COMPARISON OF FM GROUP HEARING SYSTEM WITH CONVENTIONAL HEARING AIDS - USING PROBE-MICROPHONE MEASUREMENTS

(REGISTER NO. M2K07)

An Independent project submitted in part fulfillment of the First year M.Sc (Speech and Hearing), University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING
MANASAGANGOTHRI, MYSORE - 570006

MAY 2002

Certificate

This is to certify that the Independent project entitled *"Comparison of FM Group Hearing System with Conventional Hearing aids - Using*

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Probe-Microphone Measurements is the bonafide work done in part fulfillment of the degree of Master of Science (Speech and Hearing) of the student (Register No. M 2K07).

Mysore
May 2002

Director
All India Institute of
Speech & Hearing
Mysore - 570006.

Certificate

This is to certify that the Independent project entitled *"Comparison of FM Group Hearing System with Conventional Hearing aids - Using Probe-Microphone Measurements* " has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.

Guide

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May 2002

Declaration

I hereby declare that this Independent project entitled *"Comparison of FM Group Hearing System with Conventional Hearing aids - Using Probe-Microphone Measurements* " is the result of my own study under the guidance of Dr. K. Rajalakshmi, Lecturer in audiology, Department of audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier or in any other University for the award of any Diploma or Degree.

Mysore

May 2002

Register No. M 2K07

To My Husband

Who is Everything Behind My MSc.

And to My Darling Daughter Baani

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INTRODUCTION

The primary effect of an impairment of hearing is the reduced amount of auditory information available to the individual .To ameliorates its effect hearing impaired individuals are fitted with appropriate amplification devices namely - hearing aids.

Hearing aids may make speech sufficiently loud, but not necessarily clear. The ratio of speech to noise level (S/N) impinging upon the microphone is perhaps the most important determinant of speech perception through the hearing aid. Signal to noise ratio is clearly a function of the distance between speaker and the microphone. For the individual using a hearing aid, this distance is constantly changing. At 1 to 2ft (feet), the S/N ratio may be 30 dB or more, at 6-7 ft it may be negative. The acoustic signal emanating from hearing aid thus changes (Ross, 1981).

Many researches have reported that the hearing impaired individuals not perform as well in noise as do individuals with normal hearing (Flexer, Wray and Ireland, 1989; Olsen, 1988; Finitzo-Heiber and Tilhnan 1978; Erber 1971). Hearing impaired listeners require a S/N ratio from +14 to 30 dB. i.e. 15 dB higher than that required by normal hearing persons to use their hearing as effectively as possible (Carhart and Tilhnan, 1970).

Under poor acoustic environments, linguistic redundancy helps us to perceive the message, but hearing-impaired children are in the position of double jeopardy. By virtue of their poor linguistic knowledge, they are not able to make adequate predictions about the probable message, thus they are forced to depend heavily on the acoustic signal. This, however is inadequate because of presence of distortion arising from the hearing impairment. Therefore it is essential that learning of hearing-impaired child should take place in good acoustic environment.

Also reduced auditory information impairs an individual's ability to learn and remember auditory information. (Novak & Davis 1974)

Rabbitt (cited in Sanders, 1982) has suggested mat the increased effort necessary for discrimination under poor listening conditions reduces the amount of attention that is available for processing the cognitive content of spoken message.

The effect of noise on auditory learning by hearing impaired children in becoming increasing relevant as more and more of these children are educationally placed in noisy condition of normal classrooms. In order to overcome this problem and ensure that hearing impaired individual receives the primary signal at a level significantly above the background noise loop induction systems, infra- red systems and FM systems are relied upon.

Frequency modulated (FM) system works on the principle of modulation of audio signal onto a carrier wave which is accomplished at a transmitter worn by the speaker / teacher. The microphone placed close to the mouth of the talker picks up speech at high intensity, with excellent signal to reverberation and signal to noise ratios. Receiver worn by the child then picks up the transmitted signal. It is demodulated, amplified and delivered to the child's ear. In United States the Federal Communication Commission (FCC) for "educational assistance devices for the hearing impaired" has designated 72-76 MHz bandwidth regions for FM systems operation. 32 frequencies are available in the band, allowing for multiple systems to be operating at one time within single school building (Hammond, cited in Bentler, 2000)

The improvement of the S/N ratio in noisy and reverberant environment has recognized as the primary advantage of the FM use (Ross, 1992). The FM System has been shown to present approximately 15-20 dB greater intensity of speech signal than background noise at the ear of the listener (Hawkins, 1984). Other advantages of FM over other auditory trainers /ALDs includes its portability, its battery operation, constant and consistent transmission up to 100- 300 ft and non-interference by the presence of obstruction (Davis, 1991) However, the limitation of FM System include the outside frequency - interference from certain paging systems.

An FM system may be one of the three types: self contained, personal or free field. A self-contained system is worn in place of a hearing aid. It can have the environment microphone option and thus can also work as personal hearing aid. It has adjustable controls for different degree and configuration of hearing loss. The personal FM system is more often used in conjunction with childs own hearing aid. The FM receiver can be coupled to the personal hearing aid either by direct audio input, neck loop or by silhouette. The free field FM system is used primarily for mild hearing impaired or CAPD children. The FM signal after demodulation is amplified and delivered through free field speakers placed at strategic places. It spares the children from wearing a hearing aid.

Recent advances in FM technology has made it possible to incorporate an FM receiver into BTE hearing aid, an arrangement that should in theory eliminates the size and convenience concern. The other advancements in FM system technology include-Systems with fixed hearing aid mic. reduction in FM plus hearing aid mode and Systems with FM precedence.

The advantage offered by the advancing FM technology has expanded its use for varying degree and configuration of hearing loss as well as for normal hearing children with apparent learning problem (ASHA 1991; Bess, Klee and Culbertson 1988). Davis (1991) has suggested as many as seven applications of FM systems. A few investigators have suggested usage of FM systems as the primary amplification system rather than a supplemental system (Madell, 1992; Masion & Smaldine, 1991; as cited in ASHA 1994)

As FM systems are being widely used in different configurations, it is imperative for the audiologists to explore the strategies for its assessment in different combinations. Although FM systems are amplification devices similar to hearing aids, there are some distinct differences, which need to be taken into account in developing measuring strategies. First and perhaps the most important is the input level to FM microphone, which is 10-15 dB higher owing to its close proximity to the speaker. It is important to note mat functional gain measures generally will not allow FM (amplification) system to be assessed at input levels comparable to those encountered during normal usage. With F.G.M, the input to hearing aid or FM transmitter microphone well depends upon the aided threshold of the individual and is substantially lower than the expected input to an FM transmitter microphone. For higher levels input signals, the gain will be limited by the maximum output of the system and may be considerably less than that estimated using FGM (Stelmachowicz and Lewis, 1988). Furthermore if in actual use, the FM system is operating in the nonlinear portion of its operating range, due to either output limiting or input AGC at microphone transmitter, then functional gain measures will not be valid, therefore other means of assessments are sought after which include probe microphone measurement (PMM) and 2 cc. coupler measurements.

Probe Microphone Measurements and 2 cc. Coupler analysis can be used to evaluate FM system with input comparable to that at which speech will be received. These delineate the frequency response comprehensively and evaluate the amplification provided in terms of SPL rather than gain. Probe microphone measurements are the final outcome of an amplification system, as it takes into account the changed resonatory characteristic of external auditory meats (E. A.M), body baffle effect and head diffraction effect etc (Mueller, 1992).

In the present study 2 cc coupler and probe tube microphone measurements are used to assess the performance of a unit of an indigenous FM group auditory system, which is frequently being used in therapy clinics of AIISH during group therapy sessions. Its real ear insertion gain performance is also being compared with the child's own hearing aid to see if there are other advantages the said systems provides in terms of gains and frequency response.

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Aim Of Study

- To assess the electroacoustic characteristics of the chosen FM system.
- To compare the of insertion gain of FM system with clients own hearing aids in terms of:

  Gains at different frequencies

  Frequency response range.

REVIEW OF LITERATURE

Effect of noise and reverberation on speech perception in hearing impaired.

Speech perception is an active and creative process in which listener's prior knowledge of language, the situation and the talker are all integral component of perception process (Studdert - Kennedy; 1970; Liberman and Studdert - Kennedy, 1977; Sanders, 1977; Boothryd 1978; Fry 1978). Although the hearing impaired child does have the cognitive capacity to engage in creative search for meaning in acoustic message, however, the internal contributors of the perceptual process is frequently meager and erroneous and thus reflect deficient linguistic status. Hence they need to depend more on acoustic cues. Elimination of acoustic cues by a noise and reverberation has a severe affect on speech perception of hearing impaired. Conventional hearing aids as well as hearing aids with amplitude compression lack the capability to enhance selected acoustic cues (Nabelek, cited in Nabelek,1994). "The situation of a normal hearing listeners can be described as sitting comfortably on a branch" while the situation of a special listener (hearing impaired) in like "hanging by one hand". Especially when the wind blows, hanging position is less comfortable (Nabelek 1994).

Various researchers have proved through experiments that hearing impaired listeners face great perceptual difficulties in adverse listening conditions with higher reverberation time and poor S/N ratio.

Lochner and Burger (1961, 1964) and Nabelek and Robinette (1978) have indicated that reflection or repetition of speech sounds over a period of 0-0.03 seconds enhance speech understanding in normal hearing. Presumably the normal human auditory system integrate the repetitive information over short time period and to some extent up to 0.08 seconds, thereby taking advantage of reflected speech sounds.

Unfortunately, hearing-impaired subject does not seem to benefit from rapid repetition of acoustic cues in speech over 0.02 sec (Nabelek and Robinette 1978).

Nabelek et. al., (1994) Speech recognition scores decrease in noise for both normal-hearing and hearing-impaired listener, but there were two differences of practical importance between them

I - The impaired listener performance was adversely affected by at S/Ns and T values, which did not alter the speech perception of normal hearing listener.

II - Since the hearing impaired listeners performed poorly than the normal hearing listeners, even in best listening conditions, their score became unacceptably low under mere adverse listening conditions.

Heiber and Tillman (1978) examined the effect of interaction of reverberation and noise on monosyllabic word discrimination abilities of normal hearing and hearing-impaired school age children. Performances of normal children were compared to that of hearing impaired youngsters under twelve combinations of reverberation and noise. The result indicated that performance of normal hearing groups was superior to the hearing impaired listeners in all environments.

Nabelek and Pickett (1974) :- They compared the speech perception scores of normal hearing and hearing impaired college students with moderate to profound hearing loss under different combinations of noise and reverberation. They also compared the result in monaural and binaural listening in these test conditions. The result showed that scores by hearing- impaired subjects were considerably poorer in these listening conditions. They also found that performance was further diminished by monaural listening conditions.

Comparison of performance of FM system and other amplification system

Several studies have shown that hearing impaired individuals require a S/N ratio of +10 to 15 dB to achieve the same speech discrimination scores which a normal-hearing person can achieve at zero S/N ratio. Therefore their perception is adversely affected under non-ideal acoustic conditions, as that of a regular classroom or an auditorium etc. Under such situation FM system has shown to help them perform better than with their personal hearing aids or with other Assistive Listening Devices.

Ross, Giolas and Carver (1973) found out speech identification score in eleven children with different degree of hearing loss in ordinary classroom conditions at a distance of 8-14 feet from talker, with their usual amplification condition and with an FM auditory trainer. The difference in speech identification score ranged from 12- 76 %.

Sung, Sung, Hudgson and Angelene (1976) conducted a study to investigate the intelligibility of speech transduced through a FM system installed in a classroom and conventional induction loop amplification (ILA) system to examine the applicability of FM adapter when used with commercially available hearing aids. Pre-recorded monosyllables were presented at 40dB SL with S/N ratio of 8 to 36 normal hearing subjects. Results indicated that speech transduced through FM system was significantly better than that of conventional ILA system.

Bonkeski and Ross (1984), they compared the speech discrimination scores of elderly hearing impaired in their usual listening condition to that with FM systems The above two types of scores of hearing impaired were also compared with three groups of normal hearing control subjects.

The result showed that among hearing aid subjects there was a significant superior performance with FM units ($P < 0.01$) relative to that under subject's usual listening condition. When compared with the control groups-hearing impaired under their usual listening conditions performed inferiorly ($P < 0.01$); but their performance with one of the two FM systems used was better than the controls, though the difference was not significant.

Flexer, Wray, Black and Millin (1987) used word and sentence recognition scores to compare the effectiveness of a typical FM system, an inexpensive hardware unit and the personal hearing aids in 10 hearing impaired (moderate degree) college students. Results indicated that FM unit performed significantly better than both hardware and personal hearing aids.

Selecting, Evaluating and Comparing FM Systems

As said earlier that although FM systems are amplification devices similar to hearing aids, there are some distinct differences which need to be taken in to account in developing measuring strategies. First, the input level of speech to FM microphone is more intense than to the hearing aid microphone. Second, many FM systems have several microphone input possibilities owing to its different modes of coupling.

The typical methods used for evaluating personal hearing aids may have their distinct limitations for evaluation of FM systems.

Currently there are two methods reported in literature for evaluating FM system.

A. Real Ear Measures
   1. Functional Gain measures
   2. Probe microphone measures

B. Coupler Measures

Regardless of the method the aim is to find out:

1. How much amplification is provided by selected FM system and it's coupling ?
2. Is the output of FM system sufficient to make the speaker voice heard without exceeding the listener's loudness discomfort level (LDLs) ?
3. What is the quality of the signal that the FM system provides ?

Functional Gain measurements

Van Tasell, Mallenger and Crump (1986) assessed functional gain and word recognition for nine hearing impaired school children under two conditions of FM amplification: (a) FM auditory trainer with insert earphone and (b) personal FM system with mini loop. The FM microphone - transmitter was mounted at a pre calibrated spot 1 meter in front of the loudspeaker. The subjects wearing the appropriate FM receiver and transducers were seated in the control room. The volume and tone control were adjusted at classroom use setting. Aided warble tone threshold were obtained at octave frequencies from 250Hz to 4000Hz. Presenting recorded PBK 50- word list at 72dB did the word recognition score.

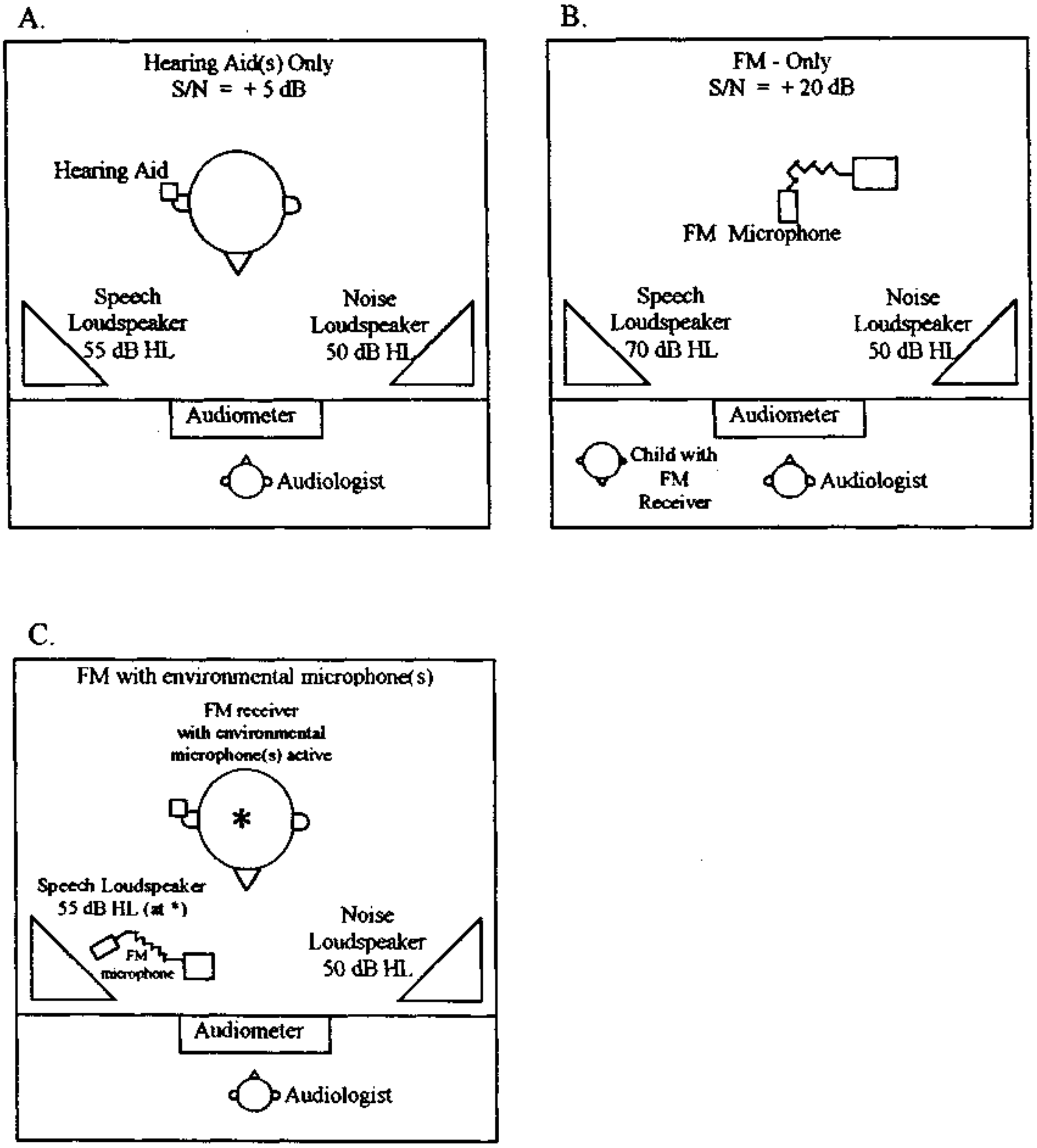
The results indicated - on the average, the insert earphone auditory trainer system provided slightly greater functional gain; the differences were most consistent at frequencies below lOOOHz. For the word recognition scores - eight of the nine subjects performed equally well with the mini loop induction system with the exception of one child whose residual hearing was limited to low frequencies.

Speech recognition ability with FM system Vs Personal hearing aids

It is often necessary and / or desirable to assess the speech recognition ability of a user with an FM system. It may also be important to compare such performance with that obtained using a personal hearing aid.

ASHA (1994) outlined speech recognition measures with FM system and personal hearing aid(s)

- Select a speech recognition test that is appropriate for the age and language of the client
- Place the hearing aid(s) on the client and setup the arrangement shown in (Figure A-next page).
- Speech is at 55 dBHL (68dBSPL) and noise at 50 dBHL (63dBHL)? producing a S/N ratio of+5dB. The loud speakers are located at plus and minus 45 degrees azimuths.
- Obtain a speech recognition score.
- Place the FM receiver set to FM- only on the client and setup the arrangement shown (Figure B-next page)
- Speech is 70 dBHL (83dBSPL) and noise is 50 dB HL (63dB HL), producing S/N ratio of +20 dB at FM microphone. The loud speakers are located at plus and minus 45 degrees azimuth. Obtain a speech recognition score.
- If speech recognition measure is desired for FM system with environmental microphone(s) active, set up the arrangement shown (Figure C-next page)
- Speech is at 55 dBHL (68dBSPL) at the client's location and noise at 50 dBHL (63dBHL), producing a S/N ratio of +5dB at the environmental microphone(s).



Physical arrangement in a sound booth for speech recognition assessment with hearing aid and with FM system.

- The FM microphone is positioned in front of the speech loudspeaker at a location designed to produce 83 dB SPL speech input to the FM microphone.
- The environmental microphone(s) on the FM system are activated
- Obtain a speech recognition score.

ASHA (1999 cited in Bentler, 2000): Gave outline for monitored live-voice assessment of speech perception with an FM system.

1. Set the controls of FM system in customary use position.
2. The audiologist/tester should wear the FM microphone but it should remain turned off unless indicated.
3. Place the hearing aid(s) and personal FM receiver (or self-contained FM receiver) on the client; seated at the calibrated spot in the sound field.
4. The two loud speaker are located at +45/-45 azimuths
5. Measure the speech perception in quiet and noise via the local microphone.
    a. Set the speech level at 55 dB HL and obtain speech perception score through the loudspeaker (in quiet).
    b. Turn on speech shaped noise at 50 dB HL, producing a S/N ratio of +5 dB. Obtain a second speech perception score (in noise).
6. Measure speech perception in quiet and noise via the FM microphone.
    a. With out making any other changes, turn on the FM microphone and obtain speech perception score (in noise).
    b. Turn off the noise and obtain a trial speech perception.

7. Evaluate the results

   a. The scores obtained in quiet by aid alone should be commensurate with other speech perception scores obtained either aided or under headphones.

   b. The score obtained in noise by aid alone should be poorer than that obtained in quiet.

   c. When FM microphone is turned on the scores in noise should return to a value that is not significantly lower than that obtained in quiet by aid alone.

      If the score remains below than that obtained in quiet the gain in the FM channel is probably too low

   d. Turning off the noise in the aid plus FM condition should not produce a significant change in scores if there is a significant increase of score, the gain in the FM channel is probably too low.

The limitation of behavioral testing along with the inability to assess the maximum out put of the FM system with threshold measurement have led to an increasing emphasis on the use of probe microphone and $2cm^3$ coupler measurements.

2cc coupler measurements

In the past coupler measures have been performed utilizing lower level of signal and / or output of the hearing aid and FM system have been equated with the same level of input.

Bess, Sinclair and Diggs (1984) as a part of their field study about the efficacy of group amplification in schools for the hearing impaired, did elecroacoustic measurements of group FM amplification using 2cc coupler. The non-directional teacher microphone / transmitter was placed at the center of the test chamber with in 5mm of test box monitor microphone. The student receiver/amp was located approximately 1 meter with its built in receiver coupled to 2cc coupler and recording microphone of the test equipment. The saturation output curve was obtained for 90dB SPL, sweep frequency signal. High Frequency Average was computed for 1000, 1600 and 2500Hz.

Total Harmonic Distortion was measured at 500, 800 and 1600Hz using a 70dB input. Finally the internal noise output of student unit was measured while the teachers unit was switched on, but without an input signal directed from the test box loudspeaker.

Lewis et.al., (1991) suggested that the desired real ear SPL as a function of frequency would be the same for amplification from a hearing aid or an FM system. Therefore, the 2cc coupler values measured with a 60dB SPL input for a hearing aid can be matched of a 2cc coupler values measured with a 75dB SPL input for the FM system. Coupler measures evaluate a FM system at realistic input levels and provide measures of maximum output and harmonic distortion (Lewis, 1991)

Seewald and Moodie (1992) proposed the following procedures for $2cm^3$ coupler for FM and system evaluation and selection.

1. Determine that the users personal hearing aids are functioning properly and have been set appropriately.
2. Measure critical electro-acoustic characteristic on the personal hearing aid (a) SSPL 90 (b) Output of the hearing aid with a 65dB SPL input at user volume control wheel (VCW) position and control settings. The measures of maximum output and output for typical input will serve as targets for adjustment of the FM system.
3. Place the microphone of the FM system in a calibrated test position. Couple the external receiver of the FM system to the 2cm^3 coupler appropriately. Obtain SSPL 90 curve and adjust the maximum output control on the FM system until the SSPL 90 curve most closely matches that obtained with hearing aid alone in step (2). Using an 80dB SPL input to the FM microphone adjust the FM VCW and tone control until the 2cm coupler output level most closely match those obtained for the hearing aid alone in step (2) above, (note that the output is being matched, not gain) The gain of FM system will be less than that of the hearing aid, because of the higher input levels.

For a personal FM system, leave the hearing aid VCW at user setting and adjust only the FM system VCW until the closest match is obtained. When the closest match has been achieved, harmonic distortion measurements should be obtained.

If a self-contained FM system is being used, the environmental microphone portion of the FM system should be assessed using the same input levels

ASHA (1999, cited in Bentler, 2000): Recommendations for 2-cc coupler assessment

1. Attach the hearing aid, or the receiver/amplifier of a self-contained FM system, to the 2-cc coupler and place in the test box with the microphone in the calibrated position.
2. Using swept tones or a complex noise, measure output as a function of frequency following standard procedures. The results should include:
    a. An estimate of maximum out put as a function of frequency.
    b. An estimate of full-on gain as a function of frequency.
    c. An estimate of full-on gain as a function of frequency at user settings for conversational in put (65 dB SPL)
    d. If the aid incorporates full dynamic range compression- estimates of user gain as function of frequency for low (50 dB SPL), typical (65 dB SPL), and (80 dB SPL) input levels.
    e. Estimates of distortion as a function of frequency under normal conditions of use.
3. Remove the hearing aid, still attached to the coupler, from the test box.
    a. If this is a personal FM system, couple the FM receiver to the personal hearing aid. Note that if Direct Audio Input is being used, the sensitivity of the hearing aid microphone may change.

The system should, therefore, be tested with input to the hearing aid microphone before assessing FM input.

b. If neck loop coupling is being used, make sure that the configuration of the loop, and the position and orientation of the aid in relation to the loop, represent real conditions of use. The ideal way to meet this requirement is to place them on the actual user. An alternative is to use another person or a manikin. With all three options, it may be necessary to support the weight of the coupler as it hangs in front of the ear.

4. Place the FM microphone in the test box in the calibrated position.

   a. If possible, turn off the local ("environmental" or hearing aid) microphone. If it is not possible, the measurements must be done in a, quiet environment such as the audiometric test booth. Note that, when testing a self-contained FM system in which the environmental microphone can be turned off, the receiver/amplifier can remain in the test box.

5. Set all volume controls to their normal use positions.

6. Repeat the out put measurements to obtain:

   a. An estimate of full-on gain as a function of frequency, for a high input level (80 dB SPL)

   b. An input versus output curve to obtain an estimate of compression threshold in the FM transmitter.

A considerable debate has ensued related to optimal relationship of teacher's microphone sensitivity relative to environmental microphone sensitivity. As a result ASHA 1999 gave outline for adjusting gain in FM channel for a personal FM system used as an accessory to an existing hearing aid.

1. Ensure that the Volume control, Tone control, Saturation Sound Pressure Level, and any compression characteristic of the hearing aid are adjusted as normally used and that the aid is functioning properly.

2. Measure output in to a 2-cm coupler for an input to the hearing aid microphone of 65 dB SPL at a frequency of 1000 Hz.

3. Couple the FM receiver to the hearing aid in the manner that is to be used. If using a standard neck loop, make sure the shape and orientation of the loop, and the distance and orientation of the aid in relation to the loop, are the same as in actual use.

4. Adjust the FM volume control of the FM receiver so that a 65 dB SPL, lOOOHz input to the remote microphone generates the same output from the hearing aid as measured with a local microphone.

5. Increase the input to 80 dB SPL. You should find that the output from the hearing aid increases by at least 10 dB. If so, then the adjustment can stand.

6. If the increase was 15 dB you may reduce the FM volume control of the FM receiver so that the output in to the 2 cc coupler falls by 5 dB.

7. If the increase is only 5 dB, increase the FM volume control of the FM receiver to provide an additional 2 or 3 dB of output (giving a 7 or 8 dB FM advantage rather than a 10 dB advantage).

8. If there is no increase of output when the input changed from 65 to 80 dB SPL, you may assume that the FM transmitter has very low compression threshold. In this case, increase the FM volume control of the FM receiver to provide a 5 dB increase of output (giving a 5 dB FM advantage).

When dealing with a self contained FM system, in which the FM receiver and amplifier or in a single unit, first adjust the characteristic of amplification via the local (environmental) microphone to match those of the users' personal hearing aid (which we assume to have been fitted properly). Then follow the procedure just outlined

Probe microphone measures (PMM)

The manner in which PMM are made will vary depending upon the system being used and the way in which the sound field is equalized (Lewis, Feigin, Karasek and Stelmachowicz (1991). In all cases, the microphone of the FM system should be placed in a position where the input is known and constant. There are two procedures that make use of PMM for evaluating FM systems, one described by Hawkins (1987) and other by ASHA (1994).

Hawkins (1987) For the personal FM system the in-situ output of hearing aid is obtained for 60dB input. The hearing aid is left in place with the probe tube still in the ear canal. The FM receiver is connected to hearing aid via direct input neck loop or silhouette adaptor. The FM microphone is positioned next to the compression microphone of the probe assembly. This positioning allows for a flat input across frequency to be delivered to the FM microphone. The in-situ output of the personal FM system is measured with 80 dBSPL input signal.

For a self contained FM system, the FM input mode is selected, an input of 80dB is given and measurements are made.

The draw back of using the procedures is that if sweep pure tone or warble pure tone is used and FM system utilizes a compression unit, the shape of frequency response in a low frequency may not be accurate. Secondly there may be presence of acoustic feedback with a high gain hearing aid due to close proximity of microphone to ear mold where sound is leaking out. (Hawkins 1987).

American Speech Language Hearing Association (1994) described the following PMM with FM system:

1. The FM microphone is placed in the calibrated spot in front of the sound field loudspeaker of probe microphone system or next to the controlling microphone of the probe system (Hawkins 1987).
2. The probe microphone tube is placed in the ear canal of the client and the FM receiver is set to receive only the FM signal .A real ear SSPL 90 curve or real ear saturation response (RESR) is obtained care

should be exercised in making this measurement so as to prevent excessive output levels in the ear to avoid discomfort. The output control is adjusted until the desired RESR is obtained, which would be either the RESR of personal hearing aid or as independently generated target values.

3. Using an 80dB SPL input to the FM microphone, the FM volume control wheel and tone control are adjusted until the desired output levels in the ear canal are obtained. If a personal FM system is used, the hearing aid VCW should be set to the typical use position and FM VCW should be adjusted for the desired out put levels.

Probe microphone measures can be used to evaluate an FM system at realistic input levels and provide information on maximum output. They are limited however, by the inability of some systems to provide information about harmonic distortion and they require the cooperation of individual being evaluated (Lewis, Feigns, Karasek, Shelmachowicz 1991).

METHODOLOGY

Subjects

Twenty-two hearing impaired children in the age range of 4-10 years participated in the study. These were divided into '2' groups depending upon the degree of hearing loss.

Group 1

1. These children had moderate to moderately severe sensori neural hearing loss.
2. The pure tone average (PTA) at speech frequencies i.e., 0.5, 1 and 2KHz ranged between 50dB - 66.7dB
3. The mean and SD of PTA were 59.3dB and 5. ldB respectively.

Group 2

1. These children had severe degree of hearing loss
2. Their pure tone average (PTA) at speech frequencies ranged between 70dB-88.6dB
3. The mean and SD of PTA were 78.3 and 6.7dB respectively.

These children were undergoing speech and language therapy at therapy clinics of All India Institute of Speech and Hearing.

- All the selected subjects had been prescribed hearing aids.
- None of the subjects had a history of ear discharge

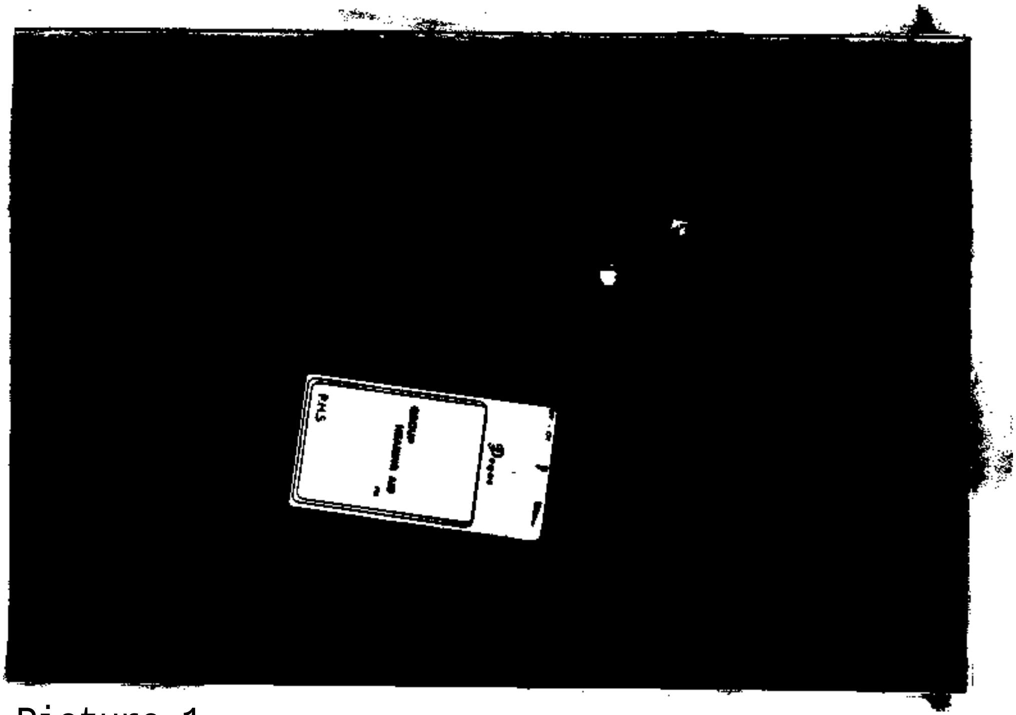
- All the subjects underwent preliminary ENT examination to rule out presence of middle ear disease and wax.

Instruments

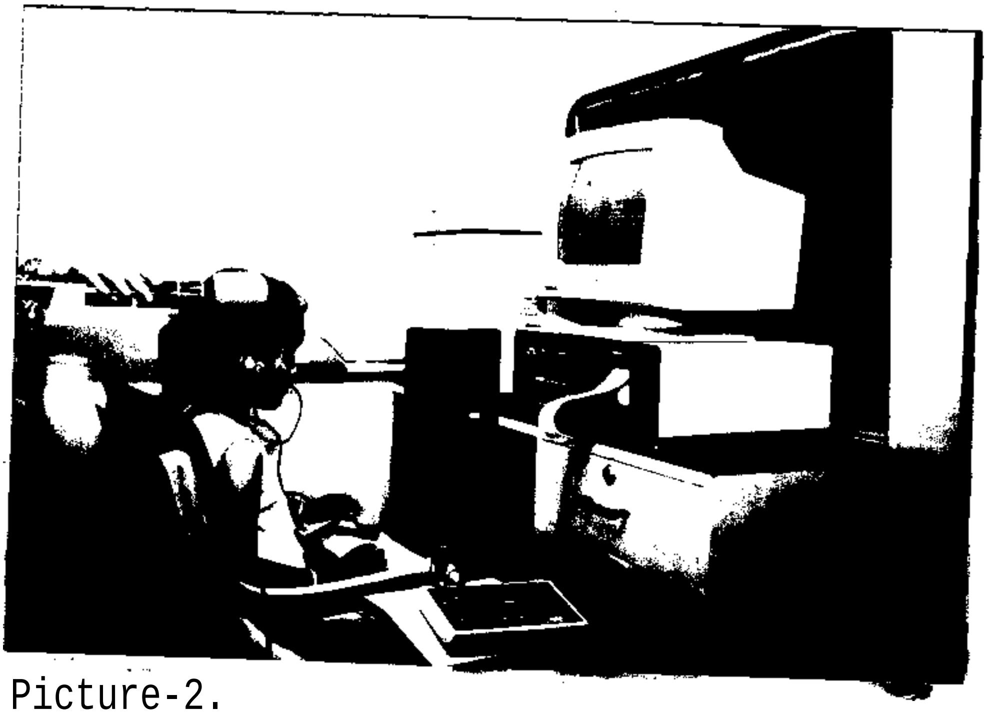
1. **Audiometer-Calibrated** diagnostic audiometers was used to get the recent audiograms of the subjects.
2. **Hearing- aid test** system-The FONIX 6500 C real time hearing aid analyzer with software version 3.09E/64K/000097F7-93.08.03 with probe tube microphone option was used to perform insertion gain measurements. The instrument was calibrated as per the instructions given in the operation manual (appendix I) and calibration was ensured throughout the data collection.
3. FM **System**-Peyas FM group hearing system model P.H.-5 (Picture-1)

   This FM system is a self-contained type and it has one hand held microphone/transmitter and twelve students' receiver units. The microphone runs on a 4 pen-torch batteries (6 volts) and the receiver unit requires 2 pen-torch batteries. Receiver unit is body worn type with 'V cord attached to two AP-180 receivers. This model has been recommended for the hearing loss ranging from moderately severe to severe degree.

   A receiver unit along with the microphone/ transmitter was selected for the present study.



Picture-1



Picture-2.

4. **Hearing** Aids-Different brands of hearing aids, which the subjects were using at that time were selected from the hearing aid stock of department of Audiology, All India Institute of Speech and Hearing to rule out the variable of malfunctioning of the subject's own aid. Among the moderate-moderately severe hearing loss cases, 4 cases were using Alps Super Master, 2 cases were using Elkon BM-81 and 2 cases were using Elkon BM-79.Among the severe hearing loss cases, 4 were using Elkon BM-78; 2 were using Elkon BM-79 and 5 were using Alps Power Master.

Test Environment

Pure tone audiometry, 2 cc coupler and Probe microphone measurements were done in sound treated, air-conditioned room. The ambient noise level in the rooms was with in permissible levels as recommended by ANSI 1991.

Procedure

2cc **Coupler measurements:**

Pre-measurement: Test-box of hearing aid analyzer was leveled as per procedure.

Setting of the equipment: FM microphone/ transmitter was placed in the pre-calibrated position in the test box. Its antenna was extended. Test box had to be kept open because of the size constraints of the FM microphone. The extraneous noise in the room was controlled.

Button receiver (earphone) of receiver unit of FM system and microphone of the hearing aid analyzer were coupled to 2cc coupler and together they were kept on a vibration free surface.

SSPL-90 curve. Under sweep frequency mode, a signal of 90 dB SPL was presented. FM system volume control was set at full on gain position and SSPL -90 curve and its data were obtained.

Input 80dBSP-Output curve - An 80dBSPL sweep frequency signal was presented output curve and its data were printed. Harmonic distortion was also measured at this level and it was found that even at full-on position the harmonic distortion remained with in permissible limits.

Probe tube microphone measurements: Testing was done under Quick — probe option using the remote module.

Child's audiogram was fed and target gain curve was obtained using POGO formula given by McCandless and Lyregaard (1983) (Appendix II).

Child was made to sit independently on a chair, facing the monitor. The height of the loudspeaker was adjusted according to child's seated position. It was placed 12" away from the child's tested ear at 45° azimuth. Headband was secured above the ears and the ear hanger was placed around the ear being tested. The reference microphone was firmly secured on the headband just over the ear undergoing testing. The probe microphone tube was measured along the length of the canal portion of ear mold. Tube was marked at point where it extends 5mm beyond the canal length of ear mold. Probe tube was inserted in the ear canal till the marked point reached the tragus notch. Here it was secured with the help of adhesive tape, to make sure that child's head movement does not displace the probe-tube position. Child was made to look at the monitor, ahead of him and instructed not to move his head. (Picture-2)

Leveling: For sound field leveling the level key on the remote module was pressed (APPENDIX III). The testing was carried out only after the sound field was leveled.

REUR: A 70dB composite signal was presented and the ear canal resonance curve was stored.

REAR & REIR-1: Ear mold with hearing aid's receiver attached to it was placed in the ear. A 70dB composite signal was presented. The lower graph displayed real ear aided response and upper graph displayed real ear insertion gain response. Volume control wheel (VCW) of hearing aid was adjusted till insertion gain curve best matched the target gain curve. This REIR was stored and copied as R1. VCW Position of Hearing aid was noted down.

REAR & REIR-2: FM microphone/transmitter was held adjacent to the reference microphone over the child's tested ear. Receiver unit with child's ear mold clasped to its button receiver was placed in the child's ear (as done for hearing aid). An 80dB composite signal was presented. Volume control wheel of receiver unit was adjusted till the insertion gain curve best matched the target gain curve. It was stored and copied as R2. VCW position for FM unit was also noted.(Picture-2)

Extraction of Data

Under the multicurve option (Appendix IV)

- Target curve was labeled as C_4 (default)
- R_1 was subtracted from C_4 : Graph and the numeric data of the subtracted curve were printed.
- R_2 was subtracted from C_4: The subtracted curve and its numeric data were printed as well.
- In the raw data of the subtracted curves, we get the numeric values in dB SPL for frequencies starting from 200 Hz to 8000 Hz at 100 Hz intervals each. (Appendix IV). Now comparison of the R_1subtracted from C_4 i.e., (C_4- R_1) and R_2 subtracted from C_4 i.e., (C_4- R_2) at discrete frequencies of 250 Hz, 500Hz, 1KHz, 2KHz, 4KHz, 8KHz would have been misleading because of presence of peaks in the insertion gain curves, therefore values throughout have been considered by averaging them in clusters. For averaging purpose the data was clustered in the following frequency groups 100-500Hz, 600-lOOOHz, 1100-1500Hz, 1600-2000Hz, 2100-2500Hz, 2600-3000Hz, 3100-3500Hz, 3600-4000Hz, 4100-5000Hz, 5100-6000Hz, 6100-7000Hz, 7100-8000Hz.
- As can be seen, for higher frequencies averaging was done for 10 frequencies interval each because insertion gain curve was never shown to reach the target at higher frequencies and thus the values obtained were of less importance. These values remained more or less same.

- In the subtracted curve data, values of ± 10 dB were considered as acceptable for the amplification device meeting the gain demand for the child.
- Values > 10 dB were the indication of under amplification and values < -10 dB were the indication of over amplification.

RESULTS AND DISCUSSION

The present study was undertaken to objectively assess the performance of a FM group hearing system.

In the first part of experiment Electro acoustic characteristic (EAC) of FM system were measured using 2cc coupler.

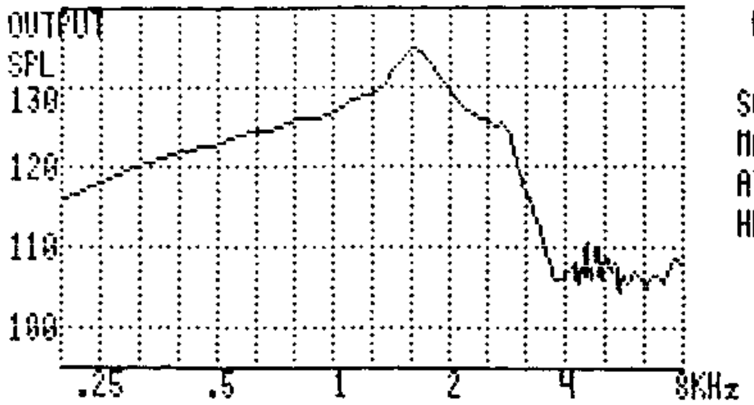
In the second part, the insertion gain of the FM system was compared with that of the conventional body level hearing aid.

For the second part of the study 22 children were selected. They were divided in two groups based on the degree of their hearing loss. Each group had eleven children.

The comparison of the two insertion gain curves was done by comparing their differences from the target curve. This was done so with a view that a direct comparison of insertion gains would have misled the results. At first glance the amplification device giving more gains would appear better, but that could have been an instance of over amplification. The aim of the study was to find out the more suitable or appropriate device catering to the child's need.

The difference from the target was subjected to independent two-tailed 't' test using statistical presentation system software (SPSS) version 10.0. The results are summarized and discussed as follows.

SSPL – 90 CURVE



PURE TONE MODE

SOURCE 90 dBSPL
MAX OUT 135.0 dBSPL
AT 1600 Hz
HF AVG 129.2 dBSPL

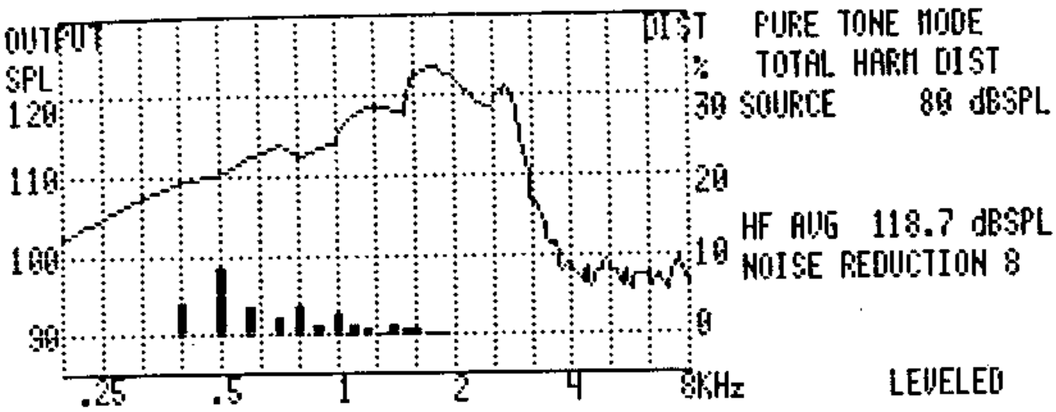
LEVELED

FREQ Hz	AMPL dBSPL	DIST N/A	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL
200	116.1		2000	129.3	3800	106.0	5600	106.6
300	119.9		2100	127.9	3900	105.8	5800	105.3
400	121.8		2200	126.9	4000	105.9	5900	106.0
500	122.8		2300	126.3	4100	107.1	6000	106.8
600	124.7		2400	126.1	4200	107.9	6300	105.4
700	124.8		2500	125.7	4300	105.6	6500	104.9
800	125.8		2600	124.9	4400	107.4	6700	106.4
900	125.8		2700	125.4	4500	106.6	7100	105.4
1000	127.0		2800	125.0	4600	110.6	7500	108.3
1100	128.3		2900	123.9	4700	105.9	8000	107.4
1200	129.1		3000	120.9	4800	110.1		
1300	130.1		3100	118.4	4900	106.0		
1400	130.8		3200	116.9	5000	108.6		
1500	133.5		3300	114.8	5100	108.4		
1600	135.0		3400	112.3	5200	106.8		
1700	134.2		3500	110.8	5300	107.8		
1800	132.5		3600	108.5	5400	107.4		
1900	130.9		3700	107.4	5500	104.5		

PURE TONE
SOURCE 90 dB
HF AVG. 129.2 dB

N.R. OFF
LEVELED

OUTPUT CURVE FOR 80 dB SPL INPUT



FREQ Hz	AMPL dBSPL	DIST %	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL
200	102.5	(TOTAL)	2000	121.8	3800	98.1	5600	96.0
300	106.9		2100	120.4	3900	98.8	5800	95.3
400	109.6	4.4	2200	119.9	4000	98.4	5900	97.5
500	110.4	8.6	2300	119.0	4100	97.8	6000	97.6
600	112.7	3.6	2400	118.6	4200	97.1	6300	97.5
700	113.9	2.4	2500	119.1	4300	96.6	6500	96.1
800	112.5	3.6	2600	120.6	4400	98.6	6700	97.6
900	113.5	1.0	2700	121.1	4500	95.9	7100	95.4
1000	114.6	2.6	2800	120.7	4600	96.7	7500	99.3
1100	117.6	1.2	2900	118.4	4700	98.1	8000	95.4
1200	118.6	0.7	3000	113.6	4800	97.9		
1300	118.3	0.5	3100	110.3	4900	99.5		
1400	117.8	1.4	3200	106.4	5000	98.9		
1500	117.4	0.6	3300	105.8	5100	97.9		
1600	122.5	0.8	3400	103.9	5200	97.8		
1700	123.5	0.4	3500	101.6	5300	97.2		
1800	123.3	0.2	3600	101.7	5400	96.0		
1900	122.3	0.1	3700	100.5	5500	97.8		

PURE TONE
SOURCE 80 dB
HF AVG. 118.7 dB

N.R. 8 X
LEVELED

2cc coupler measurements

1. SSPL 90 Curve: As can be seen from electroacoustic characteristic printout maximum output of 135 dB SPL was obtained at 1600Hz. High frequency average was 129.2 dB. The output declined steeply after around 3000Hz. And then it stabilized to the average value of about 106 dB at and above 3 800Hz.

2. Output Curve for an 80 dB SPL Input: An 80 dB SPL sweep frequency input was used to simulate the actual use input to the FM system (Lewis et. al., 1991; Seewald & Moodie, 1992; ASHA, 1994, 1999). The outputs SPL and harmonic distortion were obtained.

As can be seen, there is a gradual increase in output from 200Hz to 2800Hz.The primary and secondary peaks of maximum output are seen at 1700Hz and 2700 Hz respectively. The high frequency average (at 1000Hz, 1600Hz & 2500Hz) is 118.7 dB SPL. After around 2800Hz there is steep decline in the output with the slope falling till 3700Hz. After that the output gets stabilized at around 98 dB i.e., the FM system appears to give a uniform gain of 20dB after around 4KHz till 8KHz.

The harmonic distortion was found to be slightly higher than permissible at 500Hz.

Probe Microphone Measurements

Table 1: Insertion gain comparison of FM and Hearing aid in group 1 children (N=ll)

Frequency Range in Hz.	**Type of Amplification**	**Mean (Target gain -** Insertion gain)	S.D (Target gain - Insertion gain)	**'t' values**
200-500	FM	4.68	3.90	-0.83-NS
	Hearing aid	6.24	4.87	
600-1000	FM	2.40	2.09	-1.22-NS
	Hearing aid	2.53	2.93	
1100-1500	FM	2.10	3.35	1.08-NS
	Hearing aid	0.78	2.30	
1600-2000	FM	0.14	3.68	0.86 - NS
	Hearing aid	-1.09	3.33	
2100-2500	FM	4.12	5.04	0.92 - NS
	Hearing aid	2.35	3.93	
2600-3000	FM	14.01	3.11	0.60 - NS
	Hearing aid	12.98	4.77	
3100-3500	FM	24.84	9.75	0.35 - NS
	Hearing aid	23.55	7.73	
3600-4000	FM	31.63	8.04	1.01-NS
	Hearing aid	28.04	8.68	
4100-5000	FM	37.02	6.08	1.90-NS
	Hearing aid	31.59	7.30	
5100-6000	FM	37.58	7.63	1.00-NS
	Hearing aid	33.78	10.01	
6100-7000	FM	34.62	7.33	-0.46 - NS
	Hearing aid	36.30	9.64	
7100-8000	FM	38.87	7.39	0.10-NS
	Hearing aid	38.50	9.72	

NS = Not Significant at $p < 0.05$ *N*= Number of Subjects

As can be seen from the table 1 the insertion gain of FM system is able to reach the target gain till around 2500Hz. After that rapid decline in the gain can be seen. This is attributed to the inherent gain characteristics of the FM system. As can be seen from the EAC measures of FM system, there is a decline in the output dB SPL after the secondary peak at 2800 Hz.

The same trend was seen for the hearing aid gains. Insertion gain could reach the target gain within ± l0dB till around 2500Hz and then a decline in the gain was observed. This may be attributed to the inherent gain characteristic of the conventional hearing aids.

Comparing FM System and Hearing aid

When insertion gain of FM system and hearing aid were compared in terms of their difference from the target no significant difference was found at any of the frequency ranges. However, negative 't' values in the frequency ranges of 200-500Hz, 600-1000Hz and 6100-7000Hz indicate that at these frequency ranges Insertion gain by FM system was more than that obtained by hearing aids. Similarly a positive 't' value at rest of the frequency ranges indicate that insertion gain provided by hearing aid was more than the FM system in those frequency ranges.

i-

Table 2: Insertion gain comparison of FM and hearing aid in group 2 children (N=ll)

Frequency Range in Hz.	Type of Amplification	Mean (Target gain - Insertion gain)	S.D (Target gain - Insertion gain)	't' values
200-500	FM	5.25	3.86	1.22-NS
	Hearing aid	3.52	2.77	
600-1000	FM	1.68	3.09	1.26-NS
	Hearing aid	0.02	2.99	
1100-1500	FM	1.05	3.09	0.09-NS
	Hearing aid	0.84	2.99	
1600-2000	FM	1.68	4.96	0.67 - NS
	Hearing aid	0.16	5.62	
2100-2500	FM	5.36	6.93	1.41-NS
	Hearing aid	1.41	6.19	
2600-3000	FM	18.62	7.70	1.62-NS
	Hearing aid	11.98	11.20	
3100-3500	FM	29.21	8.26	1.57-NS
	Hearing aid	22.08	12.52	
3600-4000	FM	37.70	9.46	1.88-NS
	Hearing aid	29.12	11.78	
4100-5000	FM	40.45	9.69	1.61-NS
	Hearing aid	33.71	10.00	
5100-6000	FM	46.42	11.91	1.94-NS
	Hearing aid	38.05	7.92	
6100-7000	FM	44.95	11.53	1.67-NS
	Hearing aid	44.14	11.61	
7100-8000	FM	47.04	7.37	-0.69-NS
	Hearing aid	49.93	11.61	

NS = Not Significant at $p < 0.05$ *N*= Number of Subjects

Before we discuss the results it is to be told that to match the target curve for severe hearing loss subjects, the volume control wheel (VCW) of hearing aid remained with in 1/3 of its rotation but for FM system it had to be adjusted between 2/3 and 3/4 of its rotation. It was acceptable since the harmonic distortion was found to be within acceptable limits even at full on gain position for 80 dB SPL input (see EAC of FM system).

As can be seen from the table 2, the insertion gain of FM and hearing aid are able to reach the target gain till about 2500Hz. After this the difference between the target and insertion gain of both the amplification systems increased. This can be seen as average value of difference of target and insertion gain for both the devices progressively exceeding + 10 dB value.

Comparing FM System and Hearing aid

A positive 't' value indicates that the hearing aid provided more gains than the FM system though the difference found was not significant at $P < 0.05$.

Comparing Table 2 and Table 1

After the frequency range of 2100-2500Hz, the difference between target and insertion gain of FM system increased more in table 2 (cases with severe SN loss) than in table 1 (cases with moderate to moderately sever SN loss). This is very confirmatory to the fact that dB SPL output of FM system decreased rapidly after around 2800 Hz irrespective of the volume control wheel setting. Comparatively less difference between target and insertion gain after 25000 Hz in Table 2 and Table 1 for the hearing aids indicate that the prescribed hearing aids tried to reach target in a better way.

SUMMARY AND CONCLUSION

The improvement of the S/N ratio in noisy and reverberant environment has been recognized as the primary advantage of the FM use. This is due to the close proximity of FM microphone to the speaker (Hawkins 1984, Ross 1992).

The present study was undertaken to objectively assess the performance of a unit of an indigenous FM group hearing system using 2cc coupler and probe microphone measurements. The insertion gain of FM system was compared with the conventional body level hearing aids.

22 children using conventional body level hearing aids participated in the study. They were divided in two groups on the basis of degree of their hearing loss.

Group 1 children had moderate-moderately severe sensori neural hearing loss. Group 2 children had severe degree of sensori neural hearing loss.

Insertion gains were obtained for FM system and the hearing aid. Their differences from target gain values were compared and it was found that insertion gain with FM and hearing aid did not reach the target beyond around 2500 Hz. The gain values rapidly declined after around 2500 Hz.

The difference in the insertion gain with chosen FM system and hearing aids was never found to be of statistical significant value at $p < 0.05$.

Conclusion

Though it was found that the chosen group FM system does not provide any extra advantage in terms of better frequency response when compared with subjects own hearing aid, nevertheless its use is recommended for group therapy session for children with moderate to moderately severe sensori neural loss (at different volume control settings) whenever the ambient noise level in the room is more.

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APPENDIX I

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

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

Instruments Required

FONIX Sound Level Calibration (Quest CA-12) ; 14 mm to 1 inch adapter, probe microphone calibrator adapter and calibration clip.

Procedure

The sound level calibrator's battery was initially checked for good condition. Following this, a 14 mm - 1 inch adapter is used to connect the calibrator and the reference microphone. To calibrate the reference microphone, the calibrator was switched on the measured microphone signal was compared to the intensity of the signal (lOOOHz at HOdB) generated by the calibrator. If the intensity of the reference microphone was not within 1 dB of the calibration value, the gain of the reference microphone was adjusted with small screwdriver using control marked REFERENCE on the bottom of the quick probe module.

To calibrate the probe tube microphone, the reference microphone was removed from the calibrator and the probe tube microphone adaptor was inserted. The probe tube was fully inserted in to the calibrator adapter. It was checked to make certain that nothing was clogging the probe tube, and that it was properly connected to the body of the probe microphone. The measured microphone signal was compared with the intensity of the calibrator level. If the value of the probe amplitude was significantly below the calibration level (1 lOdB for quest CA-12), it was checked to see that the probe tube has gone all the way in to the adaptor. This was done by taking the probe calibrator adaptor out to check. If necessary, the gain of the probe microphone was adjusted with a small screwdriver using the control marked PROBE on the bottom of the remote module. Using the above procedure, calibration was done for the reference and probe microphone of the FONIX 6500-C.

Calibrating the Sound Field Loudspeaker of FONIX 6500-C

The subject wearing the headband was seated at a distance of 1 meter and an angle of 45° from the loudspeaker.

The reference microphone and the probe microphone were combined with the calibration clip. The tip of the probe tube was kept at the center of the grid of the reference microphone. Both microphones were positioned on the headband just above the ear nearest to the loudspeaker. The test signal was turned 'on'.

The rms source SPL was compared to the rms OUT SPL. If the levels were within 3 dB of each other, the calibration was correct. When the difference was greater than 3 dB, the adjustment for the loudspeaker on the back panel of the main module was adjusted, until the rms source and rms OUT SPLs were within 3 dB of each other.

APPENDIX II

POGO procedure Real Ear Insertion Gain Formula for Use VCW Position

Frequency	Formula
250	½ H L - I 0
500	½ HL - 5
1000	½HL
-2000	½HL
3000	½HL
4000	½HL

APPENDIX III

After calibrating the FONIX 6500-C system, leveling (Automatic Adjustment of the loudspeaker Response) was done as per instructions given in the instruction manual of the FONIX 6500-C.

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

A composite tone at 70 dB SPL was presented from the speaker. Depending on the instrument location and the ambient noise, one of the following three different level conditions resulted.

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

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

Following this, it was checked to see if :

(i) The speaker was too close or too far away from the reference microphone

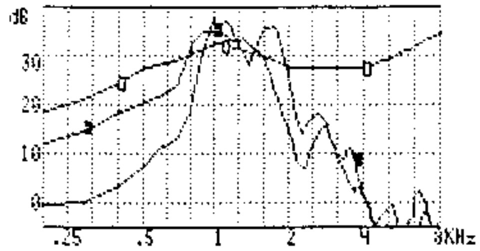
(ii) The microphone were unplugged, and

(iii) The calibration of the sound field speaker and the microphones were checked.

If still unsuccessful, calibration was repeated

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

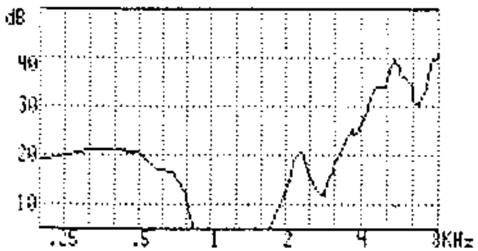
APPENDIX IV



MULTIPLE CURVES

```
 TITLE TYPE   SRC    OUTPUT   NR  NOTES ...
 REF 1 COMP  70 dB                GAIN SMOOTHED REIR
■ REF 2 COMP  80 dB                GAIN SMOOTHED REIR
□ CRV 4 TARGET INS GAIN            (POGO)
• REF 4 INVALID CURVE

[↖,↘]       TO MOVE CURSOR
[↙,↗]       TO SELECT CURVE
[CLEAR]     TO DESELECT CURVE
```



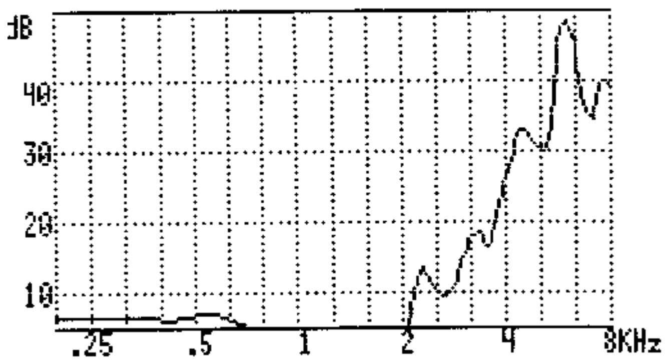
SUBTRACT CURVES

```
            TITLE TYPE   SRC    OUTPUT   NR  NOTES ...
SUBTRACT:   REF 1 COMP  70 dB                GAIN SMOOTHED REIR

            TITLE TYPE   SRC    OUTPUT   NR  NOTES ...
FROM:       CRV 4 TARGET INS GAIN            (POGO)

[↖,↘]       TO MOVE CURSOR
[↙,↗]       TO SELECT CURVE
[MENU]      FOR MAIN SELECTION MENU
```

FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL		FREQ Hz	AMPL dBSPL
200	19.0	2000	12.7	3800	24.0	5600	38.5		7400	38.1
300	20.8	2100	15.6	3900	24.3	5700	36.9		7500	39.3
400	20.9	2200	19.5	4000	26.7	5800	36.1		7600	40.2
500	20.0	2300	20.6	4100	26.8	5900	36.0		7700	41.3
600	17.1	2400	20.0	4200	29.0	6000	35.6		7800	41.4
700	15.9	2500	16.2	4300	31.0	6100	34.6		7900	41.0
800	12.2	2600	14.4	4400	32.4	6200	34.4		8000	40.8
900	1.1	2700	12.7	4500	33.2	6300	34.1			
1000	-4.8	2800	11.9	4600	33.3	6400	32.4			
1100	-2.2	2900	11.7	4700	33.3	6500	30.6			
1200	-1.6	3000	15.2	4800	33.3	6600	30.7			
1300	-2.5	3100	16.4	4900	33.8	6700	29.9			
1400	-1.3	3200	18.1	5000	35.1	6800	30.2	DIFFERENCE OF		
1500	-0.3	3300	19.9	5100	36.4	6900	31.4	TWO CURVES		
1600	-0.2	3400	22.0	5200	38.3	7000	33.4			
1700	3.5	3500	23.2	5300	39.0	7100	33.7			
1800	6.8	3600	24.4	5400	39.4	7200	34.3			
1900	9.3	3700	25.5	5500	39.5	7300	36.3	REF 9		



SUBTRACT CURVES

	TITLE TYPE	SRC	OUTPUT	NR	NOTES ...
SUBTRACT:	REF 2 COMP	80 dB			GAIN SMOOTHED REIR

	TITLE TYPE	SRC	OUTPUT	NR	NOTES ...
FROM:	CRV 4 TARGET INS GAIN				(POGO)

[↖,↘] TO MOVE CURSOR
[↙,↗] TO SELECT CURVE
[MENU] FOR MAIN SELECTION MENU

FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL	FREQ Hz	AMPL dBSPL
200	6.5	2000	1.1	3800	20.6	5600	40.9	7400	39.7
300	6.3	2100	6.5	3900	23.7	5700	44.7	7500	39.9
400	6.2	2200	11.2	4000	25.9	5800	46.4	7600	40.3
500	7.0	2300	13.3	4100	26.8	5900	48.3	7700	40.5
600	6.6	2400	12.0	4200	29.3	6000	48.6	7800	40.0
700	5.1	2500	9.8	4300	31.8	6100	47.5	7900	38.3
800	-0.9	2600	9.3	4400	32.8	6200	45.6	8000	38.4
900	-3.3	2700	10.0	4500	32.8	6300	45.3		
1000	-2.9	2800	10.6	4600	32.8	6400	43.6		
1100	-4.9	2900	11.5	4700	32.3	6500	41.0		
1200	-4.2	3000	14.8	4800	31.2	6600	39.0		
1300	0.2	3100	16.2	4900	30.6	6700	36.8		
1400	2.3	3200	17.9	5000	30.4	6800	35.4		
1500	-2.1	3300	18.5	5100	30.2	6900	34.6		
1600	-5.9	3400	17.9	5200	30.3	7000	35.1		
1700	-7.3	3500	16.7	5300	31.6	7100	34.6		
1800	-6.4	3600	17.2	5400	32.9	7200	36.2		
1900	-3.3	3700	18.9	5500	36.3	7300	37.6		

DIFFERENCE OF
TWO CURVES

REF 9