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Verification of a Proposed Clinical Electroacoustic Test Protocol for Personal Digital Modulation Receivers Coupled to Cochlear Implant Sound Processors

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Abstract

Background: Guidelines established by the AAA currently recommend behavioral testing when fitting frequency modulated (FM) systems to individuals with cochlear implants (CIs). A protocol for completing electroacoustic measures has not yet been validated for personal FM systems or digital modulation (DM) systems coupled to CI sound processors. In response, some professionals have used or altered the AAA electroacoustic verification steps for fitting FM systems to hearing aids when fitting FM systems to CI sound processors. More recently steps were outlined in a proposed protocol.

Purpose: The purpose of this research is to review and compare the electroacoustic test measures outlined in a 2013 article by Schafer and colleagues in the *Journal of the American Academy of Audiology* titled "A Proposed Electroacoustic Test Protocol for Personal FM Receivers Coupled to Cochlear Implant Sound Processors" to the AAA electroacoustic verification steps for fitting FM systems to hearing aids when fitting DM systems to CI users.

Research Design: Electroacoustic measures were conducted on 71 CI sound processors and Phonak Roger DM systems using a proposed protocol and an adapted AAA protocol. Phonak's recommended default receiver gain setting was used for each CI sound processor manufacturer and adjusted if necessary to achieve transparency.

Study Sample: Electroacoustic measures were conducted on Cochlear and Advanced Bionics (AB) sound processors. In this study, 28 Cochlear Nucleus 5/CP810 sound processors, 26 Cochlear Nucleus 6/CP910 sound processors, and 17 AB Naida CI Q70 sound processors were coupled in various combinations to Phonak Roger DM dedicated receivers (25 Phonak Roger 14 receivers—Cochlear dedicated receiver—and 9 Phonak Roger 17 receivers—AB dedicated receiver) and 20 Phonak Roger Inspiro transmitters.

Data Collection and Analysis: Employing both the AAA and the Schafer et al protocols, electroacoustic measurements were conducted with the Audioscan Verifit in a clinical setting on 71 CI sound processors and Phonak Roger DM systems to determine transparency and verify FM advantage, comparing speech inputs (65 dB SPL) in an effort to achieve equal outputs. If transparency was not achieved at Phonak's recommended default receiver gain, adjustments were made to the receiver gain. The integrity of the signal was monitored with the appropriate manufacturer's monitor earphones.

Results: Using the AAA hearing aid protocol, 50 of the 71 CI sound processors achieved transparency, and 59 of the 71 CI sound processors achieved transparency when using the proposed protocol at Phonak's recommended default receiver gain. After the receiver gain was adjusted, 3 of 21 CI sound processors still did not meet transparency using the AAA protocol, and 2 of 12 CI sound processors still did not meet transparency using the Schafer et al proposed protocol.

Conclusions: Both protocols were shown to be effective in taking reliable electroacoustic measurements and demonstrate transparency. Both protocols are felt to be clinically feasible and to address the needs of populations that are unable to reliably report regarding the integrity of their personal DM systems.

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Key Words: cochlear implants, digital modulation systems, transparency, verification

Abbreviations: AB = Advanced Bionics; CI = cochlear implant; DM = digital modulation; FM = frequency modulation; N5 = Nucleus 5; N6 = Nucleus 6; SNR = signal-to-noise ratio

INTRODUCTION

Frequency modulation (FM) systems are beneficial for children with hearing loss in a classroom setting and help to overcome factors such as distance, reverberation, and noise. Cochlear implant (CI) users experience the same difficulty as hearing aid users in challenging listening situations, and personal FM systems have been proven to improve speech understanding in adverse environments where distance, noise, and reverberation may interfere with educational performance (Schafer and Thibodeau, 2003; Anderson et al, 2005; Schafer and Kleineck, 2009). FM systems consist of a transmitter with a microphone that is worn by the talker of interest (i.e., classroom teacher), which transmits the speech signal to a receiver that is coupled to the listener's (i.e., student) device (i.e., CI sound processor). The signal can be delivered via FM radio frequency or a digital radio signal (Wolfe et al, 2013).

The AAA fitting guidelines recommend the use of objective electroacoustic measures and behavioral testing when fitting FM systems to hearing aids (AAA, 2008). Currently, AAA only recommends behavioral testing when fitting FM systems to individuals with CIs. A protocol for conducting electroacoustic measures when fitting CI users with FM systems has not been established and/or thoroughly researched. An article published in the *Journal of the American Academy of Audiology* by Schafer et al (2013), titled "A Proposed Electroacoustic Test Protocol for Personal FM Receivers Coupled to Cochlear Implant Sound Processors," described a proposed protocol for meeting electroacoustic transparency with CI sound processors and FM systems. "The goal of the proposed electroacoustic test protocol was to achieve transparency (i.e., similar average output) from the CI sound processor and the CI coupled to the FM system when providing the same inputs" (Schafer et al, 2013, p. 943). The electroacoustic test protocol used by Schafer et al (2013) was created using the current AAA (2008) protocol for measuring FM transparency with hearing aids and a study by Thibodeau et al (2005) that focused on the measurement of CI sound processor output. While the protocol was similar to the AAA (2008) guidelines, there were two notable differences:

Transparency was considered to be "achieved" if the average difference in output was equal to or within ±3 dB at 750, 1000, and 2000 Hz, while the AAA (2008) guidelines for hearing aid transparency recommend that the average difference in output should be equal to or within ±2 dB at 750, 1000, and 2000 Hz.

Schafer et al (2013) recommend a variation (i.e., use of a different transparency criterion, ±3 dB versus ±2 dB) of the AAA (2008) protocol.

Aside from these differences, there were some limitations in the study by Schafer et al (2013). First, only four processors were examined and the processor FM configurations were also different. For example, within this group, two of the four processors were Cochlear (Denver, CO) Nucleus 5 (N5) sound processors and other two were MED-EL (Durham, NC) OPUS 2 sound processors. The FM equipment also varied and included the following receivers and transmitters: Oticon Amigo R2, Oticon Amigo T20, Oticon (Somerset, NJ) Amigo T30, Phonak (Warrenville, IL) MLxi, Phonak MLxS, Phonak Campus, and Phonak Inspiro (Schafer et al, 2013). The variation in equipment (i.e., both CI sound processors and FM systems) limits the ability to predict whether transparency can be replicated across multiple FM systems of the same make and model and CI sound processors from different manufacturers in a clinical setting. Digital modulation (DM) systems were not tested in the Schafer et al (2013) study; however, with the trend moving toward the use of DM systems in classroom environments, it is an important variable to consider. DM technology is the latest, most advanced remote microphone technology platform and is adaptive. Research has proven that DM systems improve speech recognition as noise levels in the environment increase. Wolfe et al (2013) compared speech recognition in noise performance for individuals with Cochlear N5 and Advanced Bionics (AB; Valencia, CA) Harmony CI sound processors using Phonak fixed-gain FM, adaptive FM, and Roger DM technology. Results revealed that Roger DM technology provided significantly improved speech-in-noise recognition in the testing conditions with 70–80 dBA of background noise compared to the two Phonak FM configurations (Wolfe et al, 2013).

As educational audiologists, our team is motivated to assist in establishing a best practice protocol for verifying assistive listening systems (i.e., FM or DM systems) when coupled to CI sound processors. As Schafer et al (2013) summarized, the inability to perform electroacoustic test measures on CI sound processors coupled to personal FM (or DM) systems is concerning for following reasons:

1. There is currently no objective way to verify an appropriate fitting.
2. Younger children may not be able to complete speech understanding in noise testing to verify FM benefit.

3. Young children might not be able to report issues with an FM system.
4. It is important that children receive access to the primary speech signal for speech and language development.

Currently, to determine appropriate gain settings in FM/DM receivers when coupled to CI sound processors, pediatric/educational audiologists are dependent on manufacturer default settings and recommendations, child report, and/or speech recognition testing (Schafer et al, 2013). For Phonak devices, the Roger and Cochlear Implants Fitting Guide provides manufacturer recommendations for EasyGain which were determined to be the dB value where the DM receiver output impedances match the CI sound processor input impedances (Phonak AG, 2014). The AB Naida CI Q70, Cochlear N5, and Cochlear Nucleus 6 (N6) have a manufacturer recommended EasyGain of 0 dB for Roger 14 and 17 receivers (Phonak AG, 2014). Concerns abound with these verification options. Without a reliable objective protocol to validate the fitting of an FM/DM system, it cannot be determined if the default settings and manufacturer recommendations are valid when interfacing with a child's personal equipment. Child report and speech recognition abilities may vary greatly depending on factors such as age, ability, and cognitive functioning. These concerns led our team to investigate an appropriate clinical electroacoustic test protocol for personal DM receivers coupled to CI sound processors.

While attempting to implement a clinical protocol for verifying our CI recipient's DM systems, it was determined that there was a dearth of research in this area as the Schafer et al (2013) article is the only reference at this time. In fact, Schafer et al (2013) call for future studies using the proposed protocol to assess its reliability and validity. Previously, our clinical team adopted an electroacoustic test protocol based on the AAA (2008) guidelines for electroacoustic measures when fitting FM systems to hearing aids. Our team ultimately chose these guidelines because they were deemed to be more conservative based on the need to meet transparency at ±2 dB (versus ±3 dB), with a two-step protocol. Our adopted protocol involved running three electroacoustic measurement curves, which is described in detail in the "Methods" section, and then calculating transparency based on the AAA (2008) two-step protocol. After working with this protocol, it was determined that our team should compare our clinic protocol with the proposed protocol by Schafer et al (2013) for electroacoustic measurements of personal DM systems when coupled to CI sound processors. For the purposes of our clinical practice, the focus was limited to Phonak Roger DM transmitters and receivers. In our specific geographical area, many school districts are choosing to purchase and/or rent the latest technology. The DM equipment and CI sound processors in the current study were not used during the creation of the proposed protocol by Schafer et al (2013), and therefore, their suggested volume and gain settings were not applicable to our population.

The clinical questions that were determined prior to the evaluation were

1. Could transparency be achieved across groups of CI sound processors, specifically Cochlear N5/CP810, Cochlear N6/CP910, and AB Naida CI Q70? (Note: These processors were selected because they are the most common processors seen in our clinical population, and thus, there is the greatest need to be able to determine DM transparency for this group.)
2. Could transparency be achieved using DM system equipment? (Note: DM system equipment was evaluated because in our clinical population, districts are trending toward the purchase and/or rental of DM equipment versus FM equipment at this time. Again, this makes verification of DM equipment a priority for our population.)
3. When compared, were there differences in achieving transparency between the AAA (2008) hearing aid protocol and the proposed protocol by Schafer et al (2013) using the following standards:

   a. Use of Schafer's variation of the AAA (2008) protocol?
   b. Use of more stringent transparency measure (2 dB versus 3 dB)?

As previously stated, published guidelines are readily available for measuring transparency for hearing aids with FM systems, and it is imperative to create a similar protocol for measuring transparency using other current technologies (i.e., CIs and DM). This is the only way to ensure that hearing-impaired children are fit appropriately, especially given the behavioral limitations mentioned above.

METHODS

Using the abovementioned protocols (i.e., AAA, 2008 and Schafer et al, 2013), electroacoustic measurements were conducted in a clinical setting with CI sound processors and Phonak Roger DM systems to determine transparency using equivalent inputs into the CI sound processor and DM transmitter microphones. Electroacoustic measurements were performed on a total of 71 CI sound processors (17 AB Naida CI Q70 sound processors, 28 Cochlear N5/CP810 sound processors, and 26 Cochlear N6/CP910 sound processors) coupled to DM systems. Two different types of dedicated receivers were used depending on the CI sound processor manufacturer: the Phonak Roger 17 (n = 9) was used with the AB Naida CI Q70 sound processors and the Phonak Roger 14 (n = 25) was used with the Cochlear N5/CP810 and N6/CP910 sound processors.

The electroacoustic assessment of the DM advantage was conducted with the Audioscan Verifit system using the following steps and calculations. An outlined version of the steps is available in Appendix A, and schematics of the figures are found in Appendix B.

Step 1

One earbud of the CI sound processor monitor earphones (Nucleus CP900 Monitor Earphones for the Cochlear N5/CP810 and N6/CP910 sound processor and the Naida CI Listening Check for the AB Naida CI Q70 sound processor) was attached to the HA-1 coupler with putty. The other earbud of the CI sound processor monitor earphones was used by the examiner to monitor if the speech signal was consistent and if noise or interference was present. The CI sound processor microphones were positioned next to the reference microphone (as shown in Figure 1). The Verifit chamber was closed and a curve was run at 65 dB SPL using Speech-std (1). The SPL values for 750, 1000, and 2000 Hz were recorded and an average was calculated.

(Note: Cochlear N5/N6 sound processors that are programmed at our center are routinely set to a 1:1 mixing ratio; this was the case for all processors included in this study. AB Naida CI Q70 sound processors that are programmed at our center are routinely set to 50:50 audio mixing and in the second program for FM/DM systems, this was the case for all processors included in this study. Also, within this group, one headpiece mic was active but no t-mics were active.)

Step 2

The appropriate DM receiver was attached. For the Cochlear sound processors, the Phonak Roger 14 receiver was attached to the earbuds, as shown in Figure 2. For the AB sound processors, the Phonak Roger 17 receiver was attached to the bottom of the 170 battery rack, as shown in Figure 3. The Phonak DM receivers were then set to the manufacturer default gain (i.e., 0/+10 DM advantage). The CI sound processors were then placed in a sound-attenuating box outside the Verifit chamber, and the Phonak DM transmitter microphone was positioned in the test box near the reference microphone. The Verifit chamber was closed, and a second 65 dB SPL Speech-std (1) curve was run. This measure was conducted to ensure that the addition of the Phonak DM receiver did not change the output of the CI sound processor for inputs delivered to the CI sound processor microphones. The SPL values for 750, 1000, and 2000 Hz were recorded and an average was calculated.

For the proposed Schafer et al (2013) protocol, the average calculated in step 1 was subtracted from the average calculated in step 2. If the offset value was ≤3 dB, DM transparency was considered to have been achieved.

(Note: The sound-attenuating box that was used was fashioned from a typical pencil box lined with foam packing material. A small hole was bored out of one end to accommodate wires.)

Step 3

The CI sound processor was placed back in the Verifit chamber and positioned near the reference microphone. The Phonak transmitter microphone was set to the mute position as shown in Figure 4. The Verifit chamber was closed, and a third and final 65 dB SPL Speech-std (1) curve was run. The SPL values for 750, 1000, and 2000 were recorded and an average was calculated.

For the AAA (2008) protocol, the average for step 3 was subtracted from the average of step 2. If the offset value was ≤2 dB, DM transparency was considered to have been achieved. If the measured DM advantage did not meet transparency, then the gain of the Phonak DM receiver was adjusted until transparency was met.

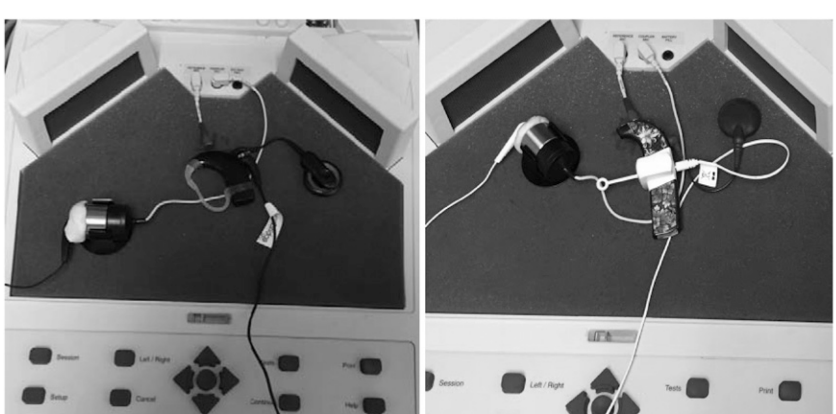

Figure 1. Configuration for step 1. The left picture indicates the configuration used for Cochlear N5/N6 sound processors and the right indicates the configuration for AB Naida CI Q70 sound processors for use in step 1. Line schematics with a key are also available in Appendix B.

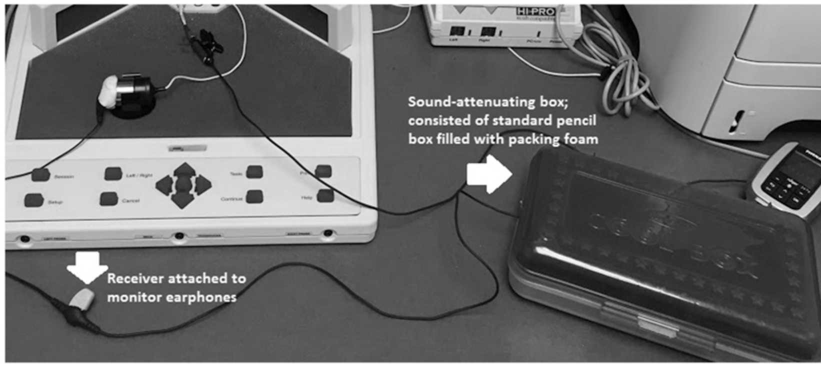

Figure 2. Configuration for step 2. This involves receiver attachment for the Cochlear N5/N6 sound processors and closed sound-attenuating box.

RESULTS

Electroacoustic Measures in a Clinical Setting

To complete the electroacoustic measures, an individual's CI sound processor was coupled with either the child's personal Phonak Roger Inspiro (i.e., transmitter) and personal Phonak Roger 14 or 17 (i.e., receiver) or the equivalent DM equipment from the clinic loaner stock. The amount of times each CI sound processor, DM transmitter, and DM receiver was used is provided in Table 1.

Cochlear N5/CP810 Coupled to Roger 14 DM Receivers

As shown in Figure 5, in the default gain setting (+0 dB), 23 of 28 CI sound processors (82.14%) met transparency using the AAA (2008) guidelines. In the default gain setting (+0 dB), 26 of 28 CI sound processors (89.29%) met transparency using the protocol proposed by Schafer et al (2013). Overall, in the default gain setting, 23 of 28 CI sound processors (82.14%) were able to meet transparency in both conditions.

For the receivers that did not meet transparency in the default gain setting (+0 dB; n = 5), the gain was adjusted to meet transparency for both protocols. Following gain adjustment, transparency was met at −2 dB for two of the five CI sound processors and at −4 dB for one of the five CI sound processors. As shown in Figure 5, after adjusting the receiver gain, 27 of 28 CI sound processors (96.43%) met transparency using the AAA (2008) guidelines and 27 of 28 CI sound processors (92.86%) met transparency using the protocol proposed by Schafer et al (2013). Overall 26 of 28 CI sound processors (89.29%) were able to meet transparency after the receiver gain was adjusted for both protocols.

Cochlear N6/CP910 Coupled to Roger 14 DM Receivers

As shown in Figure 6, in the default gain setting (+0 dB), 26 of 26 CI sound processors (100%) met transparency

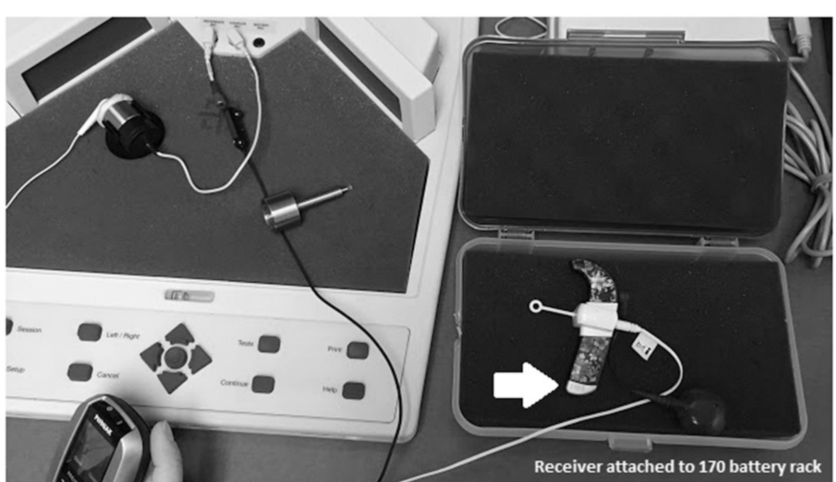

Figure 3. Configuration for step 2. This involves receiver attachment for the AB Naida CI Q70 sound processors and an open sound-attenuating box.

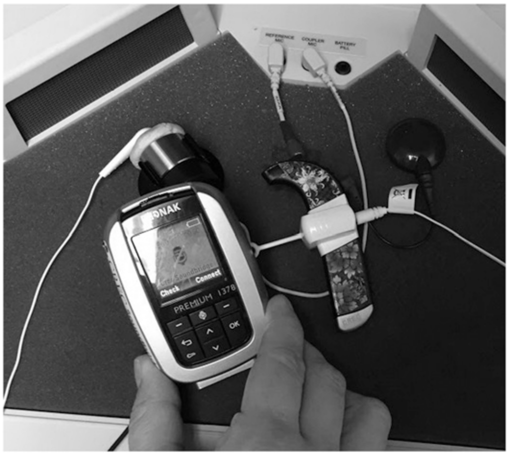

Figure 4. Configuration for step 3. This involves the mute screen on the Phonak Roger transmitter screen.

using the AAA (2008) guidelines. In the default gain setting (+0 dB), 26 of 26 CI sound processors (100%) met transparency using the protocol proposed by Schafer et al (2013). Overall, in the default gain setting, 26 of 26 CI sound processors (100%) were able to meet transparency in both conditions.

AB Naida CI Q70 Coupled to Roger 17 DM Receivers

As shown in Figure 7, in the default gain setting (+0 dB), 1 of 17 CI sound processors (5.88%) met transparency using the AAA (2008) guidelines. In the default gain setting (+0 dB), 7 of 17 CI sound processors (41.18%) met transparency using the protocol proposed by Schafer et al (2013). Overall, in the default gain setting, 1 of 17 CI sound processors (5.88%) was able to meet transparency in both conditions.

The receivers that did not meet transparency in the default gain setting (+0 dB) were then adjusted to either −2 dB (n = 3) or −8 dB (n = 13). As shown in Figure 7, after adjusting the receiver gain settings, 15 of 17 CI sound processors (88.24%) met transparency using the AAA (2008) guidelines, and 16 of 17 CI sound processors (94.12%) met transparency using the protocol proposed by Schafer et al (2013). Overall, 14 of 17 CI sound processors (82.35%) were able to meet transparency after the receiver gain was adjusted in both conditions.

DISCUSSION

As the results clearly indicate, transparency was able to be achieved using electroacoustic measures across the CI sound processors used by our clinical population (Cochlear N5/CP810, Cochlear N6/CP910, and AB Bionics Naida CI Q70) when coupled to Phonak DM receivers and transmitters. When comparing both protocols, transparency was obtained for most of the Cochlear N5 CI sound processors (n = 26), all of the Cochlear N6 CI sound processors (n = 26), and a majority of the AB Naida CI Q70 CI sound processors (n = 14). It should be noted that possible equipment concerns (dirty microphone covers, cracks in the casing, etc.) were observed for the CI sound processors that could not achieve transparency even after adjustments were made to the default receiver gain.

When using the Phonak Roger 14 and 17 DM receivers and Phonak Roger Inspiro transmitters, transparency was able to be achieved consistently in the majority of CI sound processors (n = 66), indicating that electroacoustic transparency measures can be obtained with DM equipment.

Transparency was also able to be achieved for almost all of the CI sound processors when using both the adapted AAA (2008) protocol and the proposed protocol by Schafer et al (2013). However, it is important to note that for some of the CI sound processors gain adjustments were required to meet transparency standards for either one or both protocols. Differences between the number of CI sound processors that were able to reach electroacoustic transparency for each protocol may be attributed to the stricter criteria of ±2 dB for the AAA (2008) adapted protocol. Overall, there were not large differences between meeting transparency when using the AAA (2008) versus the Schafer et al (2013) protocol.

Based on the results, if electroacoustic testing with CI sound processors and DM equipment cannot be completed and the equipment was left at the manufacturer's default

Table 1. Total Number of Times Each CI Sound Processor, DM Transmitter, and DM Receiver Was Used

Equipment Type	Equipment Name	Total Number	Range of Number of Times Used
CI sound processors	AB Naida CI Q70	17	1×
	Cochlear N5 (CP810)	28	1×
	Cochlear N6 (CP910)	26	1×
	Total CI sound processors	71	
DM transmitters	Phonak Roger Inspiro	20	1–17×
	Total DM transmitters	20	
DM receivers	Phonak Roger 14	25	1–15×
	Phonak Roger 17	9	1–5×
	Total DM receivers	34	

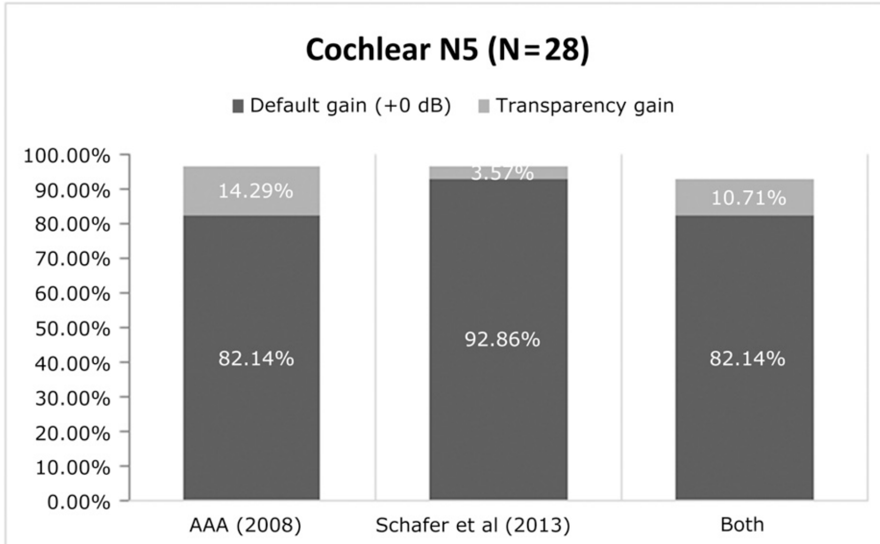

Figure 5. Percentage of Cochlear N5 CI sound processors that met transparency for the two protocols, depending on the gain setting.

receiver gain settings, the effect of the output signal could vary greatly and potentially have adverse implications. The only CI sound processor that met transparency in the manufacturer default gain setting for both protocols in this study was the Cochlear N6 (n = 26). The Cochlear N5 CI sound processor met transparency for 23 of 28 CI sound processors for both protocols with DM receivers using the manufacturer default gain setting. In contrast, the manufacturer default gain setting for the AB Naida CI Q70 CI sound processor only met transparency for one CI sound processor for both protocols. The gain setting needed to be adjusted for almost every DM receiver coupled to the AB Naida CI Q70 CI sound processor and transparency was unable to be obtained for three CI sound processors. Based on these results, it appears that the greatest consequences due to lack of transparency would occur for an AB Naida CI Q70 CI sound processor coupled to a DM receiver using the manufacturer's default receiver gain setting. If transparency cannot be obtained, then the input to the transmitter (i.e., the teacher's voice) may be at a different intensity level than the output from the DM receiver. If the receiver gain setting results in transparency not being ±2 dB or ±3dB, the student may reject the DM system due to the signal being too soft or too loud, and there may be a lack of benefit observed by either the student and/or teacher. In a noisy

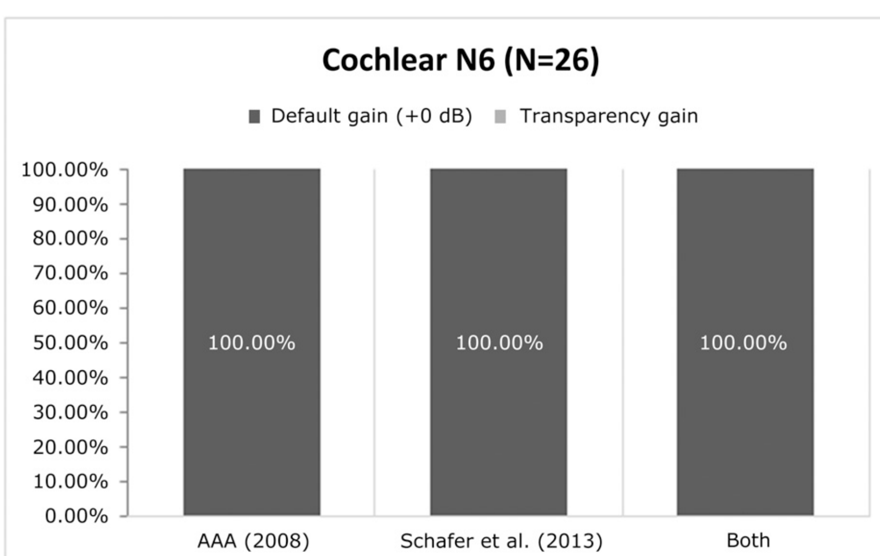

Figure 6. Percentage of Cochlear N6 CI sound processors that met transparency for the two protocols for the recommended default receiver gain.

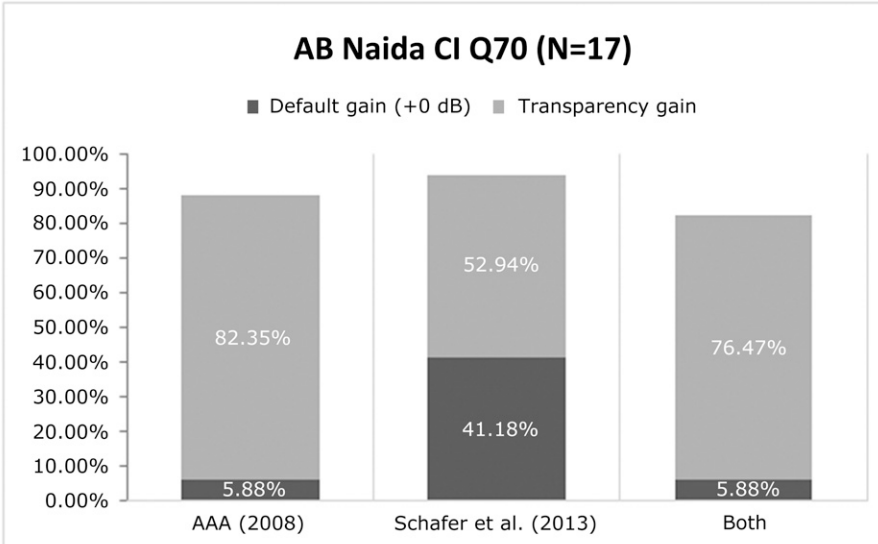

Figure 7. Percentage of AB Naida CI Q70 CI sound processors that met transparency for the two protocols, depending on the gain setting.

environment, this can potentially have an impact on the signal-to-noise ratio (SNR), which might lead to performance decrements in speech understanding for the student. A change in SNR may not be noticeable to the listener due to the fact that a 3-dB SNR has been found to be the just noticeable difference for adults with varying degrees of hearing loss (McShefferty et al, 2015).

Study Limitations

The research team would like to disclose known potential limitations in this study. Limitations include lack of feasibility to measure transparency in all currently used CI sound processors. For example, there were no MED-EL sound processors or earlier generation CI sound processors for any manufacturer (i.e., Cochlear Freedom, AB Harmony) available for measurements in our clinical population. This study was also limited to Phonak integrated DM receivers, rather than universal receivers (i.e., Phonak MLxs, Phonak MLxi, Phonak Roger X). Universal receivers (Phonak Roger X) represent a relatively small portion of the clinical population that is served in our area and thus they were not represented during our evaluation.

In hindsight, it may have also been useful to record the approximate amount of time that the electroacoustic measurements took to complete to achieve transparency. This might have provided other clinicians with useful information regarding the clinical feasibility of measuring transparency for CI sound processors in the clinical setting. While it is the opinion of this research team that electroacoustic test protocols are completely clinically feasible, the team also acknowledges that other centers may not have the same time afforded to complete educational audiological evaluations.

It should also be acknowledged that while achieving electroacoustic transparency with CI sound processors and DM equipment is a positive step in optimizing CI recipients' listening experience, additional behavioral testing would strengthen the validity of the research.

CONCLUSION

Since the AAA (2008) protocol has been in place, it has been considered best practice to use electroacoustic measurements for hearing aids connected with FM systems. By measuring transparency in hearing aids, audiologists are able to confirm that the interaction between FM technology and hearing aids is within an acceptable standard of error, and does not degrade the signal received by the listener. As mentioned earlier, this is a critical measurement given the possible behavioral limitations of some users with this type of technology. It then goes without saying that CI sound processors should also be evaluated using a similar set of standards to ensure an acceptable standard of error.

In this study, a variation of the AAA (2008) protocol and the Schafer et al (2013) proposed protocol were evaluated. Both protocols were shown to be effective in taking reliable measurements to ensure that either a ±2 dB or a ±3 dB transparency measurement could be achieved when coupling commonly used CI sound processors to Phonak DM receivers and transmitters. This study investigates a proposed protocol for electroacoustic measurements of transparency for DM equipment and is felt to be clinically feasible; it also addresses the needs of a population that requires the best access to spoken communication in order to optimize their opportunities for hearing in difficult listening situations, such as a classroom setting.

Despite some limitations in the present study, future research from other clinicians is encouraged so that consensus may eventually be reached to support regular electroacoustic transparency measurements of CI sound processors and DM equipment within the clinical setting. It is also important that future research includes behavioral testing, such as listening in noise testing using equipment which has and has not been verified with electroacoustic measures, to validate this proposed protocol for electroacoustic measures when fitting DM systems to CI sound processors and examine its role in optimizing CI recipients' speech recognition with DM equipment.

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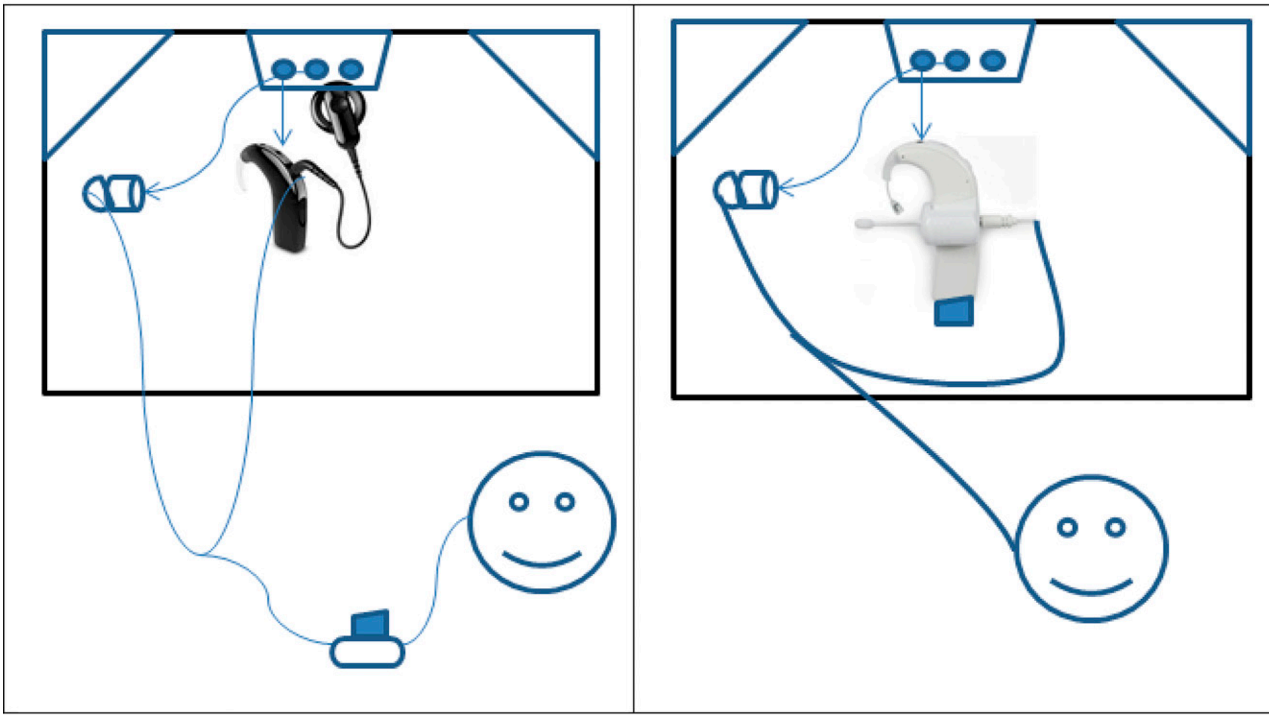
APPENDIX A

Summarized Transparency Protocols

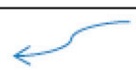
AAA (2008) (for use with hearing aid)	Schafer et al (2013) (for use with cochlear implants)
Step 1	Step 1
Attach the hearing aid to the 2-cc coupler, place in the test box with the hearing aid microphones near the reference microphone	Connect the monitor earphones to the processor
On the Verifit, choose TEST, TEST BOX MEASURES, and SPEECHMAP	Attach one earbud to the HA-1 coupler with putty; place in the sound-attenuating box
Close the Verifit and run at 65 dB SPL using Speech-std (1)	Place the processor in the test box with the processor microphone near the reference microphone
Record the SPL values for 750, 1000, and 2000 Hz and take an average	On the Verifit, choose TEST, TEST BOX MEASURES, and SPEECHMAP
	Close the Verifit and run at 65 dB SPL using Speech-std (1)
	Record the SPL values for 750, 1000, and 2000 Hz and take an average
Step 2	Step 2
Place the hearing aid outside of the test box, and attach the FM receiver and/or boot (if required)	Note the FM gain setting; plug the FM receiver into the monitor earphone cord
Turn on the FM transmitter and "connect" the transmitter to the receiver	Place the processor in the sound-attenuating box
Position the hearing aid with attached FM receiver in the sound attenuating chamber and close the box (note: hearing aid should still be attached to 2-cc coupler)	Place the FM transmitter microphone in the test box near the reference microphone
Place the FM microphone in the test box near the reference microphone, anchor if necessary	On the Verifit, choose TEST, TEST BOX MEASURES, and SPEECHMAP
Close the Verifit and run at 65 dB SPL using Speech-std (1)	Close the Verifit and run at 65 dB SPL using Speech-std (1)
Record the SPL values for 750, 1000, and 2000 Hz	Adjust the FM receiver gain until similar processor and FM curves are achieved
	Record the SPL values for 750, 1000, and 2000 Hz and take an average
	Using the recorded average difference scores, record the appropriate Step II gain setting for the electrically coupled receiver
	Transparency is achieved when the average difference score is ±3 dB
Step 3	
Remove the FM microphone from the test box put in the MUTE position	
Place the hearing aid with coupled FM receiver and 2-cc coupler back in the text box	
Close the Verifit and run at 65 dB SPL using Speech-std (1)	
Record the SPL values for 750, 1000, and 2000 Hz	
While in the TABLE view (under FORMAT OPTIONS on screen), subtract Test 3 values from Test 2 values at 750, 1000, and 2000 Hz, and then calculate a three-frequency average	
The offset value should be between ±2 dB; if not, adjust the gain settings and repeat the process until transparency offset value is met	

APPENDIX B.

Line schematics.



Key to schematics:

	Reference microphone
	Coupler microphone
	Coupler
	Earbud
	Cochlear monitor earphones
	Advanced Bionics listening check
	Receiver

Note: This appendix appears in color in the online version of this article.