PROTOCOL FOR SELECTION OF FREQUENCY MODULATED (FM) SYSTEMS FOR THE HEARING IMPAIRED INDIVIDUALS

Register No.M2kl7

An Independent Project submitted in part fulfillment for the first year **M.Sc., (Speech and Hearing)** University of Mysore, Mysore.

All India Institute of Speech and Hearing
Manasa Gangothri
Mysore

MAY 2001

Dedicated to my brothers

Dr. Srikanth, Shiva, Vijay
&
Dear friend Goutham

CERTIFICATE

This is to certify that the Independent Project entitled : **"PROTOCOL FOR SELECTION OF FREQUENCY MODULATED (FM) SYSTEMS FOR THE HEARING IMPAIRED INDIVIDUALS"** is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register **NoJM2kl7.**

Dr. M Jayaram
Director
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Mysore
May 2001

CERTIFICATE

This is to certify that this Independent Project entitled : **"PROTOCOL FOR SELECTION OF FREQUENCY MODULATED (FM) SYSTEMS FOR THE HEARING IMPAIRED INDIVIDUALS"** 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.

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May 2001

DECLARATION

I hereby declare that this Independent Project entitled **"PROTOCOL FOR SELECTION OF FREQUENCY MODULATED (FM) SYSTEMS FOR THE HEARING IMPAIRED INDIVIDUALS"** is the result of my own study under the guidance of Ms.Manjula P., Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any other University for the award of any Diploma or Degree.

Mysore **Reg. No.M2kl7**
May 2001.

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INTRODUCTION

Hearing is the primary sense through which we learn speech and language. Damage to the auditory system results in many consequences, which include reduced hearing capabilities and thus poor speech and language ability.

Amplification devices to ameliorate the effects of hearing-impairment date-back at least several centuries with their effectiveness increasing rapidly as electrical and electronic technologies became available (Lybarger, 1986).

The function of a hearing aid is to intensify the sound energy reaching an individual's ear with as little distortion as possible. Hearing aids may make speech sufficiently loud, but not necessarily clear. The amplified speech signal is still being transmitted by way of a damaged peripheral auditory mechanism to the brain for interpretation. One of the biggest limitations of the hearing aids is their inability to make spoken communication details available when there is competing noise or when the listener cannot be close to the speaker.

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

Hearing-impaired individuals, who are fitted with hearing aids do not differentiate between the speech and noise, as the hearing aids amplify the background sounds (noise) as well as the primary signal (speech). In order to overcome this problem and ensure that hearing-impaired individual's receive the primary signal at a level significantly above the background noise, many assistive listening devices were introduced that provide a better signal-to-noise (S/N) ratio. Many technological advances have been put-forward to address this issue, of which FM system is one.

Frequency Modulated (FM) system works on the principle of modulation of the audio signal onto a carrier wave which is accomplished at the transmitter worn by the speaker. This is then transmitted to the receiver worn by the listener. The receiver may be coupled to the hearing aid directly (Direct input and acoustic coupling) or indirectly via induction.

In U.S.A., the Federal Communication Commission (FCC) has allocated 72-76 MHz as the band of frequencies for auditory assistance. There are currently fourty narrow band channels allocated by FCC, that are spaced 50 kHz (0.50 MHz), apart while wideband transmission divides the band into ten wide channels spaced 0.20 MHz apart (ASHA, 1994).

FM system provides benefit for persons with hearing loss in any situation where noise, distance and reverberation create an adverse listening environment which include classrooms, automobile, airplanes, theaters, houses of worship, sports events, employment settings, etc.

Recent advances in FM technology have resulted in smaller receivers and multiple FM transmitter options. The many choices that are available today make FM amplification a viable option for anyone with hearing loss and even for persons with normal hearing in certain situations.

There are many FM options available and the choices are expanding all the time. These include - Personal FM system, Self-contained receiver FM, Sound field FM.

The improvement of the S/N ratio in noisy and reverberant environment has been recognized as the primary advantage of FM use (Ross, 1992). The FM system has been shown to present approximately 15-20 dB greater intensity of the speech signal than background noise at the ear of the listener (Hawkins, 1984).

Historically, FM systems were recommended for use only in an educational settings and only for those children with severe to profound hearing loss. However, use of these systems has been expanded to include individuals with varying degrees and configurations of hearing loss as well as normal hearing children with apparent learning problems (ASHA, 1991; Bess, Klee and Culbertson, 1986).

A few investigators have suggested usage of FM system as the primary amplification system rather than a supplemental system (Madell, 1992; Maxon and Smaldino, 1991; as cited in ASHA, 1994).

The advantages of using an FM system include portability of the instrument, battery operated, transmission is constant up to 100-300 feet and is consistent throughout the area, and obstructions do not interfere with how the persons hear the sound (Davis, 1991). However, the limitations of FM system include - although 72-76 MHz was allotted as the auditory frequency band, there is a potential for outside interference. Certain paging systems and fire call boxes use these frequencies or ones close to them - if two transmitters on the same frequency are used in close proximity, receivers will seek strongest signal i.e. capture effect.

Advances in amplification technology have made expanded use of FM systems possible. Today's systems are more flexible than those available in the past. Their increased flexibility is further enhanced in multiple means of coupling the equipment (FM) to an individual's personal hearing aid (Hawkins, 1988). Although these advances have improved the audiologist's ability to fit FM systems appropriately for a wide variety of hearing-impaired individuals, they also have resulted in greater complexity for the audiologist as he/she attempts to choose the most appropriate FM system coupling method and settings for a given individual. The increasing complexity of FM system makes it imperative that the audiologist analyze the performance appropriately when selecting and setting an FM system (Lewis, 1991). Coupler measures and real ear (functional gain and insertion gain) measurements have been reported widely in literature, mostly for classification and prescription of hearing aids. This concept has been extended to other amplification devices viz. the FM systems.

Need for the Study

The success of any (re) habilitation program for the hearing-impaired individuals will depend upon the selection and fitting of an appropriate amplification device. At present, there are no standard guidelines for performance measurements of FM systems specified by American National Standards Institute (ANSI), International Standards Organization (ISO), Bureau of Indian Standards (BIS) etc. However, American Speech Language and Hearing Association (ASHA, 1994) has provided a few guidelines for fitting and monitoring of FM systems.

In view of the increase in utility of FM systems, lack of availability of a protocol to select an FM system, the present study was a preliminary attempt to provide a protocol for fitting the self-contained FM systems.

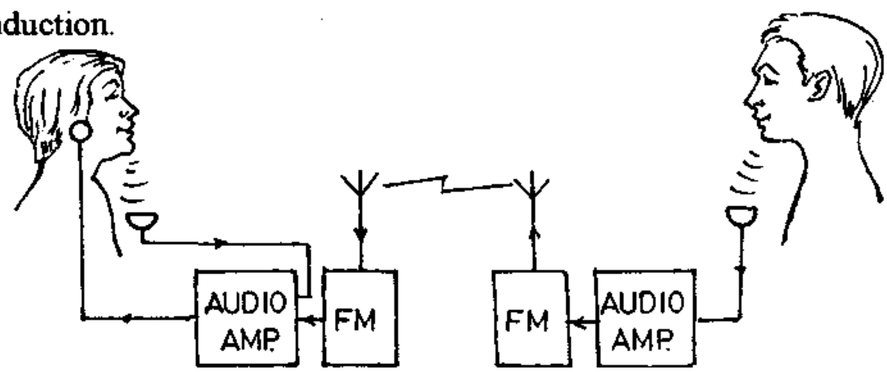
REVIEW OF LITERATURE

The importance of early identification and appropriate audiologic management of children with hearing-impairment is well known. In order to achieve optimal use of residual hearing for the development of speech and language, a consistent and non-distorted auditory signal is necessary. The major goal in fitting amplification is to improve the signal-to-noise (S/N) ratio in order to improve the understanding of speech.

Unfortunately, the ability of personal amplification device (i.e. a hearing aid) to provide an optimal speech signal to the hearing-impaired child is compromised by acoustic conditions commonly encountered in various listening environments. Speaker-to-listener distance, background noise and reverberant room characteristics combine, resulting in a deterioration in speech recognition ability in the hearing-impaired listeners regardless of age.

The FM System

Frequency modulated (FM) system works on the principle of modulation of the audio signal onto a carrier wave which is accomplished at the transmitter worn by the speaker. This is then transmitted to the receiver worn by the listener. It may be coupled directly (direct input and acoustic coupling) or indirectly via induction.



Source: Bess F. H. (1981) Amplification in education, pp: 306

Fig.2.1 : Block diagram of FM system.

In principle, FM listening allows a constant distance of approximately 6-8 inches to be maintained between the speaker's lips and the FM transmitter microphone. Thus, a greatly enhanced S/N is provided regardless of the distance between the listener and the speaker the acoustic environment (ASHA, 1991).

In USA, the Federal Communication Commission (FCC) has allocated 72-76 MHz as the band of frequencies for auditory assistance. There are currently fourty narrow band channel allocated by FCC, that are spaced 50 kHz (0.50 MHz), while wide band transmission divides the band up to ten wide channels spaced 0.20 MHz apart.

Applications of the FM system

FM system can provide benefit for persons with hearing loss in any situation where noise, distance and reverberation create an adverse listening environment, which include automobiles, airplanes, theaters, houses of worship, sports events, employment settings. Recent advances in FM technology have resulted in smaller receivers and multiple FM transmitter options. The many choices that are available today, that make FM amplification a viable option for any one with hearing loss and persons with normal hearing sensitivity.

Historically, FM systems were recommended for use only in educational settings and only for those children with severe to profound hearing loss. However, use of these systems has been expanded to include individuals with varying degrees and configurations of hearing loss as well as normal hearing children with apparent learning disability (ASHA, 1991; Bess, Klee and Culbertson, 1986).

Types and Various Coupling Methods of FM Systems

There are many FM options and coupling methods available and the choices are expanding all the time.

Types of FM system -

- Personal FM system
- Self-contained receiver FM
- Sound field FM

(i) ***Personal FM system*** *:* These are designed to be worn with personal hearing aids or coupled to the ear via light weight headphones or ear buds. With personal systems, the FM receiver is used with personal hearing aids via induction (neckloop) coupling, direct audio input (DAT) or FM receivers contained in an audioboot.

(ii) ***Self-contained receiver FM;*** These are worn in place of hearing aids and have internal controls that are set for the degree and configuration of hearing loss. These FM units are coupled with BTE or button receiver transducers and contain internal controls for output and frequency setting adjustments functioning both as hearing aid and FM.

(iii) *Sound field FM: In* this system, using the transmitter, the signal is sent to speakers strategically placed in the classroom via an amplifier. The advantage with this arrangement is that there is no equipment for the student to wear. As a result, students are not seen as being different from their peers. Children with significant impairments who refuse to wear hearing aids will derive some benefit with this arrangement.

Coupling Methods

(i) Hard-wire/induction Loop: This FM set-up operates with an induction loop that encircles an area or room like an over sized neck loop. The signal is transmitted to an amplifier and thus, via the induction loop, to the student through the T-coil of the hearing aid.

(ii) 3-D ***Mat:*** FM signal transmission is through a special flow mat that is installed beneath carpeting. The signal is picked up through the hearing aid telecoil. This system is advantageous for all students especially pre-school children, as the children will have to wear only hearing aid with telecoil position. The telecoil position on the child's hearing aid can be in any direction without interruption of the signal, hence, the name 3-D derived. Because of the powerful signal capability of this system, children with severe to profound hearing-impairment will get more benefit.

(iii) Hearing Aid/FM Combinations *:* The hearing aid/FM systems combine the benefits of hearing aid and FM technology in one unit at the ear. FM amplification systems have been designed to provide a solution for adverse acoustic environment that listeners with hearing-impairment encounter at home, in the classroom, or in many other common listening environments. A significant advantage of FM amplification over personal hearing aids has been documented for school-aged children with hearing-impairment (ASHA, 1991).

In spite of the widespread use of FM systems in educational and other situations, little attention has been directed towards specific methods of measurements and fitting. Often the typical methods used with personal hearing aids have been used. These approaches may be appropriate in some aspects, but they have distinct limitations.

Although FM systems are amplification devices similar to hearing aids, there are some distinct differences which need to be taken into account in developing measurement strategies. First, and perhaps the most important, is the input level of speech to the FM microphone is more intense than to the hearing aid microphone with the FM microphone appropriately located 6 to 8 inches from the talker's mouth, the overall level of speech is approximately 80 to 85 dB SPL (Comellise, Gagne and Seewald, 1991; Hawkins, 1984; Lewis, 1991). This is 10 - 20 dB more intense than the typically assumed 60 to 70 dB SPL input to the microphone of the personal hearing aid from one to two meters. This fact has important implications in the assessment and fitting of FM systems. If output measurements are being made to adjust and fit FM systems, then typical input levels should be employed. This is particularly important given that most FM microphone transmitters employ some type of input compression. The gain and output of the FM system may be quite different if lower level signals, which are not representative of the speech input to the FM microphone, are used in the measurement procedure.

A second issue relates to the increased complexity of the FM systems compared to hearing aids. Many FM systems have several microphone input possibilities. There is a talker's microphone as well as an environmental microphone, which can be located either at ear level or on the body worn FM receiver. There may be one or two environmental microphones, and they may be omni directional or directional. It is important that each input channel in the FM system be evaluated for proper functioning and that the microphones be positioned in the proper manner. If only the FM module needs to be assessed it is generally suggested that all others such as environmental mic be disconnected.

In a similar vein, the FM system may have more than one volume control wheel (VCW). Some units have one VCW for the FM signal and one for the environmental microphones. On personal

FM systems, there will be one VCW for the FM system and one for the personal hearing aid or two VCW for the FM system. It is important that careful thought be given to the setting of these VCWs, as certain combinations can produce undesired results (Hawkins and Schum, 1985; Hawkins and van Tasell, 1982; Lewis, 1991, 1992).

Finally, modifications must be made in some testing procedures to account for the way certain systems are physically arranged on the user. For instance, if a personal FM system with a neckloop is to be evaluated in a 2 cm^3 coupler, then the hearing aid (attached to the coupler) and neckloop must be located appropriately on a person (preferably the user) if the measurements are to be valid.

Comparison of the FM Systems and Other Hearing Instruments

The FM system has been shown to present approximately 15-20 dB greater intensity of the speech signal than background noise at the ear of the listener (Hawkins, 1984). When the mic of the FM system is held near the source.

Investigators have reported that the FM systems are highly advantageous over conventional hearing aids. 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 scores ranged from 12-76%. Sung, Sung, Hodgson and Angeleni (1976) conducted a study to investigate the intelligibility of speech, transduced through a FM system installed in classroom and a conventional induction loop amplification (ILA) system to examine the amplicability of an FM adaptor when used with commercially available hearing aids. Pre-recorded monosyllables were presented at 40 dB SL with S/N ratio of 8, to 36 normal hearing subjects. Results indicted that speech transduced through FM system was significantly better than that of the conventional ILA system.

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

Selecting and Evaluating Systems

In spite of the widespread use of the FM systems in educational and other environment, little attention has been directed toward specific methods of measurements and fitting. Often, the typical methods used with personal hearing aids have been used. These approaches may be appropriate in some aspects, but they have distinct limitations.

Currently, there are two methods reported in literature, for evaluating and verifying hearing instrument performance (Lewis, 1999).

A. Real ear measures
   (i) Functional Gain (FG) Measures
   (ii) Probe Microphone Measures

B. Coupler Measures

A. Real ear measures

(i) *Functional Gain (FG) Measures :* Functional gain is defined as the difference between aided and unaided thresholds obtained during sound field audiometry.

Evaluation of the FM system using sound field audiometry is one simple approach that eliminates the problems resulting from discrepancies between coupler and realer acoustics.

The subject's thresholds are measured in a sound field, without the hearing aid and then, under the same conditions, with the hearing aid - ear mould combination (Haskell, 1987). The difference in thresholds in the two conditions is the FG. To obtain functional gain for the aided condition, warble tone threshold can be subtract from the pure tone earphone thresholds at each frequency of measurement. Direct comparison of the two was possible because the earphone and sound field calibration procedures allowed specifications of both in dB HL (van Tasell, Mallinger and Crump, 1986).

Advantages of Functional Gain

Functional gain has a number of advantages:

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

b) It accounts for all of the individual variables that can affect real ear hearing aid gain such as, body baffle effect, head diffraction effect, ear mold and connecting tubing variations.

c) It is adaptable to a wide range of stimuli and test protocols, and it is largely independent from absolute calibration problems in sound field (Haskell, 1987).

d) It is a behavioral threshold, and reflects what the individual actually hears.

e) It is a simple procedure.

Disadvantages of Functional Gain

a) It is time consuming, if several hearing aids are to be compared or several settings on one hearing aid, repeated sets of thresholds can take substantial amounts of time.

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

c) It requires active subject participation, which can be time consuming and can increase variability.

d) Frequency specificity is often limited by stimuli available on standard audiometric equipment and time constraints associated with individual testing.

As FM systems became widely used, audiologists continued to use this approach to estimate the required gain for FM systems (Bess, Sinclair and Riggs, 1984; Freeman, Sinclair and Riggs, 1980; Hawkins and Schum, 1985; Hawkins and van Tassell, 1982; Thibodeau, 1990, van Tassel and Landin, 1980).

Van Tassell, Mallinger and Crump (1986) assessed functional gain for nine hearing-impaired school children under two conditions of FM amplification i.e. FM auditory trainer with insert earphone and personal FM system with miniloop. On the average, the insert earphone auditory trainer system provided slightly greater functional gain than did the miniloop system.

Speech Recognition Testing With FM System vs. Personal Hearing Aid

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.

Lewis, Feigin, Karasek and Stelmachowicz (1991) have described a procedure for making assessments of speech recognition ability with FM systems and hearing aids in a sound booth, which is briefly described as follows :

a) For the hearing aid assessment speech recognition is assessed with a speech signal of 55 dB HL and in a background noise of 50 dB HL, yielding a S/N ratio of +5 dB, a value typical of many classroom situations (Crandell and Smaldino, 1993; Finitzo-Hieber, 1988; Markides, 1986 as cited in ASHA, 1994). Assuming the sound field has been calibrated for a 45° azimuth, the intensity of the speech would be 68 dB SPL, a level that should be typical of the input to the hearing aid microphone. A measure of speech recognition is obtained with an age and language appropriate test.

b) To assess performance with the FM system, the user is removed from the sound booth and placed next to the audiologist near to the audiometer. The FM microphone is placed in the calibrated spot in the sound field where the user was earlier seated. The noise remains at 50 dB HL, but the speech signal is increased to 70 dB HL (83 dB SPL). This 15 dB increase in speech intensity (i.e. from 55 to 70 dB HL) is equivalent to the increase in SPL that occurs at the FM microphone (Hawkins, 1984). A speech recognition score is now obtained under these conditions. This set-up is illustrated in Fig.2.1.

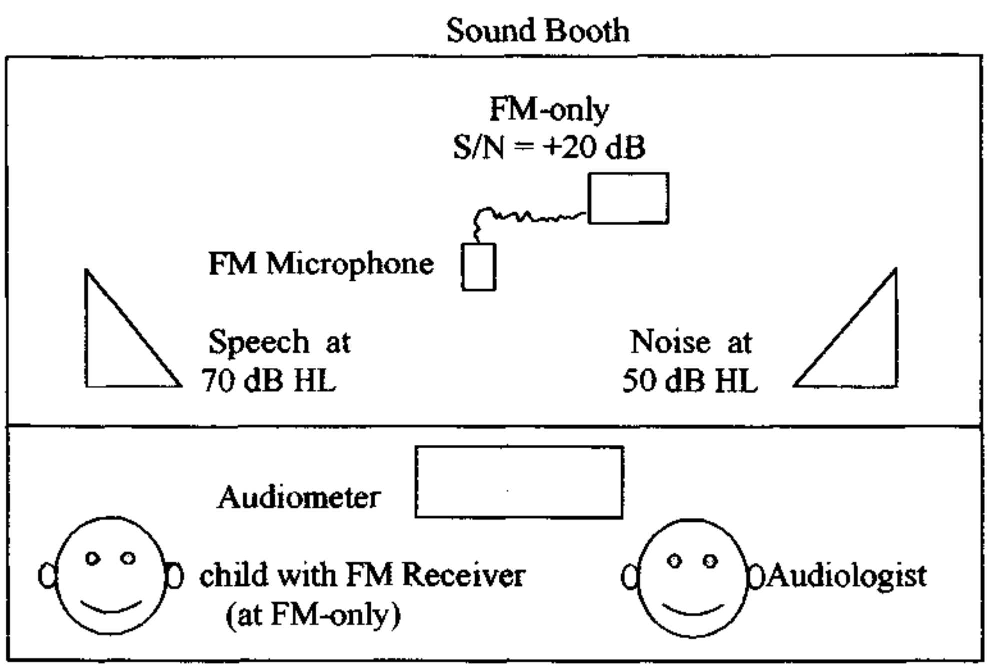


Figure 2.1: Illustration of speech perception testing in a sound booth for FM system set to FM-only model. (Lewis, 1991).

Flexer, Wray, Black, Millin, 1987; Hawkins, 1984; Madell, 1992; Ross and Giolas, 1971; van Tassell, Mallinger and Crump, 1986 reported measures of speech perception with FM systems and recommended that the FM microphone/transmitter be moved close to the loudspeaker to simulate the distance between the microphone and the speaker's mouth. Although, this is an option, it requires an additional calibration to ensure that the expected input level occurs at a particular distance.

Placing the FM microphone within the far field will simplify the calibration process. It is more expedient to position the FM microphone at the calibrated position in the sound field when possible. It is important to remember that the critical factor when testing an FM system is to ensure that the input level to the microphone approximates the levels in actual usage (Lewis, Feigin, Karasek and Stelmachowicz, 1991).

Behavioral measurements of real-ear performance such as functional gain have been recommended by few investigators (Madell, 1992; Turner and Holte, 1985; van Tassell, Mallinger and Crump, 1986), several distinct limitations of this approach have been described by Lewis, 1991; and Seewald and Moodie, 1992; as cited inASHA,1994).

The major disadvantage with the functional gain approach is that the input levels to the FM microphone at the aided threshold will typically be quite low during the measurement procedure. These lower input levels will not be representative of the talker's voice entering the FM microphone during actual use of the FM system These input level differences, combined with the fact that most FM microphone transmitters incorporate input compression, make the aided sound field threshold values difficult to interpret. While the threshold values would represent the lowest intensity signal that user could detect with the FM system, they would lead to an over-estimate of both the amount of gain of the FM signal under normal use conditions and the sensation level at which speech would be present (Lewis, 1991; Seewald, Hudson, Gagne and Zelisko, 1992; Seewald and Moodie, 1992).

The limitations of behavioral testing, along with the inability to assess the maximum output of the FM system with threshold measurements, have led to an increasing emphasis on the use of probe-microphone measurements.

Probe Microphone Measures (PMM) *:* The second method of evaluating the amount of amplification provided by an FM system is by using probe tube microphone measures. The manner in which these measures 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 the PMM for evaluating FM systems, one described by Hawkins (1987) and the other by ASHA (1994). Hawkins (1987) described a procedure to evaluate an FM system using probe microphone system which uses a compression microphone. This set-up is illustrated in Figure 2.2. The procedure is as follows:

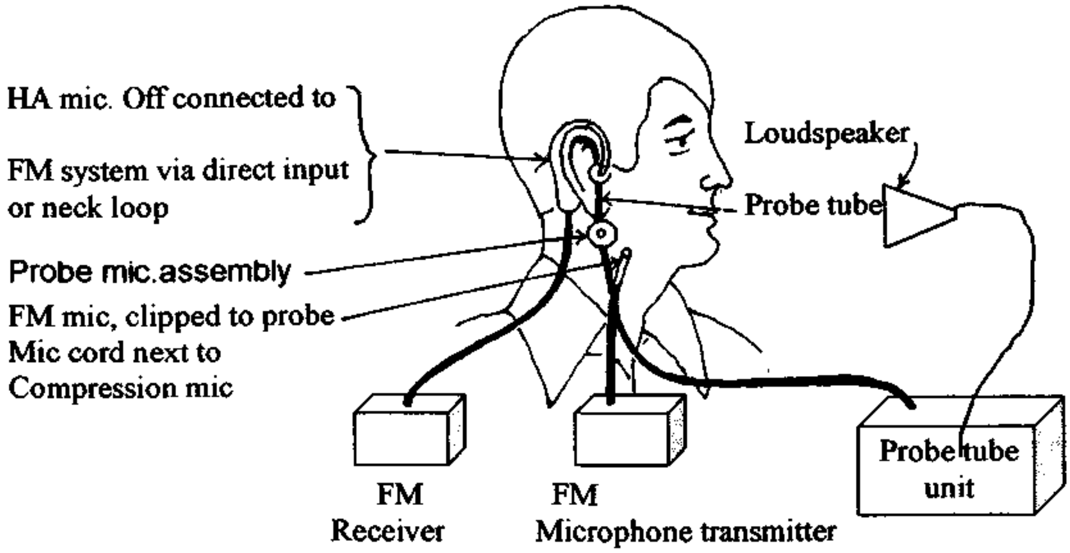


Fig 2.2: Illustration of arrangement to measure the real-ear response of an FM system attached to a hearing aid with an ear canal probe tube measurement device. The compression microphone in the probe microphone assembly serves to keep the sound pressure level constant at the FM microphone (Hawkins, 1987).

If the audiologist wishes to compare the response of a self-contained for personal FM system to the hearing aid alone, the insitu output (output SPL in the ear canal with a 60 dB SPL input) of the hearing aid by itself is first obtained. When a personal FM system is to be assessed, the hearing aid is left in place with the probe tube still in the ear canal. The FM receiver is connected to the hearing aid via direct input, neck loop, or silhouette adaptor. The FM microphone is positioned next to the compression microphone on the probe assembly (Fig.2.2). This positioning allows for a flat input across frequency to be delivered to the FM microphone. The insitu output of the personal FM system is measured with an 80 dB SPL input signal. If a self-contained FM system is being evaluated, the hearing aid should be removed and the FM system is inserted. This technique permits a rapid comparison of the real-ear response of hearing aid and the FM system.

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

American Speech-Language-Hearing Association (1994) described the following probe microphone measurements with a FM system:

(i) The FM microphone is placed in the calibrated spot in front of the sound field loudspeaker of the probe microphone system or next to the controlling microphone of the probe system (Hawkins, 1987).

(ii) 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 and to avoid discomfort. The output control is adjusted until the desired RESR is obtained, which could be either the RESR of the personal hearing aid or as independently generated target value.

(iii) Using an 80 dB SPL input to the FM microphone, the FM VCW 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 the FM VCW should be adjusted for the desired output levels.

Use of probe microphone allows measurements to be made at input levels comparable to those expected in actual use born for the FM system and hearing aid microphones. These measurements enable us to verify the real ear saturation response of the FM system (Lewis, 1999).

In addition to the above mentioned advantages, probe tube microphone measures provide a more comprehensive frequency response information than can be obtained with functional gain measures, and information can be obtained more quickly (Lewis, Feigin, Karasek & Stelmachowicz, 1991).

B. Coupler Measures

Measurements of the FM system in a 2 Cm^3 coupler can be used to adjust the FM system for appropriate amplification characteristics for an individual user.

In the past, coupler measures have been performed utilizing lower level signals and/or output of hearing aids and FM systems have been equated with the same level inputs (Hawkins and van Tassell, 1982; van Tassell and Landin, 1980). However, due to the differences in location of the speaker relative to the microphone, an input level of 70 to 75 dB SPL is more appropriate for the FM system. The desired real ear SPL as a function of frequency would remain the same for amplification from a hearing aid or an FM system. Therefore, the 2 Cm^3 coupler values measured with a 60 dB

SPL input for the hearing aid can be matched to the 2 Cm^3 coupler values measured with a 75 dB SPL input for the FM system (Lewis, Feigin, Karasek and Stelmachowicz, 1991).

Seewald and Moodie (1992) proposed the following procedure for 2 Cm^3 coupler measurements for FM system evaluation and selection.

i) Determine that the user's personal hearing aids are functioning properly and have been set appropriately.

ii) Measure critical electro-acoustic characteristics on the personal hearing aid : (a) SSPL90, (b) output of the hearing aid with a 65 dB SPL input at user volume control wheel (VCW) position and control settings. The measures of maximum output and output for typical inputs will serve as targets for the adjustment of the FM system.

iii) Place the microphone of the FM system in the calibrated test position. Couple the external receiver of the FM system to the 2 Cm^3 coupler appropriately. Obtain an SSPL90 curve and adjust the maximum output control on the FM system until the SSPL90 curve most closely matches that obtained with the hearing aid alone in the step (ii) above.

iv) Using an 80 dB SPL input to the FM microphone, adjust the FM VCW and tone controls) until the 2 Cm^3 coupler output levels most closely match those obtained for the hearing aid alone in step (ii) above (Note that output is being matched, not gain). The gain of the FM system will be les than that of the hearing aid, because of input levels.

If a personal FM system is being used, leave the hearing aid VCW at the user setting and adjust only the FM VCW until the closest match is obtained. When the closest match has been achieved, harmonic distortion measurements should be obtained and a careful listening check performed to verify that the adjusted control settings on the FM system produce a clear and undistorted speech signal.

If a self-contained FM system is being used, the environmental microphone(s) portion of the FM system should be assessed using the same input levels as were used with the hearing aid alone. The SSPL90 measured in the environmental microphone mode may be different from that measured in the FM only mode. As a result, the audiologist should recheck the 'FM only' SSPL90 of the control has been adjusted during the environmental microphone assessment (Seewald and Moodie, 1992; Lewis, Feigin, Karasek & Stelmachowicz, 1991).

Coupler measures allow evaluation of amplification received by the user at input levels comparable to those in actual use. Coupler measures provide information concerning maximum output and harmonic distortion. In addition, it does not require the user to be present for measurements. However, to predict real ear performance from coupler measures, average values and correction factors are needed to estimate real ear to coupler difference (RECD) and these measures must be added to 2 Cm^3 coupler values to predict real ear SPL (Lewis, 1999).

Real Ear Measures vs. 2 Cm^3 Coupler Measures

Functional gain measures are the least viable method of comparing hearing aid performance to the performance of an FM system because they cannot be used to evaluate an FM system at input levels comparable to those encountered in normal usage and therefore, may provide erroneous estimates of gain. In addition, they cannot provide information on maximum output or distortion levels.

Probe tube 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 on harmonic distortion and they require moderate cooperation of the individual being evaluated.

When 2 Cm^3 coupler values for appropriately set hearing aids are known, coupler measures are the most efficient and expedient assessment method. They can be used to evaluate an FM system at realistic input levels and provide measures of maximum output and harmonic distortion. In addition, they can be obtained quickly and do not require the user to be present (Lewis, 1991).

Because of the more widespread application of FM systems and the variety of systems and coupling options available, the audiologists role in choosing the most appropriate system for a hearing-impaired child has become very complex. One needs to be aware of the benefits and limitations of different coupling methods and means of evaluating FM systems.

American Speech-Language-Hearing Association (ASHA, 1994) Provided guidelines for fitting and monitoring of personal and self-contained FM systems for children and adults with hearing loss.

(i) Before selecting an FM system for personal use, it is necessary to assess the present level of receptive (auditory communication) function and to identify other factors related to device use.

Implicit in the preliminary stages is determining whether to use a personal FM system (coupled to one's own hearing aid) or a self-contained FM system (coupled directly to the ear). If a personal FM system is being considered, hearing aids should be chosen with appropriate coupling capabilities and flexibility to maximally interface with the FM system. Hearing aids should have strong telecoils, and direct audio input may be desirable as well. In addition, hearing aid switch options [such as M/T/MT] must be carefully considered so as to provide flexibility in listening arrangements.

If a self-contained system is going to be used, appropriate decisions should be made relative to the necessary gain and output requirements for that listener.

Other factors to be considered in the pre-selection process include -

- The person's ability to wear, adjust and manage the device.
- Support available in the educational setting (eg. In-service to teachers, classmates).
- Acceptance of the device.
- Appropriate situations and/or settings for use.
- Time schedule for use.
- Compatibility with personal hearing aids and other audio sources as well as options for coupling.
- Individual device characteristics and accessories.
- External source interference.
- Cost and accessibility.
- Legislative mandates.

Assessments may include, but are not limited to, audiological evaluations, observations of auditory performance in representative settings, consultations with the user or others knowledgeable of the user's performance, questionnaires and scales, hands on demonstration, and a trial period.

The issue of potential damage to the auditory mechanism should be considered when fitting any assistive listening device (ALD). This is of special concern when considering the fitting of an FM system to a person with normal hearing or mild fluctuating hearing loss (ASHA, 1994).

Flexer (1997) reported that the following factors govern the selection of FM coupling arrangements and performance characteristics, particularly in a school environment.

a) The type and degree of the child's hearing loss

b)The child's age

c) Any other disabling condition the child has

d) Family support available to the child and in the school.

e) School support available to the child (some schools provide support by an educational audiologist)

f) The child's classroom/listening needs.

g)The demands of the different acoustic/learning environments

h)The teacher instructional styles, and

i) The child's hearing aids flexibility (if a personal FM unit is used, hearing aids must have strong telecoils, 'M', 'T' and 'MT' combination switches and direct input capabilities.

Lewis (1999) reported the following factors to be considered when pre-selecting a FM device.

(i) The degree and configuration of hearing loss. As with hearing aids, decisions will need to be made about frequency output characteristics, type of coupling, etc. The user's personal hearing aids also must be considered (Whether the personal hearing aids are appropriate? Do they have features that allow coupling to an FM system, are they available to the user on consistent basis?)

(ii) The environment in which the system will be used also may affect choices. What difficult listening situations will the user encounter? In those situations will there be a primary talker? Will there be others talking who are not wearing the FM microphone (eg. group discussions)? What types of interference might the user encounter (eg. noise, reverberation, electromagnetic interference, FM interference), and how will those affect different options?

(iii) Finally, the individual characteristics of the user must be considered. How might age and physical size affect how well the individual can use the system and how well it will fit? Are there physical limitations that preclude the use of any coupling option (eg. atresia, lack of fine motor skills). Behavioral issues as well as cosmetic concerns of the user will affect how well the system is accepted both by the person wearing the receiver and the person wearing the transmitter.

Once the pre-selection is over or at least narrowed down the choices, evaluation of performance of the system is necessary to ensure that it is set appropriately for the user. After verifying the performance of the instrument, audiologist need to instruct the user as well as caregivers and other professionals, as needed, regarding the use, care and maintenance of the system.

Although FM systems are of potential benefit for many listeners in a variety of settings and applications, certain cautions/issues need to be considered (ASHA, 1994).

(i) Little regulatory consumer protection has been mandated because most of states in USA do not classify these devices as hearing aids,

(ii) FM systems are available commercially and many are purchased without consultation with an audiologist.

(iii) The American National Standards Institute has not yet issued a standard for performance measurements of FM systems,

(iv) No guidelines are currently available for the selection, evaluation and fitting of FM systems for persons with hearing loss or for use by persons with normal hearing,

(v) Researchers have raised concerns regarding specific problems related to electroacustic performance factors, for example, variability, non-linearity, lack of stability, coupling and maintenance (Hawkins and Schum, 1985; Thibodeau, 1990; Thibodeau and Saucedo, 1991).

(vi) Candidacy, effectiveness of fit, cost and lifestyles needs and aesthetics are important concerns and must be considered on an individual basis.

The audiologist's role in choosing the appropriate FM system for a hearing-impaired child has become very complex. There is no consensus on a standard for performance and selection of an FM system in spite of increase in utilization of FM system.

METHODOLOGY

SUBJECTS

Ten subjects (including five males and five females) with the age ranging from five years to ten years (mean age 6.8 years) were selected for the study. The subjects fulfilled the following criteria :

(i) The subjects had bilateral profound hearing loss (PTA > 90 dBHL)

(ii) Immittance audiometry revealed no middle ear pathology

(iii) All the subjects underwent an ENT check-up to rule out the presence of any external or middle ear problem,

(iv) All the subjects were using hearing aids for more than 2 years.

INSTRUMENTS

The following instruments were used for the study.

For Functional Gain Measurements

Sound Field Audiometer - A calibrated two channel diagnostic audiometer (Madsen OB-822) was used. The instrument was calibrated as per ANSI-S3.26 (1989) standards. Good calibration of the system was ensured throughout the data collection (Sound field audiometry calibration - Appendix I).

For Insertion gain measurements - The FONIX 6500-C hearing aid test system with computer controlled real time analysis version 3.09 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 II) and calibration was ensured throughout the data collection.

FM **system -** The FM system employed was the one marketed by Phonic Ear Inc., PE 461 FM system. The PE 461 FM system consists of a teacher microphone/transmitter and stereo (binaural) FM hearing instrument (receiver). The FM receiver consisted of ear mic microphones/earphones. (Specifications are given in Appendix HI).

When the FM system was made use of; it was made sure that the system was charged for 14-15 hours prior to use.

Hearing aids - All the subjects were using strong class body level hearing aids with 'V cord.

TEST ENVIRONMENT

Real ear measurements, both the functional gain measurements and the probe tube measurements, were carried out in sound treated rooms, where the ambient noise levels were within the permissible limits (ANSI, 1991).

TEST SIGNAL

For the functional gain measurements, warble tones (5%) were presented through the loudspeakers at various frequencies viz. 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and /pa:pa/ was used as a speech stimuli for determining Speech Awareness Threshold (SAT) or Speech Detection Threshold (SDT) measurement.

For the probe measurements, a composite signal was presented through the loudspeaker at an angle of 45 degree and intensity of 80 dBSPL.

TEST PROCEDURE FOR REAL EAR MEASUREMENTS

Functional Gain Measurements *:* The FM transmitter was placed nearest (6-8 inches) to the loudspeaker, as the FM transmitter to speaker mouth distance is approximately 6-8 inches in the real life.

The children were instructed using speech and gestures as follows : "I am going to present a tone, listen carefully and the moment you hear the tone please drop the block into this basket. Remember, you have to respond even for soft tone".

The threshold for 250 Hz, 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz were established for all the subjects without any hearing aid. The same procedure was repeated to establish the threshold using subject's personal hearing aid and FM system separately. The threshold values were recorded in a Table.

Functional gain for hearing aid and FM system was calculated at each of the above frequencies (The difference between the aided and unaided threshold at each frequency was considered as FG). The same procedure was repeated using speech as stimuli and functional gain for subject's hearing aid and FM system was calculated separately.

Insertion Gain Measurements*:* Pre-measurement procedure - The leveling of the instrument FONEX 6500-C hearing aid test system with computer controlled real time analysis version 3.09 with probe tube microphone option pressure and substitution was carried out prior to the measurement (Appendix IV).

The audiometric data was fed and the target gain curve was obtained using the POGO II formula given by the Candless and Lyregaard, 1983 (Appendix V).

The subjects was seated 12 inches from the loudspeaker. The loudspeaker were placed at 45 degree azimuth, relative to the patient's test ear. The headband was secured above the ears and the ear hanger was placed around the ear to be tested. The reference microphone as placed firmly over the headband nearer to the ear to be tested. The probe tube was placed in the ear of the subject such that it extended 5 mm beyond the canal portion of the custom ear mold. The length probe tube inserted was marked with a marker pen. The patient was instructed to look straight and not to move or talk until the test was complete.

Probe measurements - The following steps were carried out to obtain the probe measurements.

- Initially, the Real Ear Unaided Response (REUR) was measured using 80 dB SPL as input. This response gave the information regarding the ear canal resonance.

- The FM receiver's ear mic with the ear mold was then placed along with the probe tube, the FM system was switched 'on' and the Real Ear Aided Response (REAR) was obtained.

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

- The Phonic ear FM system was kept in FM mode and the volume control of the FM system was adjusted such that the insertion gain curve matched the target gain curve.

The setting of the volume control was noted (In all the cases, it was 1/3 rotation of the total volume control) and the REIG values at 200 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz were noted in a tabular form.

RESULTS AND DISCUSSION

The present study was performed in an attempt to develop a protocol for the selection of self-contained FM system for the hearing impaired individuals.

Real ear measures were performed for ten profound hearing impaired children. The present study aimed at studying whether there is any significant difference between:

(i) Functional gain (FG) for warble tones and speech with subject's hearing aid and FM system,

(ii) Functional gain and insertion gain with FM system.

To study whether there was any significant difference among the above parameters, paired sample 't' test was performed on the data using "statistical presentation system software (SPSS), 'Version 10.0' and the results were as follows:

Table 4.1 : Mean and 't' values of FG with subject's hearing aid and FM system.

Stimuli	Mean value of FG with subject's hearing aid (n= 10)	Mean value of FG with FM system (n=10)	't' value
500 Hz warble tone	23.50 (10.55)	37.00 (11.11)	10.371*
1000 Hz warble tone	24.50 (12.57)	44.00 (8.10)	9.0*
2000 Hz warble tone	26.00 (15.06)	42.00 (13.78)	6.532*
4000 Hz warble tone	10.50 (5.99)	27.00 (11.35)	3.910*
Speech	20.00 (10.27)	35.00 (8.16)	11.619*

Note: Values within brackets indicate standard deviation
* indicates significant difference at 0.05 level,
n - indicates number of subjects.

Table 4.1 showed that there is a significant difference (significant at 0.05 level) at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz between the functional gain (FG) with subject's hearing aid and the functional gain with FM system for warble tones. The mean values in the table 4.1 showed that the gain is higher for FM system than the subject's hearing aid at all the frequencies i.e., at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. The functional gain with FM system was found to be more than the functional gain with the subject's hearing aid. This finding is in consonance with the findings reported by Ross, Giolas and Carver

(1973) and Sneha (1993). Tn the present study FM system provided 13.5 dB more gain at 500 Hz, 19.5 dB more gain at 1000 Hz, 16 dB more gain at 2000 Hz; 17 dB more gain at 4000 Hz when compared with the subject's hearing aids. The present study showed difference in the gain between FM system and hearing aid to be more at mid and high frequencies (i.e. 1000 Hz, 2000 Hz, 4000 Hz) than the gain difference at low frequency (500 Hz). Whereas Sneha (1993) has reported more gain at low frequencies (i.e. at 250 Hz and 500 Hz) than at mid and high frequencies.

From the table it is also inferred that functional gain for speech stimuli (for the word /pa:pa/) was more for FM system than the subject's hearing aid. This result supports the previous studies (Ross, Giolas and Carver, 1973; Flexer, Wray, 1987). This could be due to the fact that FM systems present approximately fifteen to twenty decibels (15 to 20 dB) greater intensity of the speech signal than background noise at the ear of the listener (Hawkins, 1984). This could also be due to the fact that the hearing aid performance could have deteriorated with use. There could have been an increase in distortion and internal noise. The subjects under the present study had used their hearing aid for more than two to three years and it is possible that the internal noise of the hearing aids interfered with the detection of the speech stimuli.

In the present study, speech reception threshold (SRT) and speech discrimination score (SDS) could not be obtained, as the subjects could not identify the pictures when the stimuli were presented only through the auditory mode only. However, ASHA (1994) guidelines for the selection and evaluation of FM systems reported the importance of speech recognition ability for the selection of FM system. In the present study, SAT values had been taken into consideration. However, in the selection of any amplification device speech recognition ability should also be considered wherever possible, as the primary goal of fitting an amplification device is to amplify the speech for understanding.

Table- 4.2 : Mean and 't' values of FG and IG with FM system.

Frequency in Hertz	Mean values of FG with FM system for warble tones (n=l 0)	Mean values of insertion gain (1G) with FM system (n= 10)	't' value
500	37.00 (11.11)	35.29 (2.34)	0.474
1000	44.00 (8.09)	43.99 (2.39)	0.004
2000	42.00 (13.78)	51.02 (6.17)	1.596
4000	27.00 (11.35)	32.96 (291)	1.524

Note: Values within the brackets indicates standard deviation
n - indicates number of subjects.

Table 4.2 depicts that there is no significant difference between the functional gain (FG) for warble tones with FM system and insertion gain (IG) with FM system at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz. It indicates that the gain developed with the FM system by using the two separate real ear procedures, i.e., FG and IG, is the same.

The relationship between FG and IG in the selection of an appropriate amplification device has been a debate. But the review of literature clearly suggests that, within reasonable measurement error, the two are equivalent and are assessing the same process (Hawkins, 1987). Dillon and Murray (1987) demonstrated that FG and IG yield similar gain values and that the two should be viewed as different ways to assess the same phenomenon. Contrary to this, several other authors have queried whether IG and FG are numerically equal. McCandless (1980) has reported differences of up to four decibels (4 dB) when average across seventeen subjects and presumably had much larger differences within individual subjects. Preves and Rumoshosky (1976) reported average difference between IG and FG up to ten decibels (10 dB) and differences with in individual subjects of up to 28 dB. Preves and Orten (1978) hypothesize that such differences may be due to differences in eardrum impedance or external canal volume.

Mason and Popeika (1987) as cited in Diller and Murray (1987) reported no significant average differences between IG and FG except at 1500 Hz, where 6 dB difference was found. Dillon and Murray (1987) reported average IG was within 2 dB of average of FG except at 1 kHz, where the difference of 5 dB was significant at 0.05 level and even within individuals IG and FG estimates are mostly non-significantly different. In the present study, there was no significant difference at all the frequencies i.e. at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz, but an 8 dB difference at 2000 Hz and 4 dB difference at 4000 Hz were observed, though statistically not significant. At 500 Hz and 1000 Hz the difference between FG and IG is less than 2 dB. This is indicating that during the selection of FM system either of the real ear procedures (FG and IG) yield the same gain.

Review of literature reveals that at present there is a set of guidelines for fitting FM system issued by ASHA (1994). In view of the increase in utility of FM system and lack of protocol for the selection of FM system, the present protocol has been proposed.

Protocol for the selection of self-contained FM system

This protocol provides guidelines for fitting of self-contained FM system. It includes pre-selection criteria, selection consideration for the fitting of FM systems. A qualified audiologist is the professional who can select, evaluate and prescribe an FM system.

Pre-selection consideration

The following factors govern the pre-selection of an FM system :

i) The type, degree and configuration of hearing loss,

ii) The patient's age.

iii) Need for the FM system selection. Incase of children, their classroom/listening needs should be considered. The demands of different acoustic and learning environments should be considered.

iv) The environment in which the system is used. The type of interference the user will encounter.

v) Physical condition of the patient.

vi) Economic status and family support available to the child.

vii) Support available to the child in the school.

viii) Acceptance of the device.

Pre-selection assessment

For all young children behavioral measures must remain a part of every amplification fitting procedure. Behavioral audiological assessment may include observation of the child, auditory development checklist, amplification performance rating scales or questionnaires to the parents of young hearing impaired children. The FM system selection requires the functional evaluation of the child in the child's customary environment for determination an appropriate equipment.

In case of older children and adults, unaided and aided hearing thresholds for non-verbal stimuli such as a narrow band noise (NBN)/warble tones should be obtained across various frequencies.

The child and adult level of receptive function should be considered, such as speech detection threshold, speech reception threshold and speech discrimination score by using appropriate test material according to the age and language of the patient.

FM system selection procedures

Once the required gain is estimated for the child/adult, FM systems are prescribed based on the characteristics.

/. ***For FG measurement***

A. For non-verbal stimuli:

a) Obtain the child's or adult's threshold for warble tones or narrow band noise (NBN) across the octave frequency from 250 Hz to 4000 Hz in an unaided condition. This procedure is to be carried out, when the child/adult is seated at the calibrated position in the sound field.

b) Select an FM system based on the estimated gain requirement and keep the volume control of approximately at l/3rd position of the total volume control rotation.

c) FM transmitter microphone is to be placed nearer the loudspeaker (6 to 8 inches) of the audiometer from which signal is presented (in the real life situations the transmitter to speaker mouth distance will be approximately 6-8 inches).

d) The subject with the receiver unit can be seated near the calibrated position or nearer to the audiologist in a double room sound field set up as shown in the Figure 2.1.

e) Alternatively, the FM transmitter can be placed at the calibrated position in the sound field room and the child wearing FM receiver can be placed next to the audiologist in the control room. However, because of the transmitter to the loudspeaker distance is increased when compared with earlier (ref. C) 6-8 inches distance, difference in the gain at these two different positions of transmitter can be encountered.

f) Similarly, as explained in point 'a', obtain the thresholds at various frequencies when the subject is wearing the FM system and calculate the functional gain across the frequencies 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz. FG is the difference and between unaided and aided threshold at each frequency.

B. For Speech detection and/or recognition testing with FM systems

To assess performance with the FM system, speech detection and speech recognition scores are important. The following procedure is recommended for the measurement of speech detection (SDT/SAT) and speech recognition (SRT) scores using an FM system.

a) Find out the SAT/SDT for the word /pa:pa/ in the sound field without a FM system

b) Make the subject to sit with the FM system worn beside the audiologist and place the FM microphone nearest to the loudspeaker (6-8 inches), present the speech stimuli (the word /pa:pa/) and find out the aided (FM) SDT/SAT.

c) By subtracting the unaided SDT or SAT from the aided (FM) SDT or SAT, FG can be obtained for speech stimuli.

However, it is often desirable to measure speech recognition score instead of just the SDT or SAT. For speech recognition score, the procedure given by Lewis (1991) can be followed, which is described briefly as follows:

To assess the performance with the FM system, the user is removed from the sound booth and placed next to the audiologist (refer Figure 2.1) at the audiometer. The microphone is placed in the calibrated spot in the sound field where the user is usually seated. The speech signal is presented without any audiovisual cues at 70 dB HL (83 dB SPL) in a background noise of 50 dB HL, yielding a S/N ratio of +20 dB, a typical representative of the actual situation that would exist at the FM microphone. This arrangement addresses SRT in the FM only mode, i.e., environmental microphones are not active.

In the present study, only SAT measurements were obtained instead of speech recognition scores due to the limited ability of the subjects to identify speech when presented only through audio mode. However, procedure for speech recognition scores measurement is recommended than just speech awareness threshold in the measurement of FM performance whenever possible.

II *Probe mic measures*

In the present study, probe mic measures were carried out by using the procedure described by Hawkins (1987) (Figure 2.2). The following steps were recommended for the FM selection.

Due to the proximity of the speaker's voice to the FM microphone, the typical input to the FM system is approximately 80 to 84 dB SPL (Hawkins, 1987).

Obtained real ear unaided response (REUR) by giving an input of 80 dB SPL when the FM system is not coupled to the ear.

Feed the subject's audiometric data to obtain a target gain across various frequencies.

Place the FM microphone next to the monitoring (compression) microphone of the probe tube assembly to produce a constant sound pressure level of 80 dB SPL input to the FM system. Couple the FM receiver with the custom earmould and place it in the ear canal along with the probe tube.

Switch 'on' the FM system and give an input of 80 dB SPL and rotate the VCW of the FM system until the aided response matches the target gain. It should be seen that the VCW is rotated not more than 1/3rd of the total rotation to match the target gain. If more than 1/3rd VCW rotation is required, a higher gain FM system has to be chosen to obtain the real ear aided response (REAR). Probe tube insertion gain should be kept constant for unaided and aided conditions.

Calculate the real ear insertion gain (REIG) across the frequencies 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz (usually the insertion gain is calculated automatically by the equipment once REAR and REUR are measured).

By comparing the IG or FG with the estimated gain requirement, an appropriate FM system can be selected.

While selecting a self-contained FM system, it is preferable that an audiologist performs both FG and probe mic measurements. As reported in the present study, the FG and IG using an FM system are not significantly different.

In case of young children and difficult-to-test population, FG (by behavioral assessment procedures) could be used. However, it is preferable to do both the measurements for the selection of a self-contained FM system. The present protocol acknowledges the complexity and continuing evolution of FM technology and it is not possible to consider every configuration of design and implementation due to the evolution and complexity of the FM technology.

SUMMARY AND CONCLUSION

- The present study was aimed at the development of a protocol for the selection of a self-contained FM system, in view of lack of protocol for the selection of FM system in spite of it's widespread use.

Ten profound hearing impaired children were selected for the study. Real ear measures (both functional gain and insertion gain) were carriedout. Unaided and aided (both subject's hearing aid and FM system) sound field thresholds were obtained using non-speech stimuli (i.e. warble tones at 500 Hz; 1000 Hz, 2000 Hz and 4000 Hz) and speech stimuli (/pa:pa/) to calculate the FG. Probe mic measures were carried out by using procedure given by Hawkins (1987), for the IG measurements using self contained FM system. Due to the proximity of the speaker's voice to the FM microphone, the typical input of 80 dB SPL was given and the TG values across the frequencies 500 Hz; 1000 Hz, 2000 Hz and 4000 Hz was calculated by using FONIX 6500-C hearing aid test system with computer controlled real time analysis version 3.09 with probe tube microphone option.

Paired sample 't' test was performed on the data to find the significant difference between FG and IG. In the present study the following results were obtained.

(1) There was a statistically significant (significance at 0.05 level) difference between FG for warble tones and speech with FM system and subject's hearing aid. The FG is more for FM system than subject's hearing aid both for warble tone and speech stimuli.

(2) There was no statistically significant difference between FG and IG with FM system.

In view of this the protocol for the selection of self-contained FM system has been provided under the following heads :

1) Pre-selection criteria : includes personnel who is responsible for selection, fitting and monitoring of FM system and the factors that govern the pre-selection consideration of FM system.

2) Electroacoustic measures : Electroacoustic measures should be obtained for the verification of the gain, output, frequency response, distortion, etc.

3) Functional gain measures : Includes procedures for the FG measurement to select an FM system.

4) Probe mic measures : Includes the procedure for the IG measurement to select a FM system.

Recommendations

1. The efficacy of the present protocol can be checked by including a large number of subjects in the future study.
2. Measurement of speech recognition scores can be included in the protocol studies to calculate functional improvement with the FM system.
3. The applicability of the present protocol can checked for other types of FM systems such as personal FM system.

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APPENDIX I

SOUND FIELD CALIBRATION

Intensity Calibration

Intensity calibration for warble tones in the sound field was carried out with setting the audiometer output to 70 dB. A one inch condenser microphone (B&K 4145) with a 90 degree grid azimuth was placed at the point in the room where the head of the subject would be positioned during testing. The distance from the microphone to the loud speaker was one meter. The microphone was connected to a sound level meter (B&K 2209) and the octave filter set (B&K 1613). The output SPL was compared for the frequencies 250 Hz to 6 kHz, with the values given by Morgan et al. (1979). A discrepancy of more than 2.5 dB between the observed SPL values and the expected values (Morgan et al. 1979), was corrected by means of a internal calibration.

Microphone calibration

Microphone input calibration for speech audiometry was done by presenting a recorded 1 kHz signal at 70 dB. The VU meter gain was set so that the needle peaked at '0'. The placement of the sound level meter was similar to that done for sound field warble tone testing. The output SPL was noted on the sound level meter on the linear scale and compared with the standards (Morgan et all979). If the reading exceeded 2.5 dB, internal calibration was done.

Linearity check

The linearity of the audiometer attenuator was checked. The procedure used was similar to that utilized to check the intensity calibration except that the intensity dial of the audiometer was set at the maximum level and the frequency dial was set to 1000 Hz. The attenuator on the sound level meter was set at a level corresponding to the maximum level on the audiometer. The attenuator setting on the audiometer was decreased in 5 dB steps till 30 dB and the corresponding reading on the sound level meter was noted. For every decrease in the attenuator setting the sound level meter indicted a corresponding reduction.

Frequency response characteristics of loudspeaker

The frequency response characteristics of the free field loudspeaker were obtained using B&K signal generator (1023), free field microphone (B&K 4145), frequency analyzer (B&K 2107) and a graphic level recorder (B&K 2616). The electrical output of the signal generator (1023) was fed to the loudspeaker. The output picked up by the microphone (B&K 4145) was fed to the frequency analyzer (B&K 2107). This output was recorded on the graphic level recorder (B&K 2616).

APPENDIX II

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 adaptor, probe microphone calibrator adaptor and the calibration clip.

Procedure

The sound level calibrator's battery was initially checked for good condition. Following this, a 14 mm - 1 inch adaptor was 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 signal (1000 Hz at 110 dB) 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 a small screwdriver using the 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 into the calibrator adaptor. It was checked to make certain that nothing was clogging the probe tube, and that it was properly connected to the body of the probe microphone. The measured microphone signal was compared with the intensity of the calibrator level. If the value of the probe amplitude was significantly below the calibration level (110 dB for Quest CA-12), it was checked to see that the probe tube has gone all the way into the adaptor. This was done by taking the probe calibrator adaptor out to check. If necessary, the gain of the probe microphone was adjusted with a small screw driver using the control marked PROBE on the bottom of the remote module. Using the above procedure, calibration was done for the reference and probe microphones of the FONDC 6500C.

Calibrating the Sound Field Loudspeaker of FONIX 6500C

The subject wearing the headband was seated at a distance of 1 meter and an angle of 45 degree 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 OUTSPL. 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.

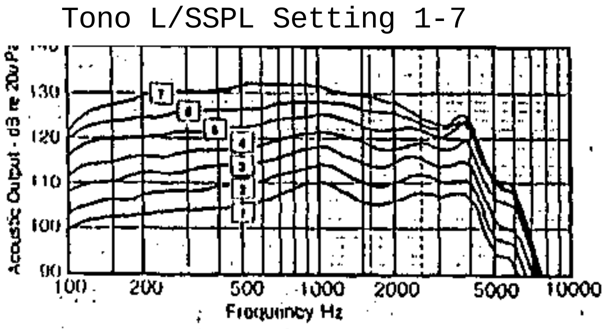
APPENDIX III

Technical Specifications

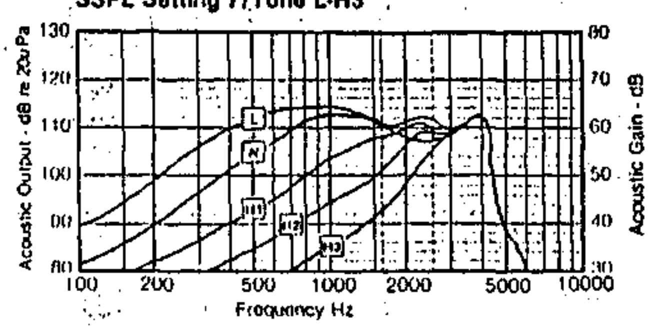
With AT392 Earmic™
Environmental Microphones
Deactivated
AT 302 ITE Earmlc

SSPL 90	=132dBSPL
HF Average SSPL 90	126 ddSPL
Full-on Gain Poak/lnput 60 dB .	64 dD
HF Average.Full-on Gain/lnput CO dD	59 dD
Froquoncy Response Range (Tone L)	140-5OOO Hz
THD at 500Hz	=11%
THD at 800hz	=7%
THD at 16OOHz	*=12%*
Equivalent Input Noise Level	=229 dBSPL
Battery Drain	=42 mA*
Attack Time	8 ms
Release Time	145 ms

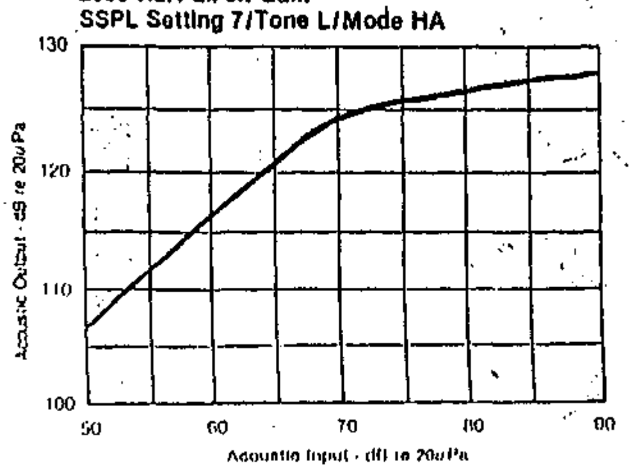
Saturated Output,
SSPL 90/Full-on Gain/Mode HA
Tono L/SSPL Setting 1-7



Frequency Response/Full-on Gain
60 dB SPL Input/FM Gain 4/Mode FM
SSPL Setting 7/Tone L-H3



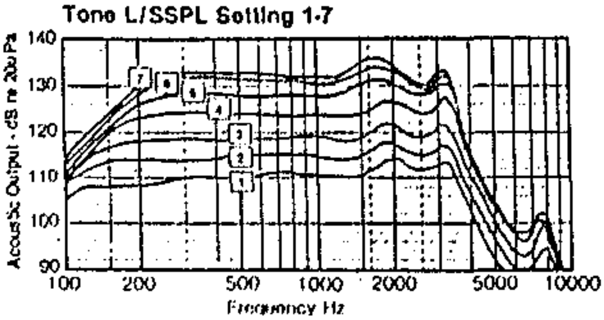
Input-Output Characteristics
2000 Hz/Full-on Gain
SSPL Setting 7/Tone L/Mode HA



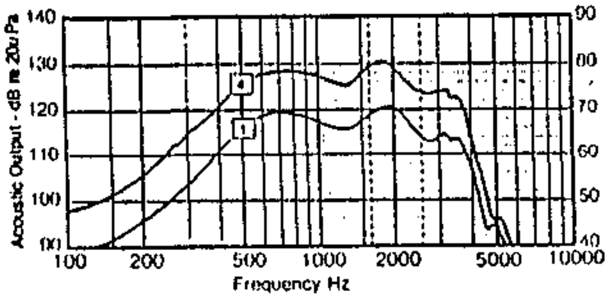
Technical Specifications

With FM Transmitter and AT 16 BNCT/470 Earphone

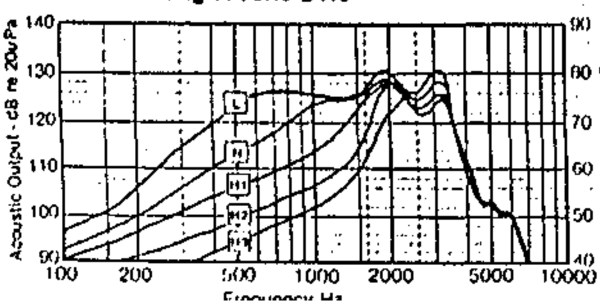
Saturated Output/SSPL 90
FM Gain 4/Full-on Gain/Mode FM
Tone L/SSPL Setting 1-7



FM Gain Control/Full-on Gain
50 dB SPL Input/Mode FM
SSPL Setting 7/Tone L/FM Gain 1-4



Frequency Response/Full-on Gain
50 dB SPL Input/FM Gain 4/Mode FM
SSPL Setting 7/Tone L-H3



Note: Acoustic Characteristics and Technical Specifications achieved with FM Transmission using various typo earphones, will be similar to the audio data (or the earphone usod.

Additional Technical Specifications

	PE461R Hearing Instrument	PE461T FM Transmitter
Audio Input Impedance	50 Kllohms	10 Kllohms
Audio Input Sensitivity (equal to 00 dB SPL Input ot 1000 Hz)	10 mV	2 mV
Housing	A B S Cycolac plastic	A B S Cycolac plastic
Rochargeablo Battery	Nickel cadmium - 2.4 V	Nickel cadmium • 2.4V
Weight	127 grams (4.5 oz.)	106 grams (3.7 oz.)
Size	89 x 63 x 24 mm (3.5 x 2.5 x .9 In.)	82 x 63 x 24 mm (3.3 x 2.5 x, .9 In.)

APPENDIX IV

After calibrating the FONIX 6500-C system, leveling (Automatic Adjustment of the loudspeaker Response) was done as per the 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 5000 Hz, 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 somewhere 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 V

The formula used to calculate the prescription of Gain and Output (POGO II) target curve from the audiogram as follows:

Frequency (Hz)	Insertion gain (dB)
250	½HTL-10dB
500	½ HTL - 5 dB
750*	½ HTL -2.5 dB
1000	½ HTL HTL
1500*	½ HTL
2000	½ HTL
3000	½ HTL
4000	½ HTL
6000*	½HTL
8000*	½HTL

Note : Frequencies preceded by an asterisk (*) are interpolated