Contribution of FM System for Speech Recognition in Noise in Cochlear Implantees

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Abstract

The aim of the study was to evaluate the influence of the FM system for each participant using a cochlear implant by evaluating the speech identification performance in noise, with and without the FM system, with different durations of cochlear implant use. The study was designed using data from 12 children with pre-lingual hearing loss using cochlear implants. The data were collected in two phases. 1) Establishing SRT in noise in CI alone condition 2) Establishing SRT in noise in CI+FM condition. 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 better SNR compared to CI alone condition. The difference in mean scores was found to be 11.66 dB which was statistically significant. The results also indicated that 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. 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, the speech perception was unaltered and that the use of FM system with a cochlear implant is an effective means to improve the perception of speech in the presence of noise. 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 by cochlear implantees, especially in class room situations.

Key words: SRT in noise, signal to noise ratio (SNR), CI alone, CI+FM

Introduction

Cochlear implant is 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 and Zeng, 2005). 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 and Purdy, 2001; Eisenberg, Kirk, Martinez, Ying and Miyamoto, 2004; Litovsky, Parkinson, Arcaroli, Peters, Lake and Johnstone, 2004; Schafer and Thibodeau, 2003).

Difficulty in noise is significant because young children with cochlear implants will encounter noise in most of the situations, including school, where there is a constant level of noise in the classroom ranging from 34 to 73 dBA (Arnold and Canning, 1999; Bess, Sinclair and Riggs, 1984; Knecht, Nelson, Whitelaw and Feth, 2002). Children require speech to be sufficiently higher than the level of noise. That is, the signal to noise ratio required is higher for children than that for adults. According to Picard, and Bradley (2001) individuals with normal hearing can perform well even in 40 dBA noise and even

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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 10-11year 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.

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 can improve speech recognition in noise among children with CIs (Ching, 2000; Ching, Psarros, Hill, Dillon and Incerti, 2001; Davies, Yellon and Purdy, 2001; Dettman, D'Costa, Dowell, Winton, Hill and Williams, 2004; Holt, Kirk, Eisenberg, Martinez and Campbell, 2005; Kühn-Inacker, Shehata-Dieler, Muller and Helms, 2004; Luntz, Shpak and Weiss, 2005; Schafer and Thibodeau, 2003; Senn, Kompis, Vischer and 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 (Nabelek and Pickett, 1974).

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 and Purdy, 2001; Schafer and 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 protocol used for testing, i.e., there could be a ceiling effect with maximum performance being 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 routine way of testing.

The aims of the present study were to study the influence of the FM system in each participant using a cochlear implant; to evaluate the speech identification performance in noise, with and without the FM system; and to evaluate the speech identification performance in noise with and without the FM system, with different durations of cochlear implant use.

Method

The study was designed using data from 12 children with pre-lingual hearing loss using cochlear implants.

Participants

All the children were in the age range from 3 to 8 years (mean age = 6.29 years). They had severe to profound hearing loss bilaterally hearing loss of pre-lingual onset. All of them were speaking in Malayalam and were attending auditory verbal training. They were using of cochlear implant, on either right ear or left ear only. None of them used a hearing aid in opposite ear. They used the CI during all the waking hours. These children had the ability to point to the pictures of the words presented in audio mode.

Table 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	CI-R(CS)
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

A calibrated audiometer with the facility for doing sound field audiometry was used. The children were using the cochlear implant system with body level speech processor, where in the sensitivity was set at 12 and volume at 9. An FM system - Campus S transmitter and MLxS receiver with micro link CI S adaptor was used. A Picture test of speech perception in Malayalam (Mathew, 1996), for children in the age group of 3 to 8 years, was used as the speech stimulus.

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 levels of speech and the noise when the participant repeated at least 2 out of 3 words being presented at a constant speech 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 also 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 45^0 Azimuth. Distance from the centre of participant's head to loud speakers was maintained at a constant distance of one meter throughout the evaluation as illustrated in Figure1. 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.

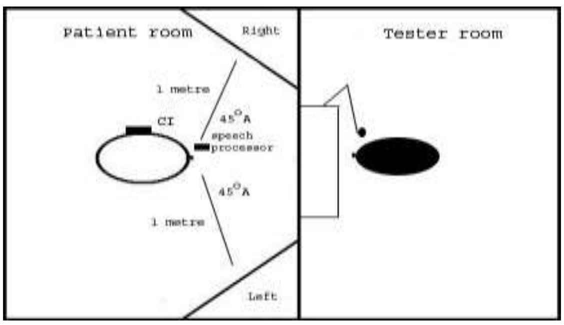

Figure. 1: Illustration of the test situation in Phase I (CI alone condition).

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 correctly identified two out of three words being presented.

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 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 were kept constant at a level of 9 and 12 respectively across measurements.

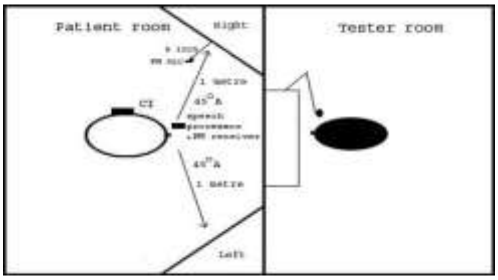

Figure 2: Illustration of the test situation in Phase II (CI+FM condition).

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). Before testing each participant, the functioning of the FM system was ascertained 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.

Figure 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.

Results and Discussion

Statistical analyses were done on the tabulated data using statistical package for social science (SPSS) software version 15. From the Figure 4 and Table 2 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 revealed that the performance with the CI+FM system was fairly higher in comparison with CI alone. On an average, the scores in CI+FM were better, 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 system helps individuals with severe to profound hearing loss, in both quiet and noise.

The individual variation of SRT in noise highlights the importance of determining an optimal listening arrangement on an individual basis (Figure 4). It was not only in the mean values, but even for each of the participants tested, the SRT in noise was higher in CI+FM condition than in the CI alone condition.

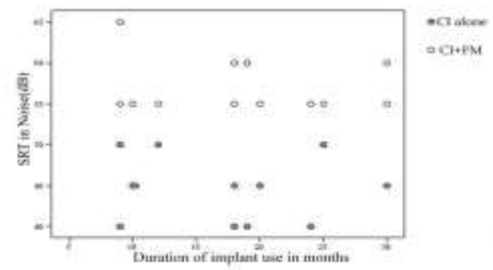

Figure. 4: SRT in noise of the 12 participants using CI for different durations of use.

Table 2: SRT in noise (dB) across different durations of implant use

	Duration of implant use	*N*	*Mean*	*SD*
	0-1 year	4	46.25	4.787
CI alone	1-2 year	5	42.00	2.739
in dB	2-3 year	3	50.00	5.000
	0-1 year	4	57.50	5.000
CI+FM	1-2 year	5	57.00	2.739
in dB	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 5, it is evident that the mean SNR 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. Earlier, Lewis, Crandell, Valente and Horn (2004) has also supported the use of FM systems in children with CIs.

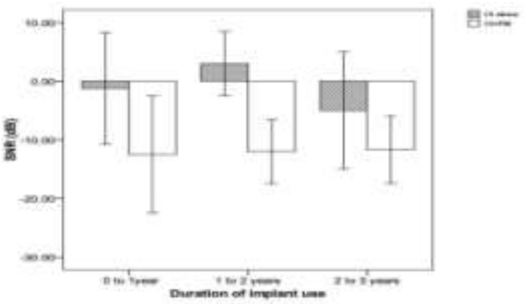

Figure 5: The SNR values across different age groups with and without FM.

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 this (Table 3), it can be noted that the signal to noise ratio was significantly better in the CI+FM condition than in the CI alone condition [t (11) = 8.21, ($p<0.001$)]. Thus, it is evident that children with cochlear implants are able to perceive speech significantly better, even when the speech is 11 to 12 dB below the level of noise. This finding proves to be effective in justifying the use of FM system in the noisy environment. This has implication in the classrooms also. The children might be able to perceive speech of teacher more clearly when FM system is used in conjunction with CI.

Table 3: Mean and standard deviation of SNR (dB) 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

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 an FM system, the performance improved to an average of 76% from 45.5%. All 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).

In a study by Schafer and Thibodeau (2006), a comparison of no-FM and FM system showed that the FM system allowed for improvements in SRT in noise up to 20 dB relative to the no-FM condition. 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.

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 6, 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.

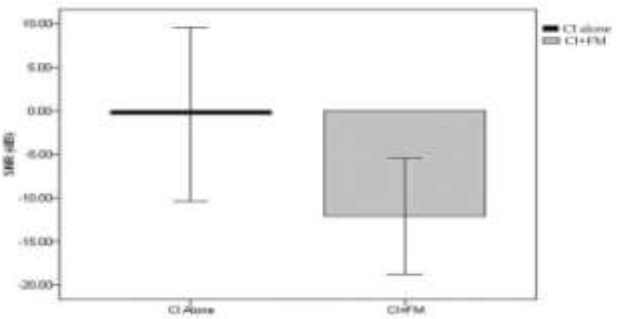

Figure 6: Overall mean and standard deviation of SNR in CI alone and CI+FM conditions.

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 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: Reliability of the response through subjective judgment

	Frequency	Percentage
Good	10	83.3
Fair	2	16.7

From the Table 4 it is evident that the majority of the participants were very consistent (83.3%) and two participants 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. This has implications in classroom situations.

Conclusions

The results of this study revealed the following:

- There was no significant effect of duration (9 months to 25 months) of CI use on the performance.
- 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.
- 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 the participant was able to perform 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, the speech perception is unaltered.
- 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.

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