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A Sound Foundation Through Early Amplification

Proceedings of the 7th International Conference 2016

Hear well or hearsay? Do modern wireless technologies improve hearing performance in CI users?

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Introduction

Persons with cochlear implants (CI) experience substantial difficulty understanding speech in noisy and reverberant environments and when speech originates from a great distance away (Schafer & Thibodeau, 2003, 2004; Spahr et al., 2007; Wolfe et al., 2009; Wolfe et al., 2013a). Research has conclusively shown that use of wireless remote microphone (RM) technology is the most effective means to improve speech recognition in difficult listening situations for pediatric CI users (Schafer & Thibodeau, 2006; Wolfe et al., 2009; Wolfe et al., 2013a). RM systems are comprised of a microphone that is worn by the primary talker of interest and wireless receivers that are coupled to a child's CI sound processor(s) or hearing aid(s). The talker's speech is captured by the microphone and transmitted via radio frequency (RF) transmission to the radio receivers, which deliver the audio signal to the child's hearing technology (e.g., CI sound processors and/or hearing aids). Figure 1 provides an example of a modern wireless RM system that might be used with a child who uses a CI for one ear and a hearing aid for the opposite ear. At signal-to-noise ratios (SNR; +5 to -5 dB) commonly encountered in realistic listening situations (e.g., classroom, automobile, sporting event), the use of a wireless RM system typically provides improvement in speech recognition in noise ranging from 40 to 80 percentage points when compared to performance with the cochlear implants alone (Wolfe et al., 2009; Wolfe et al., 2013a).

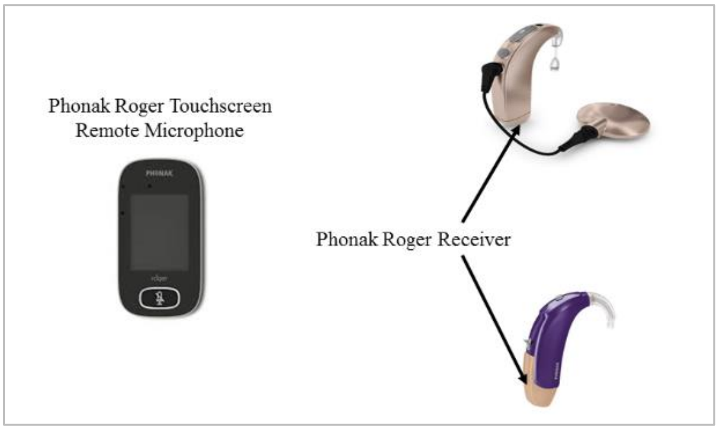

Figure 1. An example of a remote microphone system possessing a remote microphone transmitter (Phonak Roger Touchscreen) and Phonak Roger Receivers coupled to an Advanced Bionics Naida sound processor and a Phonak Sky V hearing aid.

RM systems can be categorized into two broad classes, personal systems and accessory systems. Personal systems typically feature a wireless radio receiver that can be universally coupled to CI sound processors and hearing aids of a wide variety of manufacturers. For instance, the receiver might be coupled to different CI sound processors and hearing aids by an integrated connection or by way of an adapter (see Figure 2). In contrast, RM accessory systems are typically designed to function only with a CI sound processor or hearing aid designed by the manufacturer who has created both the sound processor/hearing aid and the RM accessory. Figure 3 provides an example of an RM accessory system.

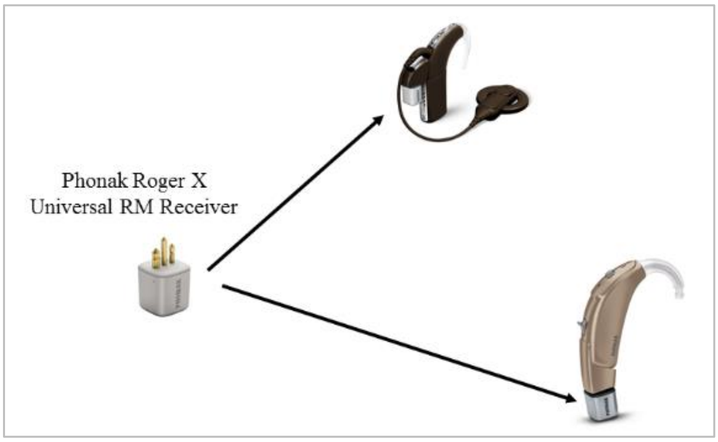

Figure 2. Phonak Roger X universal receiver coupled to a Cochlear Nucleus CP910 sound processor and a Phonak hearing aid.

Figure 3. Advanced Bionics/Phonak ComPilot remote microphone accessory system which is compatible with the Advanced Bionics Naida sound processor and Phonak hearing aids (also pictured).

A number of factors influence the benefit pediatric cochlear implant users receive from RM technology. These factors include but are not limited to:

- microphone technology included within the RM system (e.g., omni-directional, fixed directional, fully adaptive directional);
- signal processing included within RM system (e.g., fixed gain vs. adaptive gain, analog FM vs. digital);
- signal processing employed within the cochlear implant sound processor; and
- usability of the RM. system (e.g., automatic activation, availability of a multiple-talker microphone system, compatibility with a variety of cochlear implant sound processors and hearing aids of different manufacturers, ability to couple the RM system with other technologies such as computers, smart telephones, classroom technology, etcetera).

This article highlights some of the aforementioned factors with focus on the characteristics that influence the benefit cochlear implant recipients receive from RM technology along with the extent to which these factors typically influence performance.

Remote Microphone Technology

RM systems can vary substantially in the technology they employ. Two of the most important RM technologies influencing the benefit CI recipients receive are the microphone technology within the RM system and the signal processing used to process the signal captured by the microphone and deliver it to the wireless receiver. Most modern RM systems include directional microphones designed to focus on the speech of the primary talker and attenuate surrounding noise. Additionally, contemporary RM systems often feature fully adaptive microphones that alter the polar plot pattern based on the position of the microphone and the characteristics of the ambient noise. Figure 4 provides an example of the Phonak Roger Touch RM, a personal RM designed for use in educational settings. As shown in Figure 4, the Roger Touch RM utilizes a directional pattern when worn around the neck (i.e., in a vertical position, it is in "Teacher Mode"). When worn in the vertical position, the highly directional microphone mode results in primary capture of the talker's voice while attenuating surrounding ambient noise level. When the Roger Touch RM is placed on a desk (e.g., lying flat in the horizontal position), it switches to "Small Group" mode and utilizes an omni-directional polar plot pattern in quiet environments. In noisy environments, Small Group mode uses adaptive beamforming in an attempt to focus the primary axis of sensitivity toward the talker of interest while attenuating surrounding classroom noise. Additionally, in noisy environments, the microphone sensitivity is reduced to capture nearby talkers in a small group while attenuating noise from outside of the area proximal to the user.

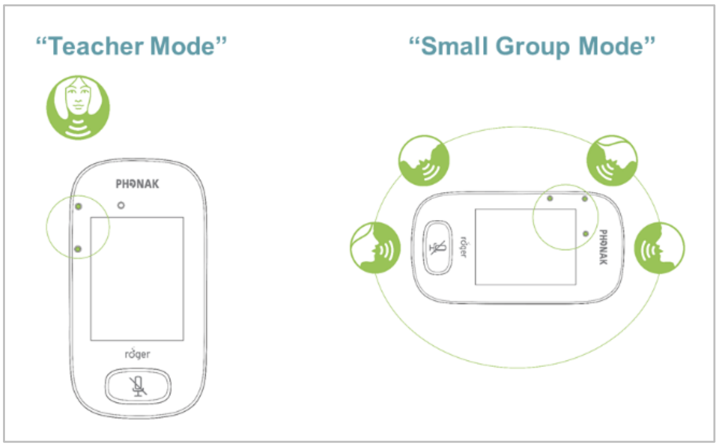

Figure 4. Phonak Roger Touchscreen remote microphone in "Teacher Mode" and "Small Group Mode."

Another important parameter by which RM systems can differ is receiver gain. The RM system receiver gain determines the strength of the signal delivered from the RM radio receiver to the CI sound processor or hearing aid. Many RM systems use a fixed receiver gain. For instance, the gain of the RM receiver is set so that the RM signal is 10 dB higher than the signal captured at the microphone of the CI sound processor or hearing aid, regardless of the ambient noise level (see Figure 5). Fixed-gain systems fail to provide an ideal signal for all listening environments. For instance, in the presence of moderate- to high-level noise (e.g., 65-75 dB SPL), a fixed receiver gain of +10 dB will be unlikely to provide the favorable SNR required for a CI user to understand speech. However, the higher receiver gain necessary for adequate speech recognition in moderate- to high-level noise would likely result in a signal that is too loud in quiet environments. As a result, the +10 dB receiver gain is a compromise that is unlikely to provide optimal performance across most environments.

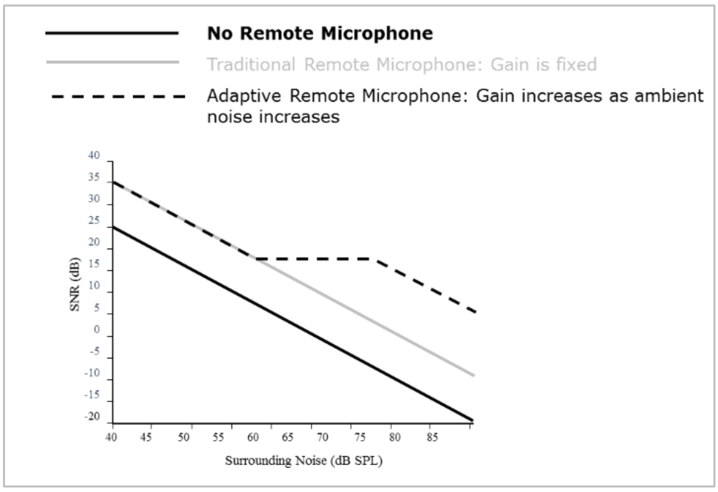

Figure 5. Illustration of signal-to-noise ratio (y-axis) as a function of ambient noise level (x-axis) in three conditions: 1) No remote microphone, 2) Fixed-gain remote microphone, and 3) Adaptive remote microphone.

RM systems with adaptive gain changes (e.g., Phonak Dynamic, Phonak Roger) seek to avoid this compromise by automatically changing the receiver gain as a function of the ambient noise level. Figure 5 provides an example of the automatic gain changes provided by an adaptive gain system. As shown, adaptive RM systems provide a favorable SNR of almost 15 dB across a wide range of competing noise levels. Previous research studies have shown speech recognition in noise improvements of 30-60 percentage points with the use of adaptive systems over fixed gain systems (Wolfe et al., 2009; Wolfe et al., 2013a). Indeed, adaptive RM technology is the gold standard RM technology for CI recipients.

RM systems also differ in the radio technology used to deliver the signal from the RM to the radio receiver. For instance, RM systems historically have used frequency-modulated (FM) analog radio transmission to deliver the signal from the RM to the radio receiver. A major problem associated with the use of personal FM systems was the potential for noise or interference when multiple FM radio signals were used in close proximity, as was common when multiple children with hearing loss used FM systems in several different classrooms within a school. Noise from FM systems was also a common problem for cochlear implant users because of the close proximity of the FM receiver to the RF transmitting coil of the CI sound processor.

Recently, RM systems have begun to employ digital radio frequency (RF) transmission to deliver the signal to the radio receiver. Digital RF has several theoretical advantages over FM analog technology. First, a digital RM can adaptively switch the RF in order to avoid interference with other nearby RF systems. This feature allows for the use of multiple digital RM systems within a close physical proximity without the concern of interference. Furthermore, CI recipients are far less likely to experience noise when using digital RF systems. Over 150 subjects have participated in research studies conducted at Hearts for Hearing in Oklahoma City, Oklahoma to examine digital RF systems with cochlear implant sound processors, and none of these subjects has reported bothersome noise or interference between the digital RF system and the CI sound processor. The virtual elimination of noise and interference with the use of digital technology should lead to the routine consideration of digital RM technology for CI recipients of all ages.

Additionally, digital RF systems allow for more precise control over the signal that is transmitted from the RM to the radio receiver. This greater precision of processing theoretically allows for more optimal provision of automatic gain changes in adaptive systems. Wolfe and colleagues (2013a) evaluated sentence recognition in quiet and in noise in a group of 44 cochlear implant recipients with their CIs alone with the use of fixed-gain FM analog, adaptive FM analog, and adaptive digital RM systems. All RM systems provided a significant improvement in speech recognition, and both adaptive systems provided better performance than the fixed-gain system. Of note, use of the adaptive digital system resulted in better speech recognition in noise than use of the adaptive FM analog system (e.g., for Advanced Bionics recipients, the adaptive digital system provided a mean improvement of over 30 percentage points at a competing noise level of 70 dBA when compared to performance with the adaptive FM analog system).

Signal processing within the cochlear implant sound processor

The input signal processing of the CI sound processor can also affect the recipient's speech recognition performance with a RM system. For example, Wolfe and colleagues (2009) examined speech recognition in 15 Nucleus CI users with and without the use of Automatic Sensitivity Control (ASC), a form of input processing that automatically changes the sensitivity of the sound processor microphone in an attempt to enhance sound quality and speech recognition in noise. With ASC disabled, Nucleus CI recipients scored near 0% correct in moderate- to high-level noise. With SC enabled, speech recognition in noise improved by 60 to 80 percentage points in moderate-level noise with use of an adaptive analog FM system.

More recently, Wolfe and colleagues have evaluated speech recognition in quiet and in noise with a group of Nucleus recipients using their cochlear implants alone and also with use of a fixed-gain digital RM accessory with omni-directional microphone technology, a fixed-gain digital RM accessory with adaptive directional microphone technology, and an adaptive digital personal FM system with adaptive directional microphone technology. Figure 6 shows results for the first five subjects who have been tested in this study. As shown, both of the systems featuring directional microphone technology provided significantly better speech recognition in noise than the RM accessory utilizing an omni-directional microphone. When comparing the two RM systems with adaptive directional microphone technology, the adaptive digital personal system offered only a modest improvement in speech recognition at the high noise levels when compared to the fixed-gain digital RM accessory possessing directional microphone technology. Wolfe and colleagues have hypothesized that the ASC input processing present in Nucleus processors compresses the gain increases of adaptive RM systems and partially nullifies the benefit typically observed in RM systems offering adaptive gain changes with increasing ambient noise levels (see Wolfe et al., 2013b for further explanation).

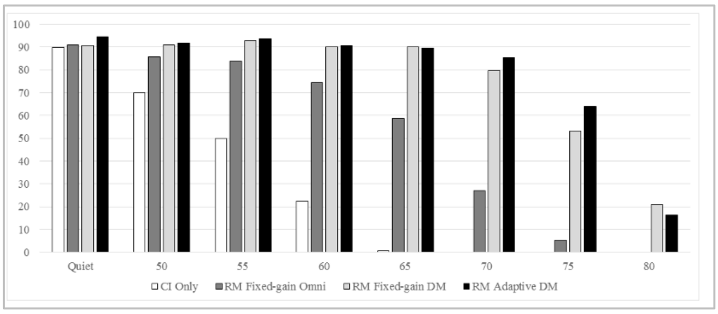

Figure 6. Mean sentence recognition scores (% correct) for 6 Nucleus 6 users in four conditions: 1) No remote microphone, 2) Fixed-gain remote microphone (RM) accessory with an omni-directional microphone (omni), 3) Fixed-gain RM accessory with a directional microphone (DM), and 4) adaptive personal RM system with DM.

Usability of the RM system

Although often overlooked in research studies, there are several practical characteristics of RM systems that influence a CI recipient's experience in realistic listening situations. For instance, personal RM systems are typically designed to be compatible with a variety of different CI sound processors and hearing aids, although RM accessories only function with the CI sound processors or hearing aids designed by the manufacturer of the accessory. As a result, a RM accessory might be incompatible with the hearing aid used on the ear opposite of the implanted ear if the devices were not manufactured by the same company. Furthermore, personal FM systems typically can be used by several children within one classroom, because the radio receivers of personal systems can be coupled to a variety of sound processors and hearing aids via special adapters (e.g., boots/shoes). Thus, the near universal compatibility of personal RM systems is a potential advantage over accessory RM systems.

Another feature of great practical importance is the RM system's capability to activate automatically when a signal is present from the RM transmitter. Children are often unable to activate their RM systems manually. Some RM accessory systems require manual activation, and as a result, the systems are unfit for routine use with children, particularly in school settings. Most personal RM systems allow for automatic activation, which is ideal for young children and children in educational settings.

Additionally, CI recipients might wish to hear multiple talkers of interest. Some RM systems allow for multiple-talker networks, in which several talkers of interest can be fitted with RMs, all of which can transmit their signal to digital radio receivers that have been included within the network (see Figure 7). Multiple-talker networks are potentially advantageous for children in classrooms with multiple teachers or for CI recipients in social situations with multiple conversational partners.

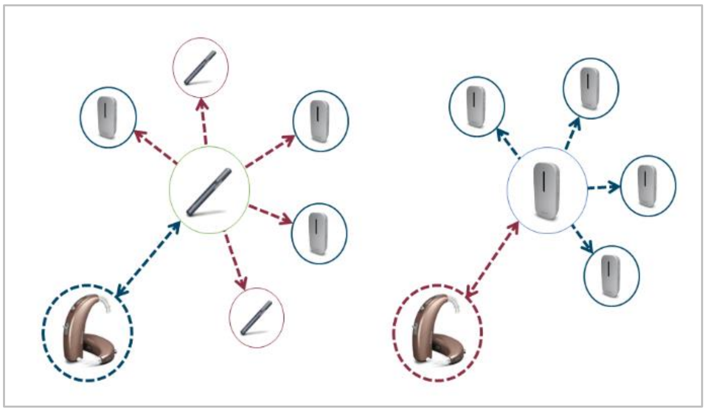

Figure 7. Illustration of remote microphone multi-talker network.

Finally, many modern RM systems possess the capability of interfacing with multiple consumer audio electronic devices. For instance, some personal RM systems can be coupled to electronic devices that contain a 3.5 mm earphone phono port. RM systems can also be wirelessly coupled to consumer electronics, such as smart telephones, by way of Bluetooth or proprietary digital RF. Furthermore, RM systems can be coupled to televisions or classroom smartboards to deliver audio signals wirelessly and directly to the user's CI sound processor or hearing aids.

Conclusion

In conclusion, RM technology should be considered for CI recipients of all ages, because it might improve speech recognition by 40 to 80 percentage points and digital systems are largely free of interference and noise. Also, adaptive systems that automatically increase receiver gain with increases in ambient noise levels are the gold standard RM technology. Clinicians should also consider several practical characteristics (such as automatic activation, compatibility with various CI sound processors/hearing aids, the capability of creating multi-talker networks, and the potential to interface with consumer electronics) when selecting the optimal RM technology for CI recipients.

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