COMPARISON OF INSERTION AND FUNCTIONAL GAIN IN HEARING AID USERS

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A Master's Dissertation submitted as part fulfillment for the Final Year M.Sc. (Speech and. Hearing) to the University of Mysore, *Mysore.*

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MAY – 1993

Dedicated to

Ma Baba,

Dada Bowdi

&

Bumba.

CERTIFICATE:

This is to certify that the Dissertation entitled ;

"COMAPARISON OF INSERTION AND FUNCTIONAL GAIN IN HEARING AID USERS",

is the bonafide work in part fulfillment for the Final Year M. Sc. (Speech and Hearing), of the Student with Reg. No. M. 9112.

MYSORE
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This is to certify that this Dissertation entitled :

"COMPARISON OF INSERTION AND FUNCTIONAL GAIN IN HEARING AID USERS",

has been prepared under my supervision and guidance.

Roopa Nagarajan.

MYSORE
MAY, 1993.

Mrs. Roopa Nagarajan,
Guide.

DECLARATION

I hereby declare that this Dissertation entitled,

"COMPARISON OF INSERTION AND FUNCTIONAL GAIN IN HEARING AID USERS",

is the result of my own study under the guidance of Mrs. Roopa Nagarajan, Lecturer, Dept. of Audiology, Alt India Institute of Speech and Hearing, Mysore, has not been submitted earlier at any University for any other Diploma or Degree.

MYSORE
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INTRODUCTION

Our life time obligation to nature is to protect, the valuable gifts which has been provided to us. One of them is hearing. The effect of the !oss of hearing is debilitating. For a young child it would effect the very development of speech and language whereas in adults it would interfere with the normal interpersonal communication. To reduce this devastating effect our primary goal is to identify the populace as early as possible and to rehabilitate them.

One major step in the rehabilitation of the hearing impaired population is the fitting of an appropriate amplification device. Hearing aid is one such device. A.G.Bel1 in 1876 invented the telephone (Jagadish,1988) and soon thereafter the principles of that instrument were considered for application to hearing aids. According to Berger (1976), it was M.R.Hutchison who invented the first practical electric hearing aid in 1898. These hearing aids served the public well for a quarter of a century, and were replaced by the electronic (or vaccum tube) hearing aid.

Currently we have electronic hearing aids to serve a variety of hearing impaired population. The choice is so vast that it becomes difficult for a clinician to choose an appropriate hearing aid which would give optimum benefit to the client.

Davis et al (1946) stated, "the purpose of a hearing aid is to enable the hard of hearing subject to hear sounds that he cannot otherwise hear but desires to hcar-particularly the human voice. . . . [It] must make speech intelligible without making it uncomfortably loud. . . . [and deliver].... a pleasing or 'natural' quality in the sound of voice and music. . . . Internal noise, whether electrical or mechanical in origin, should be reduced below the patient's threshold. . . . [Finally, the] maximum acoustic output that the instrument can produce must not cause pain or serious discomfort." No one has questioned this ideal. But the problem which still baffles all is - how can these objectives be achieved? The history of hearing aid selection procedure may be viewed as a logical sequence of answers to the above question.

As research continued in this field to select a hearing aid which would suit a patient ideally. various hypotheses cropped up. Among these the major ones, as listed by Pascoe (1985) are:

A] The fixed frequency response or Non selective Hypotheses:

According to this hypothesis, hearing aids need not be adjusted selectively for each hearing loss configuration. Minor differences in response have little effect on the listener's function. The factors that needs to be adjusted according to loss or maximum

gain and maximum out put levels.

B] The Comparative Hypothesis:

The logic put behind this hypothesis is that since aids cannot be selected through hypothetical prescription, they must be selected through actual comparison. The hearing aids can be compared in relation to word discrimination, aided and unaided responses to various verbal and nonverbal stimuli, efficiency of function for low level input, toleration of high level input and speech discrimination under poor signal to noise ratios.

These comparisons can be made with master aids or functional gain measurements and also insertion gain measurements.

C] The Prescriptive Hypothesis:

This hypothesis suggests that hearing aids should compensate for the individual characteristics of a hearing loss. This could be done by including frequency responses that are an exact reversal of the hearing threshold slope, a reversal of the most comfortable level, a response that includes gains that are equal to one-half of the hearing loss at important frequencies, a reversal of the slope that bisects the dynamic range etc.

What ever be the procedure,the ultimate objective is to fit the patient with a hearing aid which will enable

him to communicate efficiently. To achieve this, we try to find the optimum gain which would suit the person's hearing loss. This gain can be obtained using different procedures. Such as functional gain and/or insertion gain.

In this study two methods of measuring gain have been compared. They are:

1] FUNCTIONAL GAIN [IG], and

2] INSERTION GAIN [FG].

FUNCTIONAL GAIN:

Functional gain has been defined as the difference between the unaided and aided thresholds in the sound field (Skinner, 1986). To measure this, various stimuli has been used like, frequency modulated (warble) tones, narrow bands of random noise, damped wavetrains (DWTs), and amplitude modulated tones. Warble tones and narrowband noise has been more commonly used (Walker etal,1985). Many clinicians use speech stimuli to obtain functional gain (Surr et al, 1978).

ADVANTAGES 0F FUNCTIONAL GAIN:

The advantages of obtaining functional gain are that, this method reveals the summed effect of all acoustical changes produced by the aid and it's earmould. More over since it is a subjective procedure, the subject's participation is essential. Thus the subject or the patient himself is actively involved in selecting a hearing aid for

himself.

DISADVANTAGES OF FUNCTIONAL GAIN:

Functional gain is time consuming when compared to insertion gain. This cannot be administered reliably in very young children and also in difficult-to-test children. The tester has to rely on the subject's response, hence the subject should be able to reliably respond to the stimulus. Moreover both instrumentation and room noise conditions impose limitations on how low a threshold can be measured (Mason & Popelka, 1986)

INSERTION GAIN:

Insertion gain is defined as," the increase in sound pressure level (SPL) at the eardrum with the operating hearing aids inplace compared to the SPL at the eardrum without the hearing aid and with the ear canal and concha unoccluded" (Libby, 1986). In recent years, the greater use of wideband transducers and the increased capability of earmould acoustic system emphasised the need for measurements at the actual ear canal of the patient. Harford (1980), Preves (1984), Schwartz (1980) and others demonstrated the clinical potential of miniature microphone measurements in the ear canal.

Further investigations were made in order to measure the insertion gain in a clinically usable way. Lauridsen and Gunthersen in 1981 developed a method which

used a microphone connected to a soft tube inserted into the ear canal through the vent of the earmould and proved to be sufficiently easy and reliable to use in daily routine. Since then, this method has been thoroughly tested and refined, and the development of modern technology has added to the other advantages of insertion gain measurements, to a point where it is rapidly becoming a standard evaluation procedure.

ADVANTAGES OF INSERTION GAIN:

The major advantages of insertion-gain measurements compared with functional gain measurements are:

(1) for a given measurement they take much less time,
(2) many more frequencies are sampled,
(3) the nontest ear does not participate in the results,
(4) an audiometric sound treated booth is not necessary,
(5) changes in gain and frequency in ldB or lHz can also be determined,
(6) minimum co-operation from patient is required.

DISADVANTAGES OF INSERTION GAIN:

(1) the procedure is not based on the person's behavoural response (Skinner, 1986) and
(2) this cannot be used to evaluate BC hearing aids.

Functional gain and insertion gain measures are two distinctly different procedures. Functional gain is derived from indirect behavioral measurements that infer the

amount of gain provided by a hearing aid, whereas insertion gain is a physical measure of SPL of an acoustic stimulus in a patient's ear canal. We cannot automatically assume that the results of the two measurements are identical. Hence it is essential to compare the two methods to see whether they will yield similar results or not.

These two procedure have been compared by Tecca and Woodford, 1987 and Mason and Popelka, 1986). The results indicate that functional gain and insertion gain measurements are comparable. However, Tecca and Woodford (1987) found a difference between FG and IG at the lower frequencies (500Hz).

All these studies has been done using ear level hearing aids. The results cannot be extended to body level hearing aids, as microphone placement differs, for ear and body level hearing aids. For the former it is at the ear, while for the latter it is at the chest. In addition body baffle" effect can significantly change the response characteristics of a hearing aid, undesirably (Pollack, 1975).According to this, when an aid is worn on the body, its response is modified by the body and clothing. Both reflect and absorb sound. Erber (1973) states that when a body level hearing aid is worn on the chest:

1] Sound pressure at microphone is increased from 2-6 db in the range 200-800Hz.

2] Sound pressure at the microphone is decreased 5-15 db in the range 1000-2500Hz.

3] There is no significant change above 3000Hz except that output is decreased slightly in the high frequencies when the aid is covered by clothing.

4] Body baffle effects are 1-5 db greater for adults than for children in the ranges 200-400Hz and 1000-1500 Hz.

NEED FOR THE STUDY:

The purpose of this study was to compare functional gain and insertion gain in body level hearing aid users. In India, a majority of the hearing impaired population uses body level hearing aids and in most hearing aid dispensing clinics only functional gain is measured.

A few studies have been done in India to estimate functional gain in body level hearing aid users (Ravishankar etal, 1989). Studies using insertion gain have primarily concentrated on studying the effect of earmould modification (Yathiraj and Nagarajan, 1993; personal communication).

There are no studies in India that have compared the two procedures. Comparing the two procedures with reference to Indian body level hearing aids would be useful because if the two methods yield equivalent results then clinically one can use any one procedure. This may have application in evaluating children whose thresholds have been established under earphones.

REVIEW OF LITERATURE

The selection of hearing aid has become a major area for research for audiologist and/or the hearing aid dispensers. Since the development of hearing aids various selection procedures have been put forth. Selection procedures have been classified under the following category:

A] COMPARATIVE/SELECTIVE PROCEDURE,

B] PRESCRIPTIVE PROCEDURES.

COMPARATIVE PROCEDURES:

The selective procedure which is also called the comparative procedure by Carhart (1946) is based on speech audiometry for hearing aid selection. The word 'selective' here means that, from the already preselected hearing aids (may be three or four hearing aids), the appropriate one is selected using the following four criteria:

1] The greatest improvements in speech reception threshold (SRT)

2] The best discrimination score.

3] The widest dynamic range and

4] A satisfactory speech discrimination score even in the presence of noise.

In short, four dimensions of hearing aid performance are explored; effective gain, tolerance limit,

efficiency in noise and word discrimination. The steps involved in the procedure (Ross, 1978) are:

STEP.1. The subject's unaided sound field SRT, tolerance limit and discrimination scored are measured. This score served as the reference for comparison with aided score.

STEP.2. Gain control of the first instrument is adjusted until the subject reports that a 40dB HTL speech signal is at his maximum comfortable level (MCL). An aided SRT and threshold of discomfort (TD) is measured then.

STEP.3. The hearing aid is then set on maximum gain and aided SRT and TD are again measured.

STEP.4. The gain control is then adjusted to permit the subject to reach an MCL with a 50dBHTL input speech signal. The S/N ratio was also determined in this step.

STEP.5. The hearing aid is again adjusted to permit the subject to reach an MCL this time with a 40dB HTL input speech signal. The aided SRT is to be measured again for a reliability check.

Step two to five has to be repeated for each of the preselected aid. These steps permit the aids to be

compared in terms of effective gain (unaided SRT - aided SRT), widest dynamic range (aided SRT - aided TD), signal to noise ratio and relative discrimination scores. The selection of a specific aid is made on the basis of composite results.

Hodgson (1981) pointed out some advantages and disadvantages of the Carhart method:

ADVANTAGES:

1] Carhart method is thorough and intensive.

2] It gets the patient involved in decision making regarding the selection procedure, fostering psychological commitment and responsibility.

3] It involved training as a part of selection procedure.

DISADVANTAGES:

1] One of the obvious disadvantage is that it is very time consuming.

Over the time the classic procedure has been modified and shortened, probably due to time and cost consideration.

PRESCRIPTIVE PROCEDURES:

Improvement in hearing aid technology and knowledge of auditory system resulted in the development of "selective amplification" hypothesis. This refers to the tailoring of frequency response curve of a hearing aid in

conformance with the client's audiogram (Ross, 1978). The idea that the way to 'fit' a hearing aid was to provide a frequency response that 'mirrored' the audiogram seemed plausible. Within the limitation of the equipment available in the 1920's,attempt were made to construct aids that pursued that objective (Knudsen and Jones, 1935).

The audiometric information consists of data determined by threshold tests of air conduction and bone conduction. Speech reception thresholds are also found in some cases. In addition, supra-threshold tests are often conducted consisting of tests of most comfortable loudness level, threshold of discomfort and speech discrimination scores.

Since a procedure based on the mirroring of the audiogram seemed to result in over amplification of Lhe higher frequencies, a second hypothesis was advanced during the 1930's. It held that the aid's response should be fitted to the "most comfortable contour."

Three procedure were described that attempted to achieve this objective. In one, the most comfortable contour was defined by bisecting the area included between the threshold of detection and the threshold of discomfort (Balbi, 1935). A second procedure was described by Watson and Knudsen in 1940. They suggested establishing a most comfortable equal loudness contour" by first finding the

most comfortable level for 1000 Hz and then , in a series of equal loudness judgments between that frequency and others, defining the remaining levels of that contour. The prescribed amplification curve was simply the mirror image of that contour presented at a level determined by the hearing aid user through his adjustments of the volume control dial. A third procedure was proposed by Lybarger in 1944 (Lybarger, 1978). He described "a method for arriving at the optimum hearing aid response curve in which the curve was the mirror image of about half the audiogram curve in dB." This was the orgin of the "one-half rule" which was based on his empirical awareness of listener's selection of gain.

As a result of investigating the efficiency of these selective amplification procedure a third major hypothesis appeared in the mid 1940's when the result of Med Re Co and Harvard reports were published (Davis etal, 1946; Medical Research Council, 1947). The report suggested that "the pattern which yielded the best results were found to bear very little relation either to the subject's audiogram or to an equal loudness contour". Furthermore, "it is possible to specify the desirable frequency characteristics of a hearing aid more successfully by a simple general rule than by any interpretation of the patient audiogram' (Davis et al, 1946). This apparent rejection of the prescriptive assumptions led to the

development of the comparative procedures which we have discussed earlier.

In 1960, Victoreen published a description of the method he called "Otometric". This return to the prescriptive fittings made use of the comfortable listening levels in a different manner. This method seek to equalise the aided comfort contour to the normal comfort pressures other prescriptive procedures also developed with time. To name a few:

1. Berger's formula (1972),
2. The National Acoustic Laboratories (NAL) hearing aid selection procedure (Byrne 1976),
3. Prescription of gain output (POGO) and its modification (POGO II)(MaCandless and Lyregaardl983).

Another approach that has been recommended for hearing aid evaluation and selection is the use of master hearing aid. This instrument permitted rapid changes of frequency response and maximum power output which allowed immediate comparison by the prospective user. These unwearable aids were often designed to help the fitter select a specific model within the manufacturers inventory or to prescribe the required adjustments in one of their aids.

Limitations of the hearing aid selection procedures:

A] THE PROBLEMS OF THE COMPARATIVE METHODS:

1. A fundamental problem is the method used to preselect the hearing aids that will be compared. Are they chosen because they are similar or because they are different? What criteria are used to select them?

2. Another problem is the manner in which comparison are made. If they are compared through word discrimination scores, are these scores reliable and valid? If the comparison is made through subjective preference, how is the problem of delay between samples avoided?

3. A significant and difficult to solve problem is the lack of sufficient time to practice with each aid before comparison.

4. An unavoidable problem is the fact that only a very limited set can be compared.

5. Finally, we need to know if the choices made or the higher discrimination scores obtained today can be repeated tomorrow.

B. THE PROBLEMS OF THE PRESCRIPTIVE METHODS AS LISTED UY PASCOE (1985)

1. The methods that use threshold information as the only basis for the prescription of gain and frequency response assume that comfort and discomfort levels are predictable. Is this a reasonable assumption?

2. The procedures that require a definition of " most

comfortable levels" need to examine the validity and repeatability of comfort judgments.

3. Most perspective methods assume that speech is primary input and that word discrimination is the fundamental objective. How is the quality of other sounds, such as music, or the annoyance of background noise accounted for?

4. When a frequency response is not chosen by listener preference but according to the method's assumption, the initial response may be one of the rejection.

Hearing aid prescription involves a selection and evaluate process which could be either using the comparative, prescriptive or a combination of the two processes. Since the hearing aid is to be used by an individual it is important that the measurements should also be obtained at the ear of the individual ie.,hearing aid prescription should be based on real ear techniques which may be defined as" measurement of hearing aid gain at the actual ear canal of the patient."(Libby,1981). Real ear gain could be obtained by obtaining functional or insertion gain.

FUNCTIONAL GAIN:

Functional gain is measured by substracting the aided from the unaided sound - field threshold (Skinner 1986). The measurement of functional gain takes into account:

1] All the factors affecting the hearing aid output at the ear drum,

2] The effect of the eardrum and middle ear on the sound energy reaching the inner ear,

3] The way in which this sound energy is transduced to neural energy and transmitted to the brain, and finally,

4] How it is perceived by the person.

Skinner et al (1986) stated that the accuracy with which the actual real-ear gain can be estimated, with functional gain measurements,depends upon several factors. First the person needs to give reliable responses at threshold levels. Second the sound stimuli need to be frequency specific. That is, the level of sound at nontest frequencies (one or more octave away)needs to be at least 30-40 dB lower than that at the test frequency. Third, the person needs to hold her or his head in the same position in relation to the loudspeaker for all threshold determination. Changing head positions can change the level by as much as 4 to 10 dB, and this can seriously effect the accuracy of the

functional-gain estimates. Fourth, the amount of ambient noise in the test room may cause the thresholds to be masked thresholds, particularly if the aided thresholds are close to 0 dB HL. Fifth, the internal noise of the hearing aid may also mask the person's true threshold. Sixth, the threshold may be detected in response to sound at the nontest ear, if the nontest ear is not plugged and muffled or if the unaided thresholds at the nontest ear are 20 to 30 dB better than those at the test ear even when the nontest ear is plugged or muffed. Seventh, if the compression of the hearing aid causes nonlinear gain for input sound levels of 50 to 70 dBSPL and the aided thresholds are at tower levels than this, the actual functional gain for average conversational speech may not be sufficient to allow the aid to reach preferred listening levels.

When the adverse effects of the factors mentioned above are minimised, the test-retest reliability of a single threshold is approximately 2.7 dB (Standard error of the mean) and the test-retest reliability of the functional gain (two thresholds) is approximately 3. 4 dB (standard error of mean).

In a study done by Pascoe in 1975, eight hearing impaired subjects were tested with a binaural master hearing aid. This aid has "on the head" miniature transducers and has an adjustable frequency response. Five frequency

responses were used, two of them were defined by their response in a 2cc coupler:

1] Uniform coupler gain (UCG) and 2] 6dB/octave rise (6dB). The other responses were defined in terms of functional gain (difference between unaided and aided thresholds) 3) Uniform functional gain (UFG), 4) Uniform hearing level (UHL) and 5] A simulation of a commercial hearing aid.

In FIELD AUDIOMETRY both aided and unaided thresholds were obtained. The testing was carried out in a sound treated room and a pulsed stimulus was used.

The author found that functional gains can be reliably measured in clinical conditions. Reliability will depend on:

1. Careful control of the signal levels and of the subject's head position,
2. Appropriate settings (usually low) of the aids's gain in order to avoid both the masking produced by the aids internal noise and the interference of ambient noise in the room, and
3. Careful blocking of the untested ear either through the use of earplugs, earmuffs or both.

When adequate precautions are taken, functional

gain reveals the summed effect of all acoustical changes produced by the aid and its earmould.

Smith and Stenstrom (1990) did a study to find the critical differences in aided sound field thresholds in children. They took thirty children and divided them into two groups. The first group consisted of 15 children aged 5 to 9 years. The second group also had equal number of children aged 10 to 14 years. The speculation was that the younger age group would show more variability than the older children. All children were tested using frequency - modulated signals. The speakers were kept at 45^{o} and 315^{o} azimuth. The hearing aids were evaluated electroacoustically. The volume control was kept at users position. After the first aided thresholds were obtained the subjects were given a 15 minutes break. After this the testing was repeated by a second audiologist who was unaware of the first test results. The findings showed that test-retest aided sound field threshold (ASFT) variability is not greater in younger versus older children.

Similar study was done by Hawkins etal (1987). The result obtained was also very similar. They concluded that sound field thresholds can provide valuable information, however, it can be a somewhat variable measurement, especially when the subject chooses a volume control wheel position and can be contaminated by internal hearing aid

noise and/ or room noise.

Berger and Sheii (1989) studied the test-retest reliability of functional gain, aided speech audiometry and the relationship between several electroacoustic parameters to aided test results. 81 females and 56 males were taken, all were fitted with ITE or BTE's. Unaided puretone threshold weretaken. In addition SRT and WDS at 30 dBSL were obtained. Aided thresholds were obtained at the user's setting. Aided SRT and WDS were also determined. The result show that the test - retest reliability of functional gain, SRT and WDS on a group basis was found to be low. The correlation between functional gain and maximum gain of the hearing instruments were high, especially at the lower test frequencies.

In India,Ravishankar, Shashidhar and D'Mello (1989) investigated the functional gain offered by the hearing aids which belongs to the moderate and strong class (Ref.IS 10775-1984). 121 subjects with SNHL were fitted with moderate and strong class hearing aid. Evaluation was done using Madsen OB 822 audiometer and at frequencies 250 - 4000 Hz using warble tone. Speakers were placed at 45^{o} degree azimuth and at a distance of 3ft from the subject. The mean aided and unaided thresholds in moderately-severe hearing loss revealed that the maximum improvement was seen at 1 KHz and the functional gain decreased at both sides of

the frequency continuum. In the severely hearing impaired group the maximum improvement was seen at 1 KHz again and the FG decreased on both sides.The aided threshold of fell into the speech banana at 500 Hz, 1K Hz and 2K Hz. In the profound hearing loss category maximum gain was seen at 500 Hz . The functional gain seen was greatest in this group. But the mean aided threshold were far below the speech banana.

The results revealed that the functional gain was related to the severity of hearing loss only in severely hearing impaired subjects. The absence of such relationship in the moderately severe group was unexpected. However the profoundly impaired did not show positive relation because of the severity of their hearing loss and the problem with amplification at higher intensity level.

INSERTION GAIN:

In 1942, Romanow wrote: In order to express the performance of a hearing aid quantitatively, it is necessary to specify a reference condition to which the performance of any particular hearing aid may be compared and to specify the method for making such comparison. A hearing aid can be considered as an instrument which is interposed in the path between the source of sound and the listener's ear, and in this basis the reference conditions can be set up as the airpath between the source of sound and listeners ear, and the measurement of any hearing aid can then be expressed as the amplification which it introduces in the airpath to the listener's ear."

Schwartz(1980), said that it has taken almost haif a century to realise that Romanow's (1942) original ideas of real ear measurements reflect more accurately the output sound pressure spectrum of a hearing aid delivered to the plane of the tympanic membrane. The computerised probe microphone systems bring hearing aid fitting 'back to the future' and serve as a major vehicle for transposing the often artful methods of hearing aid selection to a more scientific discipline.

Insertion gain is defined as the difference between the Sound Pressure Levels (SPLs) measured in the external ear canal of the individual with and without a

hearing aid (Skinner,1986).The sound is measured with either a probe microphone or a probe tube (attached to a microphone outside the ear canal), which is placed between the tip of the earmould and the eardrum.

PROBE AND PROBE TUBE MICROPHONE SYSTEMS:

Probe and probe tube microphone systems have been developed commercially to clinically measure the unaided and aided SPL in an individual's external ear canal. The probe microphone system is a miniature silicon-covered microphone which is inserted in the space between an earmould tip and the ear drum. The major reason why this probe microphone has not received widespread acceptance are;(l) The microphone is too large to fit easily into the earcanal of a number of adults, as well as children and (2) there is a slight risk of injuring the canal wall or eardrum if placed by inexperienced clinicians.

Probe tube microphone systems avoid these drawbacks, because a very thin, flexible tube, attached to the port of the probe microphone, is placed in the earcanal instead of the microphone. The equipment includes, a loud speaker, reference an probe microphone, preamplifier, computer, computer control pure tone stimuli (FM modulated and constant), acoustic monitoring earphone for the clinician, display screen and printer. These systems also have options for measuring the electroacoustic

characteristics of hearing aids. Examples of such instruments are the Madsen IGO 1000, (Insertion Gain Optimizer), FONIX 6500. The menu driven operating system requires no computer knowledge. A screen layout of every test screen displays insertion gain both as the difference between the occluded and the unoccluded ear in dBSPL and as a relative curve in dBIG.

The unit's test capability includes insertion gain and in situ gain test types and facility for telecoil and speech tests. Different types of stimuli are available; sinusoidal tones for use under real free field conditions (in a perfect sound room) and warble tone and narrow band noise or composite speech noise for use in the clinic. The prescription data need not be manually calculated by the operator but can be automatically calculated from the audiogram data. This data may be entered in the control panel digitally or with a cursor or via a digitiser which enables the operator to copy audiograms of any size directly. The automatic calculation of prescription data may follow such programmes as the POGO or the 1/2 gain rule. Berger, Nal etc.

Expressed in dB, the insertion gain of hearing aid is the objectively measured difference between aided and unaided eardrum sound pressure (occluded = aided; unoccluded = unaided)

When the insertion gain is measured, it is of importance to control the SPL at all frequencies at a clearly defined reference point, for both the unoccluded and the occluded ear test, because the insertion gain is defined as the relative difference between the two test results.

TEST METHODS:

The various position of the reference point are defined in the IEC - 118 - 0 publication as follows.

The substitution method is a method of measurement in which the test microphone and the reference microphone, employed to measure the freefield sound pressure, are placed alternatively at the same point in the sound field.

The comparison method is a method of measurement in which the test microphone and the reference microphone, employed to measure the free field sound pressure, are placed simultaneously at two acoustically equivalent points in the sound field ie., in each of the two ear canal.

The Pressure method is a method of measurement in which the input SPL is controlled at a point close to the entry of the ear canal, in which the test microphone is situated, by pressure calibrated, reference microphone, thus substantially eliminating diffraction effects.

The ipsilateral comparison methods is the non standardised variant of the comparison method and is very

similar except that the test microphone and a 'fictive' reference microphone are placed simultaneously at the same acoustical point in the sound field i.e., at the same ear. This method avoids the fallacy that the two ear of a given subject are identical. These methods are explained figuratively in appendix-A

Ear canal resonance: The unoccluded ear test demonstrates an ear canal resonance at approximately 2.7KHz which gives an amplification of 10-15 dB at this frequency and the range around it. This natural amplification is distorted or at least reduced, when the ear mold is inserted in the ear canal, i.e., when the ear is occluded. This means that not only the hearing loss of the patient, but also the loss of natural amplification needs to be compensated.

James Jerger (1985) stated that real ear gain measurement has advanced the cause of hearing aid selection by revealing what is happening in the ear canal rather than in the 2cc coupler and showing immediately the effects on frequency response when characteristics of the hearing aid or its plumbing are changed. Jerger added, however, that a rational scheme for hearing aid selection would be to pre-select from real real measures and validate by speech audiometry.

With the advent of CPM (Computerized Probe Microphone) measuring system, scientist have attempted to

study different variables that may affect insertion gain measurements such as type of stimuli, background noise and External Ear Effect (EEE)

Pederson, Lauridsen and Birknielsen in 1982 tested the probe microphone devised by Lauridsen and Gunthersen (1981) in clinical situation, and the results were compared with those obtained with a miniature electret microphone placed in the ear canal and also with those obtained with the ear drum microphone on the acoustic manikin KEMAR. Good agreement was found between all three methods. The soft probe tube has an advantage by the way of easier placement and accuracy. Moreover there is lesser risk of injury, even in a smaller ear canals. Also an accurate placement of the probe is of less importance than that of the miniature microphone.

In another study Ringdahl and Leijon (1984) compared insertion gain measurement using two types of microphone viz., a miniature electret microphone for probe tube measurement and an ear canal microphone.

They found that the systematic differences using the ear canal microphone compared to the soft probe tube microphone ranged from -2 to 4 dB in the frequency range 0.25 to 4.0 KHz. Artificial variation in the measurements location in the ear canal or artificial variations in head position caused only a small deviation. When making

clinical hearing aid recommendations using the soft probe microphone technique, 95% of individual insertion gain measurements can be expected to fall within ± 2 to ± 8dB from the true value in the frequency range 0.25 to 4KHz.

Tecca Woodford and Kee (1987) described the results of an investigation of the short-term and long term variability of ear canal probe measures.

Sixteen adult with no middle ear abnormality served as subjects. Earcanal measures were made with a probe microphone interfaced with a hearing aid analyser. The data collection was done in a sound treated room with a corner mounted loudspeaker at 0^{o} azimuth. Signal level was at 70 dB SPL. Five measures were made from the ear canal of each subject. In the first session, one measures was made of the unaided external ear, resonance, and two measures were made while a hearing-aid was worn. In the second session another unaided and aided measures was made. The mic was removed and replaced between each measure. Time duration between 2 sessions was 1 week. Results indicated that the main short-term differences were exceedingly small never reaching 1 dB. The short term standard deviation was 1 dB to 2dB above 500Hz and 2.5 dB to 4.0 dB below 500 Hz. The main long - term insertion gain difference were also small (<1.5 dB). However the standard deviation was 1.4 dB-6.0 dB.

This data has two clinical applications. In comparing the performance of two different hearing aids, insertion gain results may show one instrument to have more high-frequency insertion gain . It should be important to determine if the difference was great enough to be real. The reported standard deviation should be useful in making judgments. Similarly the data may help to determine if true differences resulted from alternations in the settings of a hearing aid or from ear mould characteristics.

Gustav Mueller and Sweetow (1987) compared the reliability of insertion gain measures obtained with three different probe tube microphone systems. The three probe tube microphone chosen were the Acoustined HA - 2000 (Software version 2.31), the Madsen IGO - 1000 and the Rastronics CCI-10/3. Testing was conducted by each unit according to the manufacturers recommendations. Seven individuals fitted with custom ITE were used as subjects. The results showed that there mean test-retest difference and the standard deviation are quite small.

Purdy, Dodd and Keith (1989): Studied the reliability of real ear insertion gain measurements and reported intra subject standard deviation of less than 4 dB for the frequency range 250 - 4000 Hz. In this study the technical aspects of real ear measurements which may contribute to resulting variability were examined the aspect that were measured were:

1] The effect of background noise- Two levels of background noise were used to investigate the influence of background noise on measurement accuracy. White noise at 50 dB (A) has a negligible effect even with the signal level as low as 60 dB. White noise at 60 dB(A), however negated measurements with the 50dB signal.

2] To determine the linearity of frequency responses at the 60,70 and 80 dB setting- the frequency response was found to be linear.

Hawkins and Gustav Mueller (1986) stated that probe tube microphone measurements would appear to have some advantages over functional gain as a method of assessing real ear performance of hearing aids. These advantages include:

1. Elimination of subjects threshold response variability.
2. Information across the entire frequency ranges interest rather than at only octave or one half octave intervals,
3. No contamination of aided thresholds by internal noise of hearing aid and/or room noise. Room noise could be a problem with functional gain when aided hearing threshold are in the normal or in the near normal range,
4. Time efficiency of the measurement.

The above advantages are true only if one assumes that the measurements obtained from a probe tube microphone system are an accurate reflection of true real ear hearing.

The authors have tried to an answer a few questions which are:

1. Does the loudspeaker output or input signal next to the ear remain constant across frequency in a sound booth and in a reverberant room.
2. What is the effect of the probe tube insertion depth on measured output levels?
3. Does the insertion depth of the probe tube affect the insertion gain measure?

The accuracy of the loud speaker output at the reference microphone (input signal to the hearing aid) in the sound booth and the reverberant room were almost similar. The majority of the deviation are well within test-retest measurement variability for the reference B & K microphone measurements.

It was found that sometimes large differences were observed as azimuths deviated from 0 degree. It may be due to head diffraction difference occuring at the hearing aid microphone and reference microphone location, as the difference disappeared when the reference microphone was

placed next to the hearing aid microphone.

The authors also found that a good compromise probe tube location for measuring output SPL in the ear canal is approximately one-half the distance from the top of the earmould to the tympanic membrane.

The authors recommends 1) measurement should be made from 0^{o} azimuth at 1 meter and the person should be instructed not to move his/her head. 2) No reflective surfaces should be close around the head, 3) Care should be taken to maintain a constant probe tube location for unaided and aided measurements and 4) Input levels of 50, 60, and 70 dBSPL should be used for insertion gain measurement.

This study was supported by Hawkins in 1987 and Libby also in 1987. Libby adds that when the free field transfer function (External Ear Effect or EEE)does not match the receiver and tube resonance, undesirable insertion gain may occur. To reduce this we should try to match the external ear resonance of the patient to the peak of the hearing aid response.

Investigator have also compared coupler, insertion and functional gain. Mason and Popelka (1986), compared hearing aid gain using functional, coupler and probe tube measurements. They collected data from 57 hearing-impaired individuals. Functional gain was measured in a

sound field at the octave and inter octave frequencies between 250Hz and 6000Hz. The nontest ear was muffed and the subject sat at 0 degree azimuth at a distance of 3 feet from the loud speaker. Probe tube gain was measured at a constant level of 60 dBSPL at sweep frequency.

The result showed that the average difference between probe - tube gain and functional gain was 0.87 dB when all data points were considered, which indicated that probe tube gain was slightly more than functional gain. The mean data indicated that both methods are equivalent for measuring the real ear gain of hearing aids and at least one of them is necessary for accurate hearing aids measures.

Tecca and Woodford (1987), compared the functional gain and insertion gain in clinical practice. The purpose of the study was to determine the relationship between functional gain and insertion gain under typical clinical conditions. 34 subjects with mild to severe SNHL were taken. All subject had their own hearing aids with ear moulds. FG was determined as the differences between aided and unaided thresholds over 0.5, 1, 2, 3, and 4 KHz warble tone. Insertion gain was measured with Fonix 5500z and only the frequencies used for functional gain were analysed. The average difference between FG and IG were small, 1 dB or less except at 500 Hz where mean difference was about 3 dB and standard deviation values were between 5.18 dB to

7.62dB increasing with frequency. The result indicated that FG and IG yield similar results except for 500 Hz. This could be due to variability in the placement of probe microphone and/or earmould leakage.

They also found three different groups of subjects. The first group showed good agreement between FG and IG with difference in gain not exceeding 5 dB. In the second group the difference is greater than 5 dB but do not exceed 10dB at any frequencies. And in the third group there was poor agreement between FG and IG with difference exceeding lOdB at a few frequencies. Though IG and FG are comparable as a group yet, in some individuals there may be a difference in the two gains.

Harford (1981) compared the functional gain and insertion gain in 17 subjects. Both techniques showed that there was minimal gain for the low and high frequencies and substantial gain at mid frequencies. The largest median differences were found at 4 KHz. This difference in recording could be due to the reason that functional gain were measured at 5dB step and insertion gain was measured at 1 dB step.

METHODOLOGY

SUBJECTS:

Fifteen body level hearing aid user's served as subjects for this study. All subjects had sensori-neural hearing loss with no history of middle ear or external ear pathology. The unaided threshold of all subjects were measurable in the sound field. Table 1 shows the details of degree of hearing loss, and ears tested for each subject. A total of twenty five ears were tested. Four subjects (six ears) had moderate degree of hearing loss, five (nine ears) had moderately severe degree of loss and six subjects (ten ears) had severe degree of hearing loss. The mean age of the subjects was 52 years, the lowest age being 23 years and the highest being 76 years.

Data were obtained from both ears for 10 subjects and from one ear for five subjects. All subjects used their personal hearing aid with custom made ear mould. Prior to testing, all hearing aids were checked and any defect if found, were corrected. Battery voltage was also checked.

After the unaided threshold was obtained the patient was made to wear his hearing aid. The aid was then switched on and the volume and tone control was kept at the recommended comfortable setting. This level was noted down. The procedure for obtaining aided threshold was the same as

	AGE	DEGREE OF LOSS	EAR USED
1.	30 years	severe	Both
2.	56 years	Moderate	Left
3.	76 years	Moderately severe	Both
4.	36 years	Severe	Both
5.	66 years	Moderate	Both
6.	55 years	Severe	Both
7.	55 years	Severe	Both
8.	70 years	Moderately Severe	Both
9.	48 years	Moderate	Both
10.	63 years	Severe	Left
11.	61 years	Moderately severe	Right
12.	46 years	severe	Left
13.	23 years	Moderately severe	Both
14.	65 years	Moderately severe	Both
15.	33 years	Moderate	Right

TABLE-1. Showing the age, degree of loss and the ear tested of the subjects.

for unaided. Functional gain was obtained by substracting the aided auditory threshold from the unaided auditory threshold. The functional gain in dBHL was obtained at each frequency. These values were converted in dBSPL to compare them with the insertion gain values.

Four ears were used to check reliability of response. The difference was only of 1 or 2 dB as with in the limit recommended by Skinner (1986).

FUNCTIONAL GAIN MEASUREMENT

EQUIPMENT: Functional gain measurements were obtained in a two room sound treated suite using a clinical audiometer (MADSEN OB822) connected to a loud speaker (COSMIC COVOX 4500) through an amplifier (COSMIC CO 100 DELUXE MK-II). The noise levels in the test room were within the permissible limits as per ANSI, (1977) at all test frequencies.

For the purpose of the study the equipment was calibrated for warble tone at the test frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz with the speaker at 0 degree azimuth at a distance of three feet and at a height of three feet. The data was collected over a period of two months. Calibration was periodically checked. The procedure recommended by Morgan, Dirks and Bower (1979) was used for warble tone calibration. Attenuator linearity was also checked.

PROCEDURE:

Unaided and aided auditory thresholds for 5% warble tone were obtained in the sound field at frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. An ascending

- descending procedure with a 1 dB step size was used to obtain the threshold . Threshold was defined as the level at which the subject responded on at least 50% of the time.

The subject was seated facing the loudspeaker (0^{o} azimuth) at a distance of three (3) feet. The nonparticipating ear was blocked with an earplug and an ear muff. The combination of ear plug and earmuff provided an average attenuation of 34 dB. The ear in which the subject normally used the hearing aid was the test ear. both the ears were used for those who used the hearing aid alternately between the two ears. The subjects were instructed to raise their finger and indicate whenever a tone was present. They were asked to respond even at the faintest sound heard.

INSERTION GAIN MEASUREMENT:

Insertion gain measurement was also done in a sound treated room. The noise level were within permissible limits (ANSI, 1977). The MADSEN Insertion Gain Optimiser (IGO) 1000 used. Room and Probe calibration was done as instructed in manual, prior to data collected for each subject. The test system setup is given in appendix-B.

PROCEDURE:

For measuring the insertion gain the subject were seated three (3) feet from the loudspeaker at 0 degree azimuth. The speaker height was adjusted to be as the same

as for functional gain. The patients were instructed to sit still. The sweep frequency warble tone (250 Hz - 4K Hz) from the loudspeaker was maintained at a constant level of 60 dBSPL. The soft probe tube microphone was placed at the ear canal 5-6mm from the concha (a red rubber cuff that slid along the probe tube was used as a marker). The unoccluded test was carried out first without the hearing aid.

After this, without removing the probe tube, the earmould, coupled to the hearing aid receiver, was anchored at the ear. The occluded measurement was done with the hearing aid volume and tone kept at the same level as it was during functional gain. The insertion gain for warble tone was measured at 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz in dBSPL.

The functional gain and insertion gain values were then compared across frequencies as well as at each frequency.

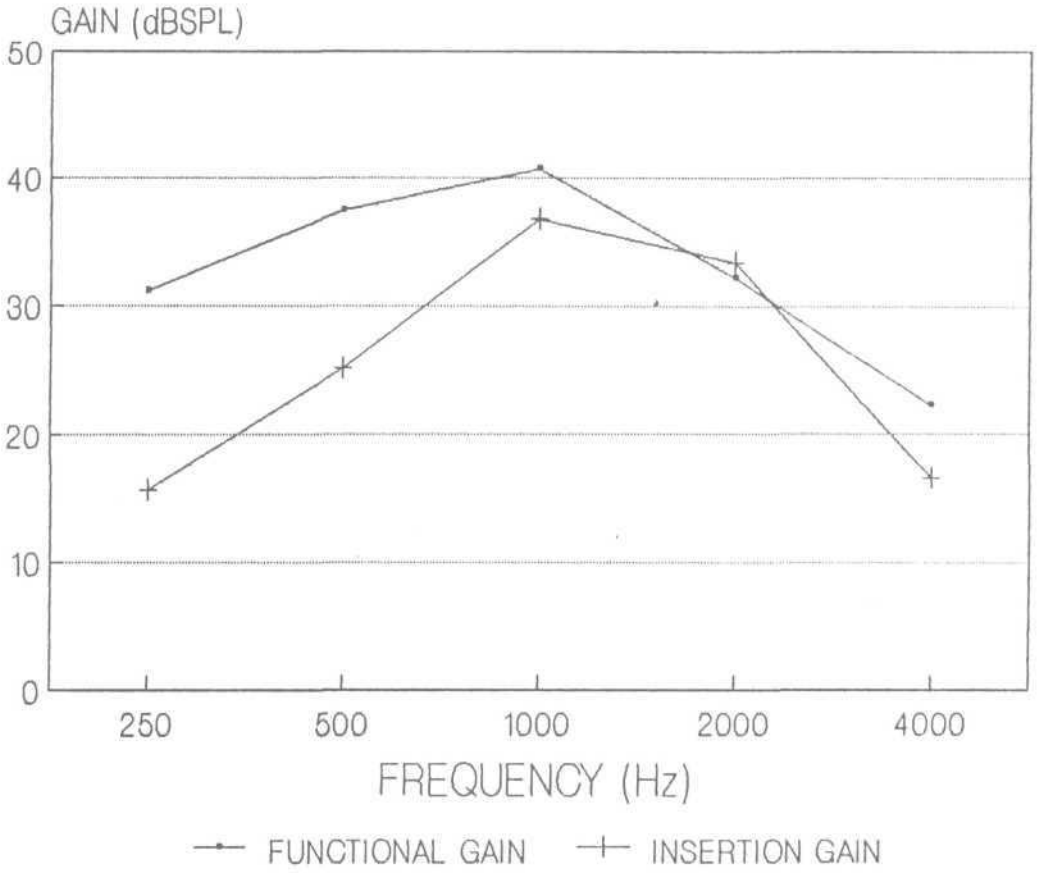
RESULTS AND DISCUSSION

The data collected was statistically analysed. Table-2 shows the mean, standard deviation and the range (minimum and maximum values) at each frequency for functional gain and insertion gain. Graph-i shows the mean values of functional gain and insertion gain at different frequencies.

FREQUENCY	GAIN (IN dBSPL)	MEAN *	STANDARD DEVIATION	MIN VALUE	MAX VALUE
250Hz	FG	31.16	10.86	12	47
	IG	15.56	13.45	-2	39
500Hz	FG	37.50	11.49	18.50	55.50
	IG	25.16	12.62	2	45
lOOOHz	FG	40.72	11.79	25	65
	IG	36.80	13.16	7	50
2000Hz	FG	32.22	11.29	9.50	54.50
	IG	33.44	13.32	9	54
4000Hz	FG	22.30	8.35	4.50	41.50
	IG	16.52	14.38	-10	50

TABLE-2. Showing the mean, standard deviation and the range of functional gain and insertion gain at each frequency. [* All values are in dBSPL].

GRAPH-I: Showing the mean values of functional gain and insertion gain at different frequencies.



The mean value of functional gain was always greater than the insertion gain except at 2000Hz, where insertion gain was marginally greater than functional gain by 1.22dB. The standard deviation was greater for insertion gain than for functional gain. This could be explained by the range (maximum-minimum value) which was greater for insertion gain.

In this study the maximum functional gain and insertion gain was seen at the mid frequency range. The results obtained concur with the results of Ravishankar etal, (1989). They have indicated that functional gain may vary as degree of hearing loss varies from mild to profound. The study showed that in the moderate to severe degree maximum gain was seen at the mid frequency region. The decreased functional gain values at two frequencies was also observed by Oja and Schow (1984).

In table-3, the mean difference and the coefficient correlation at each frequency as well as the over all difference between functional gain and insertion gain are given.

	250Hz	500Hz	1KHz	2KHz	4KHz	OVERALL DIFFERENCES
MEAN DIFFERENCE	15.56	12.34	3.92	1.22	5.78	7.28
T-VALUE	7.216 *	8.846 *	2.335	0.549	2.201	6.899 *
CORRELATION COEFFICIENT	0.623	0.830	0.779	0.604	0.433	0.672

Table-3: Showing the mean difference and correlation coefficient of functional gain and insertion gain at each frequency and also the overall difference.[* not significant at 0.05 level.

The mean values show that there was no significant difference between functional gain and insertion gain at the higher frequencies (i.e.lOOOHz, 2000Hz and 4000Hz) at 0.05 level. However, at the lower frequencies (250Hz and 500Hz) there was significant difference between functional gain and insertion gain.

There is high correlation (at 0.05 level) between functional gain and insertion gain. This positive correlation is seen at each frequency as well as overall between functional gain and insertion gain.

These results indicate that functional gain and insertion gain procedures produce similar average results in measuring the real ear responses of bodylevel hearing aid users. At 250Hz and 500Hz mean functional gain was significantly greater than mean insertion gain. This result support those of Tecca and Woodford (1987). They believed

that this finding is an artifact of the technique for measuring insertion gain. Placing the probe microphone was frequently difficult in narrow ears and in canals with sharp curve and it was difficult to place the earmould after the microphone. This could result in a leakage, which could be responsible for the decreased insertion gain at lower frequencies.

As indicated in table-3 difference between functional gain and insertion gain were 3.92 dBSPL for l000Hz, 1.22 dBSPL for 2000Hz and 5.78 dBSPL for 4000Hz. Tecca and Woodford (1987) had reported a difference of one to two dBSPL between functional gain and insertion gain at frequencies above lOOOHz. In their study they used one speaker-connected to audiometer for functional gain and to Fonix 5500Z interfaced with Starkey probe microphone for insertion gain. All evaluations were done in the same room.

While it would be ideal to use the same speaker and room for obtaining functional gain and insertion gain, it would not be practical in the clinical setting. In this study functional gain and insertion gain were compared in clinical setting that is functional gain as obtained in two room suite and insertion gain in a sound treated room with IGO. This may explain the greater difference between functional gain and insertion gain as compared to Tecca and Woodford's (1987) study. While the calibration was checked periodically and the noise levels in the rooms were within

permissible limits; there were some differences between the noise levels in both rooms especially when speaker were used for sound field evaluation.

In most of the hearing aid dispensing clinics functional gain measures are used to prescribe hearing aids. This method involves the subject's participation and hence he himself is actively involved in selecting his own hearing aid. However, this method is time consuming and hence can be replaced by insertion gain measures which can be done at a much quicker pace. This would reduce the time for hearing aid evaluation. We can also compare different responses of hearing aids and choose the best one in a short time. Other advantages of insertion gain, which are not feasible with functional gain are:

a) we can measure the inter octave frequency responses, which are difficult with functional gain due to calibration problem,

b) we can see the fine effects of minimal changes in volume and/or tone control.

c) we can see the effect of earmould plumbing like the acoustical modifications due to venting, tubing etc..

For insertion gain measurements, one has to be very careful with regards to probe tube placement. This can

sometimes be difficult especially in small ear canals or ear canals with sharp curve. Further insertion gain is only an indication of the SPL developed at the tympanic membrane. It does not indicate if the patient perceived the sound or not. Therefore, without a behavioral measure it is not possible to decide if the gain and frequency requirements are appropriate for the hearing loss of the patient. Thus as Jerger (1985) rightly puts that a rational scheme for hearing aid selection would be to preselect from real ear measures and validate by speech audiometry. The results of the study suggest that either functional or insertion gain methods can be used to obtain real ear responses at least at frequencies of lOOOHz, 2000Hz, 4000Hz for individuals with moderate to severe hearing losses.

SUMMARY AND CONCLUSIONS

This study was undertaken to investigate whether functional gain and insertion gain measures were comparable in body level hearing aid users. The data was collected from fifteen subjects (twenty five ears) having moderate to severe degree of sensori-neural hearing loss.

The data were collected in a clinical setting. Separate sound treated rooms were used to measure the functional gain and the insertion gain. Both the measurements were done at 0^{o} azimuth with the speaker distance and height kept constant from the subjects.

For functional gain a two room situation was used. It was measured using the Madsen OB822 audiometer connected to a speaker (COSMIC COVOX 4500) through an amplifier (COSMIC CO 100 DELUXE MK-II). Unaided and aided thresholds were obtained for warble tone at the octave frequencies of 250Hz, 500Hz, l000Hz, 2000Hz, and 4000Hz in one dB steps. Functional gain was measured as the difference in unaided and aided auditory threshold converted to dBSPL. Insertion gain was measured in a single sound treated room. A sweep frequency warble tone was used to obtain the insertion gain. This was obtained using Madsen Insertion Gain Optimizer(IGO)1000. The values at the octave frequencies 250Hz to 4000Hz were taken. Insertion gain was obtained as the difference in unoccluded and occluded threshold. The

data for functional gain and insertion gain were obtained in a single session for each subject.

The results indicated that functional gain was always higher than insertion gain at all frequencies except at 2000Hz. The mean difference between the two were 15.56 dBSPL for 250Hz, 12.34 dBSPL for 500Hz, 3.92 dBSPL for l000Hz, 1.22 dBSPL for 2000Hz and 5.78 dBSPL for 4000Hz. Overall mean difference between functional gain and insertion gain was 7.28dBSPL. At 250Hz and 500Hz there were significant differences between functional gain and insertion gain. Similar result have been obtained for ear level hearing aids by Tecca and Woodford (1987). This difference at the lower frequencies can be explained by the possible leakage of some frequencies when the probe and earmould are inserted together and the difficulty in putting the probe in the ears with curved or narrow canals when doing insertion gain.

At higher frequencies that is 1000Hz,2000Hz, 4000Hz there were no significant differences between functional gain and insertion gain. Therefore either method could be used to obtain real ear gain in individuals with moderate to severe sensori-neural hearing loss.

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APPENDIX - A

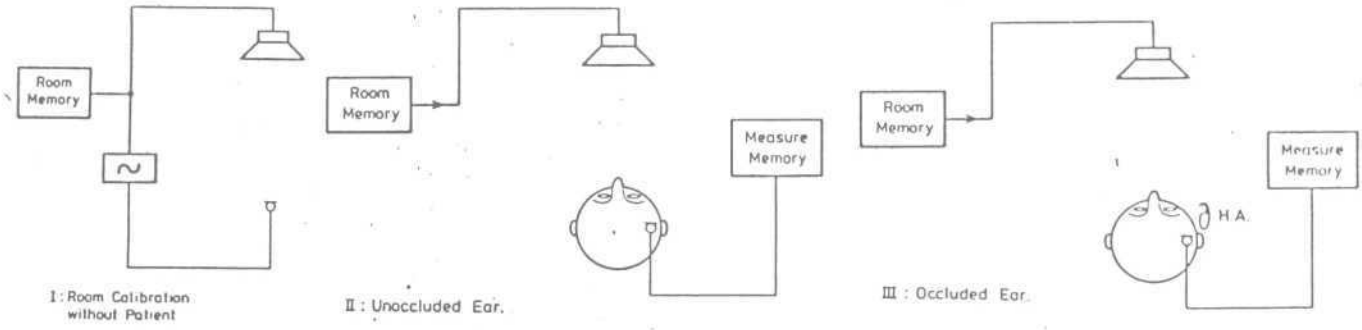

FIGURE - 1: INSERTION GAIN TEST PROCEDURE BY THE SUBSTITUTION METHOD (Madsen, 1986).

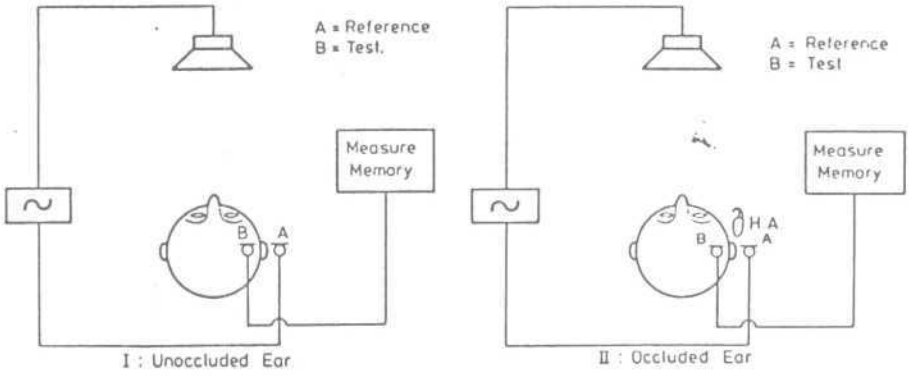

FIGURE - 2: INSERTION GAIN TEST PROCEDURE BY THE PRESSURE METHOD (Madsen, 1986).

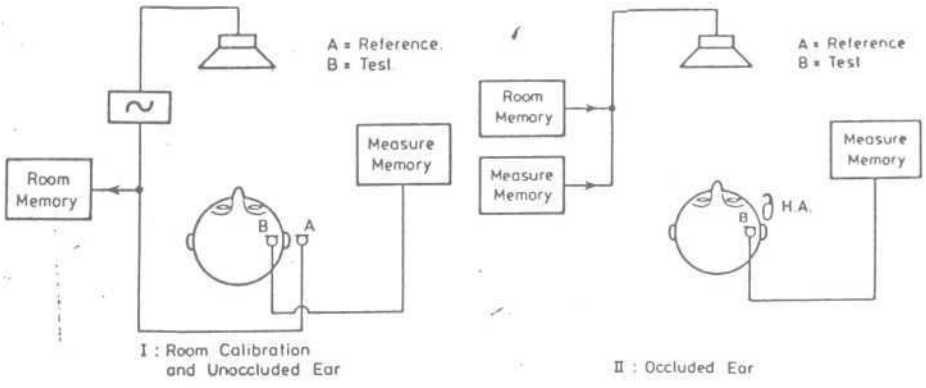

FIGURE - 3: INSERTION GAIN TEST PROCEDURE BY THE IPSILATERAL COMPARISON METHOD(Madsen, 1986).

APPENDIX-B

SETUP FOR:	TEST
TEST TYPE	Insertion
STIMULATION TRANSMISSION	Freefield
STIMULATION TYPE	Warble
PRESCRIPTION METHOD	Pogo2
UNOCCLUDED EAR TEST	Measure
TEST METHOD	Substitution
TEST LEVEL (SPL)	60 dB
MAX. SPL AT EAR DRUM	120 dB
STIMULATION LEVEL ACCURACY	4 dB
TEST SAMPLES	12/octave
FREQUENCY RANGE LOWER LIMIT	250 Hz
FREQUENCY RANGE UPPER LIMIT	4000 Hz
I/O, SPEECH & ISA TEST	On
FACTORY DEFAULT PROGRAMME	Yes