Evaluation of Wireless, Digital, Audio-Streaming Accessories Designed for the Cochlear™ Nucleus® 6 Sound Processor

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Cochlear Ltd. and the GN Resound hearing aid company recently formed a technology partnership to make Resound wireless audio accessories available to Cochlear™ Nucleus® 6 Cochlear Implant users. This portfolio of wireless accessories includes a remote microphone (Cochlear Mini Microphone), a Bluetooth® audio streaming accessory (Cochlear Phone Clip+) that may be used with mobile smart telephones or other Bluetooth-enabled personal electronics, and a television accessory (Cochlear TV Streamer 2).

Each of these accessories, which aim to enhance speech recognition, sound quality, and the overall listening experience in situations that are known to provide the most difficulty for persons with hearing loss, deliver the audio signal of interest from the accessory directly to the user's hearing instrument via digital radio frequency transmission on the 2.4 GHz globally license-free ISM (Industry, Science, Medical) band, which is the same band used by Bluetooth and many other commercial applications that use digital UHF (Ultra High Frequency) radio transmission. However, after digitizing the audio signal, these wireless accessories utilize a proprietary protocol/language to deliver the signal of interest to the receiver located within the hearing instrument. Use of a proprietary protocol reduces the delay in signal transmission, which prevents audio and visual signals from being out of synch with one another, a fact that is of particular importance for the remote microphone and television accessories. Additionally, the use of the proprietary protocol reduces the power consumption of the wireless accessories, allowing for reasonable battery current drain when used with a hearing aid or cochlear implant. Use of traditional Bluetooth audio streaming directly to a hearing aid or cochlear implant sound processor has not been feasible because the relatively high power consumption of the traditional universal Bluetooth protocol would result in unreasonably low battery life.

An ongoing research study at the Hearts for Hearing Foundation in Oklahoma City, Oklahoma has sought to determine the benefit that Nucleus 6 users receive from the use of each of the aforementioned wireless accessories. This paper describes preliminary results of the first six subjects who have participated in this study.

Methods

Participants

The first six subjects who participated in this study all used Nucleus Freedom® (CI24RE) Cochlear Implants. Three were unilateral recipients, and three were bilateral recipients. The unilateral recipients did not use a hearing aid on their opposite ear because they did not feel as though they benefited from bimodal use.
Equipment

All participants used the Nucleus 6 Sound Processor while participating in this study. Their speech recognition was evaluated while they used the Nucleus 6 Sound Processor alone and also while they used the Nucleus 6 Sound Processor with each of three different wireless audio streaming accessories:

**Cochlear Mini Microphone (see Figure 1a):**
The Cochlear Mini Microphone is a miniature, wireless remote microphone that delivers the audio signal captured at the microphone directly to the recipient’s Nucleus 6 Sound Processor via the proprietary GN Resound digital radio frequency transmission protocol on the 2.4 GHz band. The Cochlear Mini Microphone possesses a clip so that it may be attached to the talker’s clothing about six inches below his or her mouth. It also features a sensitivity control, which may be used to adjust the sensitivity of the remote microphone in order to optimize signal capture across a wide range of acoustical environments and listener needs. It may be paired to each Nucleus 6 Sound Processor for bilateral recipients.

**Cochlear Phone Clip+ (see Figure 1b):**
The Cochlear Phone Clip+ may be paired with any Bluetooth-enabled consumer electronics device (e.g., smart mobile telephone, laptop computer, tablet, etc.). Once the pairing is complete, the Cochlear Phone Clip+ receives the audio signal from the mobile telephone (or other Bluetooth-enabled personal device) via Bluetooth and streams it directly to the Nucleus 6 Sound Processor via the proprietary GN Resound digital radio frequency transmission protocol on the 2.4 GHz band. When used with a mobile telephone, the speech of the Nucleus 6 user is captured by a microphone in the Phone Clip+ and delivered back to the user’s mobile telephone via Bluetooth so that it may be heard by the person with whom the Nucleus 6 user is conversing. This approach allows for hands-free, wireless use of the mobile telephone. Bilateral Nucleus 6 users may receive the audio signal bilaterally from the Cochlear Phone Clip+.

**Cochlear TV Streamer 2 (see Figure 1c):**
The Cochlear TV Streamer may be connected to the audio output ports of a television using either stereo RCA cables or a digital optical cable. Once connected, the audio signal from the television is streamed directly to the Nucleus 6 Sound Processor via the proprietary GN Resound digital radio frequency transmission protocol on the 2.4 GHz band.
Test Conditions

Speech recognition in quiet and in noise was evaluated with and without each of the aforementioned wireless audio accessories in a 25'3" by 24'8" by 9' room that had an ambient noise level of 44 dBA. Figure 2 shows the positions of the test equipment and the participant in the room. In conditions in which speech recognition was evaluated in noise, uncorrelated classroom noise (Schafer and Thibodeau, 2006) was presented from four Genelec 8020B loudspeakers located at approximately 30, 135, 225, and 330 degrees azimuth relative to the participant.

Assessment of Performance with the Cochlear Mini Microphone

Sentence recognition in quiet and in noise was assessed with and without the use of the Cochlear Mini Microphone. The Cochlear Mini Microphone was positioned 6 inches directly below a Genelec 8020B loudspeaker that was used to present target sentences. The participant was seated 8'6" from the Cochlear Mini Microphone. Sentence recognition in noise was evaluated at competing noise levels ranging from 50 to 75 dBA in 5 dB increments. Sentence recognition was evaluated with one full list of AzBio sentences (20 sentences) per condition. The intensity of the test sentences was 85 dBA at the position of the remote microphone and 65 dBA at the location of the participant. Sentence recognition was assessed across 14 conditions:

**Nucleus 6 Only:** Quiet and Competing Noise at 50, 55, 60, 65, 70, and 75 dBA

**Nucleus 6 + Cochlear Mini Microphone:** Quiet and Noise at 50, 55, 60, 65, 70, and 75 dBA

The order of test conditions and AzBio sentence lists were randomized across participants.
Assessment of Speech Recognition Over the Telephone with Use of a Wireless Telephone Accessory

Recorded word recognition was assessed as the participants listened to one full list (50 words) of monosyllabic CNC words (Lehiste and Peterson, 1962). CNC words were delivered from a Sony CFDZW755 compact disc player and then delivered to a NEC DSX 34B BL Display Tel landline phone by way of an RCA component cable that was plugged into the THAT-2 telephone interface. Next, the landline telephone was used to make a telephone call to an Apple iPhone 4S mobile telephone from which the recorded CNC words were presented. The subject set the volume control of the Apple iPhone mobile telephone to his or her most comfortable listening level while listening to the words in quiet and left the volume control at the setting for the remainder of the study. In the condition in which telephone performance was evaluated without the use of the Cochlear Phone Clip+ accessory, the recipient held the mobile telephone next to the microphone of the Nucleus 6 Sound Processor on the ear that as preferred for telephone use. In the condition in which telephone performance was evaluated with use of the Cochlear Phone Clip+ accessory along with the Nucleus 6 Sound Processor, the Cochlear Phone Clip+ accessory was used to wirelessly deliver the speech stimuli from the mobile telephone directly to the Nucleus 6 Sound Processor. The audio signal was streamed to each sound processor for bilaterally implanted participants. Monosyllabic word recognition was assessed across 4 conditions:

- **Nucleus 6 Only**: In quiet and at a competing noise set at 65 dBA
- **Nucleus 6 + Cochlear Phone Clip+**: In quiet and at a competing noise set at 65 dBA

The order of test conditions and CNC word recognition lists were randomized across participants.

Evaluation of Speech Recognition Over a Television with the Use of a Wireless Audio Streaming Accessory

Sentence recognition in quiet and in noise was evaluated with use of the Computer-Assisted Speech Perception Testing and Training Sentence-Level Test (CASPERSENT) 3.7 sentences (Boothroyd, 2007), which serves to assess the participant’s ability to recognize audio and visual cues because the target sentences are spoken by a woman whose face is displayed on a monitor. The CASPERSENT sentences were presented from an Element ELEFW328 32” LED television (HD 720p resolution) that was located 13’6” directly in front of the participant. Audio-visual sentence recognition was assessed in quiet and in the presence of 65 dBA of competing noise both with and without the use of the Cochlear TV Streamer, which was coupled to the audio output port of the television by way of a digital optical audio cable.

The subject adjusted the volume control of the television to his/her most comfortable listening level while listening to the target stimuli in quiet without the use of the Cochlear TV Streamer. Then, audio-visual sentence recognition was assessed in the following four conditions:

- **Nucleus 6 Only**: In quiet and at a competing noise set at 65 dBA
- **Nucleus 6 + Cochlear TV Streamer**: In quiet and at a competing noise set at 65 dBA

The order of test conditions and CASPERSENT sentence recognition lists were randomized across participants.
Results

Cochlear Mini Microphone

Average speech recognition in quiet and across the noise conditions with the Nucleus 6 alone and with the Nucleus 6 + Cochlear Mini Microphone is shown in Figure 3. Data from the two quiet conditions were analyzed using a one-way repeated measures analysis of variance (RM ANOVA), and results revealed significantly better speech recognition in quiet with the Mini Microphone over the Nucleus 6 alone ($F[1,12] = 32.7, p = .002$). To examine significant differences across noise conditions, a two-way RM ANOVA was conducted and showed a significant main effect of device condition ($F[1,72] = 94.1, p = .0002$), a significant main effect of listening condition ($F[5,72] = 88.6, p < .000001$), and significant interaction effect between device and listening condition ($F[5,72] = 11.5, p < .00001$). Post-hoc analyses were conducted to examine the significant main and interaction effects using the Tukey-Kramer Multiple-Comparisons Test. The post-hoc analyses revealed significantly better ($p < .05$) speech recognition with the Cochlear Mini Microphone relative to the Nucleus 6 Sound Processor alone as well as significantly poorer ($p < .05$) speech recognition as the noise levels increased. Post-hoc analyses on the two-way interaction revealed that use of the Cochlear Mini Microphone resulted in significantly better ($p < .05$) speech recognition in noise at the 50, 55, 60, 65, and 70 dBA noise levels when compared to the Nucleus 6 alone. No significant benefit ($p > .05$) of the Cochlear Mini Microphone over the implant alone was seen for the quiet condition or the 75 dBA noise condition.

![Figure 3](image-url)
Cochlear Phone Clip+

Average speech recognition of the CNC words with and without the Cochlear Phone Clip+ is shown in Figure 4. According to a two-way repeated-measures analysis of variance used to examine the effects of the device and listening condition, there was a significant main effect of device condition ($F[1,24] = 9.0, p = .03$) and significant main effect of listening condition ($F[1,24] = 67.2, p = .0004$). Post-hoc analyses on the main effects revealed significantly better ($p < .05$) speech recognition with the Cochlear Phone Clip+ over the Nucleus 6 alone and significantly better ($p < .05$) speech recognition in the quiet condition over the noise condition.

Cochlear TV Streamer

The average speech recognition on the CASPERSENT with and without the Cochlear TV Streamer is shown in Figure 5. A two-way repeated-measures analysis of variance was conducted to examine the effects of the device and listening condition. Results suggested a significant main effect of device condition ($F[1,24] = 16.7, p = .009$) and no significant main effect of listening condition ($F[1,24] = 2.9, p = .15$). The post-hoc analysis on the main effect of device condition showed significantly better ($p < .05$) speech recognition across the quiet and noise conditions with the Cochlear TV Streamer relative to performance with the Nucleus 6 alone.
Discussion & Conclusions

• The Cochlear Mini Microphone resulted in significantly better speech recognition in a quiet listening condition when compared to performance with the Nucleus 6 alone.

• At signal-to-noise ratios ranging from 0 to +10 dB, which are commonly encountered throughout day-to-day use, cochlear implant recipients frequently experience considerable with understanding speech in the presence of the noise. Use of a remote microphone audio streaming accessory may improve sentence recognition by as much as 50 to 60 percentage points in these conditions.

• Use of the Cochlear Mini Microphone with the Nucleus 6 Sound Processor significantly improved speech recognition in noise at 50, 55, 60, 65, and 70 dBA noise levels, which represents signal-to-noise ratios ranging from -5 to +15 dB.

• The Cochlear Mini Microphone also possesses a 3.5 mm (1/8th inch) audio phone port to allow the user to connect via an auxiliary cable to the headphone port of consumer audio electronics.

• The Cochlear Phone Clip+ allows hands-free use of Bluetooth-enabled mobile telephones and may also be used to stream audio from any other Bluetooth-enabled consumer electronic device (e.g., iPad tablet, laptop, Smart TV, etc.).

• The Cochlear Phone Clip+ significantly improved word recognition in quiet and in noise over a mobile phone relative to using the phone with the Nucleus 6 Sound Processor alone.

• Use of the Cochlear TV Streamer with the Nucleus 6 Sound Processor significantly improves recognition in speech over the television in quiet and in noise.

• The CR230 Remote Assistant may be used to adjust the mixing ratio, so that the Nucleus 6 user may determine the emphasis that is placed on the signal of interest from each of the aforementioned wireless audio streaming accessories relative to the signal that is captured at the microphone of the Nucleus 6 Sound Processor. This feature may be especially valuable for those who experience considerable difficulty in noise, because they may select a mixing ratio that provides the majority of focus on the signal from the wireless audio accessory.
References

