the vent can be closed.

Type of hearing aid - The clinician can avail more inform-tion on hearing aid based on probe microphone measure. Infor-mation on real ear frequency response and insertion gain can

be obtained. in addition the clinician should know the external ear effects, natural ear canal resonance and the acoustic plumbing which finally contributes to the total amplification of the hearing aid.

Acoustic modification and toning -Real ear measurement provides a display of 144 test frequency between 125 - 8000 Hz. Ear mold plumbing is also taken into consideration. Earmold modification often is influenced by client's ear canal contributions. Real ear measurement verifies how various acoustical factors change the hearing aid performance.

IMPORTANT FEATURES:

The probe tube microphone system in the real ear measurements are microprocessor based. It has the following features.

A) A conventional micro computer typewriter like key board by which we can type and display any information related to real ear measurement on the screen.

b) A menu driven command, structure so that key strokes do not have to be kept in memory to perform the commands.

c) A coloured graphic video terminal for viewing both the menus and frequency response curves.

d) Provision for storing, recalling and erasing data via the disk.

e) The probe tube microphone system should also capable of-

- Subtraction two freqency responses
- measuring insertion or isitu gain
- audiometric data plotting
- making a hearing aid electroacoustic performance
- entering several input levels.

PRECAUTIONS:

During the real ear measurement for hearing aid selection, several precautions have to be considered.

1. Before starting the test, the probe tube is checked for holes and/or blockage by wax or moisture. The ear canal also should be checked for wax or any kind of blockage.
2. The probe tube is placed along the inferior surface of the earmold and marker is set so that the tube extends 4-5 mm beyond the tip of the earmold.
3. The probe tube measurements should be a constant for open ear (unaided) and aided measurements.
4. The client is seated close to the speaker so that reflections and reverberations are minimized and within one meter of the client, no reflection surfaces should be there.

5. Head movements on the part of the client should be avoided during testing.
6. In the aided measurements, the earmold should be fitted enuggly in the concha so that low frequency leakage is minimized.
7. These measurements can be rechecked to ensure the validity.

PRACTICAL ASPECTS AFFECTING REAL EAR RESPONSE:

a) 'Position of the probe tube in the canal is important and it should always be kept a constant.
b) The pressure distribution in a blocked ear canal and open ear canal are different. The open ear canal acts as a standing wave resonator coupled to the freefield. Whereas the blocked ear canal has a uniform sound pressure distribution upto 10 KHz.
c) At higher frequencies, probe tube becomes important for unaided ear response.
d) While making unaided to aided comparisons probe tube position must be maintained.
e) The probe tube position in relation to tympanic membrane during insertion gain measurement is very important especially when making unaided to aided comparison.
f) The free field transfer function (external ear effects) should match the receiver and tube resonances for accurate

insertion gain measurement. the residual volume which is the remaining ear carnal volume between an earmold and the ear drum has significant effect on the insertion gain.

g) The cavity ranges about 0.4 to 1 cm^3 in volume depending on size the ear canal and length of the earmold tip. A small volume results in a higher sound pressure level at the eardrum and larger volume causes SPL to drop significantly.

Thus whenever one makes use of probe tube microphones to make real ear measurements, all these practical aspects should be considered.

RATIONALE;

Real ear hearing aid selection can be either based on loudness prescriptions or on threshold based prescriptions. Threshold bailed prescription are more common as they are reliable, relatively easier and more accurate. In the loudness based gala prescriptions, the frequency bands may be amplified to most comfortable level. Yet threshold based gain frequency prescriptions are more repeatable and can be obtained for a wider range of clients.

Loudness based judgements may be used in adjunct to the threshold based prescriptions to verify or modify the gain obtained.

At the same time preferred insertion gain (one the client chooses to be most comfortable) and preferred listening level should also be taken into account during real ear hearing aid prescription. Real ear gain measurements in terms of freguency respon, e are more valid as compared to the absolute gain, This is because hearing loss at any particular frequency may affect the gain at may other frequency.

Also, the amount of seal ear gain is more consistent in the mid frequencies as compared to the extreme ends. Thus we should make a real ear threshold based selection procedure rather than loudness based prescription. Most of the prescriptive procedures also involve threshold based formulae.

PRINCIPLES 0F REAL EAR MEASUREMENTS:

Before going to actual procedure used in real ear measurements for hearing aid selection, we should glance at the principles on which it is based.

1. For differeat types and degrees of tosses, there are diffe rent hearing instrument selection procedure. Example - For a flat audiogram our hearing aid selection would be different from that of sharply falling audiogram.
2. The ideal hearing instrument response cannot be really achieved. It is just an approximation.

3. For a particular hearing loss, insertion gain predictions remains the same. This is because insertion gain is based on formulae from which it is derived.
4. For fitting aids, insertion gain and insitu measurements must be made and considered. These are often close approximation of preferred listening level.
5. The selection procedure should consider the maximum speech intelligibility and preferred listening level of a patient. Preferred listening level plays an important role in hearing aid selection.
6. Two kinds of selection procedures are used for the patients.

a) For the new wearers for whom gain required is less.
b) For the patients who have adapted to the hearing aid and require more output and gain.

7. Desirable gain canbe obtained at 4000 Hz and across frequencies.

No measurement will yield an accurate response or an ideal response. Some amount of variation will be present in the measurement procedure and the response. These practical consideration should be taken into account to make the measurement the most reliable.

PROCEDURE:

While performing real ear measurements it becomes very important for us to always make unaided and then aided measurement.

The occlusion of ear canal with an earmold effects the response. The unaided test ear has an ear canal resonance at 2.7 KHz which gives a peak response.of 10-15 dB at and around this frequency range. This natural amplification will be distorted or reduced by around 20 dB if an earmold is inserted into the canal. This means that not only the hearing loss bat also the natural amplification of the individuals need to be compensated.

Stimulus types - The test may be performed in the range of 125 H_z - 8000 Hz. But in actual practice a range of 500 Hz to 4000 Hz may be used. An ideal free field condition is needled for performing the above test. But in most clinical conditions an ideal free field test condition is not present. Only a room or office is available. This will lead to reflections from the walls which would prevent any system from keeping a constant sound pressure at the test site. Thus instead of sinusoidal test sweep frequencies, if a frequency modulated test sweep is used, or a narrow band noise sweep is used, the sound reflections become diffused.

Clinical considerations - In practice and reality real ear measurements for hearing aid selection differs a lot from the theoretical considerations. It is considered under the following steps.

A. Prescription data - Initially audiological tests should be performed and the actual hearing loss of a person should be determined. Prescription data is calculated using any of the several formulae - POGO, NAL, BERGER and so on. This is entered into the insertion gain instrument.

B. Choice of test type - Any of the test type as insertion gain, insitu gain measures or functional gain measurements can be opted for.

C. Choice of test Method - We should make a choice between four test methods that is, substitution method, comparison method, pressure method and ipsilateral comparison method. These test methods differ in the placement of reference microphone and hence differ in their applications.

These.clinical procedures will be dealt in detail.

CHOICE OF PRESCRIPTIVE PROCEDURES

The earliest procedures based on prescription data and formulae such as mirroring (west, 1937), equal loudness con-tour procedure (Watson and Knudsen, 1940), Bisection of the dynamic range (wallengels, 1967) , Shapiro's method (1976), frequency response characteristics (zelnick, 1985), are all the crudest methods. Thus they no more popular and have not been adopted for real ear measurements and computerized probe tube microphone measurements.

Let us discuss, ±n detail about some important prescrip tive procedures adopted in making real ear measurements for hearing aid selection on the computer.

Most of these procedures are based on Lybarger (1944) half gain rule, and have been further modified to suit the individual maximally. Most of the procedures are also based on threshold data rather than loudness data.

I. LYBARGER'S PROCEDURE (1944) :

This procedure evolved from the observations of the frequency response and gain which had been adjusted to the wearer’s satisfaction and comfort by trial and error method.

In this rule, an individual[1] s puretone thresholds obtained, are multiplied by 0.5 between 1000 and 4000 Hz to get the prescribed real ear gain. This formula applies mainly to cases having sensorineuralhearing loss. For those with conductive hearing less, additional gain according to Lybarger has to be given at each frequency.

That is for sensorineural hearing losses

Real ear gain = ½ PTA (at 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz)

where PTA = pure tone thresholds in dB HL.

For conductive hearing losses

Real ear gain= ½ PTA + ¼ (AC - BC) thresholds at each frequency

where PTA = puretone thresholds at each frequency in dBHL.

AC = air conduction

BC = bone conduction

This method is also popularly known as half gain rule.

II. <u>BYRNE AND TONNISSON PROCEDURE (1978)</u> :

The real ear gain in this procedure is derived using a different criteria as compared to Lybarger's half gain rule. This procedure derives its gain from preferred listening levels of speech chosen by children or admits with hearing loss who wear their hearing aids. At the same time, Byrne and Fifield (1974) found the real ear gain needed to amplify the speech to the preferred listening level, by using a formula.

Real ear gain = HTL x 0.46 + c

Where C = a constant which is a sum of 3 correction factors.

HTL = Hearing threshold level at each frequeney.

The three correction factors are as follows:

1. Difference in loudness perceived by normal hearing individuals at different frequencies (in the 60 phon equal loudness contour).
2. At specific frequency regions, the difference between the long term RMS level of speech (RMS meaning the root mean square).
3. Additional, gain required in normal hearing individuals, to bring the overall speech level to the preferred listening level.

Byrne and Fifield (1974) specify all the correction factor values for each frequency.

	Frequency in HZ.						
Correction factor	250	5000	1000	1500	2000	3000	4000
1. 60 Phon loudness contour	-2	-4	0	0	-2	-7	-8
2. Average speech level	-17	-15	0	0	+1	+1	0
3. Additional gain (PLL)	4	4	4	4	4	4	4
Total correction	-15	-15	4	4	3	-2	-4

Thus making use of these correction factors and the real ear gain formula, we can find out the actual gain at each frequency which would best suit the individual.

III. PRESCRIPTION OF GAIN OUTPUT (POGO)

McCandless and Lyregaard (1983) - This is also a modification of the Lybarger' s half gain rule.

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

1. Sound quality and not just the speech intelligibility, is an important property. A poor sound quality may lead to the rejection of the hearing aid.
2. In those methods based on speech threshold comparison, only large difference between hearing aid can be reliably assessed.
3. Speech tests take a long tine especially when there are several hearing aids and adjustments to be tested,
4. Though speech tests may adequately reject a hearing aid, they are unable to identify which electro acoustic characteristics may contribute to poor or good discrimination.

A hearing aid fitting procedure is defined as a procedare for choosing the most appropriate hearing aid adjusting to a particular (individual) ear.

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

POGO can be carried out in three major steps:

Step-1: Based on the audiometric information, calculate the required characteristic gain and maximum power output.

Step-2: Impelementation of the required gain and MPO (maximum power output). This step is time consuming and causes the greatest practical difficulties. This einvolves selection and adjustment among the hearing aids available to the dispenser.

Step-3: This include verification of acoustical performance. This involves a check of, the extent to which the objectives in step-1 have been achieved. In this, any inter-subject variations of acoustical performance of hearing aid and/ear molds must be adequately compensated.

Step-1: Required gain characteristics and maximum power output.

The required insertion gain is calculated using the formula specified for each frequency.

Frequency		Insertion gain
250 Hz	½	HTL - 10
500 Hz	½	HTL - 5
l000 Hz		½HTL
2000 Hz		½HTL
3000 Hz		½HTL
4000 Hz		½HTL

The required maximum power output is equal to the uncomfortable level in dB HL at 500 Hz, 1000 Hz and 2000 Hz. When pure tone audiometer is used, uncomfortable loudness level is expressed in dB hearing level; but When we need to convert it into dB SPL we add 4 dB.

$$MPO = \frac{UCL_{500} + UCL_{100} + UCL_{2000}}{3}$$

Step-2: Implementation of the gain and MPO. The best fitting hearing aid can be implemented in the following ways

1) The required MPO calculated using the formula should be within the adjustment range of the individual. Hence, at first this should be determined.
2) Similarly, the maximum insertion gain required in the region of 500 Hz and 2000 Hz is determined and checked if it lies within the adjustment range of the individual with permissible range of ±10 dB reserve gain.

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

The present available frequency responses of the hearing aids predominantly lie in the frequency rqnge of 250 Hz to 2000 Hz.

Step-3: Verification of acoustical performance. In this step, the extent to which the required characteristics have been achieved on the ear is to be verified. This is of utmost importance since the same hearing aid will have different characteristics on different ears due to anatomical variations. Thus using probe tube microphones, the insertion gain and MPO should be checked on every hearing impaired. How with increasing importance being given to insertiongaln measurements the probe tube microphones should be made use of, rather than a functional gain measurements. In case functional gain measurements are made, it should be compared with the insertion gain required (calculation). A deviation of ± 5 to 10 dB gain is permissible.

IV. BERGER et al PROCEDURE (1984) :

Berger, Hagberg, Rane recommended using the half gain rule at 500 Hz, 4000 Hz, 6000 Hz and an additional gain between 1000 Hz and 3000 Hz.

This gain is also called an operation gain and is the real ear gain.

The formula used is

Gain at 500 Hz, 4000 Hz, 6000 Hz +½ HTL

Gain at 1000 Hz, 2000 Hz and 3000 Hz = 0.59 to 0.67 HTL

The criteria of using real ear gain is that, it make the amplified speech energy equally loud between 500 Hz and 2000 Hz. A little less gain is commended at 4000 Hz and 6000 Hz so that a high sound pressure level would not cause damage to the cochlea and cause further deterioration and reduced speech intelligibility.

For individuals with thresholds lower than 50 dB HL, a lesser gain may be recommended at 500 Hz (0.3) In case of a noise or echoing environment, the subject would prefer lesser gain at 500 Hz (6 dB) and 1000 Hz (3 dB).

For clinical use, the prescribed real ear gain has been calculated as a function of frequency and hearing threshold level.

The values of multiplying factor used at each frequency

are as follows:

At 500 Hz gain = 0.3 x HTL

At 1000 Hz gain - 0.63 X HTL

At 2000 Hz gain = 0.67 x HTL

At 3000 Hz gain = 0.59 x HTL

At 4000 Hz gain = 0.53 x HTL

At 6000 Hz gain = 0.5 x HTL

For eases with conductive hearing loss an additional gain has to be provided. - (0.2 x (AC-BC) threshold not greater than 8 dB) should be added up.

Where AC - Air conduction

BC - Bone conduction

Thus two individuals with same hearing thresholds' the one with conductive hearing loss will have a greater gain.

V. LIBBY' S METHOD (1985) :

Libby' s Method rejects the functional gain measurement stating that functional gain cannot be effectively used with patient's who are unable to respond intelligently - For example in mentally retarded, aphasics and in eases with severe articulatory disorders.

Libby' s method is generally designed for new wearers with mild to moderate sensorl-neural hearing losses. According to Libby, subjects with mild to moderate sensorl-neural hearing losses prefer a listening level close to

one-third of the hearing threshold level. A bass cut or correction of 5 dB are made for 250 Hz to 6000 Hz and 3 dB for 500 Hz.

For severe to profound sensori-neural bearing loss subjects. one-half to one-third of the hearing threshold level is used to reach the preferred listening level of the subject.

This, like POGO. is based on 3 step paradigm,that is preselection, implementation and verification and is measured using probe tube microphone measures. After the person adapts more gain is recommended.

The fitting formula of insertion gain is as follows:

Insertion gain =1/3 HIL + C (for sensorlneural loss subjects)

Where C = correction factor.

The correction factor is specified for each frequency.

'C' from 250 Hz to 6000 Hz - 5 dB

'C' at 500 Hz = 3 dB.

Insertion gain = ¼ HIL (1000 - 4000 Hz) for conductive hearing loss cases.

Thus Libby's method is essentially based on preferred listening level of the individual.

VI. NATIONAL ACOUSTIC LABORATORIES (NAL PROCEDURE) :

Byrne and Dillon (1986) . This procedure is based on Predictability of required frequency response and overall

gain from the audiogram. Required frequency response is reasonably predictable as compared to the overall gain. The HAL procedure aims to make all parts of the frequency spectrum of the speech equally loud, when the individual wears the hearing aid at preferred listening level. When a wide range of frequency is heard, the subject can understand speech optimally with less effort. This they believe to achieve by making all parts of the speech at equal loudness. Thus Byrne and Dillon (1986) revision of HAL procedure utilizes three rules:

1. A half gain rule applied to the three frequency average hearing levels at 500 Hz, 1000 Hz and 2000 Hz.
2. A flat audiogram rule which states that for an audiogram with equal audiometric thresholds (HTL) for all frequency needs a frequency response slope rising at 9dB/octave upto 1000 Hz and falling at the rate of -2dB/octave from 1000-4000 Hz.
3. Calculation of the gain at each frequency over the whole frequency range. A 1/3 slope rule in which response slope in each part of the frequency range is varied by 31% of the difference between adjacent frequency HTLs.

Thus the overall gain prescription is obtained using a combination of rules one and three, whereas frequency response prescription is calculated by using rules two and three.

NAL can be directly calculated using the formala. But these days with computerised real ear measurements, the NAL gain and frequency response calculation has become further easier. The formula for calculating gain using NAL at each frequency is as follows:

Gain = X + 0.31 HTL + K

Where K + frequency dependent constant dependent on the gain type prescribed.

- *5%* of the sum of hearing threshold levels at 500 Hz, 1000 Hz and 2000 Hz

Gain using the real ear measurements at all frequencies are:

Frequency in Hz.	250	500	1000	1500	2000	3000	4000	6000
Real ear gain	-17	-8	-3	+1	+1	-2	-2	-2

Thus NAL hearing aid selection procedure is described as follows:

1. Perform a puretone audiometry and obtain a pure tone audiogram.
2. Decide the type of hearing aid to be selected.
3. Fit the hearing aid which closely approximates the prescribed requirement.
4. Measure the real ear gain and adjust the instrument closely to the prescribed performance.
5. Evaluate the client's performance with hearing aid to get a preferred listening level.

Thus NAL method actually verifies the performance of hearing aid using the formula. In this insertion gain has been adopted. It is based upon extensive research program, verified by clinical trials and analysis and accepted in many hundreds of thousands of fittings. All these above calculations are incorporated into a computerized hearing aid selection.

OTHER METHODS:

The above methods are the most commonly used prescriptive procedures especially While making a computerized real real measurement. There are other methods, which have also been adopted in making insertion gain measurements. They are as follows :

VII. STATE OF THE ART TEST PROCEDURE (SOTA):

This procedure is similar to the selection procedure, POGO given by McCandless and Llyregaard. It is meant to calculate predicted insertion gain and frequency response in the ear canal of the listener and verify the same using the earmold.

Step-1;

Calculation and prediction of hearing aid and earmold characteristics based on the audiomgram.

It differs from POGO in that, it is a computerized probe tube microphone measurement whereas POGO gaia canbe calculated,even without the real ear measurement.

Gain formula

Frequency in Hz	POGO Insertion gaia	Probe micro-phone insertion gain
250	½ HTL - 10	1/3 HTL - 5
500	½ HTL - 5	1/3 HTL - 3
1000	½ HTL	1/3 HTL
2000	½ HTL	1/3 HTL
3000	½HTL	1/3 HTL
4000	½ HTL	1/3 HTL
6000	-	1/3 HTL - 5

The preferred listening level with probe tube microphone was considered for hearing loss less than 70 dB HTL. The preferred insertion gain with probe microphone are closer to Fletcher's formula which is the following :

Insertion gain - 1/3 SL + ¼ CL (1000 - 4000 Hz)

Where SL = Sensorieural hearing loss

CL = conductive hearing loss

Thus, milder the hearing loss, closer to one third of hearing threshold level is recommended. Greater the loss, closer to half gain rule is recommended.

Step -2:

Implementation: We should always aim determine minimum use gain, with helps to establish comfort, reasonable sound quality good word/ recognition without much distortion.

Thus the aim should be to choose the hearing aid, ear mold coupling system which is the best fit is close to the preferred listening level.

Step-3:

Verification - when making a computerized probe tube micro-phone measurement, the ear canal resonance, insertion gain should be checked and verified.

VIII. PRESCRIPTION OF AIDED RESPONSE: (PAR) :

According to Vass (1989), the audiometric thresholds are not a valid method for prescribing gain for hearing aid selection. Prescription of aided response is probe microphone measurements. In these measurements, according to Libby (1984), true frequency response of a hearing aid, as perceived by the subject should be considered. Thus a probe microphone measurement is done to examine insitu and insert frequency response of an individual. The criteria then should be that speech intelligibility of the most important frequencies should be enhanced. for this purpose a range of 250 Hz to 6000 Hz is chosen. The most important peak frequencies are

around 2000 to 3000 Hz around which is the maximum energy concentration is present, that is the primary emphasis (p_1). This primary emphasis, if one recalls from the 2nd chapter, is the point at which maximum ear canal resonance occurs (at around 2.7 KHz). Thus at these peak frequency range, the speech intelligibility should be enhanced and ear canal resonance which is reduced due to the hearing loss should be replaced.

At the same time, we should not primarily emphasis the energy in the region of 2000 to 3000 Hz. For example, a per-son with no response to audiometric is testing at 2000 Hz and above will not likely benefit from a primary emphasis frequency response in the region of 2000 to 3000 Hz.

In such a case, the higher frequency emphasis will most often result in feedback or distortion and the subject will not receive enough gain in the frequency range of his/her residual hearing.

According to Berger (1984), the individual's preferred listening level should be considered for giving amplification. The unaided response of the patient (canal resonance) is measured especially at around p_1 region (2700 Hz). The prescriptive procedure involves choosing a p_1 (primary emphasis

peak) of 2700 Hz and measuring the amplitude at around this frequency while aided. So the aided response will be unaided response together with insertion response. For individuals with mild to moderate sensorineural hearing loss, around 10-15 dB insertiongain is sufficient. If the unaided response is around 20 dB at this frequency, the total gain (aided) will not be more than 30-35 dB at this primary resonant peak.

For a person who is not a new candidate for hearing aid use, an aided responses of the present hearing aid which is to be fitted is measured. The wearer then makes his comments and chooses his own preferred listening level. If this particular hearing aid fits him adequately, the old hearing aid may be altered slightly in terms of frequency response or as required. If the individual's hearing aid response grossly differs from the one prescribed, gross alterations are made in the hearing aid or a new hearing aid may be prescribed altogether.

Oncomparison of the insertion gain using this method and POGO across frequencies. Insertion gainfalls short of POGO by an amount of around 2½ to 8 dB. The deviations were found to be more at higher frequencies. On boosting these high frequency, a distortion of the nature of a harsh, tinny sound quality was found.

Comparison of required insertion gaia and POGO

Frequency in Hz	PAR-insertiongain	POGO insertion gain
500	**20.1 dB**	**25 dB**
1000	25.8 dB	30 dB
2000	27.5 dB	30 dB
3000	25.7 dB	30 dB
4000	22.2 dB	30 dB

IX. SELECTING HEARING AIDS FOR PATIENTS EFFECTIVELY (SHAPE):

Larry E Humes (1988) - The development of computer probe tube microphone systems has made it possible to test the hearing aids for selection in a matter of few minutes.

Hence, the development of SHAPE that is, selecting hearing aids for patients effectively, took place. It is actually a commercially available package of hearing aid selection software SHAPE actually makes use of the 3 theoretically based prescription procedures NAL (revised), POGO, and a procedure gives byCox. These three procedures are/reasonable and have clear objectives and hence have been chosen.

NAL procedure given by Byrne and Dillon (1986) is the best method to gain adequate information. It requires the least amount of information from the patient. Moreover, in

this, the gain is prescribed at all the frequencies. At the same time, POGO and Cox method which are loudness based prescriptions provide prescription for gain and SSPL-90.

All the three prescriptive procedures provide information on insertion gain. There is a provision for selecting an earmold configuration and the type of hearing aid. After the prescription, the hearing aid should be fine tuned either using insertion gain or functional gain to achieve a good match.

Later speech recognition tests should be conducted both in quiet and in the presence of noise. Both speech level and signal "to noise ratios are maintained constant at 7O d*B* SPI and +7 dB respectively. This represents our natural everyda listening environment.

Thus SHAPE or aay such procedures which incorporates many prescriptive procedures should be made use of, rather than a single procedure. Moreover, SHAPE is best quited for insertion gain measurements.

CHOICE OF TEST TYPE

Various prescriptive procedures have come into vague. Yes, unless and until, we have made the correct choice of a particular type of test, our prescription becomes meaningless. In other words, each prescriptive procedure involves a particular type of test by which we can measure the gain. The measurement of gain and simulating this to the ear of an individual is of primary importance in any procedure and any kind of measurements.

Recent advances in microphone technology and hearing aid instruments have made ear canal probe measurements much more simplified and quicker in a clinical setting. One need not rely on KEMAR manikins or 2cc coupler for the measurement of hearing aid performance. Moreover the results obtained from a manikin or an artificial ear (2cc coupler) are not accurate, hence, conversion or correction factors have to be added up to predict the actual function of the aid in the patient, s ear.

All the probe and probe tube microphone measurements - rather real ear measurements are safe and simple methods for determining real ear hearing aid performance.

Another adavantage, a major one, of these real ear measurements especially the insertion gain is that they individual. skinner (1988) noted that preferred litening lecel exists within comfortable loudness rane and the

sound at this level provides the individual with a maximum amount of information.

Moreover, least amount of effort is needed to listen than at other levels of loudness. The preferred listening level will depend on many factors like, the frequency content and range of speech, individual' s loudness growth and ao on. The prescribed seal ear gain approximates the preferred listening level since it is the most comfortable loudness level.

The real ear measurement devices measure the acoustic characteristics of the human ear canal, as it interacts with the hearing aid insitu.

Acoustic measurements performed in the ear canal with and without a hearing aid can provide much information on the overall effects of a hearing aid, earmold plumbing and and ear canal resonance of a patient.

Basically real ear measurements could be broadly classi fied under three main categories:

1. Insitu gain
2. Functional gain
3. Insertion gain.

However clinically actual gain or real ear gain is actually provided by functional gain or insertiongain.

Terminologies and their definitions:

Insitu gais -What does the term insitu imply?
Insitu means in site or in place. Thus insitu gain measurements imply measurements in the natural or in use condition. Insitu gain includes the unaided frequency response in the total response.

It stands for the difference between the sound pressure level produced by the hearing aid in the wearer' s ear and reference sound pressure level. It is a function of wearer's position.

Factional gain - It reflects subjectively measured aided and unaided measurements in the free field.

It is the difference between unaided and aided threshold with the same sound field conditions.

It has also been defined as lowered threshold sensitivity of hearing that results from the increase in sound pressure that reaches the ear drum, When hearing aid is used.

Insertiongain - It may be defined as the additional sound pressure reaching the ear drum when a hearing aid is used. It is the difference between sound pressure level produced by the hearing aid in the wearer's ear canal and sound pressure level in the ear canal with hearing aid absent. It depends on individual's position and orientation.

Let us discuss insitu and functional gain very briefly before discussing about insertion gain in length.

INSITU MEASUREMENTS:

Insitu refers to the physical testing of hearing aid performance on an actual person (or on a manikin). It gives more information about the shape of the gain and frequency response curve of a hearing aid.

It stands for loudness measurements of most comfortable loudness level and uncomfortable loudness level controlled in the residual volume of the aided ear by an insitu measurement system.

This type of measurement can be performed with computerized probe tube microphone.

Insitu gain frequency response may be affected by the depth of the probe tip in ear relative to the ear drum.

Procedure: Today, insitu measurement is done on the patients provided with hearing aid on the basis of speech audiometry. The hearing aid responses are measured at 65 dB SPL.

The hearing aid responses on insitu measurements are as follows:

Frequency in Hz.	In situ gain
250	MCL (Most comfortable level) - 10
500	MCL - 4
1000	MCL + 5
2000	MCL + 8
4000	MCL + 7
8000	MCL - 3

Most comfortable levels are in turn similar to loudness discomfort levels on which these insitu gain measures are based.

Rationale for insitu audiometry :

Insitu measurements provides gains such that the residu dynamic rang of the hearing impaired is use of. The frequency response, slope and most comfortable level a

considered in this, and thus helps in an appropriate hearing aid selection.

FUNCTIONAL GAIN:

Functional gain Yields the actual gain of a hearing aid when worn by an individual subject. But, it is a subjective measure and a behavioural response and hence has its own disadvantages.

It represents the subjective aided - unaided frequency specific measure. It can be utilized to assess a range of frequencies that are relevant to perception of speech. Aided responses can be improved by widening the hearing aid frequency response and modifying earmold acoustics. Also earmold acoustics - the sound channel has to be effective in terms of the shape and diameter. In many, the ear canals are not large enough, as in children to measure the aided probe tube microphone responses. In such a case, functional gain is of utmost importance.

Procedures Any functional gain measurement should beone in a sound treated room. An unaided test of the individual may be performed and the responses noted. Then various aided conditions (depending on number of hearing aids one is comparing) are obtained. The aided conditions reflect testing

with various earmolds. Also, the subject is seated 1 meter from a loudspeaker which is placed at the same level as the subject's ear. Most comfortable loudness levels were obtained for speech and for aided condition.

Functional gain improves over use of different earmold configuration. Ther is a significant improvement with shell mold and libby horn.

With these, functional gain can appoximate insertion gain. In patients with profound sensorineural hearing loss, functional gain has been found to yield better results, as compared to the insertion gain (Barford, 1981; Mason and Popelka, 1986; Dillon and Murray, 1987). The functional gain is advantageous over insertion gain because, the placement of probe tube microphone with respect,to an eardrum should be fairly constant. Hence there is an uncertainity of precise location of microphone which will lead to further complications. Instead, functional gain measurement is much easier, quicker and approximates the actual Insertion gain.

It has been established that functional gain is as good a measurement as insertion gain. The major/disadvantage of functional gain is that it does not take into account the ear canal resonance effects which is the basis for the

primary emphasis peak (P_1) at around 2700 Hz and which is responsible for good speech intelligibility.

Thus the functional gain measurement does not closely approximate the preferred listening level. Internal hearing instrument noise and the amplified ambient noise both may lead to invalid functional gain measurements. In the measurement of unoccluded and occluded responses during functional gain measurements often yields a functional loss due to ear canal effects.

Hence because of all the above disadvantages, functional gain is not much used though,many use it when facilities for insertion gainmeasurement is not there.

Functional gain is usually measured by substitution method (which will be discussed later) and also by using reference microphone.

INSERTION GAIN;

Insertion gain-the concept owes its origin to Ayers in 1953. When an individual wears a hearing aid, it intercepts the path between the sound source and listener's ear. Thus the air path in between the sound source and the listener' s ears can be considered as a reference. Hence, measurement of a hearing aid can be expressed as the amplification in the airpath which it introduce in the subject's ears.

The measurement of sound pressure in the ear canal is as old as 34 years, It was first reported to measure acoustic characteristics in the ear and earmold in 1956. The earmold, its shape and size have a definite influence on the appropriateness of hearing aid selection.

This was the beginning of the development of, now popular method of insertion gain measurement. At present insertion gain has developed so far that, at least in other countries especially United States, this is being used clinically for hearing aid selection.

It was only in 1981, that Insertion gain, gained its true colours and became recognised for the first time. Lauridsen and Gunthersen (1981) developed a method in which a probe tube microphone was used, which consisted of a soft, flexible, long, thin tube with a microphone placed in it. This flexible tube could be placed in the ear canal through the vent of the earmold. Reliable measures of aided responses and gain could be obtained across wide range of frequencies which could help in an appropriate precise hearing aid prescription.

At present insertion gain measurements is consider to be a standard test in the area of hearing aid seclection.

Insertion gain has been defined in many ways and many synonyms have been given. An apt definition of insertion gain is the following:
"Insertion gain is the ratio of sound pressure level at a point in the ear canal of a treated ear to the sound pressure level at the same point in the non-treated ear".

Many other synonyms like etymotic gain, orthotelephonic gain or real ear gain have all been used to mean insertion gain. Insertion gain can be measured using various prescriptive procedures. The new prescriptive procedures make use of insertion gain rather than any other gain. Apt formulae also have been given to measure insertion gain. Insertion gain is the objectively measured difference between aided and unaided eardrum sound pressure in decibels. Real ear gain or insertion gain performed using a computerized method; considers the natural ear canal resonance which primarily occurs at around 2700 Hz with an amplitude of 17 dB at frontal incidence and around 21 dB at 45° to 60° incidence.

In addition to insertion gain, consideration of insertion loss is of great significance in determing the actual insertion gain.

"Insertion loss has been defiend as the reduction of sound pressure reaching the eardrum when the electroacustic characteristics is occluded by the earmold".

Insertion gain measurements consider the external ear effects like pinna diffraction and resonances of the ear, concha, and ear canal.

Thus an ear canal resonance curve, or a transfer function of sound pressure from the free field to the ear-dram provides a basis for the measurement of the insertion gain.

Procedure involved in clinical measure of insertion gain: The insertion gain measurements, or for that matter any real ear measurements, are done in a soundtreated normally reverberant room, A non-reverberant room can dampen the reflections from the walls and ceilings. For this purpose, the walls can be covered with acoustic tiles and screens.

Placement of the probe tube: The placement of probe tube into the eqr canal is very important. The accuracy with which probe is placed in relation to the eardrum is very essential. Thus sound pressure measurement in the ear canal at different distances from the ear drum is important. Yet, large variation in the probe tube placement does not occur until the probe is moved away by more than 15 mm from the eardrum.

What is important is that when comparing the unaided and aided measurement the point of placement should be maintained constant. It has also been established that sound pressure measured by the probe placed in the ear canal through the bore of the earmold does not differ much with variation in the bore size.

Clinical procedure - For the etymotic gain measurement, one starts with measuring the unoccluded and unaided ear canal responses. For this purpose, a probe is placed close to the ear drum at a distance of 1 mm. away. In the ears/ subjects with hearing aid and earmolds placed, the probe is inserted into ear canal through the bore which is parallel to the sound canal to the same point as is done in the free ear canal measurement.

For this an easy procedure is adopted. The patients are asked to tell when the probe tip reached the eardrum and from this point it is withdrawn backwards to the same point. The point of placement in the free ear canal and the aided canal is maintained at a constant point. This is very important because any variation in this will lead to erroneous responses, which in turn will lead to a wrong judgement in hearing aid selection.

When the probe is placed at the right place, the insertion gain is measured as difference between the sound pressure level in decibels at the ear drum in the ear aided with hearing aid and earmold and sound pressure level in decibels in the free ear canal.

Thus we see that insertion gain measurements are powerful tools of hearing aid selection and they help in ferretting out problems in the responses obtained by hearing aid devices to determine malfunction or inappropriateness of the hearing aid selected to meet the acoustic needs.

The etymotic real ear insertion gain will become more popular, clinically oriented in making measurements for hearing aid/selection, evaluation and fitting. The insertion gain measures conforms closely to the preferred listening level of the individual's choice - thus maximising the utility provided by a particular hearing aid to a particular individual.

Any of the previously mentioned prescriptive procedures like NAL-R, POGO, Berger's procedure or a combination of these, can be used to measure the actual insertion gain provided by an individual.

An hearing aid is selected whose frequency response is known from the measurements in a coupler. This is then fitted

for making insertion gain measurements on the patient. Etymotic gaia is measured across a wide frequency range. If there is any discrepancy or mismatch between the required insertion gain and the gain measured through the coupler, the hearing aid is reset, or an entirely different hearing aid would be selected. This new hearing aid should have its frequency response lying somewhere close to the insertion gain measured.

This kind of procedure has been adopted to make the measurements and selection of the hearing aids much easier. By measuring the hearing aid response and preselecting it will give an idea of the hearing aid and the type that has to be selected, the large differences caused by individual ear differences make a behavioural confirmation of the gain and frequency response and the apt hearing aid that has to be selected.

REUR, REOR,REAR,REIR - WHAT ARE THEY?

Over the years, the advancement of probe tube Microphone has led to coining of several new terms. In the past, term such as 'free field to eardrum transfer function', 'wearer frequency response (ANSI, S_3.35) were used to represent real ear measurements. These were gradually replaced by terms such as insertion gain, function gain or insitu gain. Now further modifications have been made and even these terms are replaced by more complex but realistic terms.

1 • Real ear unaided response (REUR):

It is similar to wearer unoccluded ear gain. It may be defined as the change in acoustic signal that occurs when the signal is transferred from the sound field to near the eardrum at the point of measurement in the unoccluded open ear canal.

Usually there is an increase in sound pressure level in the ear canal which is chiefly due to the resonance in the external ear canal and other acoustic effects in the ear. The primary peak occurs in the region of 2700 Hz and the increase in sound pressure level is around 16-18 dB. The secondary peak is in the region of 4000 - 5000 Hz at a level of 10-14 dB.

Application of REUE: This unaided is very essential for most of the prescriptive procedure for calculating insertion gain moreover, it has many other practical applications in the hearing aid selection. If the unaided responses are irregular even the insertion gain values will be different and the target insertiongain values may not be achived. If the REUR values are known, it may be used for ordering custom in-the-ear hearing aids.

The REUR curves can be used as a reference and we can select a hearing aid the output of which mirrors the response. This is because; the hearing aid processes speech will sound more natural to the patient if the amplified frequency response of the hearing aid mirrors the patient's REUR.

More over by comparing the individual's REUR to the average REUR, the 2cc coupler gain of the hearing aid can be adjusted.

Demerits - The REUR fitting procedure believes that the desired gain response is not related to the hearing loss, that is they have equal insertion gains at all frequencies, which is of course not true.

2. Real ear occluded responses (REOR):

The REOR is the response or change in the real ear unoccluded response that occurs when the ear is occluded

with a hearing aid. This measurement is done with the hearing aid turned off. For most of the hearing aid fittings,(especially the occluded ear molds), the REOR will be below the REUR. The difference between REOR is the insertion loss.

Thus the difference between REUR and REOR gives us an idea of change in resonance and other acoustical properties of the ear canal and concha when the ear is occluded by a hearing aid or an ear mold. Also, for very high frequencies, the hearing aid attenuates the input to the ear.

Thus, when the patient is fitted with an ear mold or hearing aid, there is an insertion loss of around 20 dB. REOR has an indirect influence on all the aided measures and in finding the insertion gain since this can be altered substantially by the degree of occlusion. Yet, REOR is not measured because it is not a direct measure in the hearing aid fitting.

Demerits: Different ear mold styles with different degrees of occlusion will vary the REOR measured. Hence the REOR values will be true and valid only for one set of hearing aid and ear mold style.

3. Real ear aided response (REAR):

This refers to the absolute aided output measurement in the ear canal. REAR, is the same as insitu gain. While Measuring the REAR there is no specified input or a volume control setting.

Applications:

(1) In many of the prescriptive procedures REAR rather than insertion gain values are considered. For example - A prescriptive procedure called the desired sensation level developed by Seewald and Rolss in 1988. Using the prescriptive approach, the target values are calculated for the amplified long term speech spectrum which is then compared to the REAR.

(2) The maximum aided sound pressure level that could be present in the ear canal can be calculated Which is of utmost use in the overall hearing aid fitting process. This is an especially critical measure for young children and non-responsive patients.

In case of adults, the REAR values can be used as a cross check for loudness discomfort level measures and also used in assisting in documenting effectiveness of saturated sound pressure level - 90, hearing aid adjustments or the functioning of output limiting circuitry.

(3) REAR may also be used to check and examine/hearing aid special features such as directional microphone and compression circuitry etc.

REAR is often used to trouble shoot user complaints of hearing aid performance. Sharp peaks in the frequency response which might be causing incipient feedback or unpleasant sound quality are identified more readily in the REAR than in the insertion gain response.

4. Real ear insertion response (REIR):

This refers to the insertion gain measured in the real ear. It is the electroacoustic correlate of the behavioural measure of functional gain and the resulting values from conducting these two measures *on* the *same* patient should be very similar. When averaging insertion gain for various frequencies, real ear insertion gain rather than real ear insertion response would be obtained.

Real ear insertion response is the difference between sound pressure level in the ear canal when the person is using a hearing aid versus sound pressure occuring naturally

Thus real ear insertion response is the difference between real ear unoccluded response and the real ear aided response .In other words REIR-REUR-REAR.

Hence, real ear insertion response is a relative term rather than an absolute term and these thus may not necessarily be positive numbers. The primary use of real ear insertion response is to determine the frequency response of the hearing aid. Any prescriptive fitting procedure can be used and desired gain values can be computed which can then act as a target for REIR measurement.

71% of the fittings based on REIR are appropriate. It is the most effective and reliable method of quality assurance.

Thus we see that these terminologies provide us with a better clearer picture about real ear measurements and more so about their comparison and interaction. They give an accurate measure of frequency response and the desired gain on the wearer. Instead of using terms like wearer insertion gain, wearer frequency response curve and so on, the above terms sound more realistic and natural.

COMPARISON OF IEC (2CC COUPLER) GAIN, KEMAR GAIN, FUNCTIONAL GAIN AND INSITU GAIN WITH INSERTION GAIN.

The various gains such as coupler gain, functional gain, insitu gain and insertion gain help in selecting a particular hearing aid from a group of hearing aids. The criteria is to get a maximum benefit from the chosen hearing aid. Hence, most often, real ear gain measures are chosen rather than coupler gain measurements.

IEC-2cc coupler gain and insertion gain - The IEC gain is defined as the ratio of the sound produced in a coupler by the hearing aid to the sound pressure in the undisturbed free field. According to Dalsgaard et al. (1976) difference exists in the performance of a hearing aid under practical conditions and as measured in accordance with IEC-2cc coupler.

The real ear insertion measure with the hearing aid mounted on the patient' s head is different from that measured on coupler due to diffraction effects.

The actual earmold channel varies in dimensions from the channel of the earmold simulator of the 2cc coupler. in reality the earmold will not fit snuggly into the earcanal. It will always have some amount of leakage, which will change the frequency response especially at low frequency. The coupler

ear simulated earmold will fit in the ear canal tight which will lead to frequency response which is different from that of the real ear. Moreover, the ear canal is not a simple straight canal and hence leads to change in impedance of the volume between the earmold and eardrum of the volume. Thus acoustic impedance between the earmold and eardrum combined with impedance of the eardrum will not be equivalent to the impedance of a simple cavity.

The insertion of an earmold into the ear canal will change the resonance pattern of the ear canal. Thus, we see that insertion gain is more precise in usage than the 2cc coupler gain. Sometimes selection of hearing aids is made on the basis of finding 2cc coupler gain and equating it with real ear gain, since to this day calculation of 2cc coupler gain is common as compared to the insertion gain measurement.

To obtain insertion response curves, vhich is the actual real ear response, corrections should be applied to the 2cc coupler curves. The corrections that are appropriate are related to the type of hearing aid since the location of microphone sound entrance differs in behind-the-ear, in-the-ear or body-level hearing aid.

Correction factors are applied to the 2cc coupler (IEC) gain or response to obtain on estimated insertiongain. For

this one adds the head baffle effect and 2cc coupler to ear simulator correction and subtract the free field to ear drum transformation.

*Th*us the corrected, estimated insertion gain will be as follows:

Estimated insertion gain = 2ec coupler gain + (Head baffle effect + coupler to ear simulator correction) - Free field to ear drum transformation.

At very low frequencies, insertion to coupler gain will be more variable than at high frequencies.

Functional gain and insertion gain: Probe tube microphone measures rather than probe microphone measures are becoming more popular. Hence the validity of real ear measurement decreases as a function of frequency and is dependent onthe distance between tympanic membrane and probe tube (Gilman and Dirks, 1986).

It has been reported through many studies that insertion gain measures are more reliable as compared to the functional gain. Insertion gain measurements are quicker with better frequency resolution.

Actually the functional and insertion gainaccount for only slight differences in individuals - they both yield

almost the same results. The small differences is due to measurement errors - as proposed by many authors (Harford, 1981; Mason and Popelka, 1986, Dillon and Murray, 1987).

Functional gain and insertion gain differ in the following;

1. In normal hearing individuals in which we aim for a better gain in the frequency region in which significant gain is to be provided insertion gain should be used.
2. In case of non-linear hearing aids or hearing aids with high gain and low maximum output insertion gain measure is always preferred.
3. In cases of patients with profound sensori-neural hearing loss, functional gain measurements provide better information.

Functional gain measurements cannot be applied effectively in cases who are not able to respond intelligibly as it is a behavioural response.

It is observed through measurements made inaided and unaided condition that functional gain is theoretically smaller, than the probe tube or insertion measurements by the amounts corresponding to the free field to eardrum transfer function. There was a significant difference across frequencies.

But, it has been clear that for accurate estimates of gain for hearing aid measures, either functional gain or insertion gain is necessary.

Insitu gain and insertion gain: Insitu gain measures the frequency response of the total output sound pressure level being delivered to the ear canal of a hearing aid wearer. Thus, insitu gain for an individual for a particular hearing aid varies with different placements of the probe tube tips.

Insertion gain being the difference between the unaided and the aided condition does not vary with varying points of placement of the tip at a particular point of time and place, considering that the placement of the probe tip does not vary within unaided and aided condition.

Insitu gain frequency response may be affected by the depth of the probe tip in the ear canal relative to the eardrum.

Moreover, the response and the gain vary with the molded condition. Hence insitu gain by itself does not have any value unless and until it is compared with the unaided condition, and the external ear effects are excluded from participation. Also, unless and until the ear canal resonances is known separately in the aided condition we may not be able to know the actual real ear gain.

However, insertion gain measurements are wholly dependent upon insitu gain measures. Until and unless we know the insitu gain, we will be unable to predict insertion gain. Hence, in order to determine the actual gain of a hearing aid, not only does the insertion gain measurement become important but also the functional gain insitu gain and the coupler gain. Each of them have their own advantages and disadvantages and hence, should be applied intoto.

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COMPUTERIZED PROBE MEASURES

The advent of computerized systems has led to quicker and objective measures and an objective of recording data, in any field of learning, be it science or arts. Retronics has introduced a micro-computer CCI-10 based model which uses a computer aided self calibration probe microphone with a soft silicone tube. This has significantly improved the technology for real ear measurements. Thus, following this model, several companies have developed computerized systems for measuring sound pressure bevel at the tympanic membrane. The computerized probe microphone measures provide a quick and objective method of recording sound pressure level at the tympanic membrane.

The probe tube measurements, in addition have the following advantages.

a) The variability in terms of threshold is eliminated.
b) The entire frequency range is taken into consideration rather than discrete frequencies.
c) There is no interference of the measurement by noise,
d) The measurement especially

the computerized method is very efficient and saves lot of time.

At the same time the major disadvantages are,

a) Probe placement - variation in probe placement will yield different results.

b) Inconsistencies with the terminology and procedure suggested and used by the different manufacturers, as they adapt ANSI standards and IEC standards to their equipment.

The computerized probe tube microphone devices are capable of recording changes in sound pressure level at the tympanic membrane to as small as 1 dB and based on this many discrete points (250) in a frequency range can be sampled. These discrete points have to be? recorded and it is quite difficult to record these discrete points along the entire range of frequencies 125 Hz to 8000 Hz.

This problem has been solved by providing data point print outs and/or storage of data to computer disk.

A video monitor shows the traces of graphic print out on the XY axes. Manufacturers provide colour coding for each trace - or a specific symbol may be provided for, identifying each trace. But as mentioned above, the clinician would find it difficult to hand plot each data point from the print out. Often the traces may overlap and it may become diffi cult for the clinicians to differentiate very small diffi-rences between them.

Thus other manufacturers provide a numeric print out of the frequency sampled and the corresponding response level in decibels. This helps in precise analysis of the data at each sampled frequency. For analysis purposes, the data is entered manually into the computer for further calculation and statistical evaluation.

Manual entry of data may not only take a longer time but may yield errors. Only four manufacturing companies provide serial ports to transfer data directly to micro-computer.

Thus computerized probe microphone measures, on one hand provide a better facilities in terms of preselecting,

a) Particular prescriptive procedure, and a particular type of test so that selection of a hearing aid can be made in a matter of few minutes.

A new development:

A fairly new computerized system called the IGO-1000 or insertiongain optimizer by Madsen Electronics has incorp rated the following:

(i) Menu driven operating system which any clinician can perform without difficulty and without prior knowledge about the computer. The instructions for the next step or next stage appeass on the screen and the clinician has

to fust press the numerals onthe key board. This not only helps the clinician to perform this procedure correctly but gives a clear picture of each step being done.

(ii) A colour screen layout is present and each and every part of the test is displayed on the screen. For some data like insertion gain frequency response the display is not only in terms of numerical value but also as a relative curve. The numerical gain value is the difference between the unaided and the aided thresholds. Similarly, curves, graphs are provided wherever necessary.

(iii) IGO-1000 (Madsen) includes both insitu and insertion gain measurements - thus REAR (real ear aided response) as well as REIR (Real ear insertion response) can be performed and compared.

Various test methods have been included.speech tests also have been included.Three types of stimuli are available - warble tone, narrow band noise and sinusoidal tone. Thus making use of these we can make threshold measurements as well as aided measurements.

(iv) Prescription data is provided such programs as POGO, Lybarger's half gain rule, NAL, are provided. The clinician has to just select one of these and the gain

value is calculated automatically. There is no need for a manual operation in that. IGO-1000 Madsen has been widely used in all parts of the world.

Fonix-Computer controlled real time analyzer (1988): The Fonix 6500 real time analyser helps in selecting the hearing aid and it has a video display attached to it. It also has the capability to perform hearing aid testing to identify its various electro-acoustic characteristics. For the purpose of hearing aid selection two modes can be selected automatic or manual.

In the automatic mode of testing one can test in both unaided and aided conditions, gain insertion gain. In the screen, curves related to unaided, aided, insertion or insitu gain are obtained. The target curve can also be obtained.

Procedure: The client is placed or seated and reference and probe microphone kept in position, ear canal unaided response or resonance characteristics is obtained. Next, the hearing aid is placed in the ear. The probe tube is placed through a channel specially made in the earmold. Normal user gain setting is adjusted and set in the hearing aid, and aided response are noted, and aided gain curve is obtained. Insertion gain curve is also obtained.

Almost the same procedure is carried out for manual mode except that in this the clinician has to select all the operations for obtaining the respective curves. The insertion gain curve acts as a basis for hearing aid selection. Here, the prescriptive formulae can also be used.

The following formulae - NAL, POGO, BERBER, LIBBY' S ½ gain, 2/3 gain and 1/3 gain formulae can be used. If prescriptive formulae are used, it is based on audiogram data which can also be measured and entered in the nodule itself.

Thus we see that insertion gain or insitu gain measurements can be performed which helps in appropriate hearing aid selection.

CHOICE OF TEST METHODS

The test methods include a reference and a test microphone and for different applications, different methods of testing are chosen.

There are four test methods -

1) Substitution method
2) Comparison method
3) Pressure method
4) Ipsilateral comparison method

1. Substitution method:

This is a method of measuring the free field sound pressure level. For this, the test microphone and the test reference microphone are placed alternately at the same point in the sound field; and the sound pressure is calculated.

This method includes extreme diffraction effects of the patient's body, head and the hearing aid.

Drawback: The only draw-back of this method is that it requires identical measuring conditions. Any movements on the part of the patient or ambient distortions will result in error. It also requires a storage device to store room calibration and the occluded and unoccluded test results in memory.

2. Comparison method:

It is a method of measurement in which the test and the reference microphone are placed simultaneously for free field sound pressure at two acoustically equivalent points in the sound field, that is in each of the two ear canals.

Advantage: It compensates for variation in the ambient conditions since it is an online measuring method, the test taking place simultaneously at equivalent points in space. It also excludes extreme diffraction effects.

Disadvantage: It requires two very identical and symmetrical bodies. Patient's movements should be avoided. Both ears should be treated with probe tubes.

3. Pressure method:

This method of measurement includes a constant input sound pressure level which is controlled at the point of entry to the ear canal in which the test microphone is situated. The constant controlled input sound pressure level includes a calibrated reference microphone, this eliminating diffraction effects.

Advantage: It eliminates the diffraction effects of the hearing aid as well as of the patient's body and head.

It also takes care of ambient noise and patient's movements.

4. IPsilateral comparison method:

It is a variant of the comparison method and is a non-standard method. It is very similar to the comparison method. Here the test Microphone and the reference microphone are placed simultaneously at the same point in the sound field in the sane ear. Thus the major advantage of this method over the comparison method is that in this the two ears are not considered to be identical. Each ear is thus,tested separately.

This method of measurement involves the measurement of unoccluded ear canal resonance which is later stared. Later, the hearing aid is fitted and occluded ear test is performed so that insertion gain is obtained. It is advantageous over standard comparison method.

1. It does not require completely symmetrical body and head-shapes and identical ear canals.
2. Patient's head turning movements will not have much influence on measurement errors.
3. Only the test ear needs a probe tube.

While doing real ear measurements (cither insertion gain or inaitu gain measurements) we should he very careful in selecting one of these methods of testing, the selection of these test methods should be based on end appropriate to the testing situation sad needs

OTHER SPEECH TEST FOR HEARING AID SELECTION

During insertion gain measurements, both unaided and aided sound field thrsholds are made. Both the unaided and aided thresholds are compared with the speech spectrum in the range of 250 Hz. to 1000 Hz. If speech spectrum is greater than 20 dB above the unaided sound field threshold in the frequency range of 250 Hz to 1000 Hz, we should check whether the hearing aid wearer makes intelligibility judgements or not. Inter aid comparisons are made based on these Intelligibility tasks. Thus any people with average language skills are made to take up the task of speech intelligibility rating. Based on the inter hearing aid comparison results, the best hearing aid which can made the best intelligibility judgement is chosen for the patient. Thus we see that probe tube measurements are not the actual real ear auditory responses. Even if real ear measurements are made using probe tube Microphones, the final hearing aid selection should be based on aided and unaided speech tests like phoneme recognition articulation index and so on.

The clinician should adopt the speech spectrum amplification method in his selection procedure. This will closely approximate the client's actual/hearing and optimum audibility. This is because in everyday situation or

listening condition, the client is exposed to speech rather than puretenes. Thus the success in selecting an appropriate hearing aid depends on how well a person can effectively listen to the continuous speech.

Various types of speech spectra and various typos of speech tests have been employed in hearing aid prescription.

1. Composite speech spectrum(Robyn Cox and Jeffrey N.Moore, 1988). This consists of two types of multi talker speech spectra - simultaneous and sequential spectra.

a) Simultaneous spectra - is obtained by measuring the long term RMS spectrum produced by several talkers recorded at the same time talking together. This is used for hearing aid prescription (pascoe, 1978; Cox, 1983).

b) Sequential spectra - is obtained by measuring the long term RMS spectra for each individual talker and arithmetically averaging the obtained levels across talkers. This spectra is more appropriate than simultaneous spectra (Byrne and Tonnisson, 1976).

2. Speech recognition test:(Larry E Humes, 1989): After the prescription of the hearing aid is made using insertion or functional gain measurement. The clinician should perform

aided speech recognition test both in quiet and in presence of multitasked babble. The speech bevel is usually fixed to around 70 dB SPL and the signal to noise ratio to +7 dB so that it represents the everyday listening condition.

This test is employed in SHAPE-selecting hearing aids for patients effectively. The unaided as well as aided performance is checked using a speech transmission index.

3**. Speech intelligibility rating** :(Robyn M Cox, D.Michael McDaniel, 1989), For hearing aid evaluation, isolated words phonemes or bisyllabic words do not much give us an idea of the patient's preferred listening level.

Thus subjective judgement approaches for connected speech as stimulus should be used. For this purpose, samples of speech are chosen and listener is to make subjective ratings to samples of speech. The listener is exposed to a brief passage of connected speech and the stakes the ratings to its intelligibility.

The intelligibility rating varies from o to maximum intelligibility. This speech intelligibility rating test was developed with the aim that it would be very practical and have high validity. This test is advantageous over other

tests because it makes use of connected speech which closely simulates to everyday speech.

4. Phoneme recognition test : (Duffy. 1967; Zelnick, 1970): Speech perception is tested using CNC(Consonant nucleus consonant) words. These were more meaningful for measuring the patient' s auditory and audio-visual speech perception capability. Each phoneme rather than the whole word was given a point because it was a better method of measuring behavioural response.

Thus probe microphone measurements should adjunct these speech tests to get a true real ear sound field measure.

5. Articulation index :(French and Steinberg, 1947): Articulation index is e number ranging from 0 to 1. It represents the overall fractional pert of the total speech signal available to a listener relative to the total speech signal.

It is calculated by dividing the whole frequency range into equally intelligible bands. The contribution of each bend is then determined by the dynamic range of speech, available to me listener in that band. To reduce the contribution of some of the bands of speech spectrum;

external masking noise can be used so that parts of peech spectrum are kept below threshold.

French and Steinberg (1947) used consonant - vowel-consonant non-sense syllables to measure a subject's performance under conditions of high pass and low pass filter. They divided the frequency spectrum of 250 Hz to 7000 Hs. iato 20 non overlapping frequency bands. Each of these bands was believed to contribute to articulation index and was independent of contribution of every other band.

Thus effective sensation level for a band of speech was considered as the difference between the peak level of speech in the band and the individual'a hearing threshold or finding the total effective masking whichever was higher.

Kryter (1962a, 1962b) included corrections for upward and downward spread of masking effects and also when speech levels in a particular band exceeded the listener's loudness discomfort level of rthat band.

Kryeter's spectrum levels were obtained using running speech with pauses. Kryter also provided weights for calculating the articulation ind from octave and one-third octave band. He assumed a 30 dB dynamic range.

Dugal, Braida and Duslach (1980) used articulation Index based on French and Steinberg (1947). They assumed that the masked threshold in a given band reflects the quiet threshold in the band. He also used a factor known as proficiency factor to fit the articulation index results to the speech recognition data to predict the performance of hearing impaired individuals. A modified articulation index is often used to compare the performance of hearing aids using 3 methods - NAL, POGO, and BBRGER's method. It was found that Berger's method produced higher articulation index. The lowest articulation index Was produced using NAL.

6. **Connected speech test**: It is the test of intelligibility of every day speech used for measuring hearing aid benefit. It consists of 48 passages of conversationally connected speech. Bach passage contains 25 key words for scoring. For the normal hearers, all the passages are equally intelligible. For a hearing impaired person several of these passages are administered, scored and averaged. Also signal/to babble ratio is found. This is the best method of intelligibility because it involves connected speech which is similar to everyday life.

In conclusion, we can say that speech intelligibility tasks are a must and should always be an adjunct to the real

ear probe tube measurement to actually get the true real ear gala and conform to the preferred listening level.

It has also been observed and suggested that hearing impaired individuals need more preferred insertion gain when lisatening to others speek than when listening to themselves speak. This depended wholly on individual's hearing, earmold venting etc. Difference in preferred insertion gain leads to significant performance difference.

REAL EAR MEASURMENTS - ITS ADVANTAGES AND LIMITATIONS

These days, a clinician would always prefer using real ear measurement tacniques because they have Many advantages,

1) Thay effer direct insitu data from the ear canal of the person who is being given amplification.
2) The real ear measurements are also quick methods and these measurements may be done in a span of few minutes.
3) Tha transfer formula as in coupler measurements are unnecessary.
4) In this, all the peaks and valleya of the fraquency response are revealed because it consists of a sweep frequency tracing.
5) The other ear need not ba masked.
6) The acoustic modifications when hearing aid and earmold are placed on the ear can ba verified. external ear resonance changes can also be verified.

Limitations:

Yet there are may limitations which we should always glance at.

Tha major limitations are -

1) There is no standardised instrument for measurement.
2) It often yields unreliable results and frequency responses above 5 KHz.

3) In children, where the ear canals are too small, the microphone or probe cannot be accommodated.
4) Before the gain level is reached, often a feedback occurs.
5) Even to this day, we cannot signify a few values like anti-resonance dips, large peaks, etc.

Real ear probe tube assessment provides useful information regarding size and shape of acoustic signals at the eardrum. Real ear probe tube measurements is the best tool in ferretting the problems present in the response curves of a hearing aid, or in determining malfunction of a hearing aid selected.

This technology will hopefully advance further and will be used clinically all over the world.

The greatest advantage of using real ear probe tube computerised methods for hearing aid selection is that the clinician can visualize for himself, the frequency response of a hearing aid when placed over patient's ear canal. The clinician can also make needful adjustments in either the hearing aid itself or the earmold, venting etc. So that the desired response (insertion gain response) is obtained aad it closely approximates to the preferred listening level.

Real ear method is the only objective method used so far. The future trend points more towards objectivity and hence tho future of probe tube microphone Measurements is itself encouraging.

Hearing aid users need more of preferred insertion gain, so the clinician have to use a method, such as this, which *is* objective and quick and which gives maximum satisfaction to the user.

Further research has to be done in this area. Real ear mesurement methods have to be altered to suit those clients with abnormal external ear so that even in such patients, we can make an objective measurement and fit the ear with an appropriate hearing aid if necessary.

Research has also to be done on how size and volume of the ear canal become important dimensions in making real ear measurements.

CONCLUSION

Sullivan (1986) states -Real ear measurement allows us to tie up loose ends we used to handle by the seats of our pants. There will always be an interpersonal aspect of fitting aids but we are no longer dealing with it as an art. It can now become a science with an interpersonal aspect".

Real ear measurements are useful for determining.

- Gain and frequency response, real ear $SSPL_{90}$, quality of frequency response, acoustic modification effects, difference between use gain and full-on-gain, the performance of hearing aids and comparing between them, electroacoustic adjustments, and binaural matching.

A time will come when all the clinics will opt for life time investment on computerised method of measurement for hearing aid selection since this will prove beneficial by its objectivity and quicknes.

Of course one should keep in mind that one cannot wholly depend on insertion gain measurements and the importance should be given to speech intelligibility tests so that more accurate responses are obtained.

Recently a self administrative inventroy kown as
"Development of profile of Hearing Aid Performance"is used.

This profile quantifies performance with a hearing aid in everyday life. The profile assess experience with amplif ication in terms of speech communicatlon is three types of listening situation and is terms of reaction to amplified environmental sounss. It has been found to be useful in evaluating and comparing different approaches to hearing aid fittings. The profile can be clinically used to assess existing hearing aid fitting.

we should start depending on what is "Real" and not what is "artificial" (like the coupler) in making decisions about hearing aid fitting, So that the hearing aid wearer feels maximally comfortable with it.

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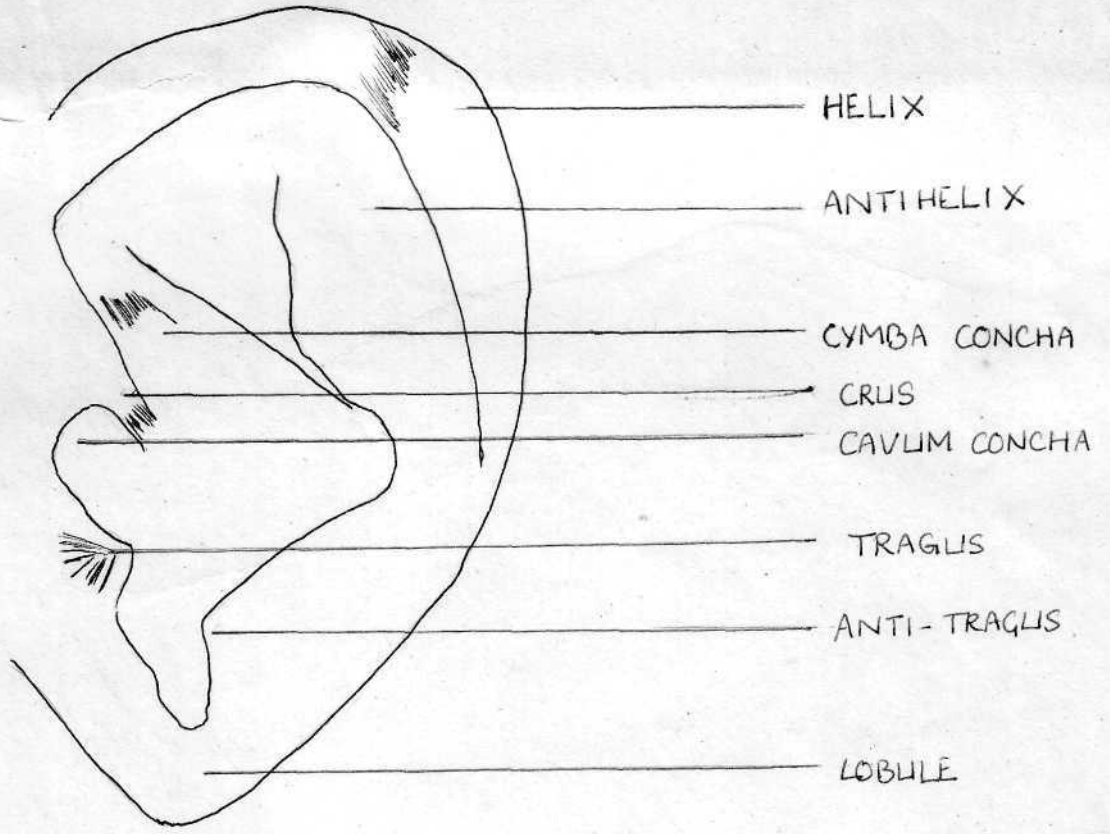
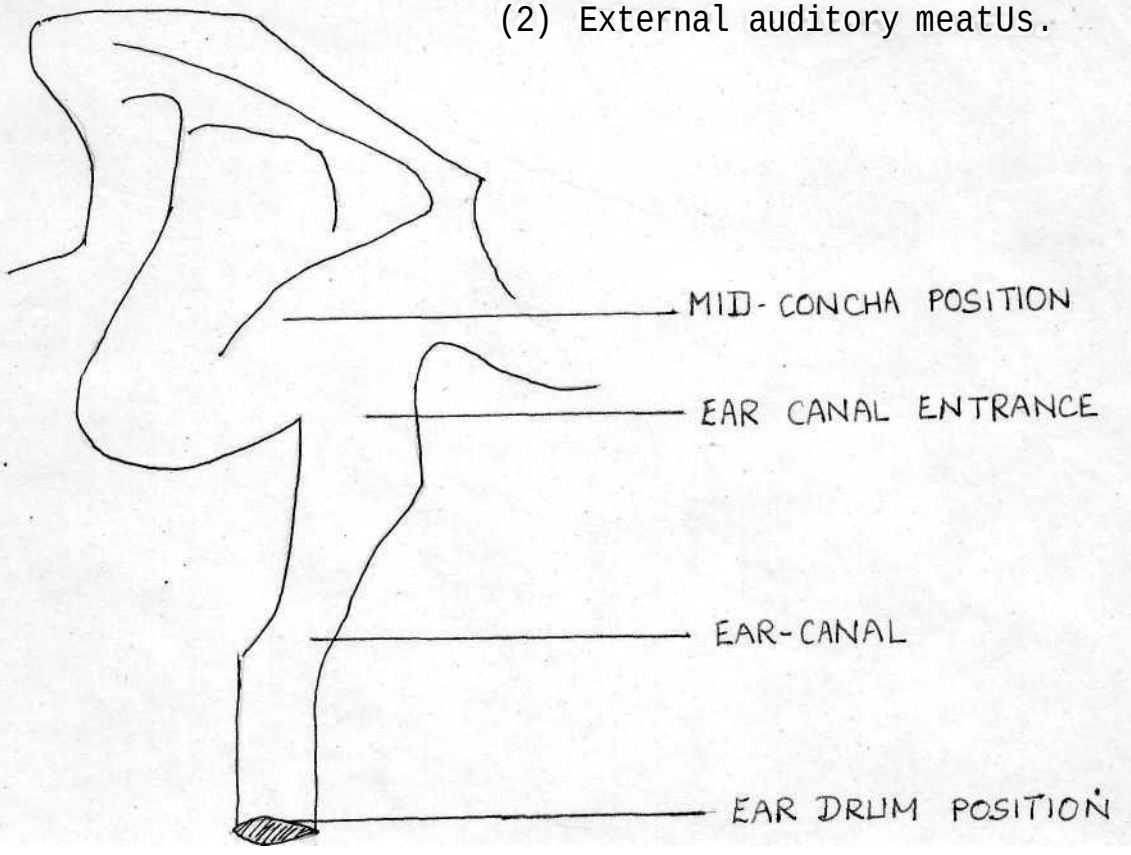
_EAR : EXTERNAL ANATOMY

I



These diagrams represent
(1) Pinna and its components
(2) External auditory meatUs.

II



TRANSFORMATION OF SOUND PRESSURE FROM THE FREE FIELD TO THE HUMAN EARDRUM

HEAD AND TORSO EFFECTS

HEAD: Inter-aural time difference at all frequencies

Inter-aural phase difference and pressure amplitudes

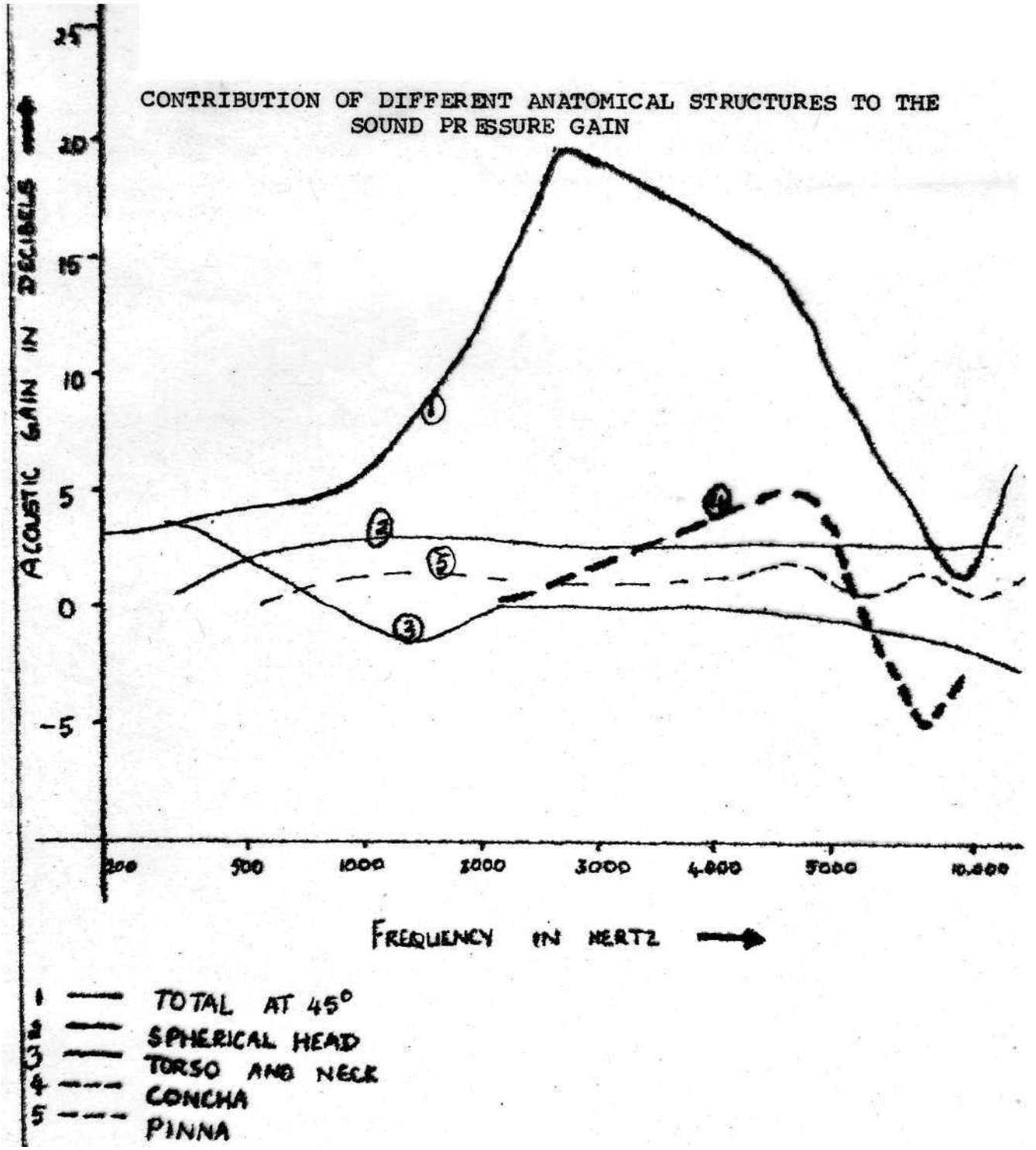
0 - 1000 Hz,

TORSO - AMPLITUDE REDUCES BETWEEN 1000 - 2000 Hz.

PINNA FLANGE, CONCHA AND EAR CANAL EFFECTS

	RESONANCE	PRESSURE GAIN
External ear as a whole	Primary resonance at 2.7 KHz.	At 0° azimuth 17 dB gain.
Concha only	4-5 KHz	10 dB Gain
Pinna flange only	4 KHz	3 dB gain
EAR CANAL ONLY.		
Pinna + concha	3-6 KHz	Mote than 10 dB gain.
Ear canal + concha	1.5-7 KHz	Substantial acoustic pressure gain.
Total gain from all components,	2.5 KHz	About 20 dB gain,
	2-5 KHz maximum at 45° azimuth...	A broadened

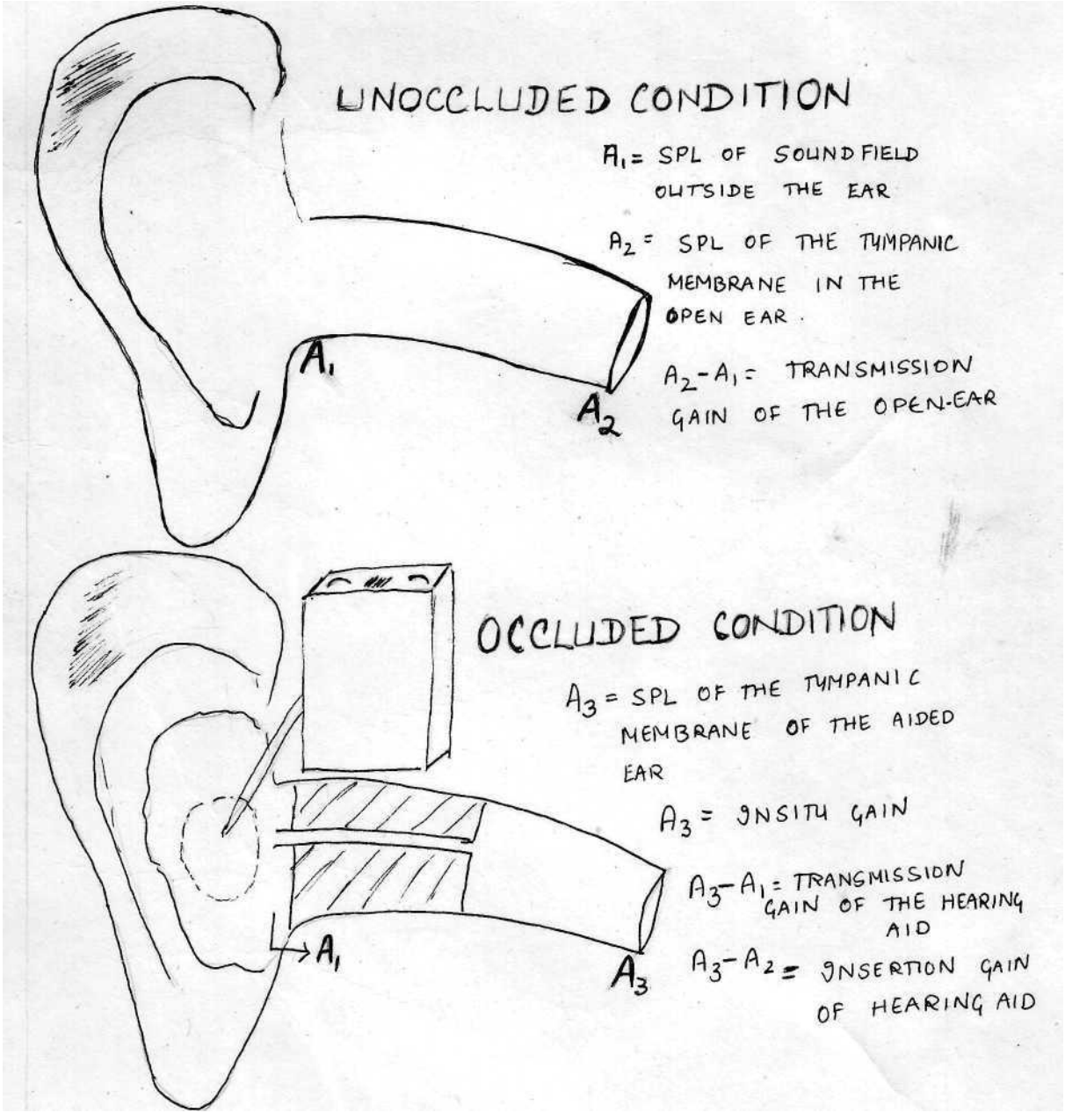
This table shows the contributions of various components of external ear, and head in transformation of sound pressure from the free field to the ear drum through the External Ear. Resonance peaks values (KHz) as well as corresponding pressure gain(dB) are given.



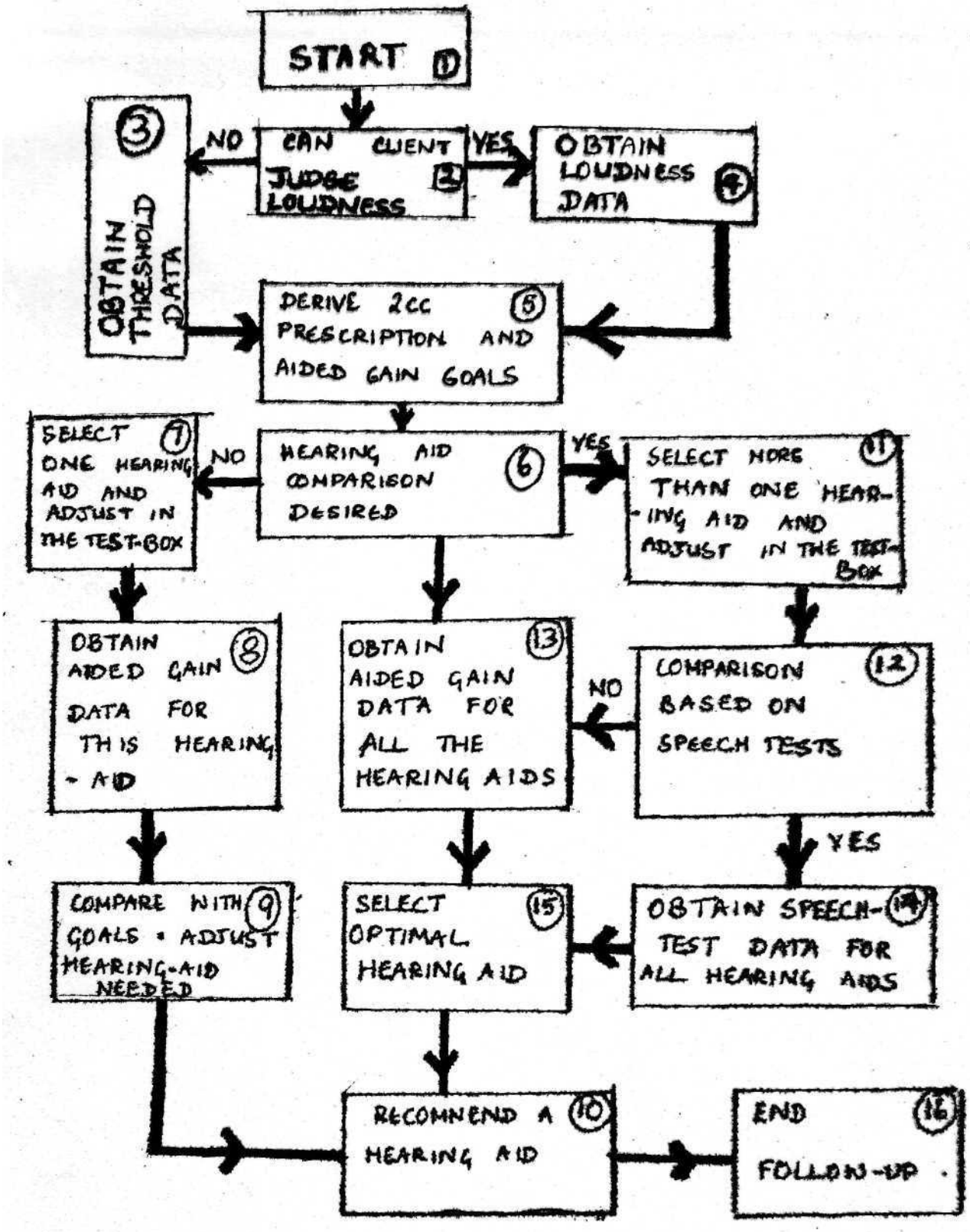
This graph represents acoustic pressure gain in decibels on the Y axis across frequencies in Hz on X axis of various components of external ear. The peaks of the curves show points or regions of resonance,

ACOUSTIC MODIFICATIONS OF HEARING AIDS

Acoustic modifications of hearing aid/earmold can be used to alter the performance of hearing aid to suit individual requirements.



FORMAT OF THE PRESCRIPTIVE PROCEDURE



THRESHOLD-BASED, LOUDNESS BASED, COMPARATIVE SPEECH TESTS AND COMPARATIVE AIDED-THRESHOLD GAIN PRESCRIPTIONS

TERMINOLOGIES

EXTERNAL EAR EFFECTS (EEE): Includes resonance and diffraction effects of pinna, concha as effected by acoustic coupling.

REAR EAR MEASUREMENTS: It is defined as the actual gain provided by a hearing instrument for an individual as the hearing instrument is worn and not measured in 2cc coupler. Real ear gain can be estimated by insertion gain, insitu gain or functional gain.

CORFIG: This term ts given by Killion and Monser. This term means COUPLER RESPONSE FOR FLAT INSERTION GAIN. The CORFIG response is the correction factor that is subtracted from a coupler gain to predict INSERTION GAIN.

COUPLER GAIN (2cc coupler): Coupler sound pressure level - Input sound pressure level.

FUNCTIONAL GAIN: Functional gain is defined as the difference between the unaided and aided thresholds of hearing. It is represented as

Fg.= Aided threshold - Unaided threshold.

FUNCTIONAL LOSS: F_L

INSITU GAIN: Insitu gain can be defined as the onsite position gain which is the difference between aided ear canal sound pressure level in total and input sound pressure level

INSITU GAIN = Aided SPL - Input SPL

INSITU LOSS: Insuta loss can be defined as the difference between occluded canal SPL (Sound pressure level) and input sound pressure levels

INSITU LOSS - OCCLUDED canal SPL - INPUT SPL,

Insertion Gain: defined as the increase in sound pressure level at the ear drum with the operating hearing aid in place compared to the sound pressure level at the ear drum without the hearing aid and with the ear canal and concha unoccluded.

Insertion gain = INSITU GAIN - External ear effects.

Insertion gain takes into account the modification of natural gain due to head diffraction and concha and ear canal resonances, when the ear canal is closed with as earmold.

INSERTION GAIN may be obtained in many way.

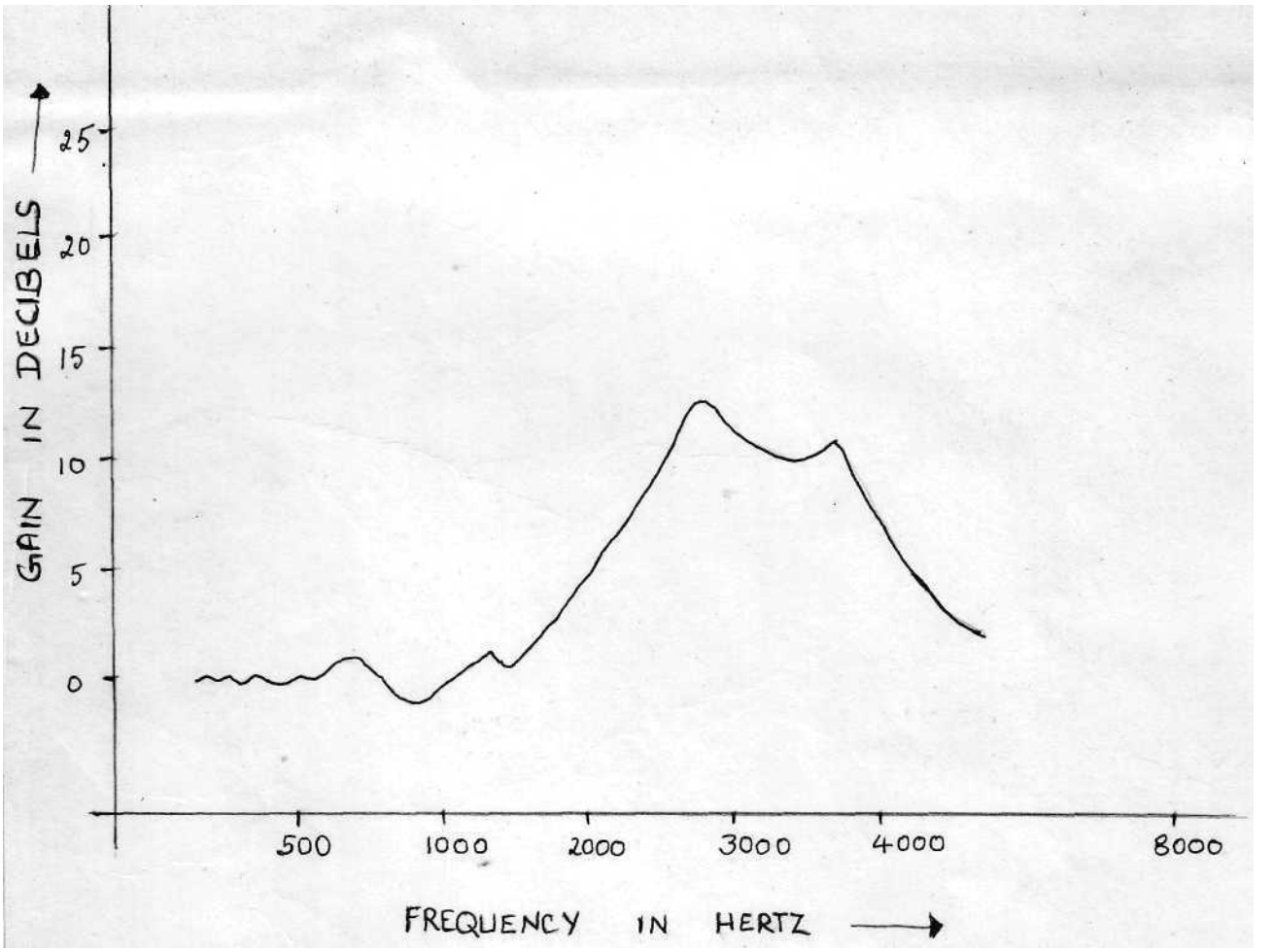
INSERTION GAIN PROBE - Direct measurement on a person using a PROBE MICROPHONE.

INSERTION GAIN KEMAR - Using Zwislocki coupler or KEMAR manikin.

INSERTION GAIN COUPLER - Using 2cc coupler.

INSERTION LOSS - INSITU LOSS - EXTERNAL EAR EFFECTS. It is caused by earmold occlusion which modifies the natural resonance of the ear. It can be defiied as the reduction in sound pressure reaching the ear drum when a hearing aid is used.

PROBE TUBE MICROPHONE RESPONSE IN THE EAR CANAL



The typical response that is obtained from a probe tube microphone measurement taken near the tympanic membrane in the open ear canal is shown above.

PRESCRIPTIVE PROCEDURES - FORMULAE

I. LYBARGER'S HALF GAIN RULE (1944):

REAL EAR GAIN (For sensorineural hearing losses) = ¼ *PT*A (

(it 1000 Hz, 2000 Hz 3000 Hz, 4000 H_z) .

Where PTA = pure tone thresholds in dB HL.

REAL EAR GAIN (for conductive hearing losses) = ½ PTA + ¼

(AC-BC) thresholds at each frequency

Where PTA = pure tone thresholds at each frequency in dBHL.

AC = air conduction

BC = bone conduction

II. BYRNE AND TONNISSON PROCEDURE (1978) :

REAL EAR GAIN = HTL x 0.46 + C where HTL = Hearing threshold level.

C = Correction factor

Frequency in Hz.C =	250	500	1000	1500	2000	3000	4000
60 Phon loudness contour	-2	-4	0	0	-2	-7	-8
Average Speech level	-17	-15	0	0	+1	+1	0
Additional gain (PLL)	4	4	4	4	4	4	4
Total C	-15	-15	4	4	3	-2	-4

III. PRESCRIPTI0N OF GAIN OUTPUT (POGO): By McCandless, G.A., and Lyregaard, P.E, (1983).

GAIN = ½ HTL at 1000 Hz, 2000 Hz, 3000 Hz and 4000 Hz.

= ½ HTL -10 at 250 Hz.

= ½ HTL - 5 at 500 Hz.

$$\text{MAXIMUM POWER OUTPUT} = \frac{UCL_{500} + UCL_{1000} + UCL_{2000}}{3}$$

Where UCL - Uncomfortable level at respective frequencies.

IV. BERGER' S METHOD (1984) :

GAIN = ¼ HTL at 500 Hz, 4000 Hz, 6000 Hz.

Where HTL = Hearing threshold level.

GAIN = 0.59 to 0.67 HTL at 1000 Hz, 2000 Hz, 3000 Hz,

where HTL = Hearing threshold level.

For clinical use, the prescribed real ear gain is as follows:

Frequency in Hz.	**Gain**
500	0.3 x HTL
1000	0.63 x HTL
2000	0.67 x HTL
3000	0.59 x HTL
4000	0.53 x HTL
6000	0.5 3 x HTL

Where HTL Hearing threshold level.

For cases with conductive hearing loss,

Additional gain = 0.2 x (AC-BC) threshold not greater than 8 dB.

AC = Air conduction

BC = Bone conduction

V. LIBBY's METHOD ((1986): For mild to moderate hearing losses and new wearers.

INSERTION GAIN: 1/3 HTL ± C (for mild to moderate hearing losses)

= ¼ or 2/3 HTL ± C (severe to profound hearing losses)

HTL = Hearing threshold level.

C = Correction factor.

C = 5 dB at 250 H_Z , 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz.

C = 3 dB at 500 Hz.

VI. NATIONAL ACOUSTIC LABORATORIES (NAL procedure) by Byrne and Dillon (1986).

GAIN = X + 0.31 X HTL + K

Where K = frequency dependent constant dependent on gain type prescribed.

X = 5% of the sum of hearing threshold levels at 500 Hz 1000 Hz, 2000 Hz.

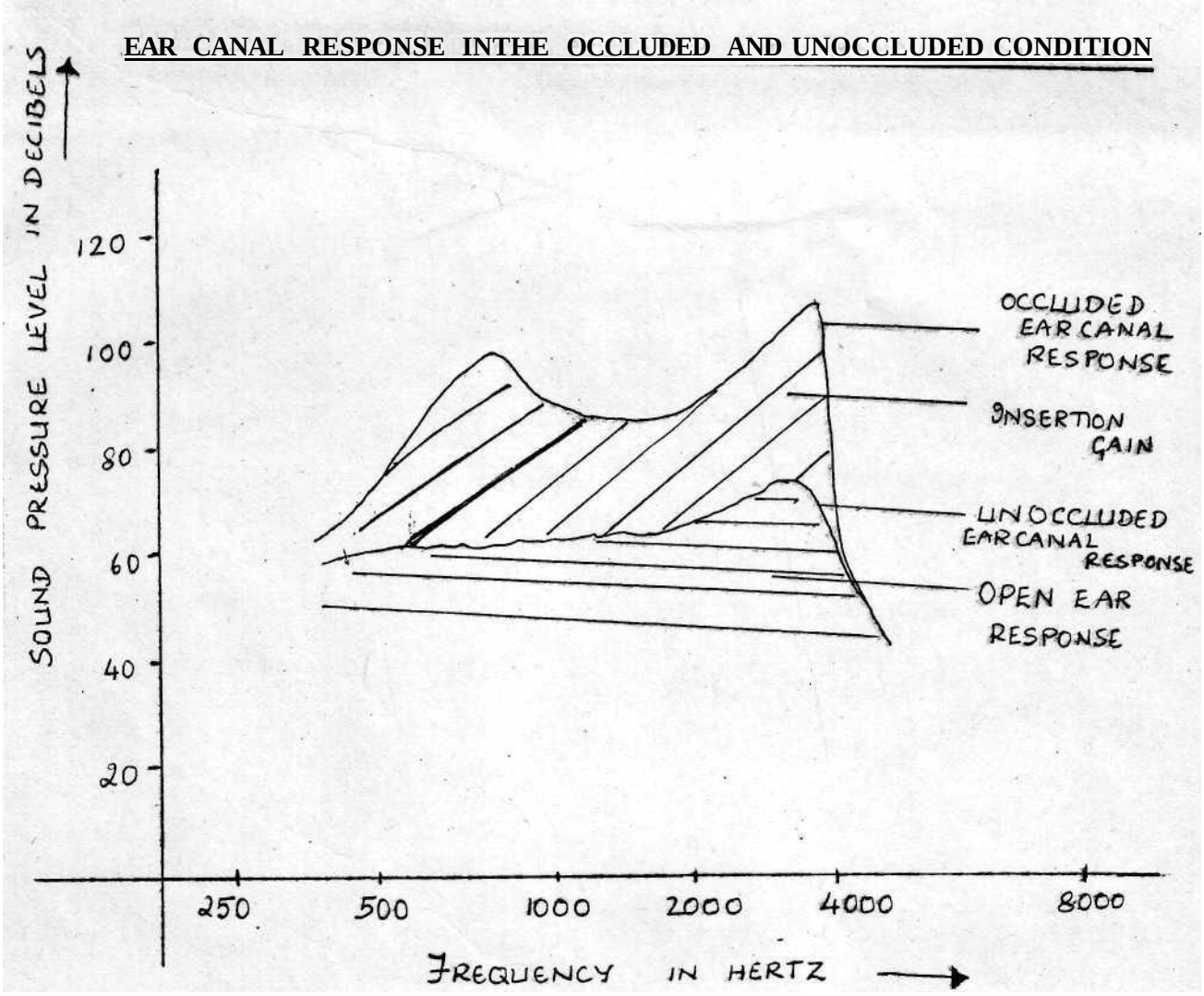
0.31 x HTL =0.31 times the hearing threshold level (puretone) at the frequency considered.

K value for real ear measurements:

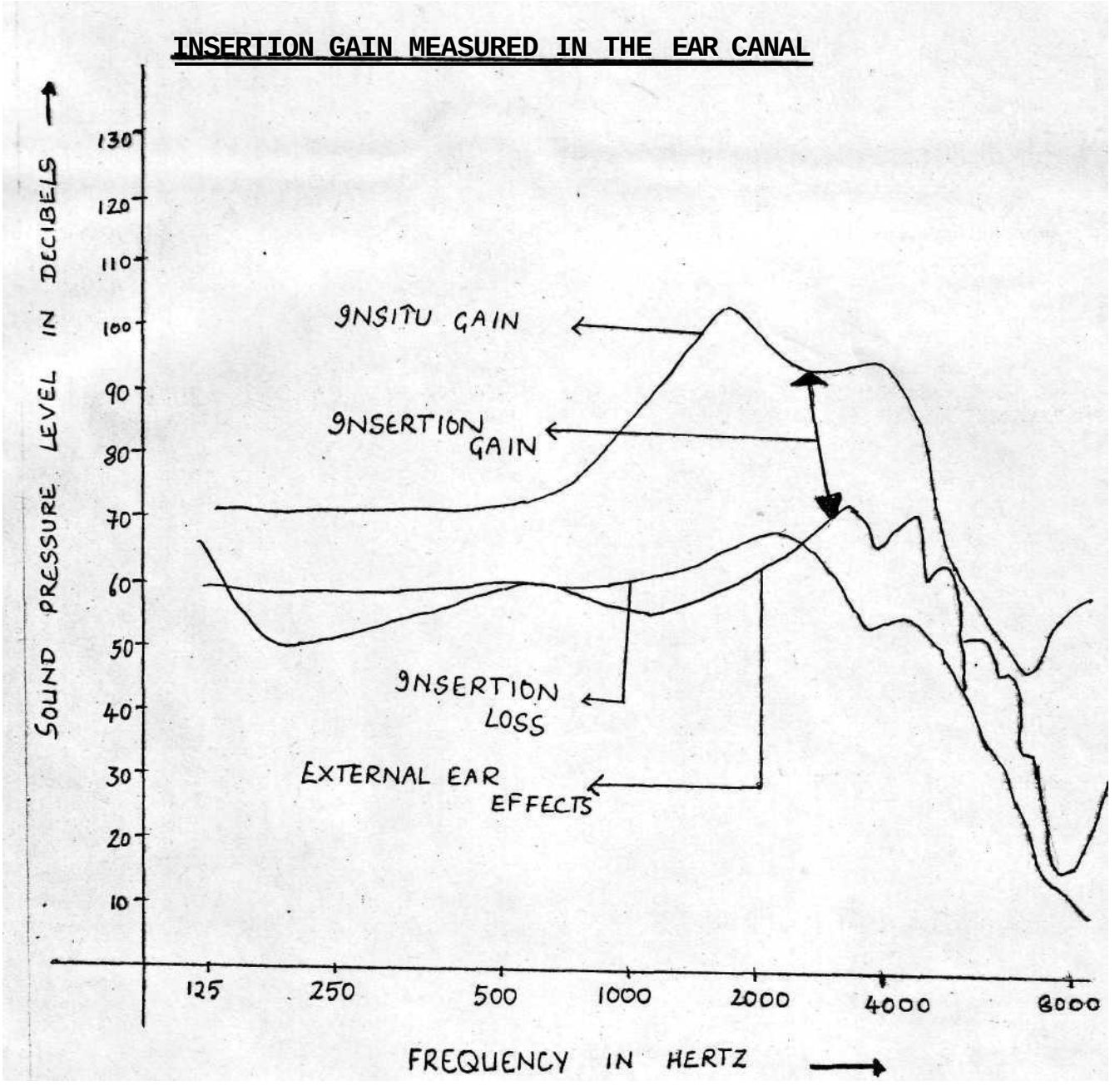
FREQUENCY (in Hertz)

	250	500	1000	1500	2000	3000	4000	6000
K Values	-17	-8	+1	+1	+1	-2	-2	-2

EAR CANAL RESPONSE INTHE OCCLUDED AND UNOCCLUDED CONDITION

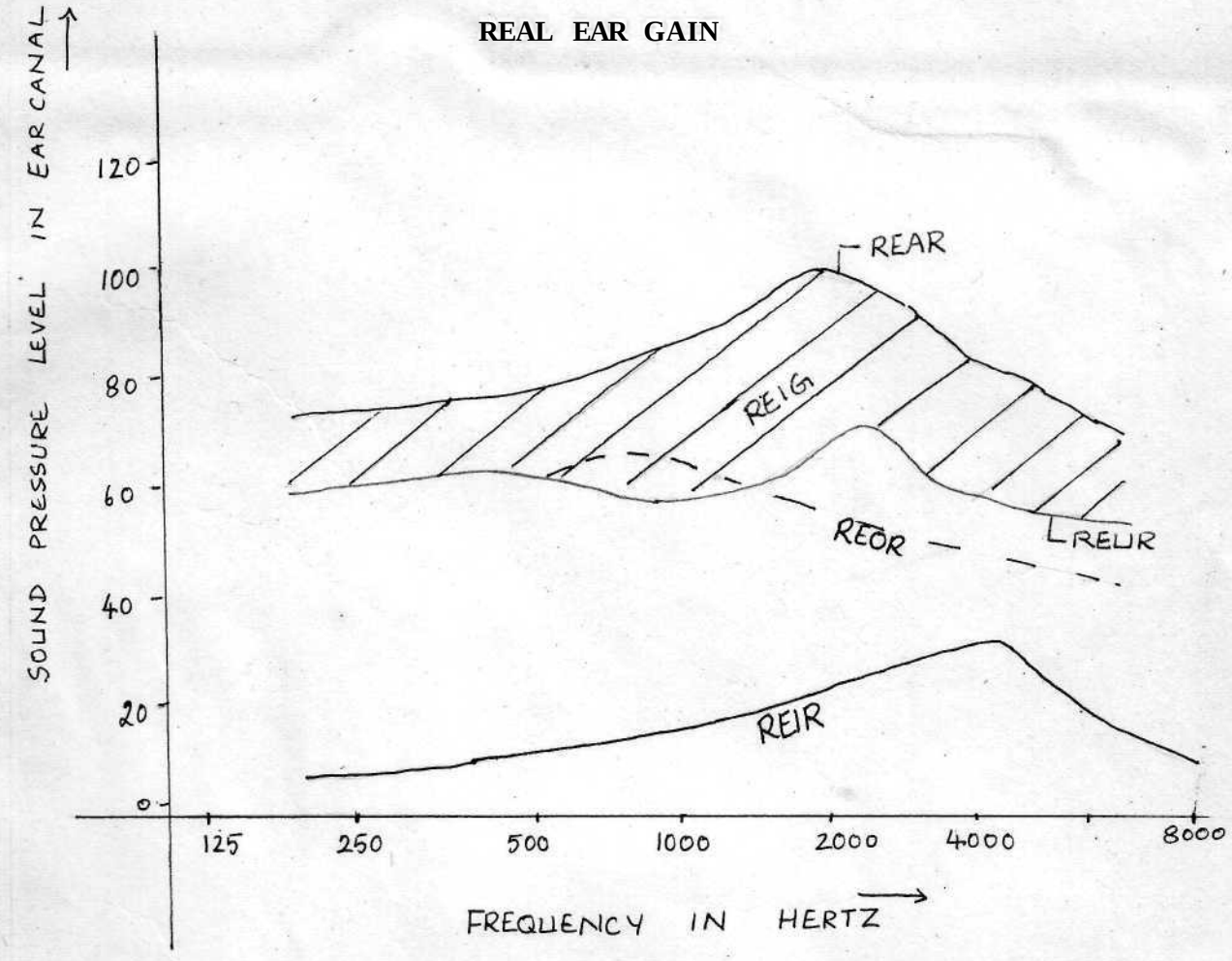


This curve denotes the insertion gain (the difference between the occluded and unoccluded ear canal response.



This graph represents the ear canal response in occluded and unoccluded condition. X axis represents the frequency in hertz and Y axis sound pressure level reaching the eardrum in decibels.

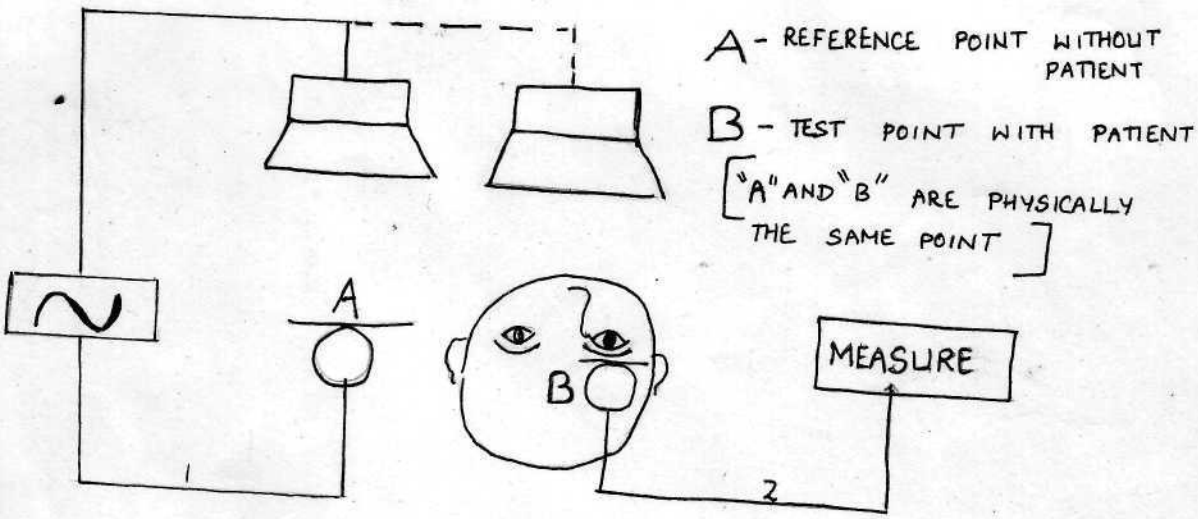
REAL EAR GAIN



REAR REUR REOR REIG SHOWN IN THE DIAGRAM

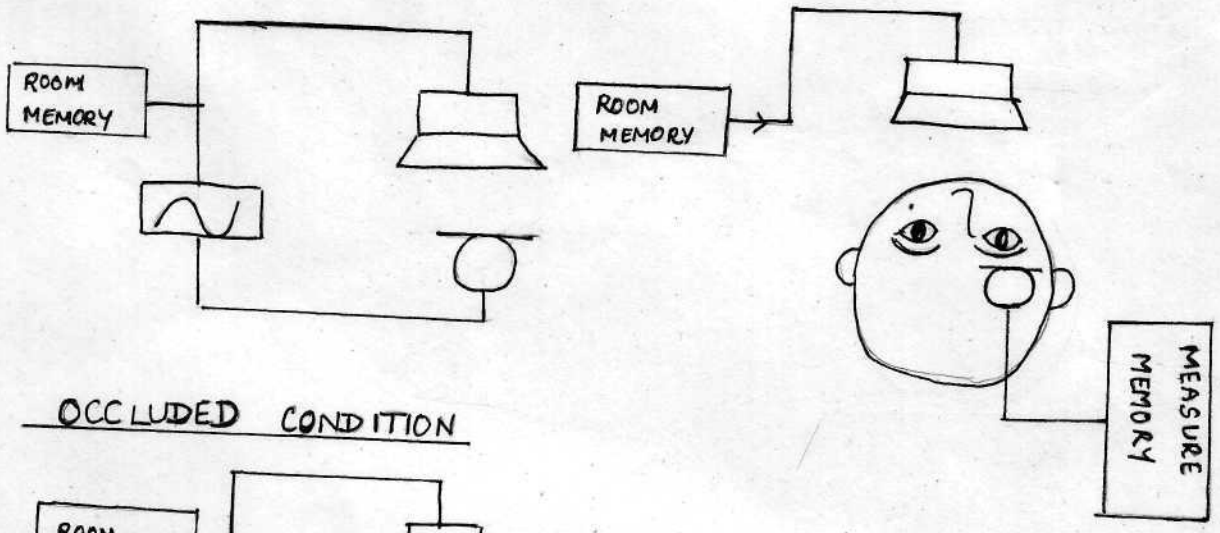
Test Methods

R. Substitution Method

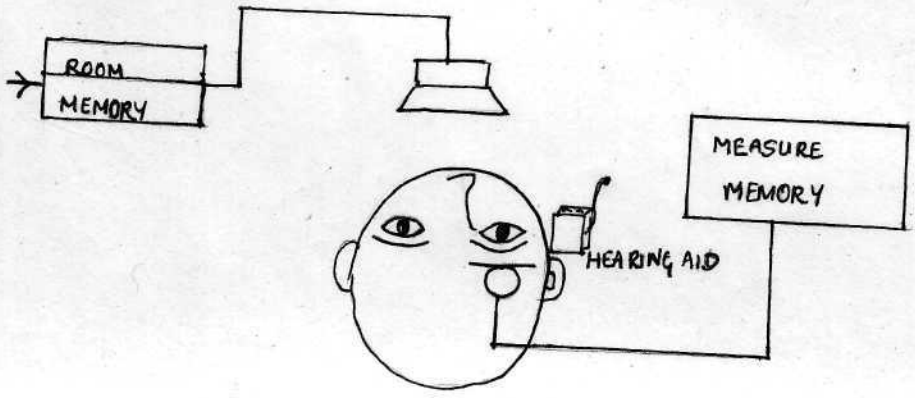


INSERTION GAIN TEST PROCEDURE BY "SUBSTITUTION" METHOD

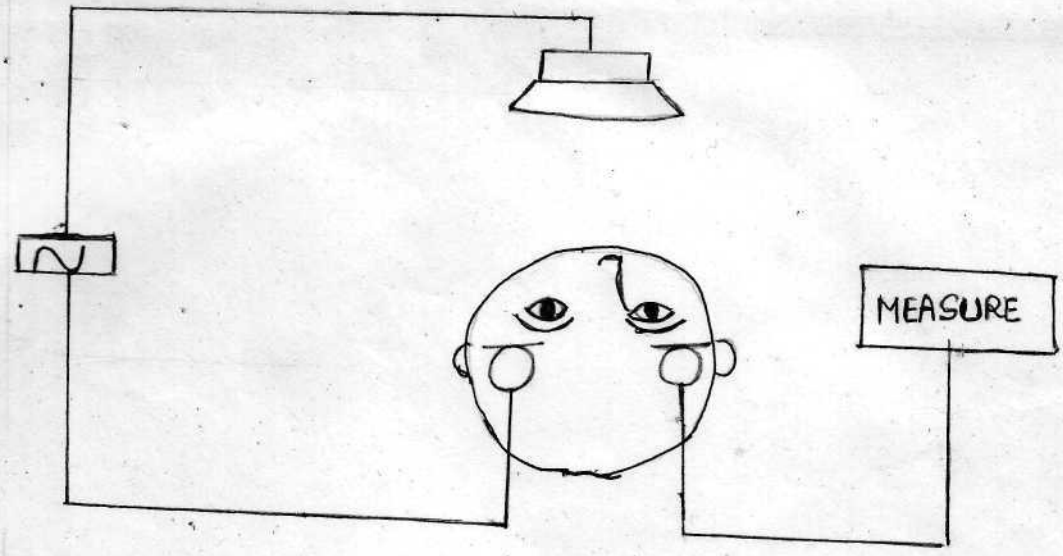
UNOCCLUDED CONDITION



OCCLUDED CONDITION



B. Comparison Method

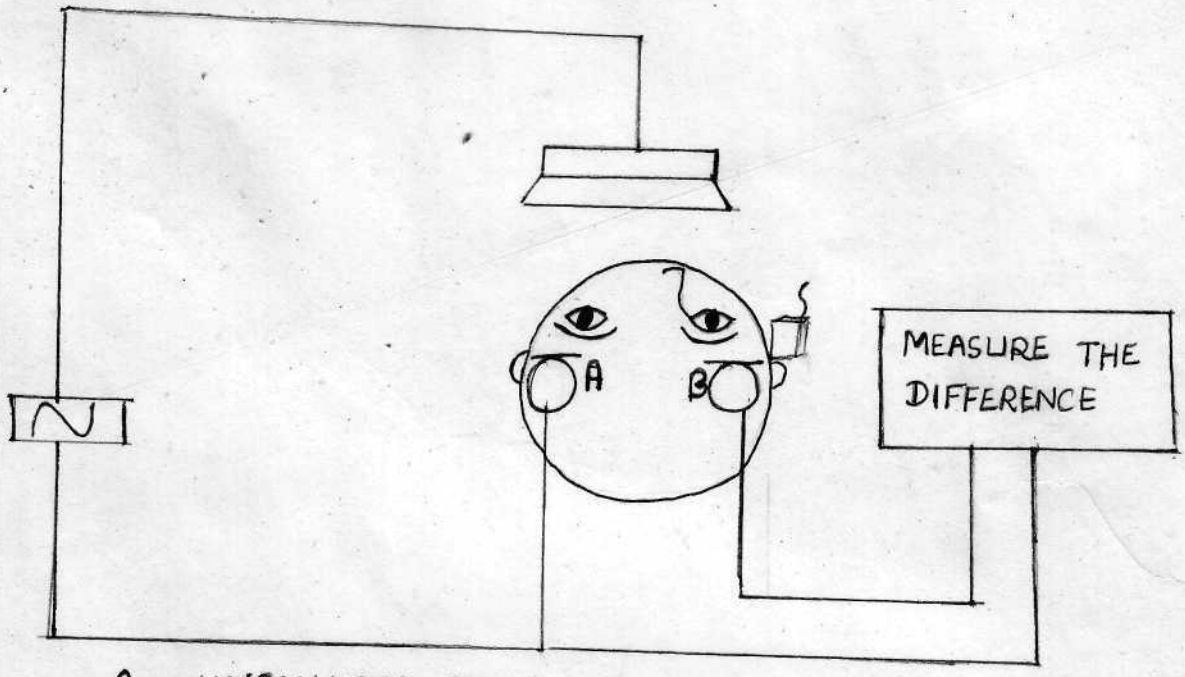


A - REFERENCE POINT

B - TEST POINT

A AND B ARE ACOUSTICALLY AT THE SAME POINTS

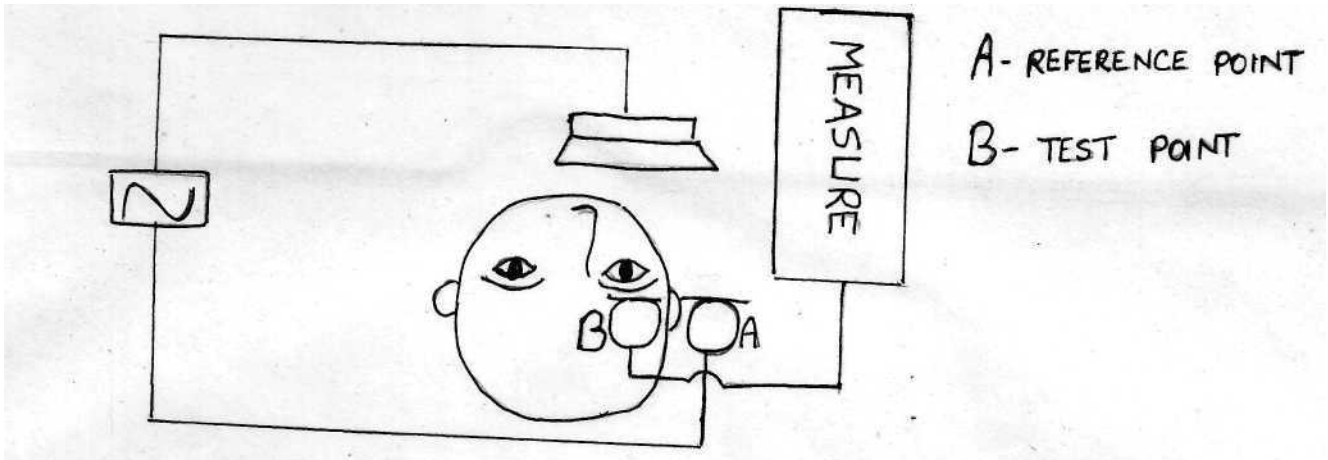
INSERTION GAIN TEST PROCEDURE BY "COMPARISON" METHOD



A - UNOCCLUDED CONDITION

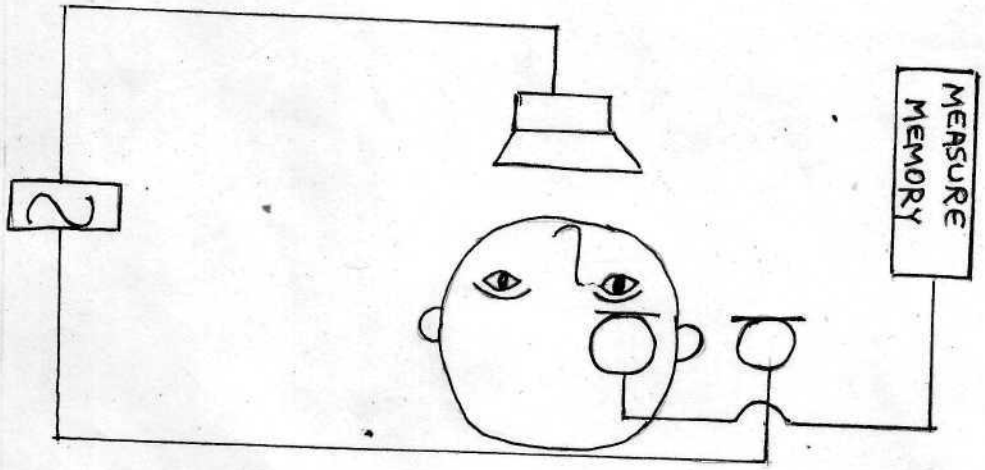
B - OCCLUDED CONDITION

e. PRESSURE METHOD

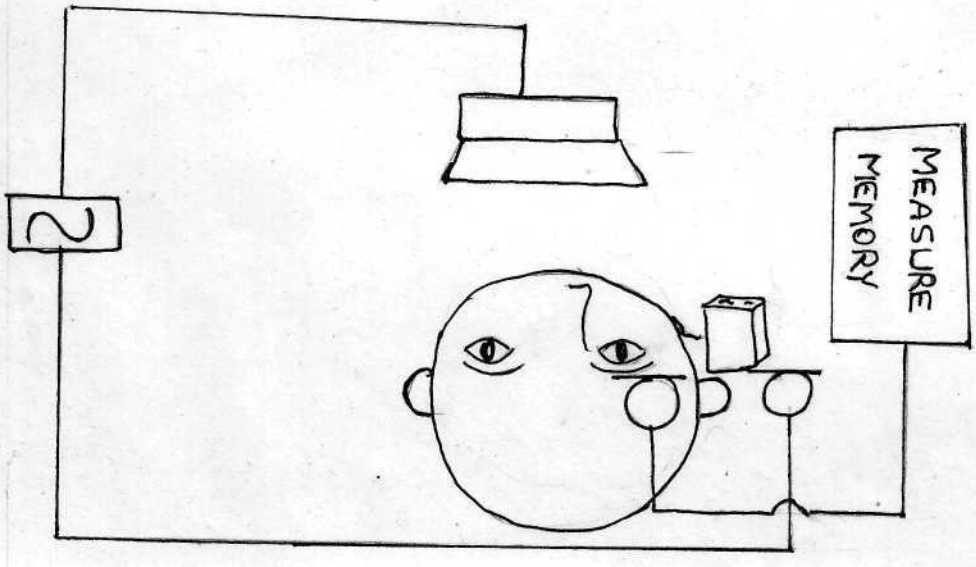


INSERTION GAIN TEST PROCEDURE BY "PRESSURE" METHOD

UNOCCLUDED CONDITION



OCCLUDED CONDITION



D. IPSILATERAL COMPARISON METHOD