Effect of Hearing Aid Coupled with FM System on Speech Recognition

Vidya Mohan & P Manjula*

Abstract

In difficult-to-hear situations frequency modulated (FM) systems can improve an individual's ability to understand speech like in noisy environments and at greater speaker-to-listener distances. By preserving the desired signal strength, the system enhances the speech-to-noise ratio (SNR) at the listener's ear, thereby facilitating speech recognition. There is a dearth in literature regarding the differences between the performance with a hearing aid alone vs HA plus FM modes of amplification. 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 and hearing aid+FM system. The results confirmed the transparency of the FM system. The DAI coupling resulted in an increase in the internal noise compared to hearing aid alone mode. In the presence of noise the speech recognition was better with FM+HA mode than with HA alone mode.

Introduction

In the recent years there has been a significant increase in the options/devices available for individuals with hearing impairment. Individuals with hearing loss often complain of difficulty in understanding speech, especially in noisy environments. In such difficult-to-hear situations like in noisy environments and at greater speaker-to-listener distances frequency modulated (FM) systems can improve individual's ability to understand speech. By preserving the desired signal strength the system enhances the speech-to-noise ratio (SNR) at the listener's ear thereby facilitating speech recognition. All these are attained by the placement of 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. This SNR remains constant as the talker moves around. Wireless transmission of the resulting signal is more convenient than a wired connection (Boothroyd, 1992). In an ideal situation an FM system that is connected to a hearing aid (HA) maintains the frequency-output characteristics of the hearing aid (i.e., transparency) and enhances the signal-to-noise ratio (SNR) of the listening environment.

The FM systems can be either used independently 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). 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 improvement of speech perception in noisy and

* Lecturer in Audiology, All India Institute of Speech and Hearing, email: manjulap21@hotmail.com

reverberant environment has been recognized as the primary advantage of the FM systems (Ross, 1992). The FM system has been shown to provide approximately 15 to 20 dB greater intensity of speech signal than the background noise (Hawkins, 1984).

Chilsolm, Mc Ardle, Abrams and Noe (2004) showed that in noisy situations those with hearing impairment heard better with FM systems. Majority of the established goals for FM use involved better hearing in noise than hearing aid alone. 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).

The audiologist who works with hearing aids should be aware of the effect of coupling the FM system with the hearing aid. An audiologist who works with FM and hearing aids must evaluate if the addition of the FM results in the optimal use of the FM-HA combination (transparency). 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 with the following 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.

Method

Participants

Eleven participants were included in the present study fulfilling the following criteria:

- age range between 15 to 55 years of age
- acquired hearing impairment with moderate to severe sensori neural hearing impairment
- fluent speakers of Kannada
- naïve hearing aid users

Instrumentation

- A calibrated two-channel sound field 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 participant 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 for performing the electroacoustic measurements.

Speech material

Recorded PB word list in Kannada developed by Yathiraj and Vijayalakshmi (2006) was used. There were eight lists in the test material of which four were used in the present study. Each of the lists had 25 PB words.

Environment

Testing was carried out in a sound treated double room. Ambient noise levels were within permissible limits

Procedure

The data were collected through the coupler and real ear measurements.

1. 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.
2. Measurements were carried out to evaluate the following:
    1. The aided scores in noise and in quiet, in HA alone and FM+HA modes.
    2. The speech recognition performance in noise, 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 participant and proprietary fitting procedure using the PC with HiPro, NOAH-3 and the hearing aid fitting softwares.
b) Initially the leveling of FP40-D was done by placing the coupler microphone in the reference position in the test chamber.
c) The 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 microphone which was in turn connected to the hearing aid test system. The hearing aid microphone was placed in the reference position within the test 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 and recorded 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 in turn connected to a test microphone of the Fonix FP 40-D hearing aid test system

d) This assembly was placed on a foam pad at least 2 feet (60 cm) from the transmitter
e) The lapel microphone of the FM transmitter was kept inside the sound chamber of FP40-D hearing aid test system at the reference 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 and recorded using a composite signal of 65 dBSPL as the input signal. The overall 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.

Step 3: FM/HA Ratio

a) The same setup as in Step 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. Measurements were carried out to evaluate the following:

a) Measurement of aided thresholds.

The aided thresholds in the 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 aided thresholds thus obtained were compared. The participant was instructed to respond to the FM tone, even for the softest one. Data thus obtained for each measure and for each subject were tabulated for statistical analysis. The above procedure was repeated for all the participants in hearing aid alone and FM+HA modes.

b) Measurement of SRS in noise and quiet conditions

i) 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.

ii) SRS in quiet and in noise, in hearing aid alone mode

- The participant was located at the calibrated position in the sound field with the signal being presented through the loudspeaker positioned at 45 degrees azimuth on the side of the aided ear of the participant.
- 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 ear mold.
- Care was taken to ensure that there was no effect of different word list on the SRS.
- The participant was instructed to repeat the words he/she heard. The tester with normal hearing and knowledge of Kannada wrote down the

oral responses for scoring. Each correct word was given a score of 1, the maximum score was 25.

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

iii) *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 participant. The participant was then seated in the test room along with the tester.
- The FM microphone and the transmitter unit (TU) were placed in the calibrated spot in the soundfield where the participant was seated earlier.
- Without making any changes the FM system and hearing aid were turned on.
- Recorded word list was presented at 80 dBHL through the loudspeaker. The SRS was measured in quiet and in HA+FM mode. The presentation level was 80 dBSPL.
- Instructions and scoring were same as that mentioned in step b).
- 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 loudspeakers. Thus the SRS in noise was measured in FM+HA mode.
- 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.

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

Results and Discussion

1. *The Transparency of FM system*

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

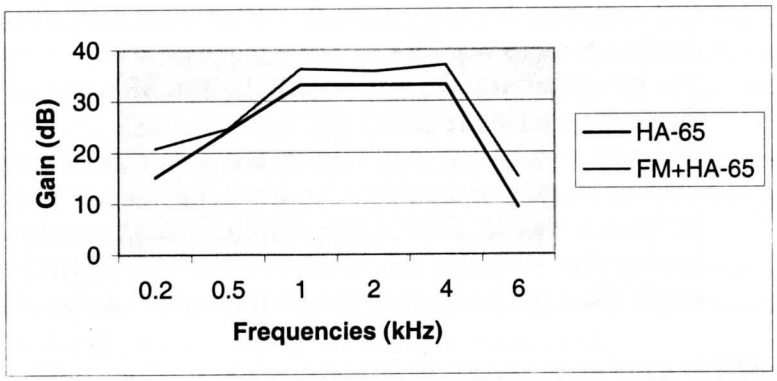

Figure 1: Gain at different frequencies in HA and FM+HA modes with an input of 65dBSPL.

Repeated measures ANOVA showed there was a 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 (p>0.05). Also there was no significant difference between these modes (p<0.05) at 4 KHz and 6 KHz at an input of 65 dBSPL. 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 at least 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 said that the FM+HA coupling maintain the frequency output characteristics of hearing aid showing the transparency of FM system.

2. The FM/HA ratio

Figure 2 depicts the mean and standard deviation of the gain obtained in the coupler at 200 Hz, 500 Hz, 1 KKz, 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.

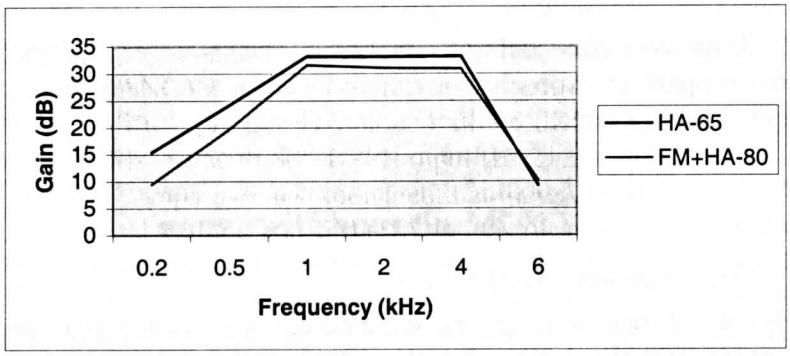

Figure 2: Gain at different frequencies in HA at 65 dBSPL and in FM+HA mode with 80 dBSPL

Repeated measures ANOVA showed that there was a 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, 1 KHz, 2 KHz, 4 KHz and 6 KHz ($p>0.05$) except at 200 Hz ($p<0.05$). This could be because of the increase in internal noise due to DAI coupling of FM system compared to hearing aid alone mode (Hawkins & Van Tasell, 1982). This can affect the very low frequencies more than 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 ($t<0.001$). In noise the speech recognition scores were better with FM+HA mode than in HA alone mode. This was evident also from Figure 3 where the SRS in noise was higher in FM+HA mode compared to HA alone mode.

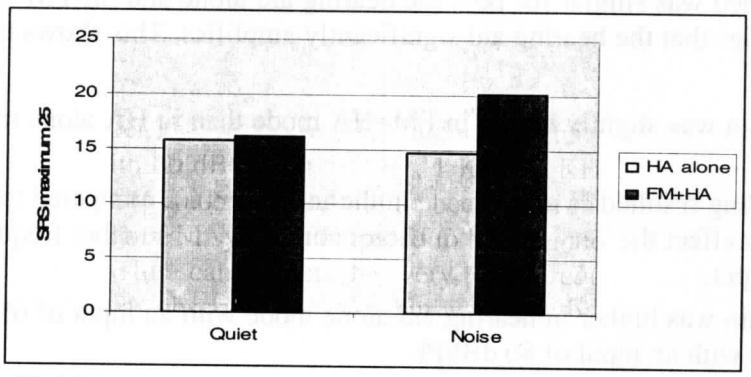

Figure 3: SRS in quiet and in noise with HA alone mode and FM+HA modes.

In quiet, there was no significant difference between the SRS of HA alone and FM+HA modes. This conforms to that reported by Hawkins, and Van Tasell (1982), Hawkins and Schum (1985), Auriemmo, Keenan, Passerieux and 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 thresholds 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 ($t >0.001$) at 1 KHz, 2 KHz and 4 KHz. But a significant difference existed between the two modes at 500 Hz where the thresholds were lower in HA alone mode than in FM+HA mode. Higher aided threshold at 500 Hz with FM+HA mode could be due to the effect of internal noise of FM system with DAI coupling on low frequencies as explained earlier. These results are depicted in Figure 4.

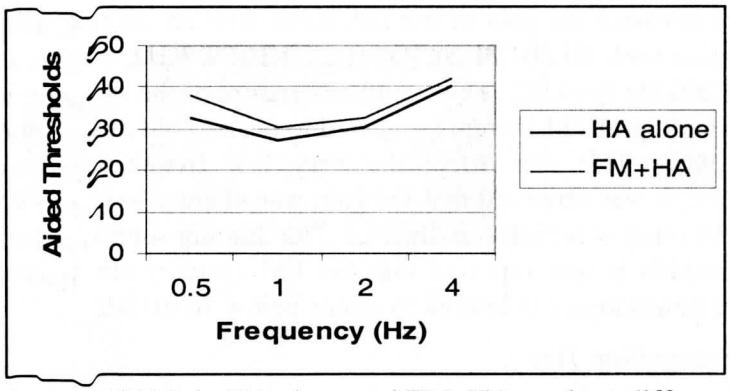

Figure 4: Aided thresholds in HA alone and FM+HA mode at different frequencies

Conclusions

From the findings of the present study it can be inferred that:

1. The gain obtained was similar for both the hearing aid alone and the FM+HA modes at least 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.
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.
5. It was also found that transparency is limited to inputs below 70 dBSPL.
6. 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.
7. 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 as explained earlier.

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