J Am Acad Audiol 19:585–594 (2008)

Optimizing the Benefit of Sound Processors Coupled to Personal FM Systems

DOI: 10.3766/jaaa.19.8.2

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Abstract

Background: Use of personal frequency modulated (FM) systems significantly improves speech recognition in noise for users of cochlear implants (CI). There are, however, a number of adjustable parameters of the cochlear implant and FM receiver that may affect performance and benefit, and there is limited evidence to guide audiologists in optimizing these parameters.

Purpose: This study examined the effect of two sound processor audio-mixing ratios (30/70 and 50/50) on speech recognition and functional benefit for adults with CIs using the Advanced Bionics Auria® sound processors.

Research Design: Fully-repeated repeated measures experimental design. Each subject participated in every speech-recognition condition in the study, and qualitative data was collected with subject questionnaires.

Study Sample: Twelve adults using Advanced Bionics Auria sound processors. Participants had greater than 20% correct speech recognition on consonant-nucleus-consonant (CNC) monosyllabic words in quiet and had used their CIs for at least six months.

Intervention: Performance was assessed at two audio-mixing ratios (30/70 and 50/50). For the 50/50 mixing ratio, equal emphasis is placed on the signals from the sound processor and the FM system. For the 30/70 mixing ratio, the signal from the microphone of the sound processor is attenuated by 10 dB.

Data Collection and Analysis: Speech recognition was assessed at two audio-mixing ratios (30/70 and 50/50) in quiet (35 and 50 dB HL) and in noise (+5 signal-to-noise ratio) with and without the personal FM system. After two weeks of using each audio-mixing ratio, the participants completed subjective questionnaires.

Results: Study results suggested that use of a personal FM system resulted in significant improvements in speech recognition in quiet at low-presentation levels, speech recognition in noise, and perceived benefit in noise. Use of the 30/70 mixing ratio resulted in significantly poorer speech recognition for low-level speech that was not directed to the FM transmitter. There was no significant difference in speech recognition in noise or functional benefit between the two audio-mixing ratios.

Conclusions: Use of a 50/50 audio-mixing ratio is recommended for optimal performance with an FM system in quiet and noisy listening situations.

Key Words: FM system, speech recognition

Abbreviations: CNC = consonant-nucleus-consonant; FM = frequency modulation; HINT = Hearing in Noise Test

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Sections of this paper were presented orally at the 11th International Conference on Cochlear Implants in Children, April 2007, in Charlotte, NC, and at AudiologyNOW! 2007 in Denver, CO.

Funding for participant payment, participant travel, and hospital/institutional review board fees was provided by Advanced Bionics Corporation. The FM equipment was provided on loan by Phonak, and subjects were provided with the opportunity to purchase the equipment at a discounted rate after completion of the study. The authors of this manuscript received no compensation from overseeing the study, analyzing the data, or preparing the manuscript.

Sumario

Antecedentes: El uso de sistemas personales de frecuencia modulada (FM) mejora significativamente el reconocimiento del lenguaje en ruido en sujetos con implante coclear (CI). Existen, sin embargo, un número de parámetros ajustables del implante coclear y del receptor FM que pueden afectar el desempeño y el beneficio, y existe evidencia limitada para guiar al audiólogo en la optimización de estos parámetros.

Propósito: Este estudio examinó el efecto de dos tasas de mezcla de audio de un procesador de sonido (30/70 y 50/50) sobre el reconocimiento del lenguaje y los beneficios funcionales para adultos con CI utilizando el procesador de sonido de Advanced Bionics Auria®.

Diseño de la Investigación: Diseño experimental de medidas completamente repetidas. Cada sujeto participó en cada condición de reconocimiento en el estudio, y se recogieron datos cualitativos con cuestionarios.

Muestra del Estudio: Doce adultos usando el procesador de sonido Auria de Advanced Bionics. Los participantes tuvieron puntajes de reconocimiento del lenguaje mayores de 20% con palabras monosilábicas consonante-núcleo-consonante (CNC) en silencio y habían utilizado su CI al menos por seis meses.

Intervención: El desempeño fue evaluado a dos tasas de mezcla de audio (30/70 y 50/50). Para la tasa de mezcla de 50/50, se dio igual énfasis a las señales del procesador de sonido y del sistema FM. Para la tasa de mezcla de 30/70, la señal del micrófono del procesador de sonido se atenuó en 10 dB.

Recolección y Análisis de los Datos: El reconocimiento del lenguaje fue evaluado a dos tasas de mezcla de audio (40/70 y 50/50) en silencio (35 y 50 dB HL) y en ruido (+5 de relación señal-ruido) con y sin un sistema personal de FM. Después de dos semanas de utilizar cada tasa de mezcla de audio, los participantes completaron cuestionarios subjetivos.

Resultados: Los resultados del estudio sugieren que el uso de un sistema personal de FM resultó en una mejoría significativa en el reconocimiento del lenguaje en silencio a niveles bajos de presentación, reconocimiento del lenguaje en ruido y beneficio percibido en ruido. El uso de la tasa de 30/70 resultó en un reconocimiento del lenguaje significativamente más pobre para el lenguaje a bajo nivel que no fue dirigido al transmisor de FM. No existió diferencia significativa en el reconocimiento del lenguaje en ruido o beneficio funcional entre las dos tasas de mezcla de audio.

Conclusiones: El uso de una tasa de mezcla de audio de 50/50 es recomendada para el desempeño óptimo con un sistema de FM en situaciones de silencio y ruidosas para escuchar.

Palabras Clave: Sistema FM, reconocimiento de lenguaje

Abreviaturas: CNC = consonante-núcleo-consonante; FM = modulación de la frecuencia; HINT = Prueba de Audición en Ruido

Advances in cochlear-implant technology continue to allow for significant improvements in outcomes for persons with severe to profound hearing loss. Many recipients of cochlear implant are able to communicate by telephone (Zeng, 2004), and children born with profound hearing loss often develop age-appropriate spoken-language abilities upon receipt of a cochlear implant and specialized therapy (Moog and Geers, 2003; Nicholas and Geers, 2006). Many people with cochlear implants, however, continue to experience difficulty when listening to soft speech (Firszt et al, 2004), speech spoken from a distance, and signals in the presence of noise (Nelson et al, 2003; Stickney et al, 2004).

Personal frequency-modulated (FM) systems have long been recognized as an effective method to improve speech understanding in the aforementioned listening situations (Hawkins, 1984). A personal FM system is comprised of a transmitting and a receiving unit. Typically, a speaker of interest, such as a teacher, wears the transmitter, which is coupled to a microphone that is positioned within six to eight inches of the speaker's mouth. The speaker's voice is received by the microphone, converted to a radio signal, and sent to the receiver, which is directly coupled to the cochlear implant speech processor of the person with hearing loss. Such a configuration overcomes the distance between the speaker and the person with hearing loss and also may improve the speech-to-noise ratio at the listener's ear.

Previous studies suggest that the use of personal FM systems significantly improve speech recognition in noise for users of cochlear implants (Davies et al, 2001; Maddell, 2004; Schafer and Thibodeau, 2004, 2006). However, some audiologists may be reticent about recommending personal FM system for users of cochlear implants because of concerns about the variability of performance, lack of understanding about the benefits, intimidation about the systems, and limitations regarding cost (Phonak AG, 2003). As a result, many audiologists and other professionals recommend use of personal sound field and classroom sound-field systems, which often do not allow for significant improvements in speech recognition in noise for people who use cochlear implants (Crandell et al, 1998; Schafer and Thibodeau, 2004).

Reluctance to use personal FM systems with cochlear implants is most likely attributable to uncertainty about coupling, optimization of the sound processor or receiver, and hesitation related to battery-life issues. In the past, cumbersome cables and adaptors were necessary to allow for direct coupling of personal FM receivers to cochlear implant speech processors. The cables and adaptors were attached to the FM receiver and then to the user's clothing. As a result, many potential recipients were reluctant to use a system that was inconvenient and uncomfortable. Secondly, optimization of the speech processor and personal FM interface typically requires the audiologist to adjust multiple parameters, and formerly, no guidance existed as to how the parameters should be set to maximize benefit. Finally, the use of a personal FM receiver increases power consumption of the external speech processor resulting in issues of reduced battery life.

Technological advances in cochlear implant speech processors and FM systems address many of the aforementioned issues with the recent development of miniaturized FM receivers and specialized adaptors for cochlear implant speech processors. For instance, Phonak Hearing Systems has miniaturized FM receivers (Microlink MLxS) that may be coupled to speech processors with specialized adaptors. One specialized adaptor includes the Advanced Bionics iConnect™ for the Auria® sound processor. The iConnect is an earhook that allows for wireless coupling of a Phonak MLxS personal FM receiver to the Auria ear level speech processor (see Figure 1). The iConnect operates with an independent power source, a size 10 hearing aid battery. Therefore, use of the iConnect coupled to a personal FM receiver has a negligible effect on the current drain of the speech processor battery. Furthermore, unlike many personal FM/cochlear implant interfaces, the iConnect does not have any switches or controls that require adjustment on behalf of the audiologist or patient. The only requirement is the switch of the user's earhook for the iConnect adaptor. Therefore, previous inconveniences associated with personal FM use for cochlear implant wearers are no longer applicable. The improved use of ease and cosmetics of the cable-free system make it a more viable option for adult users who previously have been reluctant to use personal FM systems.

Questions do remain pertaining to the adjustment of sound-processor parameters to optimize performance for people using cochlear implants and personal FM systems. For instance, the Auria sound processor

Figure 1. Phonak MLxS FM receiver coupled to the Advanced Bionics Auria processor via an iConnect adaptor.

possesses an audio-mixing feature that allows the cochlear-implant microphone to remain active while the system is connected to the FM receiver. Thus, users can hear a combination of their voice, environmental sounds or voices, and the signal transmitted by the FM system. The Auria sound processor allows for programming of three audio-mixing settings, which include 50/50, 30/70, and 10/90. The ratio describes the relative strength of the inputs from the sound processor and personal FM system. Previously, the most common mixing ratio for the Auria was 30/70. According to the manufacturer, a 30/70 ratio provides a 10 dB reduction in gain for input from the speech processor microphone resulting in greater emphasis for the signal from the FM transmitter. Today, however, some clinicians prefer the 50/50 setting to allow users to monitor their own voices and hear environmental sounds.

There is a paucity of studies examining FM system acceptance and benefit in adults who use cochlear implants, particularly in the area of yielding optimal benefit from adjustable sound-processor parameters. Therefore, the goal of this experiment was to identify parameters that will optimize the performance of adults using cochlear implants and personal FM systems. Specifically, the effects of two audio-mixing ratios, 50/50 and 30/70, were evaluated for a group of adults using the Advanced Bionics Corporation HiResolution™ cochlear implant system, iConnect adaptor, and a Phonak personal FM system. Performance

Table 1. Participant Demographics

Participant	Age	Duration CI Use	Duration Deafness Before CI	Internal CI
1	40;7	3;4	9;0	CII
2	69;5	2;8	2;6	CII
3	75;0	1;5	2;0	90K
4	69;10	2;9	2;6	CII
5	48;8	2;7	2;0	CII
6	49;0	2;1	2;0	90K
7	59;7	2;0	6;0	90K
8	54;6	2;5	0;6	90K
9	77;1	9;2	1;0	CII
10	59;10	1;11	1;0	90K
11	60;9	2;6	10;0	90K
12	45;5	2;7	1;2	90K

Note: Ages are given in years; months. CI = cochlear implant.

was evaluated with and without the FM system for speech-recognition tests administered in quiet at two presentation levels and in noise. Testing in quiet was primarily completed to determine the audibility of speech signals in the environment with the FM system attached but inactive, while testing in noise is standard practice for assessing benefits of FM systems. Listening benefits in everyday situations, comfort, and ease of use were assessed via questionnaire.

The analyses of the data collected in the quiet and noise conditions will (1) identify any significant improvements in performance while using the FM system with the two audio-mixing ratios and will (2) examine any significant effects of the two mixing ratios on performance when the FM system is in active and inactive modes. The data from the questionnaires will be analyzed to determine how adults with cochlear implants rate the sound quality, ease of use, and benefits of using the FM system at the two audio-mixing ratios relative to their sound processor alone.

METHODS

Participants and Cochlear Implants

As shown in Table 1, the 12 adults in the study were 18 years of age or older and used the Advanced Bionics CII or 90K internal cochlear stimulator with the Auria speech processor. In addition, participants had greater than 20% correct speech recognition on consonant-nucleus-consonant (CNC) monosyllabic words in quiet. The adults used their cochlear implants for at least six months and had no previous experience with a personal FM system coupled to their cochlear implant.

Stimuli and Questionnaire

The adults' speech recognition was assessed in quiet and in noise in a total of 12 conditions. Speech recognition in quiet was assessed with and without the FM system by presenting full 50-word lists of CNC monosyllabic words at 50 dBA (soft speech) and 65 dBA (average conversational level speech). A percent-correct score was obtained for each condition. Speech recognition in noise was evaluated with and without the FM system using two ten-sentence lists of the Hearing in Noise Test (HINT) per condition (Nilsson et al, 1994). A +5 signal-to-noise ratio was used, where the HINT sentences were presented at 65 dBA and Central Institute for the Deaf four-talker babble at 60 dBA. The stimuli lists used for each listening condition were randomly selected. The speech recognition in noise score was determined by calculating the percentage of words repeated correctly per list and averaging the scores for the two lists of sentences used per condition.

The questionnaire, developed by the authors, in conjunction with Advanced Bionics Corporation, assessed the patient's perceptions of the clarity of sound and ease of communication in a variety of listening environments as well as the convenience and comfort of cochlear implant and FM-system use. A similar questionnaire was administered at each of the three testing sessions with differences relating to what device was being rated (Auria or FM system). A condensed version of the questionnaire is provided in Appendix 1. The full questionnaires used more specific wording related to the Auria or personal FM system with iConnect adaptor and additional examples of some of the listening situations.

Equipment and Sound Booth Arrangement

The speech and noise stimuli were presented in a double-wall sound booth using a GSI 61 audiometer, GSI loudspeakers, and two Sony Super Audio compact disc (CD) players (SCD-CE595). The signal loudspeaker was at a distance of one meter from the listener at 0° azimuth. The noise was presented from a loudspeaker positioned one meter from the subject at 180° azimuth (directly behind the subject). The signal and noise were presented with the two separate CD players. All stimuli were presented via CD and were calibrated in dBA using a Type 1 sound level meter.

The FM transmitter used for the study was the Phonak SmartLink. During the two-week trials with the FM system, the participants were trained to use the three microphone settings on the transmitter (Omni, Zoom, SuperZoom). However, during speech-recognition testing the transmitter microphone was set for the directional Zoom setting and was placed six inches from the single-coned loudspeaker positioned at 0° azimuth. The FM receiver was the Phonak MicroLink MLxS, which was coupled to the Auria with the Advanced Bionics Corporation iConnect adaptor. The FM receiver

Table 2. Summary of Testing Sessions and Conditions

Session 1	
Questionnaire 1	Ratings: Auria® Sound processor FM system fitting and counseling
Session 2	
Questionnaire 2	Ratings: Mixing ratio 1
1	Mixing ratio 1: CNC 50, FM on
2	Mixing ratio 1: CNC 50, FM off
3	Mixing ratio 1: CNC 65, FM on
4	Mixing ratio 1: CNC 65 with FM off
5	Mixing ratio 1: HINT +5 SNR, FM on
6	Mixing ratio 1: HINT +5 SNR, FM off
Session 3	
Questionnaire 3	Ratings: Mixing ratio 2
1	Mixing ratio 2: CNC 50, FM on
2	Mixing ratio 2: CNC 50, FM off
3	Mixing ratio 2: CNC 65, FM on
4	Mixing ratio 2: CNC 65 with FM off
5	Mixing ratio 2: HINT +5 SNR, FM on
6	Mixing ratio 2: HINT +5 SNR, FM off

Note: Order of mixing ratios was counterbalanced. Testing conditions and stimuli lists within each testing session were randomized. CNC = consonant-nucleus-consonant; HINT = Hearing in Noise Test; FM = FM system; SNR = signal-to-noise ratio.

was programmed for the manufacturer default +10 FM-advantage setting, which is designed to provide an FM signal that is 10 dB more intense than the signal from the processor microphone. The two mixing ratios (30/70, 50/50) used in the study were programmed into the Auria sound processors using a computer and standard software for the CII or 90K cochlear implant.

Procedures

Fitting and testing was conducted in three different sessions. The questionnaires were completed at all three sessions, and speech recognition was tested during the second and third sessions. The sessions and testing conditions are summarized in Table 2.

Session 1. At the beginning of the first session, the participants were asked to complete the questionnaire as it related to their perceptions with their Auria processor. Then, participants were fit with the FM system and given detailed instructions about the care, use, and maintenance of the system. The instructions also included a description of listening situations where the FM system may be helpful and what microphone settings on the FM transmitter (Omni, Zoom, and SuperZoom) would provide optimal performance in various environments. Then, the initial mixing ratio was programmed into the participant's speech processor. The selection of the initial mixing ratio for each participant was counter-balanced whereby half of the subjects started with the 50/50 mixing ratio and the other half started with the 30/70 mixing ratio. Subjects were blinded as to which mixing ratio they were using. The participants were asked to use the FM system every day for two weeks at the initial mixing-ratio setting.

Session 2. At the end of the two-week trial period, each participant returned for the second session. The participants completed the questionnaire regarding ease of communication and sound quality of the FM system with the initial mixing-ratio setting. Then the adults' speech recognition in quiet and in noise was tested using the initial mixing-ratio setting. The order of the speech-recognition conditions was randomized. Upon completion of testing, the mixing ratio was reprogrammed from their initial setting to the second setting. Participants were asked to use the FM system for an additional two weeks with the new mixing ratio.

Session 3. In the third testing session, the adults completed the questionnaire related to clarity of sound and ease of listening with the second audio-mixing setting. Then, speech recognition was evaluated with the second mixing ratio with the order of the conditions randomized. At the conclusion of the study, participants returned the systems and were asked if they would recommend personal FM use to other persons using the Auria speech processor.

RESULTS

Speech Recognition in Quiet

Mean percent correct speech recognition in quiet (CNC monosyllabic word test) is provided in Figures 2 and 3. The planned analyses for the quiet conditions addressed the effect of using an FM system at two signal levels and two audio-mixing ratios. In addition, the effect of the two audio-mixing ratios was examined for performance when the FM system was either active or inactive but attached.

Four paired *t*-tests (two-tailed) were conducted to determine the effect of FM-system use in quiet environments, and a Bonferroni correction was used to account for multiple comparisons. Each analysis compares an "FM off" and "FM on" condition. The average performance for each comparison is illustrated in Figure 2.

At a presentation level consistent with soft level speech (50 dBA), use of the FM system (FM on) significantly improved performance relative to no FM system (FM off) at the 50/50 mixing ratio ($t[12] = -6.85$, $p < .001$) and the 30/70 mixing ratio ($t[12] = -7.57$, $p < .001$). These significant results suggest that the FM system provides benefits ranging from 23 to 41% in a quiet environment with soft speech. Conversely, when speech was presented at a level consistent with average conversational speech (65

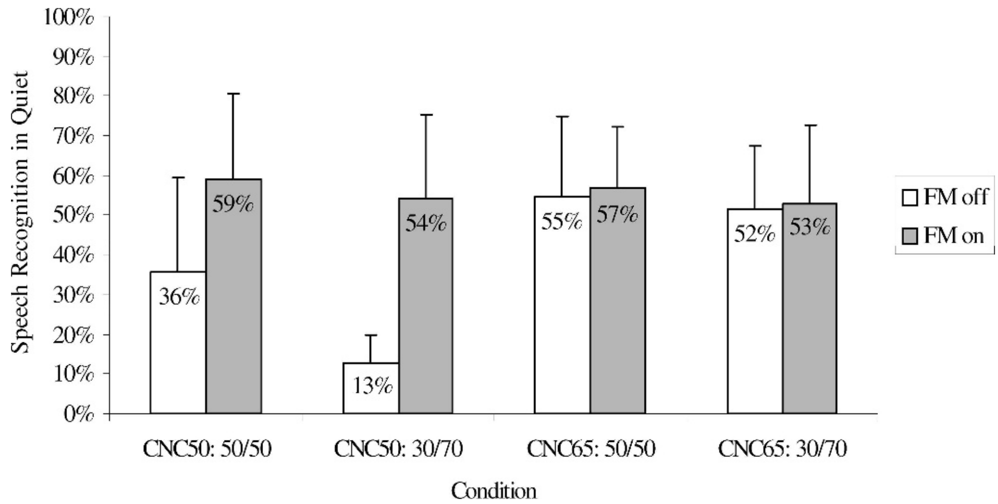

Figure 2. Percent correct speech recognition in quiet plotted for comparisons between FM-off and FM-on conditions. Ratios are audio-mixing settings programmed into the sound processor, and lines represent standard deviations. CNC = consonant-nucleus-consonant monosyllabic words; FM = use of the FM system.

dBA), there was no significant benefit of using the FM at the 50/50 ($t[12] = -0.72$, $p = .49$) or the 30/70 mixing ratios ($t[12] = -0.44 = .67$, $p = .67$). Therefore, significant benefits of FM system use are not evident in quiet environments when speech is presented at typical conversational levels.

Four additional t-tests (two-tailed) were employed to examine the effects of the two audio-mixing ratios when the FM transmitter was either active or inactive. These analyses were also corrected for multiple comparisons using the Bonferroni equation. Each analysis compares the performance in the 50/50 and 30/70 mixing-ratio conditions, and average performance for these comparisons is shown in Figure 3. For testing conducted with the FM transmitter deactivated (FM off), there was a significant effect of audio-mixing ratio for stimuli presented at 50 dBA ($t[12] = 4.02$, $p = .002$). However, there was no effect of audio-mixing ratio for speech presented at 65 dBA ($t[12] = 1.2$, $p = .25$) when the FM system was inactive. Similarly, when the FM transmitter was active, there was no significant effect of audio-mixing ratio at the 50 dBA ($t[12] = 2.18$, $p = .051$) or the 65 dBA ($t[12] = 1.74$, $p = .11$) presentation levels. As a result, the audio-mixing ratio does not appear to affect speech recognition in quiet with the FM on or FM off, with the exception of the 50 dBA condition with FM off. The speech-recognition performance in the 30/70 audio-mixing condition was significantly poorer (13%) than performance in the 50/50 condition (36%). These findings suggest that when the FM system is deactivated, the 30/70 mixing ratio may hinder the ability to hear speech in the environment presented at soft levels.

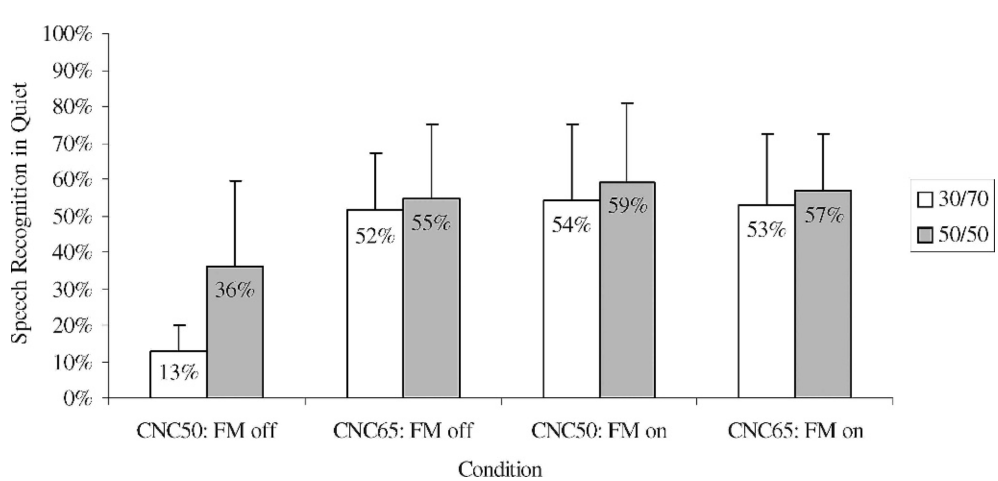

Figure 3. Percent correct speech recognition in quiet plotted for comparisons between audio-mixing ratios. Ratios are audio-mixing settings programmed into the sound processor, and lines represent standard deviations. CNC = consonant-nucleus-consonant monosyllabic words; FM = use of the FM system.

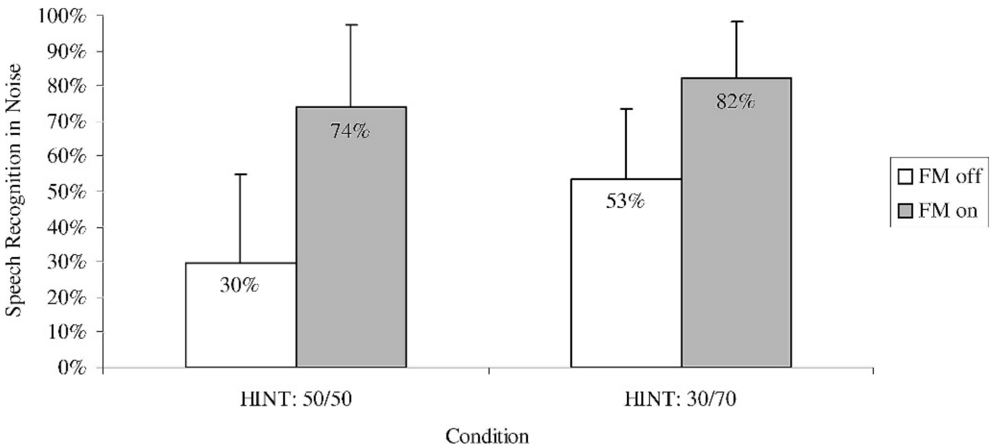

Figure 4. Percent correct speech recognition in noise plotted for comparisons between FM-off and FM-on conditions. Ratios are audio-mixing settings programmed into the sound processor, and lines represent standard deviations. HINT = Hearing in Noise Test; FM = use of the FM system.

Speech Recognition in Noise

Mean results for speech recognition in noise using the HINT at a +5 signal-to-noise ratio are provided in Figure 4. The following analyses were corrected for multiple comparisons using the Bonferroni equation. Two paired *t*-tests (two-tailed) were conducted to determine the effect of using the FM system at the two audio-mixing ratios. As expected, use of the FM system significantly improved performance by 29 to 44% relative to a cochlear implant alone at both the 50/50 ($t[12] = -8.28$, $p < .001$) and 30/70 ($t[12] = -8.28$, $p < .001$) mixing ratios.

Another set of paired *t*-tests (two-tailed) were used to examine potential changes in speech recognition at the two audio-mixing ratios when the FM transmitter was active (FM on) or disabled (FM off). When the FM system was disabled, there was a significant effect of audio-mixing ratio ($t[12] = -3.9$, $p = .002$), with the 30/70 audio-mixing ratio providing significantly better speech-recognition performance. This finding is not surprising given that the 50/50 audio-mixing setting introduces more noise into the sound processor when compared to the 30/70 setting. When the FM transmitter was enabled, there was no significant effect of mixing ratio ($t[12] = -1.59$, $p = .14$).

Questionnaires

Ten participants completed all three questionnaires assessing ease of listening, convenience, and comfort with daily use of the Auria and personal FM system. For the first questionnaire, the participants were asked to rate perceptions about their Auria sound processors. The second and third administration of the questionnaire required the participants to rate the sound quality and comfort of the personal FM system with the iConnect adaptor coupled to the Auria set for either the 30/70 and 50/50 audio-mixing ratio.

The questionnaire, shown in Appendix 1, was analyzed to determine any changes between the ratings with the Auria and the ratings after use of the FM system at the two audio-mixing ratios (30/70, 50/50). Using the ratings from the questionnaire with the Auria alone, the 95% confidence intervals were calculated. These 95% confidence intervals were used to determine significant increases or decreases in ratings for individual participants on the two FM-system questionnaires. The results of these comparisons are shown in Table 3.

According to the results of the questionnaire comparisons (Table 3), the majority of users report significant increases in the clarity of sound, ease of listening, and sound quality with the FM system relative to their Auria sound processor alone. The responses indicated that subjects did not perceive a statistically significant difference for the 50/50 and 30/70 audio-mixing ratios. For clarity and sound quality ratings, the greatest benefits were noted for listening in the car and for understanding speech over the television, where 60–80% of participants reported improvements with the FM system. Ease of listening ratings suggested that 70–80% of participants enjoyed benefits for small and large groups, in the car, and while watching television. Minimal differences in the ease of use, comfort, and security of equipment were detected between the ratings for the two mixing ratios. Interestingly, the same participant reported significant decreases in all areas of the questionnaire despite the fact that this adult received substantial gains in speech perception in noise and quiet when using the FM system. This patient experienced static on several FM-system channels, had difficulty learning to use the SmartLink transmitter, and was hesitant to use the FM system.

Table 3. Percentage of Signficant Increases and Decreases on the Questionnaire When Using the Personal FM System at the Two Audio-Mixing Ratios

	50/50 Mixing		30/70 Mixing	
	↑	↓	↑	↓
1. Clarity of Sound				
a. Listening in a small group	50%	20%	40%	20%
b. Listening in a large group	60%	10%	60%	10%
c. Listening in the car	80%	10%	80%	10%
d. Listening to the television	70%	0%	70%	0%
2. Ease of Listening				
a. Listening in a small group	80%	20%	80%	20%
b. Listening in a large group	70%	10%	60%	10%
c. Listening in the car	80%	10%	80%	10%
d. Listening to the television	70%	0%	70%	0%
3. Ease of Use				
a. How easy is volume adjustment?	0%	20%	0%	20%
b. How easy is program adjustment?	0%	0%	0%	0%
4. Comfort				
a. How comfortable?	20%	10%	20%	10%
b. How comfortable when wearing accessories (e.g., hats, eyewear)?	0%	30%	0%	30%
5. Sound Quality				
a. Rate quality in noisy, small groups	40%	10%	40%	10%
b. Rate quality in noisy, large groups	60%	10%	60%	10%
c. Rate quality in the car	60%	10%	60%	10%
d. Rate quality for TV	70%	10%	70%	10%
6. Security of Equipment				
a. How securely does your Auria/ iConnect stay in place?	0%	10%	10%	10%

Note: Significant increases and decreases in participant ratings are indicated in columns with the up and down arrows, respectively. Significance was calculated using 95% confidence intervals.

An average battery life of 30 hours was reported for the size 10 hearing aid battery used to power the iConnect, and only one of ten patients reported a change in the life of the battery for the Auria when using the FM system (a decrease from twelve to ten hours). Nine of ten patients indicated that they would recommend use of the FM system and iConnect to other Auria users, with the lone dissenter stating that she preferred to use her T-Mic™ over the iConnect because the T-Mic allowed for easier telephone use, an important skill for her job as an office assistant.

Other subjective comments about the FM system highlight important aspects of FM-system use for adults using cochlear implants. Several of the users commented on the complexity of the FM transmitter. Phonak, the manufacturer of the SmartLink transmitter, does have a simplified version of the transmitter. However, the other entry-level transmitter does not have Bluetooth technology, which was reported as a benefit by several participants when using their cell phones. In addition, several users reported some interference with the FM system on some channels. The interference was resolved after trying several channels, making access to several channels an important aspect of the FM-system fitting. Finally, most of the participants reported significant benefits of the FM system in minimal to moderate noise but continued to experience difficulty in high levels of noise.

Overall, the ratings on the questionnaire and the subjective comments provide evidence that the FM system is beneficial for adults with cochlear implants. While the users did not perceive differences in the two audio-mixing ratios, results of the speech-recognition testing suggest that audibility of speech sounds in a quiet environment may be hindered by the 30/70 setting. Therefore, use of the 50/50 is recommended as the optimal audio-mixing ratio for users of the Auria sound processor coupled to a personal FM system with the iConnect adaptor.

DISCUSSION

Several findings of this study are relevant to the clinical optimization of personal FM systems for persons with cochlear implants. First, the use of FM technology significantly improved performance for soft spoken speech in a quiet environment, with a mean improvement of 41% for the 30/70 mixing ratio and 23% for the 50/50 mixing ratio. Such dramatic improvement is encouraging given the difficulties persons with cochlear implants often encounter with understanding low-level speech (Firszt et al, 2004). An example of a situation where this benefit may improve performance would be an adult or child listening to a lecture in a quiet classroom setting. If the lecturer moved across the classroom, the speech would presumably reach the person's cochlear implant speech processor microphone at a low-level, and the listener would be at a great risk for missing important information. If, however, a personal FM system was used, the level of the lecturer's voice would be maintained and preserved regardless of his or her location relative to the listener.

With regard to the two mixing ratios under study, the assessment of speech recognition in quiet at a low presentation level indicated that speech perception may suffer for soft speech that is not directed to the FM microphone when using the 30/70 mixing ratio. When the speech was not directed to the FM transmitter, mean speech recognition scores for soft speech decreased from 36% to 13% when the mixing ratio was changed from 50/50 to 30/70. As such, the 30/70 mixing ratio may be detrimental when the user needs to hear signals that are not directed to the FM transmitter. An example of such a situation would be an adult or child using an FM system in a classroom while the primary wears the FM microphone. If another talker in the classroom provided a spoken answer or response to a statement from the lecturer, the person with a cochlear implant would be less likely to hear the peer response when using a 30/70 mixing ratio. As such, 50/50 mixing ratios should be employed in the classrooms, lecture halls, and other situations in which incidental listening is important.

As expected, the use of personal FM technology significantly improves speech recognition in noise for adults using cochlear implants. For the adult participants in this study, use of the FM system allowed for a mean improvement in speech recognition of 29% for the 30/70 mixing ratio and 44% for the 50/50 mixing ratio compared to the performance with the cochlear implant alone. This dramatic improvement is encouraging given the difficulties persons with cochlear implants often encounter in noise (Nelson et al, 2003; Stickney et al, 2004). No significant differences were detected for speech recognition in noise with the two audio-mixing ratios for the FM-on or FM-off conditions.

Participants were queried about their performance in difficult listening situations when using the personal FM system for the two different two-week periods, and all participants noted that use of the FM system improved performance in noisy listening situations. There was no overwhelming preference for one mixing ratio over the other, although two subjects reported that they could hear better in noise with the 30/70 mixing ratio. Nine of ten subjects who completed the questionnaires noted that they would recommend the use of personal FM systems for other users of cochlear implants. The subjects also reported that the iConnect and personal FM system were comfortable to wear and simple and convenient to use. Four of the twelve adult subjects who participated in the study chose to purchase the FM system at the end of the study, and interestingly, these four participants had the poorest speech recognition scores in noise without the use of an FM system. As such, use of personal FM technology may be particularly appealing for persons who experience substantial difficulty with communication in noise.

Two of the adults who purchased the FM systems have been provided with three different speech-processor programs, 50/50 mixing ratio, 30/70 mixing ratio, and “FM only.” For relatively quiet situations, when the adults are listening from a distance (i.e., television in the living room or a lecture in an auditorium), the 50/50 mixing ratio is frequently selected. In environments with moderate noise levels, the two adults report use of the 30/70 mixing ratio to enhance speech recognition in noise. Use of the 30/70 mixing ratio in noisy environments is less likely to impair incidental hearing, because other talkers will naturally raise their vocal levels to be heard over the noise. When communicating with one person in environments with adverse speech-to-noise ratios, the adults report that they occasionally select the program with FM only input to optimize their ability to hear the speaker of interest in the presence of competing noise.

CONCLUSIONS

- Adults with cochlear implants experience significant improvements in speech recognition for low-level speech and speech in noise with use of a personal FM system.
- No differences in speech-recognition performance in noise were detected for 30/70 and 50/50 audio-mixing ratios, and most subjects did not perceive a difference between the two mixing ratios.
- Use of the 30/70 audio-mixing ratio results in decreased performance for signals that are not directed to the FM transmitter, such as in a classroom, auditorium, sanctuary, or large lecture hall where a cochlear implant user may need to hear responses from other persons positioned throughout the room.
- Study participants were generally pleased with the benefit they received from the personal FM system and typically reported that it was simple and comfortable to use.

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APPENDIX 1: Patient Questionnaire

Please rate the following questions by checking the box that applies.

	1. Very Difficult	2. Somewhat Difficult	3. Somewhat Easy	4. Easy	5. Very Easy
1. Clarity of Sound					
a. Listening in a small group	☐	☐	☐	☐	☐
b. Listening in a large group	☐	☐	☐	☐	☐
c. Listening in the car	☐	☐	☐	☐	☐
d. Listening to the television	☐	☐	☐	☐	☐
2. Ease of Listening					
a. Listening in a small group	☐	☐	☐	☐	☐
b. Listening in a large group	☐	☐	☐	☐	☐
c. Listening in the car	☐	☐	☐	☐	☐
d. Listening to the television	☐	☐	☐	☐	☐
3. Ease of Use					
a. How easy is it to adjust the volume of your Auria/iConnect?	☐	☐	☐	☐	☐
b. How easy is it to adjust the program setting of your Auria/iConnect?	☐	☐	☐	☐	☐

	1. Very Uncomfortable	2. Somewhat Uncomfortable	3. Somewhat Comfortable	4. Comfortable	5. Very Comfortable
4. Comfort					
a. How comfortable is your Auria/iConnect?	☐	☐	☐	☐	☐
b. How comfortable is your Auria/iConnect when wearing accessories (e.g., hats, eyewear)	☐	☐	☐	☐	☐

	1. Extremely Low	2. Low	3. Moderate	4. High	5. Extremely High
5. Sound Quality					
a. Rate the quality in noisy, small group situations.	☐	☐	☐	☐	☐
b. Rate the quality in noisy, large group situations.	☐	☐	☐	☐	☐
c. Rate the quality while listening in the car.	☐	☐	☐	☐	☐
d. Rate the quality while listening to the television.	☐	☐	☐	☐	☐

	1. Very Insecurely	2. Somewhat Insecurely	2. Somewhat Securely	4. Securely	5. Very Securely
6. Security of Equipment					
a. How securely does your Auria/iConnect stay in place?	☐	☐	☐	☐	☐

Please provide an answer for questions 7–10 in the box to the right of the question.

7. On average, how many hours does your Auria battery last?	☐
8. Approximately how long does the iConnect battery last?	☐
9. Did you experience any reduction in Auria battery life when using the iConnect?	☐
10. If you answered yes to the previous question, approximately how many fewer hours?	☐