CONTRIBUTION OF FM SYSTEM FOR SPEECH RECOGNITION IN NOISE IN COCHLEAR IMPLANTEES

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**A dissertation submitted in part fulfillment for the final year
Masters of Science (Audiology)
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May - 2008

Dedicated to....

My dear

Achan &

Amma

CERTIFICATE

This is to certify that this master's dissertation entitled ***"Contribution of FM system for Speech Recognition in Noise in Cochlear Implantees"*** is the bonafide work done in part fulfillment of the degree of Master of Science (Audiology) of the student with Reg. No. 06AUD015. 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 other Diploma or Degree.

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CERTIFICATE

This is to certify that this master's dissertation entitled ***"Contribution of FM System for Speech Recognition in Noise in Cochlear Implantees"*** has been prepared under my supervision and guidance. It also certified that this has not been submitted in any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled ***"Contribution of FM system for Speech Recognition in Noise in Cochlear Implantees"*** is the result of my own study and has not been submitted in any other university for the award of any diploma or degree.

Place: Mysore
May 2008

Reg. No. 06AUD015

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Chapter 1

INTRODUTION

Cochlear implants are one of the most significant technological achievements of the 20th century that have improved the life of individuals with severe to profound hearing loss. Listeners with cochlear implant can achieve scores of 70% to 80% in quiet but are particularly challenged by understanding speech in noise (McGuire, Carroll & Zeng, 2005). This problem is alleviated to some extent when a hearing aid is used on the opposite ear (Tyler, Parkinson, Wilson, Witt, Preece & Noble, 2002), with bilateral cochlear implants (Litovsky, Parkinson, Arcaroli, Peters, Lake, & Johnstone, 2004) and with the use of an FM system on one or both sides (Schafer & Thibodeau, 2006).

Children with cochlear implants (CIs) often experience reductions in speech recognition in noise ranging from 20% to 35% relative to quiet listening conditions regardless of the type of speech and noise stimuli (Davies, Yellon, & Purdy, 2001; Eisenberg, Kirk, Martinez, Ying, & Miyamoto, 2004; Litovsky, Parkinson, Arcaroli, Peters, Lake, & Johnstone, 2004; Schafer & Thibodeau, 2003). Difficulty in noise is significant because young children with cochlear implants will encounter noise in all aspects of their lives, including school, where there is a constant level of noise in the classroom ranging from 34 to 73 dBA (Arnold & Canning, 1999; Bess, Sinclair & Riggs, 1984; Knecht, Nelson, Whitelaw & Feth, 2002).

Children require speech to be sufficiently higher than the level of noise. That is, the signal to noise ratio required for children is higher than that for adults. According to Picard, and Bradley (2001) individuals with normal hearing can perform well even in 40 dBA noise and even when reverberation is about 0.5 seconds. Younger children, having normal speech processing in noise for their age, would require noise levels ranging from 39 dBA for 10-1 lyear olds to only 28.5 dBA for 6-7year olds. In contrast, groups suspected of delayed speech processing in noise may require levels as low as only 21.5 dBA at age 6 to 7 years. As one would expect, these more vulnerable students would include the children with hearing-impairment in the course of language development and also non-native listeners.

Many children with CIs are enrolled in pre-school by the age of three and will be educated in classrooms that are often noisier than those of older children (Picard & Bradley, 2001). In addition, children who receive CIs often move into larger, partially or fully mainstreamed classrooms (Daya, Ashley, Gysin & Papsin, 2000; Picard & Bradley, 2001; Tobey, Geers, Rekart & Buckley, 2004). Adding to all of these challenges, younger children with CIs may have more difficulty hearing than older children with CIs because on an average speech recognition in noise improves with age (Eisenberg, Shannon, Martinez, Wygonski, & Boothroyd, 2000; Stelmachowicz, Hoover, Lewis, Kortekaas & Pittman, 2000). Although Persons With Disability Act (1995) mandates that children with hearing loss should receive a free and appropriate education in the least restrictive environment, classrooms with excessive noise and signal-to-noise ratios as poor as -6 dB will not allow for a suitable listening environment (Picard & Bradley, 2001). Therefore, acoustic factors that may contribute to educational restrictions for children with CIs are the presence of noise in the classroom, distance from the teacher, and reverberation. Identifying possible solutions to address these problems are imperative as children with CIs are already facing deficits including delays in speech and language development and reading ability (Balmey, Sarant, Paatsch, Barry, Bow & Wales (2001); Geers, 2004; Tomblin, Spencer & Gantz, 2000).

Use of a second CI (bilateral input), an hearing aid (HA) on the non-implant ear (bimodal input), and frequency modulation (FM) system input to one or both sides improve speech recognition in noise among children with CIs (Ching, 2000; Ching, Hill, Brew, Incerti, Priolo, & Rushbrook, 2005; Ching, Psarros, Hill, Dillon & Incerti, 2001; Davies, Yellon & Purdy, 2001; Dettman, D'Costa, Dowell, Winton, Hill, & Williams, 2004; Holt, Kirk, Eisenberg, Martinez & Campbell, 2005; Kiihn-Inacker, Shehata-Dieler, Muller & Helms, 2004; Litovsky, 2004; Luntz, Shpak & Weiss, 2005; Schafer & Thibodeau, 2003; Senn, Kompis, Vischer & Haeusler, 2005). The use of a second CI or an HA on the non-implant ear improves speech recognition in noise and may provide several binaural benefits including binaural summation, binaural squelch, reduction of the head shadow effect, and improved localization (Cox, DeChicchis & Wark 1981;Nabelek & Pickett, 1974).

Bilateral cochlear implants improve speech recognition in noise for children with CIs when the speech and noise are spatially separated, particularly when the noise is presented toward the second implant (Kiihn-Inacker, Shehata-Dieler, Muller, & Helms, 2004; Litovsky, Parkinson, Arcaroli, Peters, Lake, & Johnstone, 2004; Senn, Kompis, Vischer, & Haeusler 2005). The studies include various speech stimuli (bi-syllabic words and sentences), competing noise (speech noise, babble) and speaker arrangements. The findings of the studies are consistent that the speech recognition in noise improves for the majority of the children when using two implants relative to one. Bimodal input (CI and hearing aid on non-implant ear) also significantly improves speech recognition in noise for children with CIs when the speech (words, phrases) and noise (babble, speech noise) are presented from the same speaker (Ching, 2000; Ching, Psarros, Hill, Dillon & Incerti, 2001; Dettman, D'Costa, Dowell, Winton, Hill & Williams, 2004; Holt, Kirk, Eisenberg, Martinez & Campbell 2005; Luntz, Shpak & Weiss, 2005) or when the speech and noise are spatially separated (Ching, Hill, Brew, Incerti, Priolo & Rushbrook, 2005). When the gain on the HA is adjusted to allow for loudness balancing between the HA and CI, children show even larger gains in speech recognition in the bimodal condition relative to the CI alone (Ching, Psarros, Hill, Dillon & Incerti, 2001). Children's speech recognition significantly improves with binaural input (either bilateral or bimodal) relative to a CI alone regardless of stimuli, type of noise, and speaker azimuths.

Apart from improving speech recognition in noise an FM system provides direct access to the talker's voice through a teacher-worn transmitter and a student-worn receiver coupled to the CI speech processor. Use of an FM system also reduces the negative effects of distance from the speaker, and reverberation in the environment because of the placement of the transmitter microphone 3 to 6 inches from the mouth of the speaker. If a bilateral or bimodal input is used along with an FM system, a child may receive even greater improvements in speech recognition in noise from the combination of binaural benefits and improved signal to noise ratio.

For children using a single CI, speech recognition in noise significantly improves when using an FM system (Davies, Yellon & Purdy, 2001; Schafer & Thibodeau, 2003). There are reports of investigations where in improvement was not observed when an FM system was coupled to a CI. Crandall, Holmes, Flexer, and

Payne (1998) studied word recognition for eight children and ten adults with CIs and they found that there was no benefit using FM system and there was no change in the results obtained between adults and children. The lack of benefit of using the FM system in cochlear implantees can be because of the problem in the protocol used for testing, i.e., there could be a ceiling effect with maximum performance reached with the CI alone condition. Another reason could be that of optimizing the FM parameters. Hence, this study evaluates the performance of FM system when coupled to a cochlear implant using relatively new measures - the speech recognition threshold (SRT) in noise and the signal to noise ratio (SNR) measurement - which are more effective than the standardized way of testing as mentioned in the literature.

Need for the study

There have been equivocal findings on the speech identification performance when a cochlear implant is coupled with an FM system. These differences in the reports could be due to the methodological variations such as the placement of FM transmitter microphone, presentation level of signal and noise, speech performance measure used in different studies. Hence, it is proposed that the effectiveness of the FM system when coupled to a CI be evaluated using an appropriate protocol that reflects the improvement in performance with addition of an FM device.

Aims of the study

The aims of the present study were:

1. To study the influence of the FM system for each participant using a cochlear implant

2. To evaluate the speech identification performance in noise with and without the FM system with different durations of cochlear implant use.
3. To evaluate the speech identification performance in noise, with and without the FM system

Chapter 2

REVIEW

Cochlear implantation is an option for individuals with severe-to-profound hearing loss when hearing aids cannot provide adequate audibility of speech. Children with cochlear implants may develop open-set speech recognition in quiet listening situations when they are implanted at an early age and rehabilitated (Geers, 2004; Geers, Brenner & Davidson, 2003; Osberger, Zimmerman-Phillips & Koch, 2002; Waltzman, Cohen, Green & Roland, 2002). Despite this achievement, children with cochlear implants often experience reductions in speech recognition in noise ranging from 20% to 35% relative to quiet listening conditions regardless of the type of speech and noise stimuli (Davies, Yellon & Purdy, 2001; Eisenberg, Kirk, Martinez, Ying & Miyamoto, 2004; Litovsky, Parkinson, Arcaroli, Peters, Lake & Johnstone 2004; Schafer & Thibodeau, 2003).

The benefits provided by frequency modulation (FM) systems to school-age children who use cochlear implants can be determined through speech recognition testing (Davies, Yellow & Purdy, 2001; Schafer & Thibodeau, 2003). For children using a single CI, speech recognition in noise significantly improves when using an FM system and listening to spatially separated speech and noise (Davies, Yellow & Purdy, 2001; Schafer & Thibodeau, 2003). Currently, research addressing speech recognition performance in adults with bilateral hearing aids also showed significantly better performance with FM-system input to two ears relative to one (Lewis, Crandell, Valente, & Horn, 2004).

Armstrong, Pegg, James, and Balmey (1997) compared the perception of speech in quiet and in noise by adults using a cochlear implant on its own or a cochlear implant and hearing aid together. The study was a laboratory study using subjects' own speech processors. Two groups of cochlear implant users, Australian and American, with some residual hearing in the non-implanted ear were selected as subjects. The pure tone average thresholds at 500 Hz, 1 kHz, and 2 kHz were 75 tol 12 dB HL. Cochlear implant together with conventional hearing aid was used by them. The hearing aid was used in the ear opposite to the implant. Speech perception was evaluated using recorded lists of CUNY sentences and lists of CNC words in quiet and in background noise. Results indicated that speech scores were significantly higher with implant and hearing aid together compared to implant alone. The binaural advantage was greater in background noise than it was in quiet for CUNY sentences in the American listeners. Thus it was concluded from the study that adults with severe-to-profound hearing impaired adults may benefit from combined fitting of implants and conventional hearing aids in opposite ears.

Lewis, Crandell, Valente, and Horn (2003) reported that the major consequence of sensorineural hearing loss (SNHL) is communicative difficulty, especially with the addition of noise and/or reverberation. The purpose of this investigation was to compare two types of technologies that have been shown to improve the speech-perception performance of individuals with SNHL, directional microphones and frequency modulation (FM) systems. Forty-six adult subjects with slight to severe SNHL served as subjects. Speech perception was assessed using the Hearing in Noise Test (HINT) with correlated diffuse noise under five different listening conditions. Results revealed that speech perception was significantly better with the use of the FM system over that of any of the hearing aid conditions, even with the use of the directional microphone. Additionally, speech perception was significantly better with the use of two hearing aids used in conjunction with two FM receivers rather than with just one FM receiver. Directional microphone performance was significantly better than omni-directional microphone performance. All aided listening conditions were significantly better than the unaided listening condition.

Boothroyd, and Iglehart (1998) conducted experiments with class room FM amplifications. The objective of the study were to quantify the benefits of FM amplification for persons with severe and profound hearing loss; to compare a body-worn and a behind-the-ear FM system; and to measure the effects of reducing FM microphone sensitivity relative to hearing aid sensitivity. Recognition of phonemes in lists of consonant-vowel-consonant words was measured in 13 teenage students with severe and profound hearing loss. Presentation was by live voice at 10 feet from the listeners and 12 inches from the FM microphone/transmitter. Students listened: *a)* via a body-worn and a behind-the-ear system; *b)* with the FM microphone/transmitter on and off; *c)* in noise and in quiet. Systems were adjusted so that sinusoidal inputs of 65 dB SPL gave equal gains via the FM and hearing aid microphones. In a follow-up study, the gain via the FM microphone was reduced so that a sinusoidal input of 65 dB SPL into the hearing aid microphone produced the same output as a sinusoidal input of 80 dB into the FM microphone (as recommended in American Speech-Language-Hearing Association, 1994). Results indicated that addition of the FM microphone signal to that available from the hearing aid microphone was equivalent, on average, to doubling the number of independent channels of information available to the listeners. In addition, FM benefit was present in both quiet and noise but was somewhat greater in noise. Contrary to prediction, however, noise interfered with phoneme recognition even under the aid+FM condition, which may be either due to the reduced FM settings in the receiver or due to the improper separation of speech and noise by the FM system. The differences between the body-worn and behind-the-ear systems were small, but there was a measurable advantage for the body-worn system under the aid+FM condition. Reducing FM microphone sensitivity by 15 dB virtually eliminated the FM benefit. Forty-four percent of the variance in phoneme recognition (averaged across listening conditions) could be explained by better-ear, three-frequency average pure-tone threshold. Vowels were recognized more easily than consonants, and initial consonants were recognized more easily than final consonants, but the FM benefit was present for all three phonemes. The findings confirm the value of FM amplification for persons with severe and profound hearing loss, in both quiet and noise. The negative effects of noise were not completely eliminated, however, under the aid+FM condition. This finding can be attributed to a reduction of gain in the FM channel, when speech input was used, because of compression limiting in the microphone transmitter. The superiority of the body-worn system under the aid+FM condition suggests a need for higher saturation sound pressure level in the behind-the-ear system when used with persons having severe and profound hearing loss. The findings do not support use of an "equal output" criterion for adjusting relative gains via the FM and hearing aid microphones, at least for persons with very severe and profound hearing loss operating under the conditions tested in this study.

Anderson, and Goldstein Colodzin, & Iglehart, (2005) reported that children typically learn in classroom environments that have background noise and reverberation that interfere with accurate speech perception. Amplification technology can enhance the speech perception of students who are hard of hearing. This study used a single-subject alternating treatments designed to compare the speech recognition abilities of children who were hard of hearing. They were using hearing aids with each of three frequency modulated (FM) or infrared devices. Eight children in the age range from 9 to 12 year with mild to severe hearing loss repeated Hearing in Noise Test (HINT) sentence lists under controlled conditions in a typical kindergarten classroom with a background noise level of +10 dB signal to noise ratio (SNR) and 1.1s reverberation time. Participants listened to HINT lists using hearing aids alone and hearing aids in combination with three types of SNR enhancing devices that are currently used in mainstream classrooms *(a)* FM systems linked to personal hearing aids, *(b)* infrared sound field systems with speakers placed throughout the classroom, and *(c)* desktop personal sound field FM systems. Results indicated that the infrared ceiling sound field system did not provide benefit beyond that provided by hearing aids alone. Desktop and personal FM systems in combination with personal hearing aids provided substantial improvements in speech recognition. This information can assist in making SNR enhancing device decisions for students using hearing aids. In a reverberant and noisy classroom setting, classroom sound field devices are not beneficial to speech perception for students with hearing aids, whereas either personal FM or desktop sound field systems provide listening benefits.

Iglehart (2004) carried out a study to evaluate speech perception by students with cochlear implants using sound-field systems in classrooms. According to Iglehart, sound-field systems can increase speech-to-noise ratios in classrooms and thus improve the use of audition. These systems were used by 80% of the students with cochlear implants who used an FM system in the classroom. The study compared speech perception by 14 school-age children who were cochlear implant recipients, via two classroom sound-field systems, one wall-mounted and the other a personal or desktop system (desk top sound field speakers). The testing was conducted in two classroom environments, one noisy and reverberant (typical of many classrooms) and the other ideally quiet with short reverberation time.

Table 2.1: Mean and standard deviation (SD) of SRS in ideal and poor environment with FM system

	SRS in ideal environment		*SRS in poor environment*	
	Mean	*SD*	*Mean*	*SD*
CI Alone	41%	13	13%	*9*
Wall FM System	50%	16	25%	11
Desktop FM System	48%	17	38%	15

In the quiet room with low reverberation, both sound-field systems produced improved phoneme recognition (Table 2.1), but there was no significant difference between the two. In the noisy room with high reverberation, the sound-field benefits were greater, and the desktop systems provided more benefit than the wall-mounted systems. This finding contradicted that reported by Boothroyd, and Iglehart (1998). They reported that the noise interfered with phoneme recognition even under the aid+FM condition, i.e., as the noise level increased there was more difficulty in speech perception even in aid+FM condition.

Differences in the reports on the addition of FM system with a cochlear implant could be accounted for by the use of optimal settings on the FM system and/or procedural variations. Previously there has been research carried out to find the benefits of FM system by ASHA (2002). Guidelines for the fitting and monitoring of FM system have been provided by ASHA (2002). The test arrangement for evaluating the FM system is shown in Figure 2.1. The child is seated in the sound booth facing the loudspeaker at one-meter's distance with all equipment in place and activated. The examiner is seated facing the audiometer wearing the FM transmitter, but it is in the off position. In order to examine the benefits of a signal presented into the FM transmitter, the examiner must present the speech via monitored live voice while wearing the microphone. Although this adds to the test variability compared to using recorded materials, the benefit received through the use of the transmitter is typically several times greater than the possible variability. Because the testing uses monitored live voice at a fixed presentation level, the result will be a percent correct score. The recommended signal level is 55 dB HL with speech noise presented at 50 dB HL. Both signals can be presented from the same speaker. Although not stated in the ASHA guidelines, it is important to note that if the initial performance equals or exceeds 80% correct, then the noise must be increased to a 0 dB SNR and another list presented.

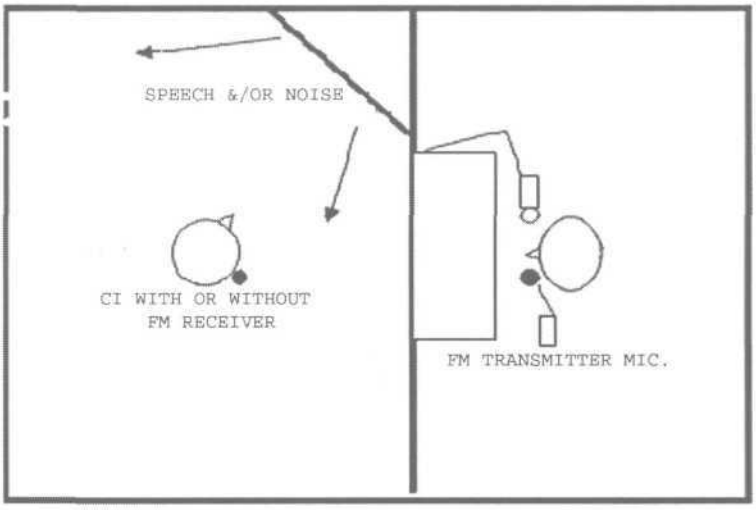
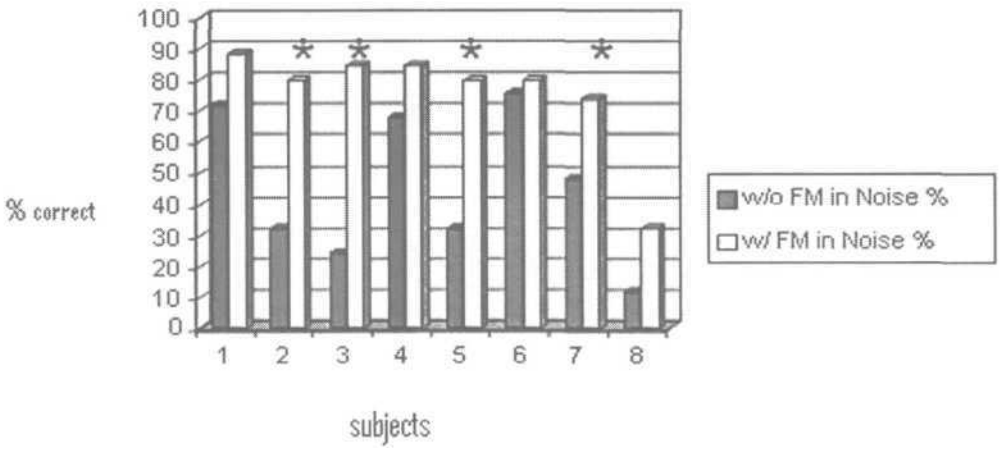


Fig. 2.1: Testing arrangement used for verifying the use of FM system

Thibodeau, Schafer, Overson, Whalen, and Sullivan (2005) stated that it is important to note that if the initial performance with the same reference (ASHA guidelines 2002); equals or exceeds 80% correct, then the noise must be increased to a 0 dB SNR and another list presented. The results of this verification protocol with eight students with cochlear implants, mean age 7.88 years are shown in Figure 2.2. There were a variety of cochlear implants and FM systems worn by the eight students who were evaluated at their user settings. The average speech recognition for single words presented in speech noise at +5 SNR was 45.5%. With the use of the FM system, the performance improved to an average of 76% correct. All of the students showed improved performance with the FM system with the 95% confidence interval ranging from 13 to 47%. As expected, the lower the performance in noise without the FM, the greater the benefit that was observed with the FM system. Although the sample size was small, one may consider the low end of the 95% confidence interval (13%) as an estimate of the minimal improvement expected when an FM system is used with a CI. It should be noted that this guideline is based on a sample of children who were tested at user settings without the benefits of any fine tuning to CI or FM settings.

If the protocol is followed and the improvement with the FM system is less than 13%, then changes to the FM receiver settings or the FM device arrangement should be considered. For example, with the Phonak MLxS miniature "cube-like" FM receiver, changes to the FM advantage may be made through programming software while the CI/FM receiver is turned on and placed in an FM Programming Interface.



Note: * significant improvements re: Thornton and Raffin (1988)

Fig. 2.2: Adapted from Thibodeau, Schafer, Overson, Whalen, and Sullivan (2005) Individual scores for children with a cochlear implant, tested in noise, with and without an FM system.

Schafer, and Thibodeau (2006) measured speech recognition performance in noise was examined in children with cochlear implants when using *(a)* a second CI (bilateral group), *(b)* a hearing aid on the non-implant ear (bimodal group), and *(c)* a frequency modulation (FM) system on one or both sides. While always maintaining use of the first cochlear implant, two groups participated in six conditions each using various listening arrangements with the second cochlear implant, hearing aid, or FM system. Speech-in-noise thresholds measured in terms of signal to noise ratio (SNR) were determined using simple phrases, classroom noise, and a method-of-limits approach. The results did not indicate group differences across any conditions. In the no-FM-system condition, no significant benefit of bilateral or bimodal input was found relative to a single cochlear implant. In the FM-system condition, thresholds were significantly lower (up to 20 dB) relative to all other conditions when FM-system input was provided to the first-implanted side or to both sides simultaneously, as illustrated in Figure 2.3.

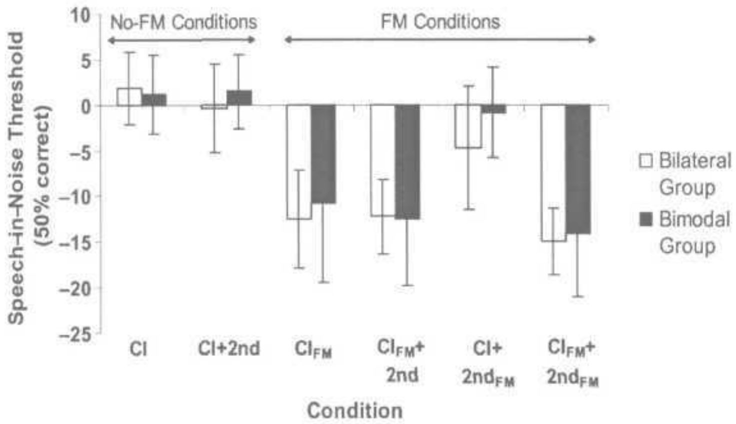


Fig. 2.3: Average SRT in noise for the bilateral and bimodal groups (Adapted from to Erin C. Schafer & Linda M. Thibodeau, 2006)

Speech-in-noise thresholds of children did not improve when providing input to the second side with a cochlear implant or a hearing aid relative to a single cochlear implant. However, children with CIs had better speech recognition in noise with the use of an FM system on one or both sides relative to the conditions with no FM system. Binaural conditions with a single FM receiver on the second cochlear implant or hearing aid yielded significantly poorer performance than any other FM condition.

Schafer, and Thibodeau (2004) studied speech recognition abilities of adults using cochlear implants with FM system. Speech recognition was evaluated for ten adults with normal hearing and eight adults with Nucleus cochlear implants at several different signal to noise ratios. The three FM system arrangements used in the study were desktop, body worn, and miniature direct connect. Participants were asked to repeat Hearing In Noise Test (HINT) sentences presented with speech noise in a classroom setting and percent correct word repetition was determined. Performance was evaluated for participants with both normal-hearing and cochlear implant with the desktop sound field system. In addition, speech recognition for participants with cochlear implant was evaluated using two FM systems electrically coupled to speech processors. When comparing the desktop sound field and the no-FM condition, only the listeners with normal hearing made significant improvements in speech recognition in noise. When comparing the performance across the three FM conditions for the cochlear implant listeners, the two electrically coupled FM systems resulted in significantly greater improvements in speech recognition in noise relative to the desktop sound field system.

How ever, there are also studies demonstrating no improvement when FM system is used. Crandell, Holmes, Flexer, and Payne (1998) studied word recognition for eight children and ten adults with cochlear implants and they found that there was no benefit using FM system and there was no change in the results obtained between adults and children.

Table 2.2: Word recognition scores in CI alone and CI+FM condition

	CI alone	*CI+Sound Field FM*
Quiet	72%	70%
Noise	70%	69%

This variability in the result may be attributed due to factors related to optimization of FM with the CI and factors related to the testing protocol used. Hence, the present study was designed with an intention to evaluate the effect of addition of an FM system to a cochlear implant.

Chapter 3

METHOD

The study, intended to document the benefits of the FM system coupled to a cochlear implant (CI), was designed using data from 12 children with pre-lingual hearing loss using cochlear implants. The following method was used to study the benefits of FM system in these children.

Participants

12 children who met the following criteria served as the participants for the study:

i. All children had severe to profound hearing loss
ii. Hearing loss of pre-lingual onset
iii. Age range from 3 to 8 years (mean age = 6.29years)
iv. Malayalam speaking children and all were attending auditory verbal therapy.
v. Users of cochlear implant, on either right ear or left ear. None of them used a hearing aid in opposite ear. They used the CI during all the waking hours.
vi. The children had the ability to point to the pictures of the words presented in audio mode.

Table 3.1: Demographic data of the participants.

Participant No.	*Ear Implanted*	*Age at implantation (in months)*	*Stable map*	*Duration of training after implant (in months)*	*Type of implant*
1	Left	25	Yes	25	CI-24M
2	Right	24	Yes	18	CI-24M
3	Right	34	Yes	24	CI-24M
4	Right	31	Yes	20	CI-24M
5	Right	50	Yes	9	Contour
6	Left	42	Yes	9	CI-24M
7	Right	61	Yes	18	CI-24M
8	Right	23	Yes	18	CI-24M
9	Left	53	Yes	17	CI-24M
10	Right	94	Yes	11	CI-24M
11	Right	73	Yes	10	CI-24M
12	Right	74	Yes	24	CI-24M

Equipment and Material Used

The following equipment and material were used:

1. A calibrated audiometer with the facility for doing sound field audiometry.
2. Cochlear implant system used by the children, with body level speech processor where in the sensitivity was set at 12 and volume at 9.
3. FM system - Campus S transmitter and MLxS receiver with micro link CI S adaptor.

4. Picture test of speech perception in Malayalam (Mathew, 1996), for children in the age group of 3 to 8 years, as the speech stimulus.

Test Environment

A two room audiometric set-up which was acoustically treated.

Procedure

The procedure involved measurement of speech recognition threshold in noise, i.e., SRT in noise. The speech was presented at a constant conversation level and the level of the noise was varied to obtain the SRT. For the purpose of this study SRT in noise was defined as the difference between the speech and the noise level when the participant repeated at least 2 out of 3 words being presented at a constant level.

The data were collected in two phases:

Phase I: Establishing SRT in noise in CI alone condition

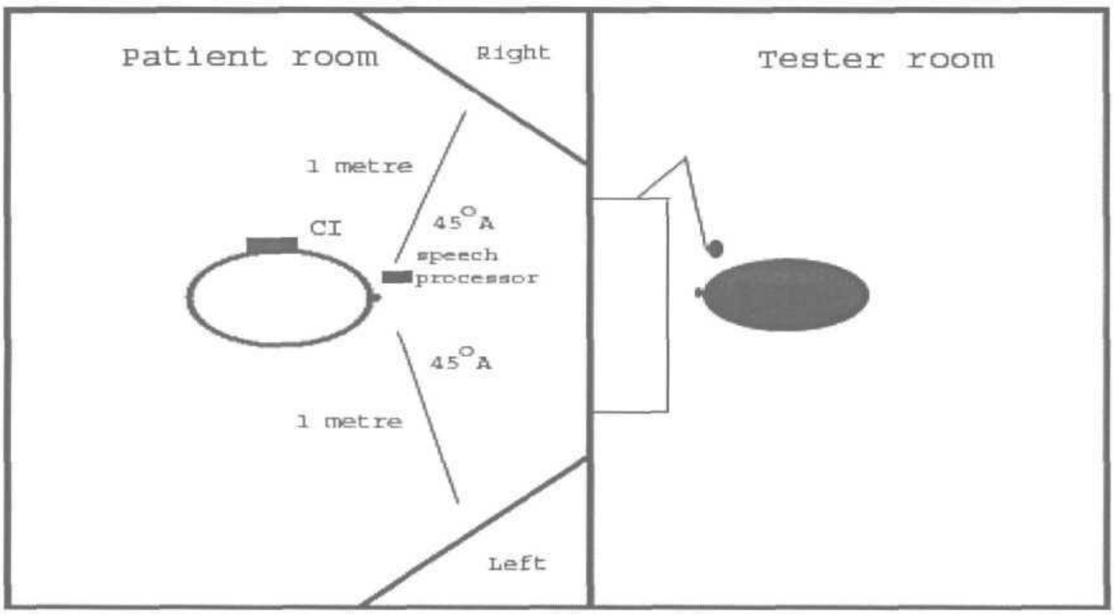
Phase II: Establishing SRT in noise in CI+FM condition

Phase I: Establishing SRT in noise in CI alone condition

Prior to the evaluation, familiarization of the test words in the picture test of speech perception in Malayalam (Mathew, 1996) was ensured for all participants. It was ensured that the speech processor sensitivity was at 12, volume was set at 9 and that the processor of the CI was working satisfactorily. The participant was seated in the test room. The loud speakers were located on the right and left side of the participant at 45° Azimuth. Distance from the centre of participant's head to speakers was maintained at a constant distance of one meter throughout the evaluation as illustrated in Figure 3.1. The signal was delivered through the loud speaker that was closest to the implanted ear. The noise was delivered through the other loud speaker.

Participant was seated in the test room. The picture book was placed on a stool in front of the child. Each page in the book contained four pictures per stimulus word. Turning of the page in the picture book and noting the number of pictures correctly identified was done by a helper inside the test room sitting beside the child.

The participant was instructed to point to the picture which was being presented through the loud speaker by the tester. The speech was presented through monitored live voice. There were two familiarization items to make sure that the participant had understood the task correctly.



Fig, 3.1: Illustration of the test situation in Phase I (CI alone condition).

During the test procedure, monitored live voice was used to present the speech stimulus. The intensity of the speech through the loud speaker was kept constant at 45 dB HL. The starting level for speech noise was 30 dB HL. At this level, i.e., speech at 45 dB HL speech noise at 30 dB HL, three words were presented. The level of the noise was varied till the participant identified two out of three words correctly.

Scoring

The speech recognition threshold (SRT) in noise and signal to noise ratio (SNR) were noted and tabulated for each participant. For the purpose of the study, the speech recognition threshold in noise was defined as the intensity of the noise at which the speech presented at a constant level of 45 dB HL was identified correctly by the participant. The level of noise at which there was correct repetition of at least two out of three words, being presented at a constant level of 45 dB HL, was noted as the speech recognition threshold in noise. For the purpose of the study, the SNR was defined as the difference between the levels of speech and noise at this point.

Phase II: Establishing SRT in noise in CI+FM condition

The microphone of the FM transmitter was positioned on a tripod stand at a distance of 6 inches from the speaker through which speech stimuli was presented, as represented in Figure 3.2. The volume control of the CI-S adaptor was kept constant at the maximum level. The volume control of the CI speech processor and sensitivity of microphone was kept constant at a level of 9 and 12 respectively across measurements.

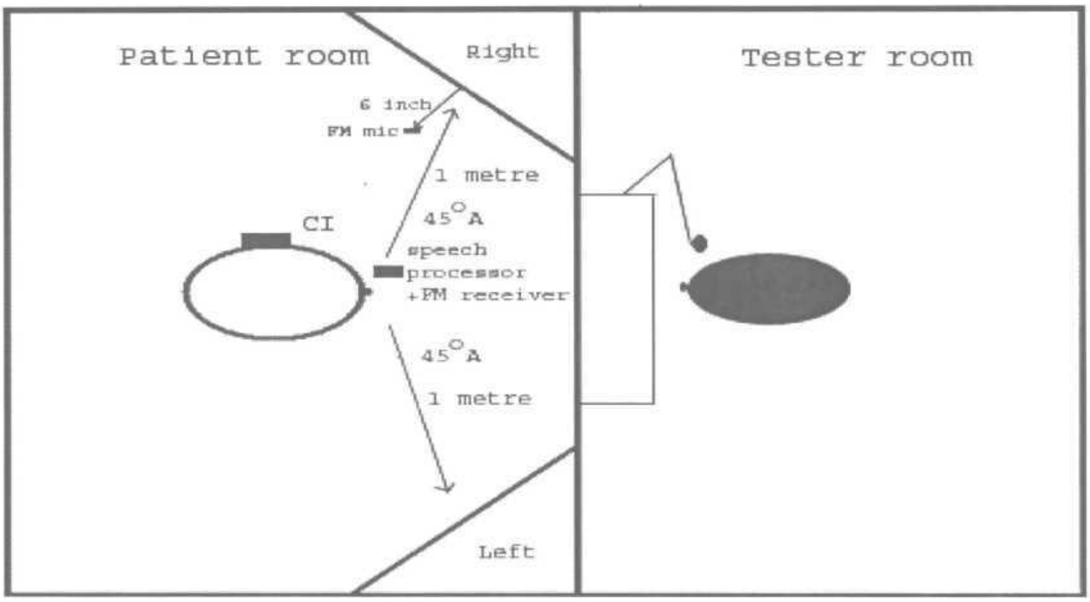


Fig. 3.2: Illustration of the test situation in Phase II (CI+FM condition).

Full charge of the FM system and the CI was ensured before the test. Connecting the FM system in this phase followed the steps mentioned below (as shown in Figure 3.3). Before testing each participant, the functioning of the FM system was confirmed by speaking into the microphone of the FM receiver from the next room and noticing the segment meter variation in the CI speech processor. This was done after setting the CI+FM in the following manner:

1) Prior to the connection the speech processor, FM receiver and transmitter were turned off.
2) The orange cable was plugged into the CI-S adaptor.
3) The FM receiver was connected to the adaptor and the setting of the receiver was kept in double green dot position which is meant for use in FM+M mode so that both the environmental noise and the signals from FM are being received by the CI speech processor.
4) The internal gain setting of the FM receiver was set at the optimized level of 10 dB, as specified in the product specification.

5) The speech processor was then turned 'on' followed by turning the FM transmitter and CI-S adaptor 'on'.

6) Synchronization of the transmitter and receiver of FM system was done.

Fig 3.3: Coupling of FM receiver to the body level speech processor through the adaptor.

The speech recognition threshold in noise and SNR were measured in CI+FM condition using the procedure similar to that in Phase I.

Scoring

At the end of Phase I and Phase II, speech recognition threshold in noise and SNRs were obtained for each participant. The speech recognition threshold in noise and SNR for each participant was tabulated for statistical analysis.

Chapter 4

RESULTS AND DISCUSSION

The aim of the present study was to evaluate the speech recognition performance with and without the FM system in children using cochlear implants. Data were collected from 12 children using cochlear implant for different durations. Statistical analysis was done on the tabulated data using statistical package for social science (SPSS) software version 15.

The following statistical tests were performed to analyze the data:

- Descriptive statistics to examine the central tendency and variation of the performance in children using cochlear implant without and with FM system
- Kruskal-Wallis test to compare the performance of the participants with respect to the duration of implant use.
- Paired t-test to compare the performance of the two test conditions (performance in noise, with and without FM)

From the Figure 4.1 and Table 4.1 it is seen that the mean value of the speech recognition threshold (SRT) in noise obtained in the CI+FM condition was well above that obtained in the CI alone condition. This reveals that the performance with the CI+FM system is fairly higher in comparison with CI alone. The scores in CI+FM were better, on an average, by 11.66 dB compared to CI alone condition. The noise levels were much higher when the participants correctly pointed to the pictures in the CI+FM condition than in the CI alone condition, which reflects the benefit of FM system. The participants were able to point correctly even when the noise was 10 to

15 dB higher than the signal in CI+FM condition, which clearly demonstrates the FM advantage. Boothroyd, and Iglehart (1998) reported that the FM benefit was present both in quiet and noise conditions, but was somewhat greater in noise. In their study, vowels were recognized more easily than consonants, and initial consonants were recognized more easily than final consonants, but the FM benefit was present for all three groups mentioned here. According to them the FM amplification helps individuals with severe to profound hearing loss, in both quiet and noise.

The individual variation shown in the responses highlight the importance of determining an optimal listening arrangement on an individual basis (Figure 4.1). It was not only in the mean values, but even for the participants tested, the SRT in noise was higher in CI+FM condition than in the CI alone condition.

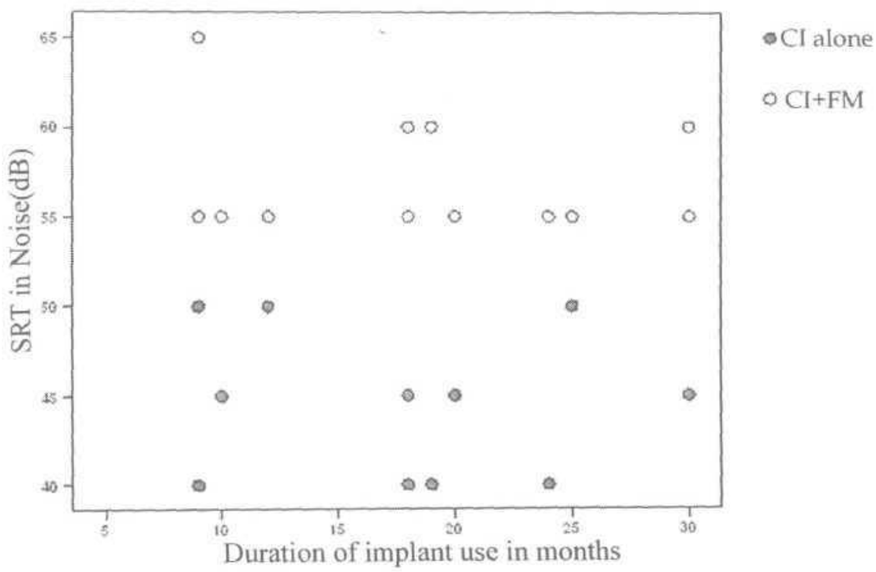


Fig. 4.1: SRT in Noise of the 12 participants using CI for different durations of use.

APPENDIX

Picture test of speech perception in Malayalam by Mathew (1996).

1.	എലി	ell
2.	ആട്	a:d∂
3.	മരം	maram
4.	മുഖം	mugham
5.	കോഴി	ko:rI
6.	നെററി	n∂ t̄ I
7.	താക്കോൽ	ta: k̄o|
8.	നാവ്	n̪a:v∂
9.	മുട്ട	mutta
10.	മൂക്ക്	mu: k̄Λ
11.	തൊപ്പി	t̪0p̄I
12.	ആന	a:na
13.	പശു	pa∫u
14.	വീട്	vi:ḍa
15.	സോപ്പ്	so: p̄∂
16.	ഇല	Ila
17.	ചെവി	t∫evI
18.	പക്ഷി	pak∫I
19.	വള	vala
20.	കുട	kuḍa
21.	ജനൽ	dʒ∂n∂l
22.	ബസ്സ്	bΛs̄∂
23.	നായ്	na:ja
24.	പൈസ	paIsa
25.	ബാഗ്	bæ:gΛ
26.	ബ്രഷ്	bra∫Λ
27.	ബോൾ	b̪a lΛ
28.	തല	t̪ala
29.	പൂവ്	pu:v∂
30.	മാങ്ങ	ma:ηa
31.	ആണി	a:nI
32.	വാതിൽ	va:d̪il
33.	ഡോക്ടർ	d∂:kt∂r
34.	സൈക്കിൾ	saIkIl
35.	ഷൂസ്	∫u:s∂
36.	ചെടി	t∫eḍI
37.	മാല	ma:la
38.	തോക്ക്	t̪o:k̄a
39.	പൂച്ച	pu:t∫a
40.	പല്ല്	p∂llɐ
41.	മഴ	maṛa
42.	പേന	pe:na
43.	വാച്ച്	va:t∫ɐ
44.	കാറ്	ka:ṛ∂
45.	നൂല്	nu:lɐ
46.	വായ	va:ja
47.	ദേഹം	d̪e:h∂m
48.	മേശ	me:∫a
49.	നഖം	nagh∂m
50.	പാന്റ്	pæ:nd∂

Table 4.1: SRT in noise across different durations of implant use

	Duration of implant use	*N*	*Mean*	*SD*
CI alone in dB	0-1 year	4	46.25	4.787
	1-2 year	5	42.00	2.739
	2-3 year	3	50.00	5.000
CI+FM in dB	0-1 year	4	57.50	5.000
	1-2 year	5	57.00	2.739
	2-3 year	3	56.67	2.343

The comparison of different durations of use was done to find out whether there was any significant effect of duration of implant use in understanding speech in noise. Kruskal-Wallis test revealed that there was no significant effect of duration on the performance across varying durations of implant use.

From the Figure 4.2 it is evident that the mean SNRs with FM system is much higher than that without the FM system. Further, it can be observed that there was a difference in the mean SNR with different durations of use in the CI alone condition, though the difference in the mean SNRs with CI+FM condition was not much. To see if this difference was significant, Kruskal-Wallis test was administered. It was seen that there was no statistically significant difference in the performance with and without FM for the three durations of cochlear implant use. The performance with FM showed relatively lesser variation compared to CI alone condition. The lower the performance in noise without FM system, the greater the benefit that was observed with the FM system. Lewis (2004) supported the use of FM systems in children with CIs.

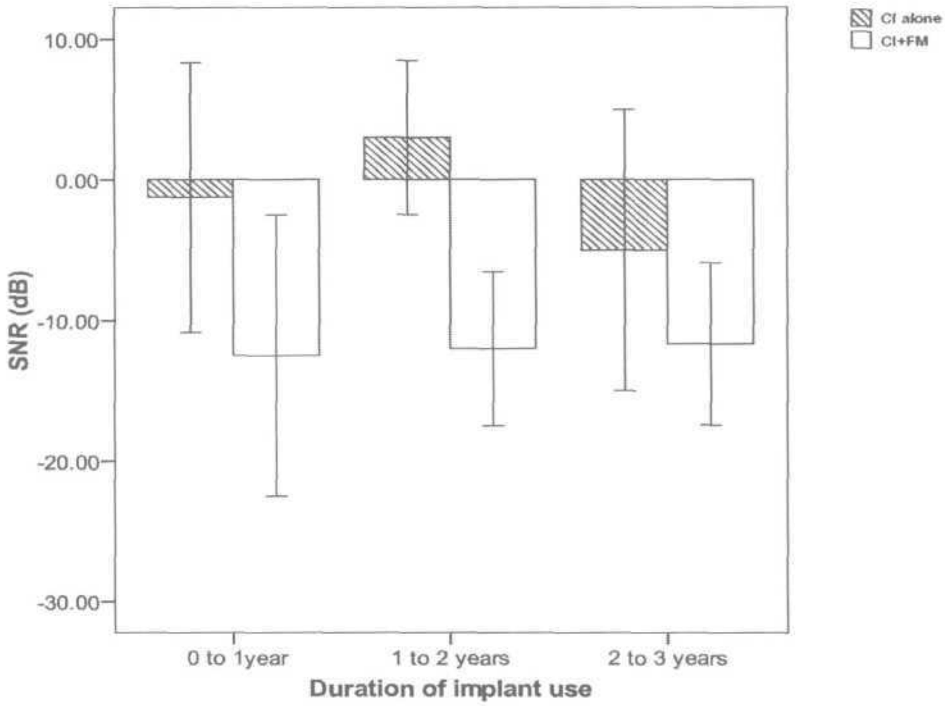


Fig. 4.2: The SNR values across different age groups with and without FM.

As there was no significant difference between the performances in using cochlear implants for different durations, all the participants were grouped as one single group in all the future application of statistics. To examine if there was any significant difference between the two test conditions, paired t-test was performed. From the Table 4.2 it can be noted that the signal to noise ratio was significantly better in the CI+FM condition than in the CI alone condition. Thus, it is evident that children with cochlear implants are able to perceive speech, even when the speech is 11 to 12 dB below the level of noise which might prove to be an effective finding for using FM in the class room environment. The children might be able to perceive speech of teacher more clearly when FM system is used in conjunction with CI.

Table 4.2 Mean and standard deviation of SNR in CI alone and CI+FM conditions.

	Mean	*N*	*Std. Deviation*
CI alone	-0.4167	12	1.438
CI+FM	-12.0833	12	0.965

The results revealed that the mean scores obtained in the two test conditions i.e.; CI alone and CI+FM, were significantly different and that the CI+FM condition gave SNR compared to CI alone condition [t (11) = 8.21, (p<0.001)]. The mean difference was found to be 11.66 dB which was statistically significant (p<0.001). Thibodeau (2005) has also reported similar findings that the average speech recognition for single words presented in speech noise at +5 dB SNR was 45.5% with CI alone condition. With the addition of the FM system, the performance improved to an average of 76% from 45.5%. All of the students showed improved performance with the FM system with the 95% confidence interval, ranging from 13 to 47%. Further, the lower the performance in noise without the FM, the greater the benefit that was observed with the FM system. An FM system provided direct access to the teacher's voice through a teacher-worn transmitter and a student-worn receiver plugged into the CI speech processor. Use of an FM system reduced the negative effects of distance from the speaker, noise, and reverberation in the environment because of the placement of the transmitter microphone 3 to 6 inches from the mouth of the speaker (in this study the placement was 6 inches in front of the signal speaker).

Armstrong, Pegg, James, and Blarney (1997) suggested that the use of a second CI or an HA on the non-implant ear, and an FM system allows for improvements in speech recognition in noise ranging from 10% to 30% or 0.3 to 3.0

dB relative to a single CI alone. These findings are in consensus with the present study.

In a study by Schafer, and Thibodeau (2006), a comparison of no-FM versus FM system showed that the FM system allowed for improvements in SRT in noise up to 20 dB relative to the no-FM condition, and statistically significant differences were detected among the FM-system conditions with FM-system input to the first CI or to both sides providing superior performance. It was also reported that for a child with a single CI, use of an FM system may provide more improvement in speech recognition in noise than the addition of an HA or a second CI. In their study, addition of an FM receiver to a single CI allowed for an average improvement in SRT in noise of 13.3 dB relative to the single CI alone. The large improvements are not surprising considering the ability of the FM system to reduce the deleterious effects of the noise and the distance from the talker.

Davis, and Haggard, 1982; Day, Browning, and Gatehouse, 1988 have opined that the FM system should be considered for children with CIs, which may be a more cost-effective solution for improving speech recognition in noise than a hearing aid or a second CI. They concluded that when children with CIs are using binaural input, FM input to both sides should be considered as it may allow for binaural redundancy (diotic summation) of the FM signal.

Apart from the absolute value of SRT in noise, the relative measure of speech and noise as reflected in the use of signal to noise ratio (SNR) was also evaluated. It is to be noted that lower values of SNR indicates good speech recognition in the presence of noise. In Figure 4.3, lower SNR values indicate that the participants performed well even when the difference between speech and noise was less. Further, the negative SNR values indicate better performance in the presence of noise, even when the level of noise was higher than that of speech.

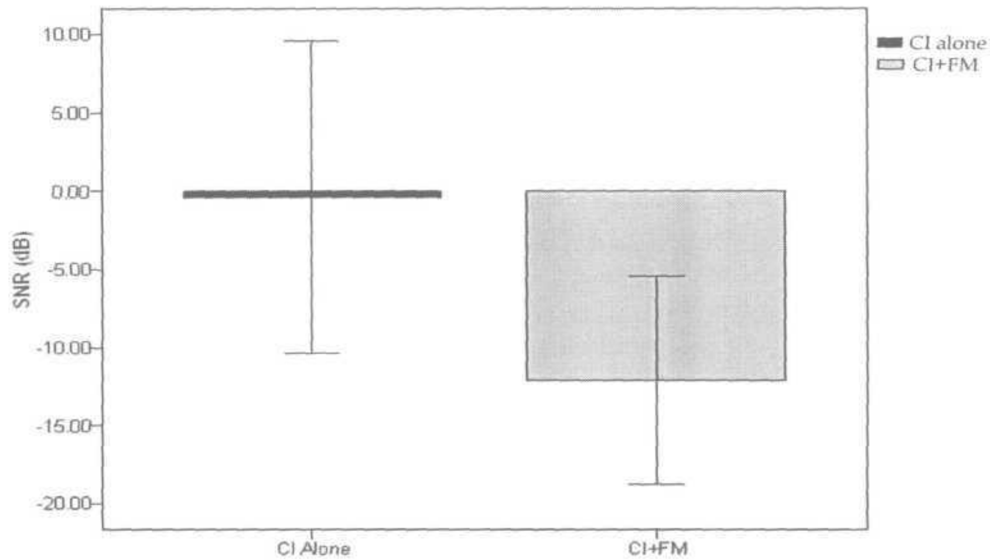


Fig. 4.3: Overall mean and standard deviation of SNR in CI alone and CI+FM conditions.

Arnold, and Canning (1999) in their study reported that difficulty in understanding speech in noise was significant because young children with CIs will encounter noise in all aspects of their lives, including school, where there is a constant level of noise in the classroom ranging from 34 to 73 dBA. Since the noise levels are so high in class rooms there will be difficulty in understanding speech especially for individuals with hearing impairment. In such situations, FM system will definitely be useful.

Iglehart (2004) stated that sound-field systems can improve speech-to-noise ratios in classrooms and thus improve audition. Anderson, and Goldstein (2004) reported that desktop and personal FM systems in combination with personal hearing aids provided substantial improvements in speech recognition. This information can assist in making SNR enhancing device decisions for students using hearing aids or cochlear implants. It was also reported by them that in a reverberant and noisy classroom setting, classroom sound field devices are not beneficial to speech perception for students with hearing aids and cochlear implants, whereas, either personal FM or desktop sound field systems provide listening benefits.

Noise levels less than 40 dB A and reverberation times of about 0.5 seconds were considered to be optimum by teenagers (12-years-olds and older) and young adults having normal speech processing in noise (Picard & Bradley, 2001). To maintain the optimum listening situation of keeping the effect of noise at a lower level, use of FM will be helpful.

The inter-judge reliability of the responses by the participants was validated by comparing the rating of the tester, with the two other audiologists. There was a subjective three point rating scale which described the child performance of the child in terms of good, fair and poor responses. After each evaluation, three audiologists rated the performance independently on the subjective observation of the child response. The speed and accuracy of pointing with and without confusions was the key for demarcating the participants' performance as good, fair or poor. It was found that all the three judges gave the similar rating (good/fair/poor) for a particular participant.

Table 4.3: Reliability of the response through subjective judgment

	Frequency	*Percentage*
Good	10	83.3
Fair	2	16.7

From the Table 4.3 it is evident that the majority of the participants' responses were very consistent (83.3%) and two subjects gave fair responses (16.7%). Thus, the results indicate that the responses of almost all the participants were consistent and reliable through out the study.

These results suggest that an FM system should be considered for children with CIs, which may be a cost-effective solution for improving speech recognition in noise, especially in classroom situations.

A summary of the findings are given below:

1. There was no significant difference among the participants, with and without FM system, with different durations of CI use ranging from 9 months to 25 months.
2. The FM should be considered for children with cochlear implants as it proves to be a cost-effective solution for improving perception of speech in noise
3. The protocol used can be considered as an effective procedure to evaluate the benefit from an FM system in the presence of noise.

Chapter 5

SUMMARY AND CONCLUSION

A way to improve the signal to noise ratio is to use a hearing device that increases the level of the signal or the teacher's voice and brings the signal more effectively to the student's ear. The FM system is such a device that helps to improve the signal to noise ratio especially in individuals with hearing impairment. As the signal is picked up at the level of speaker's mouth, the effect of the background noise that affects the speech perception is being alleviated to a greater extent. It is seen from the review of literature that the FM systems can be used in combination with the cochlear implant so that there is an improvement in the speech identification performance of cochlear implantees in the presence of noise.

This study aimed at evaluating the benefits of an FM system when used in conjunction with cochlear implants. In this study, SRT in noise and signal to noise ratio (SNR) were established for 12 children with pre-lingual hearing loss using a cochlear implant. The duration of use of CI ranged from 9 to 25 months.

The data were collected in Phase I and Phase II. In Phase I, SRT in noise and SNR were established in CI alone condition. In the Phase II SRT in noise and SNR were established in CI+FM condition. The children were instructed to point to the picture which was being presented in a live mode by the tester. Thus, at the end of Phase I and Phase II, two SRT in noise and two SNRs were obtained for each participant, one with CI alone and the other with CI+FM conditions. These data were tabulated for statistical analysis.

The results of this study revealed the following

- The SRT in noise obtained in the CI+FM condition was higher than that obtained in the CI alone condition. This implies that with the CI+FM system is fairly superior to that with CI alone and that the CI user can cope with higher levels of noise in the CI+FM condition than with CI alone condition.

- There was no significant effect of duration (9 months to 25 months) of CI use on the performance.

- The SNR with CI+FM condition was, on an average, higher by 11.66 dB compared to the CI alone condition. That is, when the noise was higher than the speech by up to 11.66 dB participant performed better in CI+FM than in CI alone condition. This implies that children with cochlear implants and the FM systems are able to perceive speech, even when the speech is 11 to 12 dB below the noise level which might prove to be an effective finding for use of an FM in the class room environment.

From the results we can conclude that

- There is a significant improvement in the speech perception in noise when FM system is coupled to a cochlear implant. Even when the noise was 10 to 15 dB higher than the signal, there is unaltered speech perception.

- Use of FM system with a cochlear implant is an effective means to improve the perception of speech in the presence of noise.

Clinical implications

FM system should be considered for children with CIs, which may be a cost-effective solution for improving speech recognition in noise. The findings of this study support the use of FM system in cochlear implantees, especially in class room situations. Thus these findings can be disseminated to the parents, school authorities and other centers to justify the need for use of an FM system. The protocol used to determine the benefit of the FM system is also found to be suitable for evaluating the benefit of FM systems.

Recommendations for future research

1) More number of participants could be included in the study for generalization of findings.
2) Other models of cochlear implants and FM systems could be included.

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APPENDIX

Picture test of speech perception in Malayalam by Mathew (1996).

1. എലി	elI	30. മാങ്ങ	ma:ŋa
2. ആട്	a:d∂	31. ആണി	a:nI
3. മരം	maram	32. വാതിൽ	va:$^{d}_{n}$il
4. മുഖം	mugham	33. ഡോക്ടർ	d∂:kt∂r
5. കോഴി	ko:rI	34. സൈക്കിൾ	saIkIl
6. നെററി	n∂ t̄ I	35. ഷൂസ്	∫u:s∂
7. താക്കോൽ	ta: k̄o|	36. ചെടി	t∫eḍI
8. നാവ്	n̪a:v∂	37. മാല	ma:la
9. മുട്ട	mutta	38. തോക്ക്	$^{t}_{n}$o:k̄a
10. മൂക്ക്	mu: k̄Λ	39. പൂച്ച	pu:t∫a
11. തൊപ്പി	$^{t}_{n}$0p̄I	40. പല്ല്	p∂lla
12. ആന	a:na	41. മഴ	maɹa
13. പശു	pa∫u	42. പേന	pe:na
14. വീട്	vi:ḍa	43. വാച്ച്	va:t∫a
15. സോപ്പ്	so: p̄∂	44. കാറ്	ka:r∂
16. ഇല	Ila	45. നൂല്	nu:la
17. ചെവി	t∫evI	46. വായ	va:ja
18. പക്ഷി	pak∫I	47. ദേഹം	$^{d}_{n}$e:h∂m
19. വള	vala	48. മേശ	me:∫a
20. കുട	kuḍa	49. നഖം	nagh∂m
21. ജനൽ	dʒ∂n∂l	50. പാന്റ്	pæ:nd∂
22. ബസ്സ്	bΛs̄∂		
23. നായ്	na:ja		
24. പൈസ	paIsa		
25. ബാഗ്	bæ:gΛ		
26. ബ്രഷ്	bra∫Λ		
27. ബോൾ	$^{b}_{n}$a lΛ		
28. തല	$^{t}_{n}$ala		
29. പൂവ്	pu:v∂		