EFFECT OF HEARING AID COUPLED WITH FM SYSTEM ON SPEECH RECOGNITION

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A dissertation submitted in part fulfillment for the degree of

Master of Science (Audiology),

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ALL INDIA INSTITUTE OF SPEECH & HEARING,

MANSAGANGOTHRI, MYSORE-570006

APRIL 2006.

CERTIFICATE

This is to certify that this Masters Dissertation entitled **"EFFECT OF HEARING AID COUPLING WITH FM SYSTEM ON SPEECH RECOGNITION"** is a bonafide work in part fulfillment for the Master's degree (Audiology) of the student **Registration no: A0490015.** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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CERTIFICATE

This is to certify that this Masters Dissertation entitled **"EFFECT OF HEARING AID COUPLING WITH FM SYSTEM ON SPEECH RECOGNITION"** has been prepared under my supervision and guidance. It is also certified that this Masters Dissertation has not been submitted earlier to any other University for the award of any Diploma or Degree.

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DECLARATION

I hereby declare that this masters dissertation entitled "**EFFECT OF HEARING AID COUPLING WITH FM SYSTEM ON SPEECH RECOGNITION"** is the result of my own study under the guidance of **Mrs. P. Manjula,** Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for that award of any Degree or Diploma.

Mysore
April 2006

Registration no: A0490015

DEDICATED TO

MY FAMILY

&

KSKCU

……….who is my support and inspiration

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INTRODUCTION

In the recent years, there has been a significant increase in the options/devices available for individuals with hearing impairment. Patients with hearing loss often complain of difficulty in understanding speech, especially in noisy environments. By providing information about hearing loss and communication strategies, audiologists may reduce the patient's frustration. However, they will find noisy environments difficult places for communication. Assistive listening devices provide useful, but often overlooked solutions to the problems patients experience when listening in noisy environments.

In such difficult-to-hear situations, frequency modulated (FM) systems can improve an individual's ability to understand speech in noisy environments and at greater speaker-to-listener distances. An FM system delivers the desired signal without the degradation of signal due to noise or reduction in intensity caused by acoustic signals traveling across distance. By preserving the desired signal strength, the system enhances the speech-to-noise ratio (SNR) at the listeners ear, thereby facilitating speech recognition. All these are attained by the placement of the microphone within a few inches of the talker's mouth. As a result the speech level and the SNR are typically 15 to 20 dB higher than at the listener's location. Wireless transmission of the resulting signal is more convenient than a wired connection (Boothroyd, 1992).

Historically, FM systems have been primarily used in lecture type settings, such as classrooms and auditoriums. Recent advances in FM technology, including miniaturized receivers that can be coupled directly to a behind-the-ear(BTE) hearing aid or build into a hearing aid, easy to use hand-held transmitters, make the FM systems increasingly user friendly for adults and children.

The FM systems can be either used independent, or if the output is insufficient, it can be coupled to the user's hearing aid. There are various ways of coupling of FM system to a hearing aid, such as Direct Audio Input (DAI), Neck Loop (NL), and Silhouette Inductor (SI). In DAI coupling, the electrical signal from the FM receiver unit is delivered to the hearing aid via an input jack. In Neck Loop (NL) coupling the electrical signals from the FM receiver is directed to a wire loop located around the individual's neck. The electromagnetic field around NL is picked up by the telecoil of the hearing aid and amplified. In silhouette inductor (SI). The electrical signal from the FM receiver is delivered to a thin inductor that is within a device that resembles the shape of a BTE hearing aid case. An electromagnetic field is generated around the SI that is picked up by the telecoil of the hearing aid. It is possible to use anyone of the several manufacturer's FM systems and couple it to a number of different hearing aids in one of these three ways. However, how these various combinations change the hearing aid's output is not clear.

Need for the Study

There is a dearth in literature regarding the differences between the performance with a hearing aid alone vs HA plus FM modes of amplification. Existing studies (Hawkins & Van Tasell, 1982; Hawkins & Schum, 1985; Auriemmo, Keenan, Passerieux & Kuk, 2005) have reported equivocal findings on the effect of FM system coupled to a

HA. The audiologist who works with hearing aids should be aware of the effect of coupling the FM system with the hearing aid. This helps to know if coupling an FM system with the hearing is not detrimental for speech understanding. Further the audiologist should also be aware of the effect of coupling on the Signal to Noise Ratio (SNR) advantage of the HA plus FM mode of amplification. Thus, the present study was carried out.

Objectives

1) To evaluate the transparency of FM system when coupled to a hearing aid with DAI coupling. That is, to evaluate if the performance with the HA alone and FM+HA modes are similar.
2) To investigate the SNR advantage of the FM system, i.e., the ratio of the FM output to the hearing aid output when used in FM+HA mode.
3) To compare the aided thresholds and speech recognition scores with and without noise , in hearing aid alone and FM+HA modes, with DAI coupling.

Chapter-2

REVIEW

Individuals with hearing impairment exhibit problems in understanding speech, especially in noise and reverberation (Boney & Bess, as cited in D.E. Lewis, J.A. Feigin, A.E. Karasek & P.G. Stelmachowicz, 1991). These problems cannot be solved by hearing aids alone because hearing aids amplify background sounds as well as the primary signals (Nabelek, Donahue & Letowski., Mc Alister, as cited in Lewis, D. E., Feigin, J. A., Karasek, A. E. & Stelmachowicz, P. G, 1991). Hearing aids make acoustic signals sufficiently loud, but not necessarily clear, hence the biggest limitation of most hearing aids is their inability to make available details of speech in the presence of competing background. However, with recent digital noise reduction technologies incorporated in hearing aids, the problem is solved to some extent. In such noisy background, the FM systems are of great help for speech perception as they improve the Signal-to-Noise Ratio (SNR).

As mentioned earlier, the improvement of speech perception in noisy and reverberant environment has been recognized as the primary advantage of the FM systems (Ross, 1992). The FM system has been shown to present approximately 15-20 dB greater intensity of speech signal than the background noise (Hawkins, 1984). This increase in SNR is required to maximize the auditory capabilities, especially speech understanding, language and the resultant academic success for children (Ross & Giolas, 1971). Reported additional benefits of an improved SNR includes increased attention span, reduced distractibility and increased sound awareness/discrimination (Blake, Field, Foster, Platt & Wertz, 1991). For these reasons, the importance of the FM systems for individuals with a hearing impairment cannot be underestimated.

In addition, the FM systems are incorporating directional microphones before FM transmission, thus permitting further improvement of SNR at the FM remote microphone. This allows the user to make decisions based on the listening environment. There are instances where in the gain provided by an FM system alone may be insufficient, especially for higher degrees of hearing loss. In such situations, coupling of the FM system to a hearing aid has been recommended (Hawkins & Schum, 1985).

Hawkins, and Van Tasell (1982) have investigated the electro acoustic characteristics of various personal FM system configurations such as coupling the FM systems with direct audio input (DAI) and neckloop (NL). Saturation sound pressure level 90 ($SSPL_{90}$) and frequency response curves were obtained with different hearing aids in the microphone mode and FM+HA coupling. Their results suggested, a large and variable frequency response differences between the hearing aid alone and NL coupling and minor differences with DAI coupling. Higher internal noise levels were found for both NL and DAI coupling.

Chilsolm, Mc Ardle, Abrams, and Noe (2004) coupled the hearing aid to Phonak ML8 FM receivers with DAI. They compared the hearing aid's response with NAL-R insertion gain target and HA+FM response. All the patients were experienced hearing aid users. Among the clients, after five individual sessions, some indicated difficulty in hearing conversation in noise, with hearing aids. However, in noise they heard better with FM systems. Majority of the established goals for FM use involved better hearing in noise than hearing aid alone.

Nelson, LaRue, and Rourke (2004) fitted subjects monaurally with an omni directional linearly programmed hearing aid and later coupled their hearing aids to a Phonak MLx FM receiver with DAI. Word identification scores were found based on full word scoring, in hearing aid alone and FM+HA modes (omnidirectional, 44 degree zoom and 22 degree zoom). It was found that the word recognition scores were statistically greater for all FM conditions when compared to the hearing aid alone condition. Word recognition scores were statistically better for the directional FM conditions compared to the omnidirectional FM conditions. They also concluded that the subject characteristics such as hearing thresholds, communication styles, word recognition scores in quiet, can affect the benefit they received from the FM system.

Boothroyd (2004) in his study took twelve adults with mild to severe hearing loss. They were fitted with BTE FM systems and given a trial period of two weeks. Phoneme recognition was measured before and after the trial period in quiet and noise conditions. He found that FM assisted phoneme recognition in noise was as good as the aided phoneme recognition in quiet. For low input levels, the phoneme recognition in noise was better than in FM+HA mode than HA alone mode. He also said that optimal benefit from these and similar accessories will require considerable counseling, instructions and coaching.

Hostler (2003) connected the digital signal processing hearing aids to the FM system with DAI. He obtained the frequency response curve with 65 dBSPL input under hearing aid alone and FM+HA condition. He found that when FM receiver was coupled with the hearing aid, the curve obtained with a 65 dBSPL input through the FM system was about lower than that obtained with the hearing aid alone mode.

In an ideal situation, an FM system that is connected to a hearing aid maintains the frequency output characteristics of the hearing aid and enhances the SNR of the listening environment (Auriemmo, Keenan, Passerieux & Kuk, 2005). A transparent system will ensure consistent audibility whether an individual with hearing impairment uses the hearing aid alone or FM+HA coupling. They presented a three-step protocol for measuring both the transparency and the FM/HA ratio in one measurement session.

In another study, Hawkins, and Schum (1985) did electro acoustic measurements on four hearing aids and then repeated with the hearing aids connected to FM system via DAI, NL and SI. The measurement included frequency response for all the types of coupling and hearing aid alone modes. In the results all the DAI responses showed reduced output compared to NL and SI coupling and also to hearing aid alone mode. For DAI coupling method, the frequency response with two different manufacturers equipment were similarly showing increased output in the lower frequencies and reduced output in the higher frequencies.

A study done by Nelson (2005) recommended procedures for obtaining the electro acoustic measurements of FM+HA modes and the transparency was also found. The results showed that the transparency that can be obtained through FM system is limited. For an FM system to be completely transparent it must process signal linearly and most FM systems are not linear processors. Typically, FM systems are linear below 70 dBSPL, therefore, transparency is limited to inputs below 70 dBSPL.

All the above studies show the importance of the use of FM system with the hearing aids due to its transparency and SNR advantages in understanding speech. However, most of these studies have used only coupler measurement. Hence it needs to be investigated if there is an effect of transparency and FM/HA ratio on the speech recognition performance.

Chapter-3

METHOD

The study intended to evaluate the performance with the FM system coupled with hearing aid using DAI (FM+HA) and hearing aid (HA) alone modes. To accomplish the above, the following method was designed.

Subjects

Eleven subjects were selected for the present study. The subjects fulfilled the following criteria.

- Acquired hearing impairment with moderate to severe sensorineural hearing impairment.
- Age range between 15 and 55 years.
- Fluent Kannada speakers.
- Naïve hearing aid users.

Instrumentation

- A calibrated two-channel soundfield audiometer to perform the routine audiometry and aided testing.
- Two digital hearing aids with a fitting range for moderate to severe degrees of hearing loss. Each subject was tested with one hearing aid.
- Personal computer with HiPro, NOAH-3 and hearing aid fitting software for programming the digital hearing aids.
- Solaris FM system which had provision for DAI coupling with hearing aid.

- A calibrated hearing aid test system, Fonix FP 40-D for performing the electroacoustic measurements.

Speech Material

Recorded Kannada word lists, with all the speech sounds in the language which was developed by Yathiraj and Vijayalakshmi (personal communication, November 26, 2005). There were eight lists in the test material, of which four were used for the study. Each of the lists had 25 words. Each list consisted of all the speech sounds of Kannada.

Environment

Testing was carried out in a sound treated environment. The ambient noise levels were within permissible limits. (re: ANSI 1991; cited in L.A. Wilber, 1994).

Procedure

To evaluate the objectives of the study, the data was collected through the coupler and real ear measurements.

I. Coupler measurements were carried out to evaluate the following:

1) The transparency of the FM system.
2) The ratio of FM output to HA output when used in FM+HA mode, i.e, FM/HA ratio.

II. Real ear measurements was carried out to evaluate the following:

1) The aided thresholds, in HA alone and FM+HA modes.
2) The speech recognition performance, in noise and in quiet, in HA alone and FM+HA modes.

I. 1) The assessment of transparency and FM/HA ratio:

This was done using a three step protocol (Auriemmo, Keenan, Passerieux & Kuk, 2005).

Step 1: Obtaining a Reference Measure.

a) The digital BTE hearing aid was programmed according to the hearing loss of the subject and proprietary fitting procedure, using the PC with HiPro, NOAH-3 software and the hearing aid fitting software.

b) Initially, the leveling of FP40-D was done by placing the coupler microphone in the test position in the sound chamber.

c) The digital BTE hearing aid was then connected to the HA-2 2cc coupler through an adaptor. The other end of the coupler was connected to the test or coupler microphone which was inturn connected to the hearing aid test system. The hearing aid microphone was placed in the calibrated position within the sound chamber.

d) The hearing aid was given a composite signal at 65 dBSPL. The output in dBSPL at different frequencies such as 200 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 6 kHz was measured, in HA alone mode. The overall root mean square (rms) output was also recorded.

Step 2: Transparency

a) The receiver unit of the FM system was coupled to the BTE hearing aid through direct audio input (DAI).

b) The hearing aid was then attached to HA-2 2cc coupler through an adaptor.

c) The 2 cc coupler was inturn connected to a test microphone of the Fonix FP 40-D hearing aid test system.

d) This assembly was placed on a foam pad atleast 2 feet (60 cm) from the transmitter as shown in Figure 3.1.

e) The lapel microphone of the FM transmitter was kept inside the sound chamber of FP40-D hearing aid test system, at the test position. The transmitter was kept outside the chamber.

f) Then transmitter and receiver were switched “on” and it was ensured that both were having similar transmitting/receiving frequency. The trimmer control on the receiver unit of the FM system was set to DAI.

g) The output, in dBSPL, of the FM+HA system at 200 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 6 kHz was measured using a composite signal of 65 dBSPL as the input signal. The overall root mean square (rms) output also was noted.

h) These performances measured in Step 1 and in Step 2 were compared in order to measure the transparency of FM system.

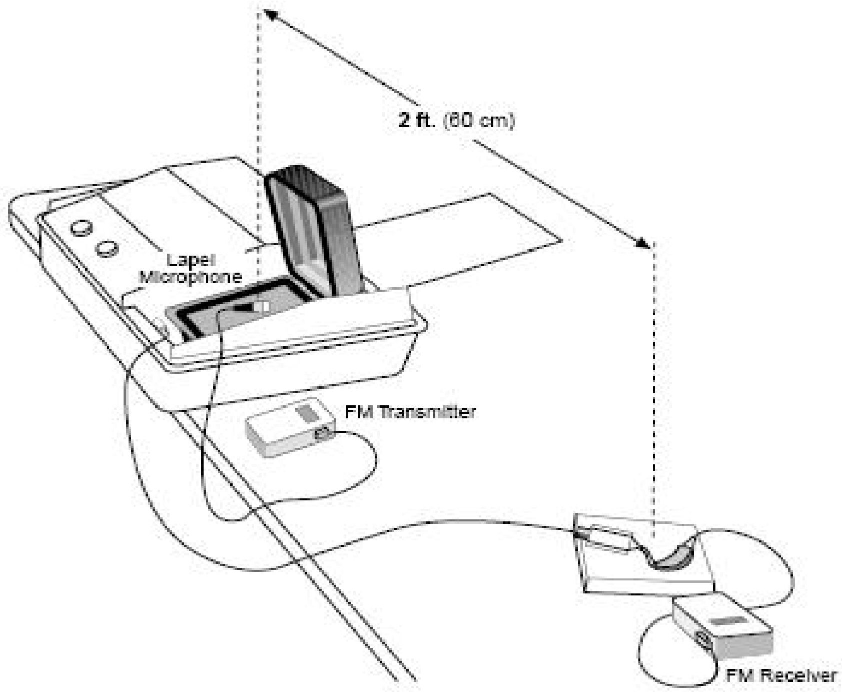

Figure 3.1: Set-up for coupler testing FM coupled to BTE hearing aid.

Step 3: FM/HA Ratio.

a) The same set-up as in Step 2 (Figure 3.2) was used. The output in dBSPL, of the hearing aid in FM+HA mode was measured with a composite signal at 80 dBSPL. The rms output was also recorded.

b) The difference in output between Step 3 and Step 1 gave the FM/HA ratio or relative output of the combination of the FM system and the hearing aid.

II. 1) Real ear measurements for aided thresholds.

The aided thresholds in sound field were measured for FM tones at 500 Hz, 1 kHz, 2 kHz and 4 kHz, in both HA alone and FM+HA. The subject was instructed to respond to the FM tone, even for the softest one. Data thus obtained for each measure, for each subject, was tabulated for statistical analysis. The above procedure was repeated for all the subjects in hearing aid alone and FM+HA modes.

II. 2) Real ear measurements to obtain the SRS in noise and in quiet conditions was done in the following three steps

a) *Fitting of Digital BTE*

Fitting of digital BTE hearing aid was done such that the aided thresholds were within speech spectrum. The speech recognition testing was performed, in a sound field condition in the presence of noise, to evaluate the efficiency of the FM system.

b) *SRS, in Quiet and in Noise, in Hearing Aid Alone Mode.*

- The subject was located in the calibrated position in the soundfield, with the signal being presented through the loudspeaker positioned at 45 degrees azimuth on the side of the aided ear of the subject.

- The recorded word list was routed through the auxiliary input of the audiometer to the loudspeaker on the side of the ear to which hearing aid was fitted with earmold.

- Care was taken to ensure that there was no effect of the order of the word list on the SRS.

- The subject was instructed to repeat the words he/she heard. The tester with normal hearing and knowledge of Kannada, wrote down the oral responses.

- The presentation level was 45 dBHL. The SRS was obtained in quiet, in the hearing aid alone mode (Figure 3.1). Each correct word was given a score of “1” and the maximum score was 25.

- The above step was repeated in the presence of noise from the loud speaker located on the side opposite to the test ear (Figure 3.2). The presentation level for speech was 45 dBSPL. The speech noise was routed through the other loudspeaker, such that the SNR was maintained at +5dB. Thus, the SRS in noise was obtained in hearing aid alone mode.

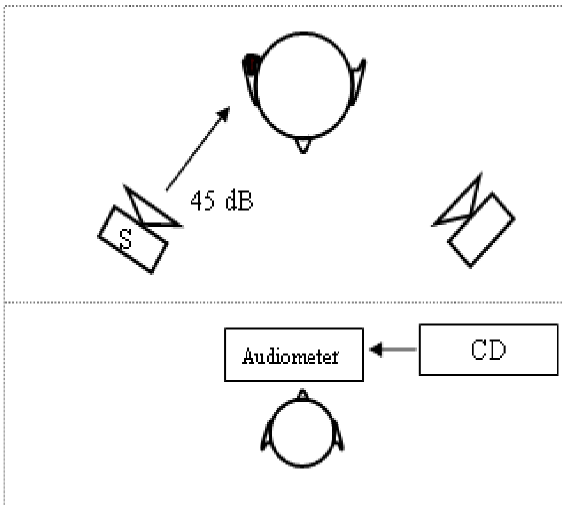

Figure 3.2: SRS in hearing aid alone condition in quiet.

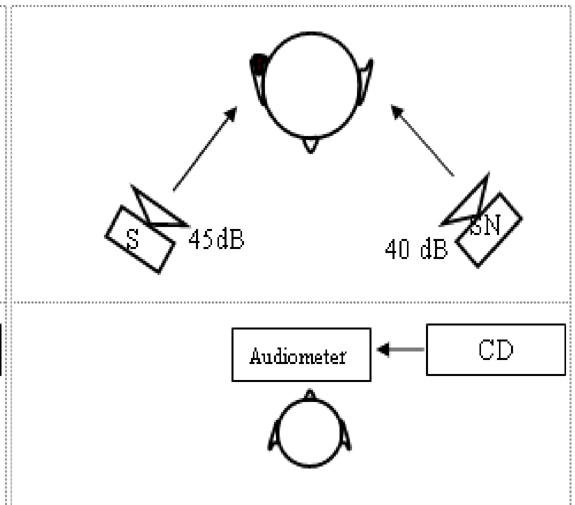

Fig 3.3: SRS in hearing aid alone in speech noise

(S-speech, SN-speech noise, C-client, A-audiologist)

c) SRS in quiet and in noise, in FM+HA mode.

- The receiver unit (RU) of the FM system was coupled to the hearing aid using the DAI coupling. This set was worn by the subject. The subject was then seated in the test room along with the tester.
- The FM microphone and the transmitter unit (TU) was placed in the calibrated spot in the soundfield where the subject was seated earlier.
- Without making any changes, the FM system and the hearing aid were turned “on”.

- Recorded word list was presented at 80 dBHL through the loudspeaker. The SRS was measured, in quiet, in HA+FM mode (Figure 3.3). 80 dBSPL presentation level was used as microphone of the FM system is near to speaker's mouth and due to this the input level will be high.
- Instructions and scoring were same as that mentioned in the previous step.
- Care was taken to ensure that there was no effect of order of different word list on the SRS.
- Recorded words were presented at 80 dBSPL through the loudspeaker. Speech noise was presented, such that the SNR was maintained at +5dB, through the other loudspeaker (Figure 3.4). Thus, the SRS in noise was measured, in FM+HA mode.

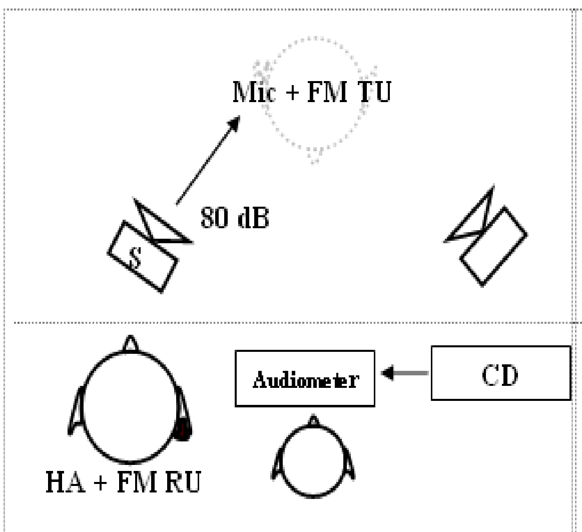

Figure 3.4: SRS in FM+HA condition in quiet

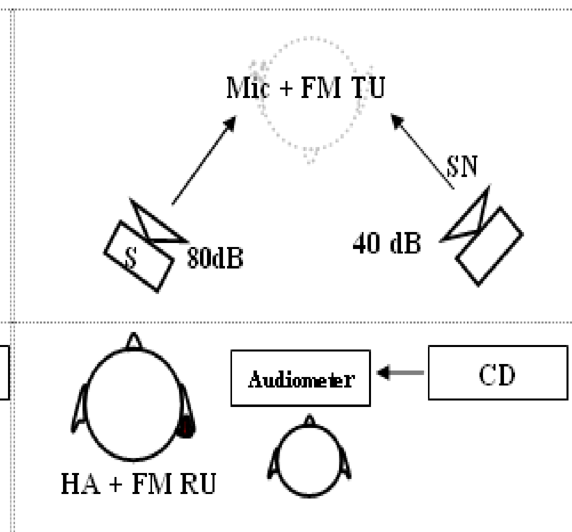

Fig 3.5: SRS in FM+HA condition with speech noise.

- These different SRS measures were compared to obtain the information about the efficacy of the FM+HA over the HA alone mode in speech recognition.

Chapter-4

RESULTS AND DISCUSSION

Data was collected to evaluate the transparency of the FM system, FM/HA ratio and to compare the speech recognition through a hearing aid alone vs. hearing aid+FM modes.

1) Transparency of FM System

Figure 4.1 shows the mean and standard deviation of the gain obtained, in the coupler, at 200 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 6 kHz, in HA alone and FM+HA modes with DAI coupling. The input level was 65 dBSPL. The Figure 4.1 shows that the coupler gain is slightly higher in FM+HA mode than in HA alone mode, with an input of 65 dBSPL.

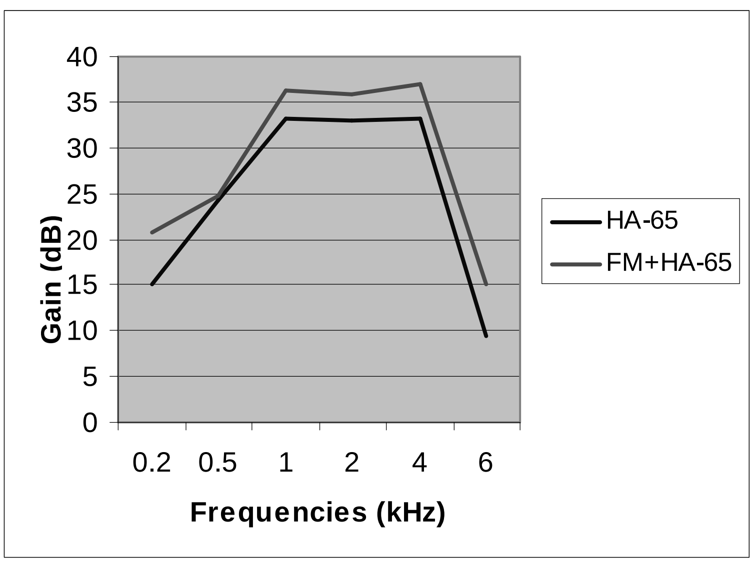

Figure 4.1: Coupler gain at different frequencies in HA alone and FM+HA modes, with an input of 65 dBSPL.

Repeated measures ANOVA showed that there was significant difference between the three modes of amplification i.e., HA alone with 65 dBSPL input, FM+HA with 65 dBSPL input and FM+HA with 80 dBSPL input [$F (2, 20) = 13.034$, $p < 0.001$]. The Bonferroni multiple comparison test indicated that there was no significant difference between the gain of HA alone and FM+HA modes of amplification at 200 Hz, 500 Hz, 1 kHz and 2 kHz and 4 kHz ($p>0.05$) at 65 dBSPL input level. Also there was significant difference between these modes at 6 kHz, with an input of 65 dBSPL ($p<0.05$).

This shows that there was a transparency of the FM system. That is, the gain was similar for both the HA alone and the FM+HA modes atleast in the frequencies that the hearing aid significantly amplifies. This finding is in accordance with that of Auriemmo, Keenan, Passerieux, and Kuk (2005) and Hawkins, and Van Tasell (1982) which reported that the FM+HA coupling maintain the frequency output characteristics of hearing aid. Figure 3 shows the transparency of FM system.

2) The FM/HA Ratio

Figure 4.2 depicts the mean of the gain obtained, in the coupler at 200 Hz, 500 Hz, 1 kHz, 2 kHz, 4 kHz and 6 kHz, in HA alone with an input of 65 dBSPL and FM+HA with DAI coupling, with an input of 80 dBSPL.

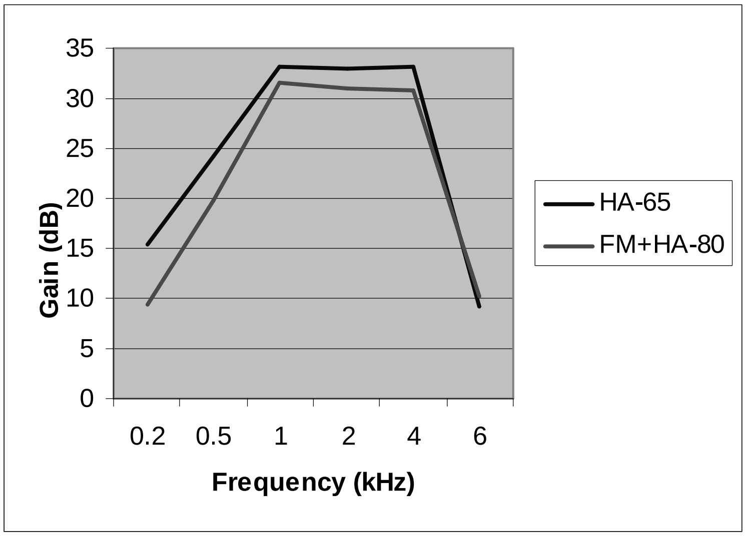

Figure 4.2: Coupler gain at different frequencies in HA alone with 65 dBSPL input and in FM+HA mode with 80 dBSPL input.

Repeated measures ANOVA showed that there was significant difference between the three modes of amplification i.e., HA alone with 65 dBSPL input, FM+HA with 65 dBSPL input and FM+HA with 80 dBSPL input [$F(2, 20) = 13.034$, $p < 0.001$]. The Bonferroni multiple comparison test indicated that there was no significant difference between the gain of the HA alone with 65 dBSPL and FM+HA modes of amplification with 80 dBSPL at 500 Hz, 1kHz and 2 kHz, 4 kHZ and 6 kHz ($p>0.05$) except at 200 kHz ($p<0.05$). This can be explained with the study of Hawkins and Van Tasell (1982) which reported that, the DAI coupling resulted in an increase in the internal noise compared to hearing aid alone mode. This can affect the very low frequencies compared to the other frequencies.

It was observed that the gain was slightly lower in FM+HA mode as the level of the input was high (80 dBSPL). This finding supports that of Nelson's (2005) study in which it was reported that the FM systems are linear below 70 dBSPL, therefore, transparency is limited to inputs below 70 dBSPL.

3) Speech Recognition Test

To compare the speech recognition scores between the HA alone and FM+HA modes in quiet and in noise, paired samples t-test was performed. The results revealed that there was a significant difference between the two scores ($t<0.001$). Table 4.1 shows the t-value and significance level of difference for Speech Recognition Scores (SRS) in quiet and Speech Recognition Scores (SRS) in noise

Table 4.1: T value and significance of SRS in quiet and SRS in noise.

	SRS in quiet	SRS in noise
t-value	.714	5.49
Sig.	.492	.000

The FM+HA mode showed better speech recognition scores in noise than HA alone mode. This is evident also in Figure 4.3, where the SRS in noise was higher in FM+HA mode compared to HA alone mode.

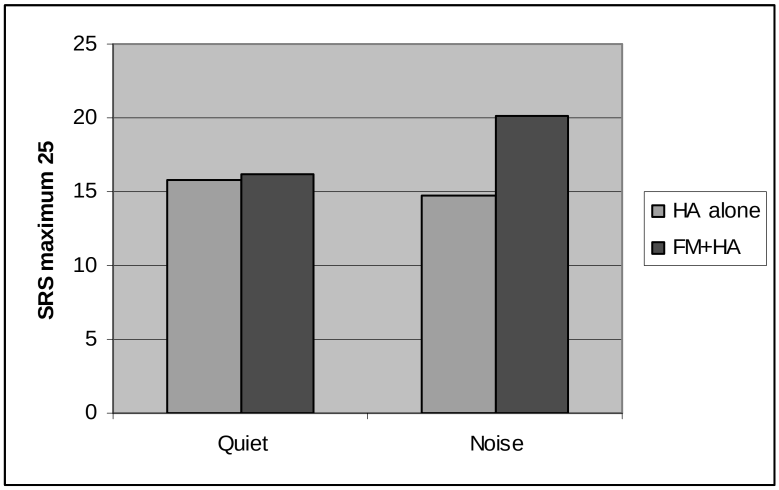

Figure 4.3: SRS in quiet and in noise in HA alone mode and FM+HA modes.

In quiet, there was no difference between the SRS of HA alone and FM+HA modes. This is in accordance with the studies reported in literature (Hawkins & Van Tasell, 1982; Hawkins & Schum, 1985; Auriemmo, Keenan, Passerieux & Kuk, 2005), that have demonstrated the SNR benefit of FM+HA system, compared to HA alone mode.

4) Aided Thresholds

Paired samples t-test was done to examine the difference in aided threshold with HA alone and FM+HA modes. The results revealed that there was no significant difference between the aided thresholds in HA alone and FM+HA modes ($p>0.05$) at 2 kHz and 4 kHz. But a significant difference was found between the two modes at 1 kHz and 500 Hz, where the thresholds were higher in FM+HA alone mode than in HA alone mode (p<0.01). This can be due to the effect of internal noise of FM system with DAI coupling on low frequencies as explained earlier.

Table 4.2: t-values and significance level at different frequencies for aided thresholds in HA alone and FM+HA modes.

	500 Hz	1 kHz	2 kHz	4 kHz
t- value	3.71	4.18	1.61	1.17
Sig.	.004	.002	.138	.267

The Figure 4.4 shows the aided thresholds obtained at HA alone mode and FM+HA modes at different frequencies. In the figure it can be seen that the aided thresholds are poorer in FM+HA mode than in hearing aid alone mode.

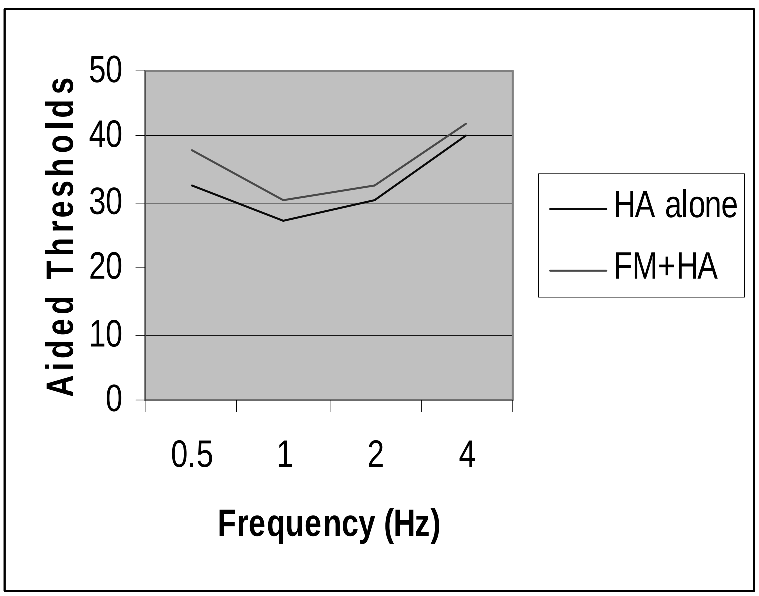

Figure 4.4: Aided thresholds (dBHL) in HA alone and FM+HA modes at different frequencies.

Finally it was found that the FM system is transparent when coupled with HA at the frequencies the HA amplifies significantly. It was also found that the FM systems are linear below 70 dBSPL, therefore, transparency is limited to inputs below 70 dBSPL. In noise Speech recognition scores where found to be better with FM+HA modes than HA alone. It was also found that the internal noise of FM system with DAI coupling can effect the low frequencies.

Chapter-5

SUMMARY AND CONCLUSIONS

An almost universal complaint of adults with hearing loss is the difficulty in understanding speech in the presence of back ground noise. Assisstive listening devices provide useful, but often overlooked, solutions to the problems adults experience when listening in noisy environments. Use of FM system, for example, can result in dramatic improvements in speech recognition in noise.

The present study aimed at evaluating the effect of coupling FM systems to hearing aids in electroacoustic measurements and speech recognition. The coupling used was Direct Audio Input (DAI). Several studies have shown an improvement of speech perception in noisy and reverberant environment and also have mentioned the SNR advantage when FM system is coupled with hearing aids. A three step protocol was administered to find the transparency and FM/HA ratio. Also aided thresholds and Speech Recognition Scores (SRS) in quiet and in noise were measured. The above measures were done both in HA alone mode and FM+HA modes with DAI coupling. The results are given below:

1) The gain obtained was similar for both the hearing aid alone and the FM+HA modes atleast in the frequencies that the hearing aid significantly amplifies. This shows the transparency of FM system.
2) The coupler gain was slightly higher in FM+HA mode than in HA alone mode with an input of 65 dBSPL, though not statistically different.

3) The DAI coupling resulted in an increase in the internal noise compared to hearing aid alone mode. This can affect the very low frequencies compared to the other frequencies when there is high level input.

4) The coupler gain was higher in hearing aid alone mode with an input of 65 dBSPL than with FM+HA mode with an input of 80 dBSPL. This could be because the transparency is limited to inputs below 70 dBSPL.

5) In quiet, there was no difference between the SRS of HA alone and FM+HA modes. The FM+HA mode showed better speech recognition scores in noise than HA alone mode.

6) There was no significant difference between the aided thresholds in HA alone and FM+HA modes at 1 kHz, 2 kHz and 4 kHz, except at 500 Hz. This can be due to the effect of internal noise of FM system with DAI coupling on low frequencies.

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