FM for Cochlear Implants

Chapter 12

Effects of FM Receiver Gain on Performance with Cochlear Implants

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Introduction

Children and adults who use cochlear implants (CIs) often achieve open-set speech recognition in quiet environments; however, listening in noise severely degrades performance. For example, speech recognition may decline by 35 to 47 % relative to performance in quiet conditions (Schafer & Thibodeau, 2003, 2004). Given the deleterious effects of noise, frequency-modulated (FM) systems are often recommended to improve the signal-to-noise ratio for the listener. Use of FM systems often significantly improves performance, but to what extent, is dependent on the type of FM receiver in use.

Types of FM receiver for Cochlear Implants

Three types of FM receivers used with CIs include classroom soundfield, desktop soundfield, and electrically-coupled receivers. Classroom soundfield receivers transmit the FM signal through one or several mounted loudspeakers, while desktop soundfield receivers encompass one small loudspeaker, which is often placed on a desk or table in front of the listener. Soundfield systems often allow for improvements in signal-to-noise ratio for several students in a classroom, and they do not require any specialized equipment for the listener. However, research on soundfield systems for adults and children with CIs suggest that classroom (Crandall et al, 1998) and desktop receivers (Schafer & Thibodeau, 2004) do not always result in significant improvements in performance. Electrically-coupled FM receivers plug into CI speech processors with specialized receivers, adaptors, and cables, and bring the FM signal directly to the listener's ear. This type of system does require individualized equipment for the listener, but according to research, it consistently and significantly improves speech-recognition performance in noise (Anderson et al, 2005; Schafer & Thibodeau, 2003, 2004; Wolfe & Schafer, in press, 2008).

Electrically-coupled receivers connect to currently-used CI speech processors via (1) specialized receivers with cables, (2) FM adaptors, (3) FM earhooks, or (4) design integration/direct connect. Specialized receivers include the Phonak MicroLink CIS (MLxS/MicroMLxS receiver) and the Oticon Amigo FM-CI adaptor (Amigo receiver). One example of a specialized receiver is shown in Figure 1.

Figure 1. Example of a specialized receiver: Platinum processor coupled to Microlink CIS

These receivers attach to most ear-level or body-worn speech processors with specified cables. Only one specialized adaptor is currently available, the ESPrit 3G MicroLink adaptor, which
is shown in Figure 2.

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Figure 2. Example of a FM adaptor: ESPrit 3G processor coupled to a MLxS receiver with a ESPrit 3G MicroLink adaptor.

This adaptor is used to connect Phonak MLxS/MicroMLxS or Oticon Amigo receivers to the Cochlear Corporation ESPrit 3G speech processor. Two types of FM earhooks are available from Advanced Bionics Corporation, which include the iConnect Adaptor and the Auxiliary Audio Earhook. The iConnect earhook, shown in Figure 3, is used to connect Phonak MLxS/MicroMLxS or Amigo receivers to the Advanced Bionics Auria speech processor.

Figure 3. Example of a FM earhook: Harmony processor coupled to MLxS receiver with the iConnect earhook.

The Auxiliary Audio Earhook is used to connect specialized receivers with cables to Advanced Bionics CII or Platinum behind-the-ear speech processors. The final type of coupling is through design integration or a direct electrical connection of the receiver. Currently, the only design-integrated receiver is the Freedom FM, shown in Figure 4, which is designed for use with the Cochlear Corporation Freedom speech processor.

Figure 4. Example of design integration: Freedom processor coupled to MicroLink Freedom FM.

The FM receiver on the Freedom FM is integrated into a battery pack for the speech processor. The body-worn Freedom processor allows for direct connection of a Phonak MLxS/MicroMLxS or Oticon Amigo receiver through an accessory socket on the speech processor.

Which Type is Optimal?

Comparisons of speech-recognition performance in noise with various types of receivers yield variable results. For example, Anderson and colleagues (2005) report that desktop soundfield and electrically-coupled receivers significantly improve performance, while classroom soundfield receivers do not. No performance differences were detected between the desktop soundfield and electrically-coupled receivers. Schafer and Thibodeau (2003, 2004) provide similar results for desktop soundfield and electrically-coupled receivers. However, adults with CIs did not receive any significant benefit from use of the desktop soundfield systems (Schafer & Thibodeau, 2004).

Given the inconclusive findings of these studies, we are conducting a meta analysis to provide a consensus as to which type of system provides the greatest improvements in speech-recognition performance (Schafer & Kleineck, 2008). Preliminary results suggest that desktop soundfield and electrically-coupled receivers significantly improve performance relative to the CI alone; however, the electrically-coupled receivers provide significantly greater gains in speech recognition than the desktop receivers. Classroom soundfield systems did not significantly improve speech-recognition performance and yielded significantly lower gains than the electrically-coupled receivers. Overlapping 95 % confidence intervals suggest no differences in speech-recognition improvements between the classroom and desktop soundfield receivers. Preliminary findings of the meta analysis provide strong evidence that electrically-coupled systems provide the greatest improvements in speech recognition in noise for users of CIs.

FM Receiver Gain

On many newer FM receivers, including the Phonak MLxS/Micro MLxS and Oticon Amigo, the audiologist has the ability to adjust the receiver gain. The receiver-gain setting determines the relationship of the signal from the FM system and the signal from the speech processor microphone. On the Phonak receivers, the gain is adjusted with a specialized FM-programming interface and software. The gain of the Oticon Amigo may be adjusted with using the Amigo Transmitter (T21) or a Wireless Receiver Programmer. The Phonak and Oticon receiver both have a 30-dB range for setting FM gain.

It is possible that gain setting higher than +10 would be preferred by listeners and would result in better performance.

According to the American Speech-Language-Hearing Association Guidelines for Fitting and Monitoring FM systems (2002), the user should receive at least a +10-dB FM advantage relative to the environmental signal. The simple solution to achieving the recommended +10-dB FM advantage would be to adjust the receiver gain to +10; however, this programming will not ensure the recommended setting nor will it guarantee the optimal gain for an individual with a CI. The first challenge with CIs is the inability to do an informal listening check or conduct electroacoustic testing, which would allow for an objective measurement of the +10-dB FM advantage. Second, there are several speech-processor parameters that may interfere with the actual advantage to the listener including the sensitivity setting, audio-mixing ratio, and the input dynamic range. Sensitivity settings control the input from the speech processor microphone, with lower settings providing less environmental input. There is some evidence that lower sensitivity settings may improve speech-recognition performance of children using CIs and specialized receivers (Aaron et al, 2003). Similar to FM gain, audio-mixing ratios (e.g., 50/50, 30/70) determine the relationship of the signal from the FM system and the speech processor. Data from Auria users suggest that the mixing ratio will not affect performance in noise with an FM system, but some settings (30/70) may reduce the person's ability to hear environmental signals through the speech processor in quiet environments (Wolfe & Schafer, in press). The effects of input dynamic range of the speech processor will be examined in the discussion section. Finally, there is no data to suggest the optimal FM receiver gain for users of CIs. It is possible that gain setting higher than +10 would be preferred by listeners and would result in better performance.

While there are several parameters to explore with CIs, the purpose of the following manuscript is to describe the effects of receiver gain on speech perception in noise and subjective reports of adults and children using CIs and FM systems. We begin by presenting data from five children using CIs and electrically-coupled FM systems. This data is followed by results from 15 adults using FM receivers coupled to various speech processors. Descriptions of these data will be followed by clinical recommendations for adults and children using FM systems coupled to their speech processors.

Data from Children

Participants included five children, ages 5 to 13 years, using unilateral (N=1) or bilateral CIs (N=4). The child using a unilateral CI had an Auria behind-the-ear (BTE) speech processor, while all bilateral CI users used an Auria on the second-implanted ear. The children with bilateral CIs used a Platinum body-worn (N=2), Platinum BTE (N=1) or Auria (N=1) speech processor on the first implanted ear. Children had at least six months of cochlear-implant use with their second implant, and a score greater than 20 % correct for monosyllabic word-recognition testing in a quiet condition in the ear used for testing (HiResolution 90K with the Auria).

Testing was conducted in two sessions. The first session included all behavioral speech-recognition testing and a parent questionnaire. This was followed by a two-week trial with the FM system set to the gain level yielding the best performance. The second session only involved a post-trial, follow-up questionnaire.

During the speech-recognition testing, children used the Advanced Bionics Corporation iConnect adaptor, Phonak MicroLink MLxS receiver, and Campus S transmitter set to a directional microphone setting. While the FM system was in use, the microphone of the Phonak CampusS transmitter was placed six inches from the single-coned loudspeaker, directly in front of the center of the cone. Speech-recognition assessment in quiet and noise was only conducted with Auria speech processors. Therefore, all of the children with bilateral CIs were tested while only using their later-implanted 90K CI system with the Auria BTE speech processor. The children's Auria sound processors remained at the default audio-mixing ratio of 50/50 during all measurements.

Assessment of speech recognition in quiet was completed in four conditions with the use of the Phonetically-Balanced Kindergarten (PBK-50) monosyllabic word-recognition test (25-word list) or the Multisyllabic Lexical Neighborhood Test (MLNT) word-recognition test (two 12-word lists). Percent-correct word recognition in quiet was assessed with and without the FM system at two presentation levels: 35 dB HL (consistent with soft-spoken speech) and 50 dB HL (consistent with average conversational level speech). The order of the four quiet conditions and the stimuli lists were randomly selected.

Percent-correct sentence recognition in noise was assessed in five listening conditions using two randomly-selected, 10-sentence lists of the children's version of the Hearing In Noise Test (HINT-C). Sentences were presented at 65 dBA from a loudspeaker at 0 degrees azimuth while continuous four-talker babble (Central Institute for the Deaf) was presented at 60 dBA from a loudspeaker at 180 degrees azimuth. The children were tested without the FM system (implant alone) and with the FM system at four different FM-advantage settings (10, 12, 14, and 16 dB).

The parent questionnaire was used to assess the children's listening aptitude in a variety of situations when using the CI alone and CI coupled to the personal FM system. It was designed to assess perceptions of the convenience and comfort of the implant and FM system, as well as the clarity of sound and ease of communication in a variety of environments. The questionnaire, administered during the first session, examined perceptions about the Auria processor. Following the two-week trial, the questionnaire assessed opinions regarding the personal FM system. During trial periods, children using bilateral CIs used two FM receivers. Children using bilateral Auria processors used an iConnect adaptor coupled to the Phonak MLxS receiver for each ear while the other children with bilateral implants used the Phonak MLCI MicroLink adaptor to couple the MLxS receiver to the speech processor for their first implanted ear. When completing the second questionnaire, the families were asked to focus only on their experience with the iConnect FM adaptor.

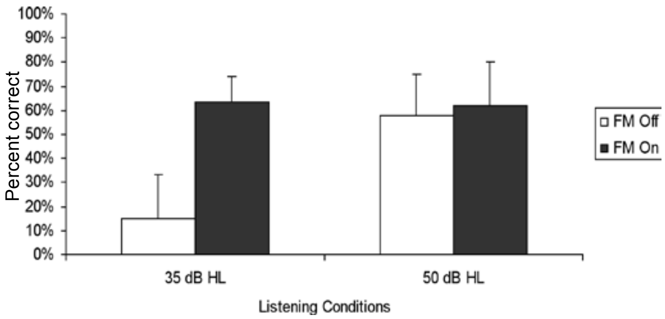

Figure 5. Effects of Receiver Gain on Speech Recognition in Quiet of Five Children with Auria Sound Processors.

Mean results for the speech recognition in quiet conditions are provided in Figure 5. Two t-tests (two-tailed) were conducted to examine differences between the FM on and FM off conditions in quiet at the two stimuli-presentation levels, 35 and 50 dB HL. At the 35 dB HL presentation level, a significant difference was detected between average performance in the FM off (15 %) and FM on (64 %) condition ($p < .01$). However, at the 50 dB HL presentation level, no significant differences were detected between the FM-off (58 %) and FM-on (62 %) conditions ($p > .05$). These findings suggest that use of an FM system significantly improves speech-recognition performance in quiet when listening to low-level speech (35 dB HL), while the benefit at conversational levels (50 dB HL) was minimal.

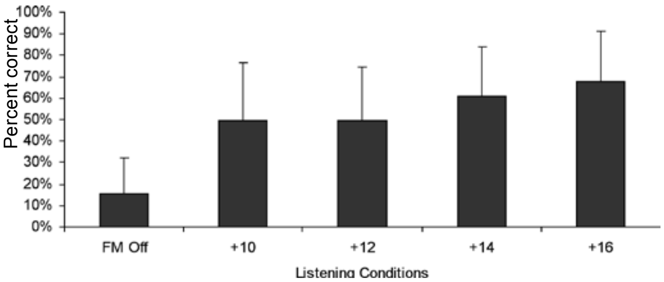

Figure 6. Effects of Receiver Gain on Speech Recognition in Noise of Five Children with Auria Sound Processors.

Mean results for the speech recognition in noise conditions are provided in Figure 6. The five speech-recognition conditions in noise were analyzed with a one-way repeated measures analysis of variance. The results of the analysis, with a Geisser Greenhouse adjustment, indicated a significant difference across the conditions ($p < .0001$). Post-hoc testing, using the Tukey-Kramer adjustment for multiple comparisons, indicated that the average speech recognition in the FM-off condition (16 %) was significantly poorer than performance in all conditions with the FM system ($p < .05$). In addition, average performance at the +16 FM receiver-gain setting (68 %) was significantly better than scores at the +10 (50 %) and +12 (50 %) settings. When examining individual scores, all children performed best with the +16 receiver-gain setting. No significant differences were detected between performance with the +14 receiver-gain setting (61 %) and the other conditions with the FM system. These analyses suggest that the FM system significantly improves speech-recognition performance in noise regardless of the FM receiver gain setting. In addition, there is a significant effect of the receiver gain, with the +16 or +14 FM-advantage settings providing optimal performance.

The results of the questionnaire suggest that the FM system significantly improved listening for all children in at least one area of the questionnaire. No parent rated significant improvement with FM in a quiet setting, but several reported substantial benefit in small groups and in the classroom. Three out of five parents suggested that their children had significantly better performance in noise with the FM system. When adding the FM system to the Auria with the iConnect, no parent rated difficulty with changing processor settings (i.e., volume and program) or with retention. In fact, two of five parents reported that the FMs were significantly more comfortable for their children when using the iConnect adaptor relative to the regular earhook. Three children commented on the simplicity and comfort of the personal FM system with the iConnect adaptor for the Auria compared to personal FM use with the Platinum body-worn and BTE processor, which both require cables and modular adaptor. All of the parents stated that they would recommend the personal FM system and iConnect earhook to others. Two families purchased the system, and the other families discontinued use due to satisfactory performance without the FM system.

Data from Adults

Data collection is in progress with adults to examine the effects of receiver-gain settings on speech-in-noise thresholds for sentences in noise. To date, we have data from fifteen adults using various speech processors, which include Advanced Bionics Auria (N=5), Cochlear Corporation ESPrit 3G (N=5), and Cochlear Corporation Freedom (N=5). The adults were tested with Campus

S transmitters with directional lapel microphones and Phonak MLxS/Freedom FM receivers. When the FM system was in use, the transmitter was suspended 6 inches from the loudspeaker. The adults were tested in the following conditions: (1) no FM, (2) FM on with gain at +6, (3) FM on with gain at +10, (4) FM on with gain at +14, and (5) FM on with gain at +20. The speech stimuli consisted of the Bamford-Kowal-Bench Speech-in-Noise Test (BKB-SIN) from Etymotic Research. This multiple-list test measures a 50 % correct sentence-in-babble threshold using a modified-adaptive procedure. Results are provided in dB and suggest the signal-to-noise ratio necessary for the adult to achieve 50 % of key words in the sentences correct. Speech was presented from a loudspeaker at 0 degrees azimuth, and noise was presented from a loudspeaker at 180 degrees azimuth.

A two-factor repeated measures analysis of variance was used to analyze the data as a function of type of speech processor and listening condition. As shown in Figure 7, the adults required positive signal-to-noise ratios to achieve 50 % of key words correct regardless of the speech processor in use.

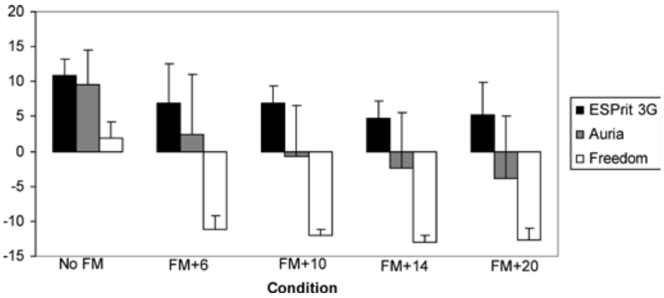

Figure 7. Speech-in-noise thresholds of adults with and without FM receivers set to four gain settings.

Given that lower scores are better, it appears that use of the FM system improved performance relative to the no-FM condition. The analysis revealed a significant effect of the type of speech processor ($p < .05$), a significant effect of listening condition ($p < .05$), and an interaction between speech processor and condition ($p < .05$). Post-hoc testing suggested that the Freedom processor allowed for significantly better performance ($p < .05$) than the other two processors. The differences among processor groups may not be indicative of true difference in processors given the small subject pool for this pilot study. Post-hoc testing also suggested that speech recognition in all four FM conditions was significantly better ($p < .05$) than performance in the no-FM condition. Comparisons among the FM conditions revealed that average speech recognition at the +6 gain setting was significantly poorer than performance in the +14 and +20 gain conditions. No performance differences were detected among the +10, +14, and +20 conditions. Closer examination of the FM conditions shows that receiver gain only affected scores of Auria users, while performance for ESPrit 3G and Freedom users did not change across FM conditions. This finding could be related to the input dynamic range of the speech processor, which will be explored in more detail in the discussion section.

The majority of the adults reported that it was easier to hear the sentences and the man's voice was much clearer when the FM system was in use. Several adults reported perceptual differences among the FM conditions, with a preference for the+10 or +14 settings. In addition, some participants disliked the +20 gain setting because it was distorted or too loud. When paired with subjective comments, preliminary data suggest that adults may derive the most benefit from gain settings of +10 or +14. Further research is necessary to examine why increases in receiver gain did not affect performance of adults using ESPrit 3G and Freedom speech processors.

Discussion

Overall, use of the FM system substantially improved speech-recognition performance of adults and children with CIs for listening to soft speech in quiet and typical speech in noisy conditions. The behavioral data is strongly supported by parent questionnaires and subjective comments from the children and adult data, respectively. In addition, there appears to be an effect of receiver gain for most adults and children. According to the children's speech recognition in quiet, connecting the FM receiver does not appear to negatively affect speech perception of signals not directed to the FM transmitter. The combined data from these two studies suggests that receiver-gain settings of +14 to +16 are preferred by adults and children and allow for optimal speech-recognition performance in noise. Finally, receiver-gain settings may be more important for users of Auria versus ESPrit 3G and Freedom speech processors, which may be related to the input dynamic range of the speech processor.

Input dynamic range is a fixed level that describes the range or window of inputs that are coded by the speech processor. This range is within the person's overall electrical dynamic range. The fixed input dynamic range on the ESPrit 3G and Freedom processors is 30, while the range on the Auria sound processor is 60. Previous research supports that lower input dynamic ranges may allow for better performance in noise than higher levels (Spahr, Dorman, & Loiselle, 2007); however, this may not be the case when FM receivers are electrically-coupled to speech processors. For example, if the processor is coding inputs from 40 to 70 dB, and the FM signal for higher gain settings results in levels above 70 dB, additional receiver gain will not lead to improvements in performance. Therefore, the narrow input dynamic range of the ESPrit 3G and Freedom processors may disallow for the true representation of performance across receiver-gain settings. This limitation is less likely to happen with a 60-dB range of inputs in the Auria speech processor. Further research is necessary to examine our hypothesis related to input dynamic range.

Clinical Recommendations

Selection of receiver gain for a person using a CI appears to be an important aspect of an FM-system fitting. While the data from children and adults suggest optimal benefits at a +14 or +16 setting for the Phonak receivers, individualized testing will be necessary to determine the best setting for each patient. Furthermore, additional receiver-gain research is necessary for the Oticon receiver. We propose that the FM-system fitting include speech-recognition testing in noise as well as subjective questionnaires.

Speech-recognition testing may be conducted in the soundbooth or in a classroom environment through the use of a portable boom box, detachable one-cone loudspeakers, speaker wire, and an inexpensive sound level meter. The loudspeakers should be at a distance of at least three feet from the listener, and the transmitter microphone should be suspended at a distance of three to six inches from the single cone of the speech loudspeaker. The noise loudspeaker should be behind or to the side of the listener, which simulates preferential seating in a classroom.

For speech-recognition materials, we recommend using the BKB-SIN. The split track version of the BKB-SIN allows for presentation of the speech and noise signal from different loudspeakers. BKB-SIN is highly sensitive for detecting differences among listening conditions. When using two list pairs for each condition, differences in scores of adults with CIs must only be 3.1 dB to meet the 95 % confidence interval. When using this test to examine benefits with FM systems, the audiologist should include a condition without the FM system and with the system, set to two or three receiver-gain settings.

Subjective testing may be conducted through questionnaires developed by the audiologist or adapted from existing questionnaires (i.e., Screening Instrument For Targeting Educational Risk [S.I.F.T.E.R.], Anderson, 1989; Children's Auditory Performance Scale [C.H.A.P.S.], Smoski et al, 1998). The questionnaires should be given to the patient, parent, and classroom teacher before and after the FM-system fitting. Regardless of the questionnaire used, the patient should be asked about preferences for different settings and experiences in various listening environments (i.e., quiet, noisy, group). Another effective method of determining experiences with an FM system is patient journaling. Using this technique, patients are given specific questions to consider on a daily basis, and they are also asked to note any listening differences with the FM system.

An FM-system fitting that includes speech-recognition testing as well subjective assessment allows for individualized recommendations for each patient. Because speech-processor settings, including sensitivity, audio-mixing ratio, and input dynamic range, may also affect the user's performance, the subjective measure is imperative to ensure an optimal fit for each patient. When making final recommendations, results from the behavioral and subjective measures may be combined with published data to make a strong evidence-based case for FM-system use and specific receiver settings.

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