Research Article

Measuring Sound-Processor Thresholds for Pediatric Cochlear Implant Recipients Using Visual Reinforcement Audiometry via Telepractice

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Purpose: The goal of this study was to test the feasibility of using telepractice for measuring behavioral thresholds (T levels) in young children with cochlear implants (CIs) using visual reinforcement audiometry (VRA). Specifically, we examined whether there were significant differences in T levels, test time, or measurement success rate between in-person and remote test conditions.

Method: Data were collected for 17 children, aged 1.1–3.4 years. A within-subject AB-BA (A, in-person; B, remote) study design was used, with data collection typically occurring over 2 visits. T levels were measured during each test session using VRA for one basal, middle, and apical electrode. Two additional outcome measures included test time and response success rate, the latter of which was calculated as the ratio of the number of electrode thresholds successfully

measured versus attempted. All 3 outcome measures were compared between the in-person and remote sessions. Last, a parent/caregiver questionnaire was administered at the end of the study to evaluate subjective aspects of remote versus traditional CI programming.

Results: Results showed no significant difference in T levels between in-person and remote test conditions. There were also no significant differences in test time or measurement success rate between the two conditions. The questionnaires indicated that 82% of parents or caregivers would use telepractice for routine CI programming visits some or all of the time if the option was available.

Conclusion: Results from this study suggest that telepractice can be used successfully to set T levels for young children with CIs using VRA.

In the first year following cochlear implantation, numerous follow-up visits are required for programming the cochlear implant (CI) sound processor. Programming levels can change substantially over the first few months of activation (e.g., Hughes et al., 2001), necessitating more frequent visits with the CI audiologist during the first year. Additional visits are often required for very young children because of their limited ability to attend, cooperate, and communicate what they hear. This added burden can be difficult for families who travel significant distances to CI centers, which are not widely located due to their specialized nature. One potential solution is to program the CI remotely via telepractice. The goal of the present study was to empirically evaluate the feasibility of using telepractice to

remotely program CIs for very young children using visual reinforcement audiometry (VRA).

To create an optimal CI sound-processing program, numerous behavioral measures are needed from a CI recipient. These include threshold levels (T levels) and either most comfortable (M levels for Advanced Bionics devices) or loud but comfortable levels (C levels for Cochlear Ltd. devices and M levels for MED-EL devices). Contemporary CIs have anywhere from 12 (MED-EL) to 22 (Cochlear Ltd.) intracochlear electrodes. Ideally, T and C or M levels should be obtained for all electrodes and should be repeatable to be considered reliable. Although some shortcuts can be used to reduce the amount of behavioral information needed to construct a basic CI program (e.g., Overstreet, 2004; Plant et al., 2005), the need for multiple visits remains.

Programming levels are easily obtained for adults and older children who have experience with sound and the language skills to communicate what they hear. Programming CI sound processors for young children, however, is challenging for several reasons. First, deaf children lack experience with sound, so it is difficult for them to make

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loudness judgments that are necessary for setting CI program levels at the upper end of the behavioral dynamic range. Second, young children typically lack the language to convey what they hear. As a result, CI audiologists tend to set C or M levels at a predetermined amount above behavioral thresholds and/or use objective measures to aid in setting program levels (e.g., Gordon, Papsin, & Harrison, 2004; Hughes, Brown, Abbas, Wolaver, & Gervais, 2000). Last, a child's ability to attend, cooperate, and engage in a task to measure behavioral thresholds is limited by age and developmental level. As a result, it can be difficult to get enough reliable behavioral information to construct a basic, appropriate program for a young child within a standard clinical visit.

The use of telepractice for CI programming has primarily been investigated for adult recipients. A handful of studies have compared CI programming levels obtained in person versus remotely for adult recipients (Eikelboom, Jayakody, Swanepoel, Chang, & Atlas, 2014; Hughes et al., 2012; McElveen et al., 2010; Ramos et al., 2009; Wesarg et al., 2010). Ramos et al. (2009) examined M levels that were obtained in person versus remotely for a group of five adult recipients of Advanced Bionics devices. Data were reported for one basal, middle, and apical electrode. M levels that were obtained remotely were within 11 clinical units (CU) of those obtained in person, and none of the differences were statistically significant. McElveen et al. (2010) used a different approach and compared speech-perception performance for a group of seven recipients of Cochlear Ltd. devices who were programmed remotely versus another group of seven recipients who were programmed in person. The results showed no significant difference in performance between the two groups. A limitation of that study, however, was that it did not use a within-subject design. Wesarg et al. (2010) carried out a multicenter within-subject study with 69 cochlear recipients who were programmed in person and remotely by the same audiologist within a 2-day period. Results from that study showed no significant differences in T or C levels between the remote and in-person programming methods. The average difference in T or C levels between programming sites was less than 1 current-level (CL) unit. A limitation of the study was that the T and C levels were derived from an existing program that was opened and adjusted at each of the test visits, as opposed to beginning each session with a blank program (i.e., blinded). Hughes et al. (2012) measured T and C or M levels for a group of 29 adults and older children with Cochlear Ltd. or Advanced Bionics devices. Programming levels were obtained using an ABA design, where the first set of measurements were obtained in person, then remotely, and then in person. The results showed no significant effect of location for either T or C/M levels. Finally, Eikelboom et al. (2014) measured M levels for 11 recipients of MED-EL devices using a split-half design. Participants' processors were programmed in person and remotely by the same audiologist. The results showed no significant difference in M levels between in-person and remote conditions. In general, these studies with adults have found that

programming levels are similar for both methods, demonstrating the feasibility of remote CI programming for this more straightforward population.

In contrast to postlingually deaf adults, different audiologic testing methods are used with young children to measure behavioral thresholds. For children who are approximately 3–6 years of age, conditioned play audiometry (CPA) is used. With this method, a play assistant conditions the child to respond to sound by engaging in a simple play task, such as dropping a block in a bucket or putting a ring on a peg (e.g., Nielsen & Olsen, 1997; Talbott, 1987). In a recent study from our laboratory (Goehring & Hughes, 2017), 19 children with CIs were tested using CPA in person versus remotely to assess the viability of using telepractice for this younger population. Results showed no significant differences in T levels between the two test locations. In addition, the amount of testing time and success rate in obtaining responses when attempted did not differ between remote and in-person conditions. These results demonstrate that remote programming procedures can be used successfully for young children with CIs when CPA methods are necessary.

Currently, CIs have regulatory approval in the United States for profoundly deaf children as young as 1 year old. In some cases, such as with meningitis, children might receive a CI before 1 year old (this is considered an off-label use of the device). For this younger population, VRA is typically used to obtain behavioral thresholds. VRA is a standard audiometric technique that requires conditioning a child to turn toward a lighted and/or an animated object in response to sound (Liden & Kankkonen, 1961). For the conditioning phase, a suprathreshold sound is played to the child at the same time that a lighted or an animated object is activated. The object is placed toward one side of the child so that the child's visual response to the auditory stimulus (i.e., head turn) is obvious. Once the child is conditioned, the testing phase begins. During the testing phase, the sound is played, and if the child looks at the object, then the tester activates the lighting or animation of the object. This technique is typically utilized for children up to approximately 3 years old (or older, depending on the child's developmental level). To date, no study has reported on the feasibility of using telepractice for obtaining behavioral thresholds in young children using VRA, including for children with normal hearing.

The goal of the present study was to compare behavioral T levels obtained in person versus those obtained remotely using traditional VRA testing methods to determine whether differences existed between the two conditions. As with our earlier study using CPA (Goehring & Hughes, 2017), we only evaluated T levels because they are a more straightforward and reliable measure than upper comfort levels (C or M) for this age group. Young children cannot scale or rate loudness, so the upper comfort levels are typically set above T levels by some fixed amount or by using some combination of objective measures (e.g., Gordon et al., 2004; Hughes et al., 2000). Because the procedures used to set upper comfort levels are more subjective and

can vary widely across clinicians, we chose to focus on T levels as the primary outcome measure for this study. In accordance with our earlier study (Goehring & Hughes, 2017), we also evaluated test time and measurement success rate for the two test conditions, as well as questionnaire responses from caregivers that rated the acceptance and usability of remote programming. The null hypothesis was that there would be no significant differences in T levels, test time, or measurement success rate between the in-person and remote conditions. The alternative hypothesis was that the in-person and remote conditions would differ; therefore, two-tailed tests were used to determine in what direction any potential differences occurred. On the basis of results from our earlier study (Goehring & Hughes, 2017), we anticipated that outcomes from the questionnaire would generally view remote programming as a feasible alternative to in-person CI programming for very young children.

Method

Participants

Seventeen pediatric CI recipients participated (seven boys, 10 girls). The mean age at participation was 1.9 years (range = 1.1–3.4 years) and the average length of CI use was 8 months (range = 0.2–1.4 years). Participants used devices from different manufacturers: 11 Advanced Bionics devices, three Cochlear Ltd. devices, and three MED-EL devices. Ten children had bilateral CIs; six received CIs in sequential surgeries, and four were simultaneous. Children with bilateral CIs were only tested in one ear. For those with sequential bilateral implants, the test ear was the one that was implanted the longest. For those who received bilateral CIs simultaneously in a single surgery, the test ear was chosen at random. Six children used a hearing aid on the opposite ear, and one child used a single CI with no hearing aid on the opposite ear. Devices for the nontest ear (hearing aid or CI) were removed during the test sessions. Additional participant demographics are listed in Table 1. Written informed consent was obtained from each child's parent or guardian. Families were compensated for hourly participation and received a travel stipend. This study was approved by the Boys Town National Research Hospital Institutional Review Board under Protocol 13-09-XP.

Study Design

This study used the same design as reported by Goehring and Hughes (2017) for the older children tested using CPA. An AB-BA design was used, with each pair of sessions typically spaced over two visits. The in-person condition (A) occurred in the laboratory. The remote condition (B) occurred with the programming audiologist in the laboratory and the child, caregiver, and test assistant in another room in the same building. Data were collected over two visits, with the exception of three children (C50, C78, and F25) whose limited cooperation required additional visits to obtain a full data set. The test order for

the first visit was the in-person condition first, followed by the remote condition (AB), with the test order reversed for the second visit (BA). Short breaks were provided between the two conditions at each visit. The average time from the first to the second visit was 7 days (range = 1–28 days; see Table 1). Including the added visits for the three aforementioned participants, the average time from the first to the last visit was 13.5 days (range = 1–87 days; see Table 1). In all but three cases (C78, C82, and M4), the same programming audiologist and test assistant were used across visits within a participant. For these three cases, the original test assistant was not available for the second visit so a different assistant assigned to the study participated. For the first 10 participants, the test assistant was either an audiologist with 1–2 years of clinical experience or a speech-language pathologist with extensive experience working with children with CIs. For the remaining seven participants, the two test assistants were not audiologists but had some background in the field. To train for the task of test assistant, these two individuals watched recorded sessions from the study prior to the research visits in which they participated and were coached throughout the test sessions by the programming audiologist. For an individual who is used to interacting with young children, we found that it would typically only take a few trials to be proficient in the task.

Equipment Setup

For the in-person condition, the commercial programming software for each device manufacturer resided on a Dell Optiplex 780 desktop PC with the Windows 7 operating system. The specific software was as follows: SoundWave v. 2.3.23 (Advanced Bionics), Custom Sound v. 4.3 (Cochlear Americas), and Maestro v. 6.0.1 (MED-EL). All testing was completed using a manufacturer-specific laboratory processor so that changes were not made to the participant's daily program. Device-specific commercial interfaces and programming cables were used to connect to the processor used by each participant.

For the remote condition, the programming audiologist remained in the laboratory and used the same PC to gain remote access to a Hewlett-Packard ProBook laptop computer (with Windows 7) located at the remote site with the participant. Remote access was achieved using Windows Remote Assistance, which creates an encrypted pathway between two computers. The same commercial programming software and CI hardware used in the in-person condition were also located at the remote site. The test assistant connected the child's processor to the programming cable at the beginning of the session.

To achieve a bidirectional audio and video connection between the two sites, a Polycom HDX 7000 System (Polycom Inc.) with a 28 × 16-in. video monitor was used in the laboratory, and a CISCO system (CISCO Systems) with a 52 × 29-in. video monitor was used at the remote site. Figure 1 shows an illustration of the equipment setup at the programming audiologist's site (left panel) and at the remote site (right panel) for the remote testing condition.

Table 1. Subject demographics.

Subject ID	Age at test (years)	Internal device	Processor type	No. of days first to last visit
C50	2.4	HiRes 90K 1J	Neptune	(3, 28) 87
C57	1.3	HiRes 90K Hi Focus Mid Scala	Neptune	28
C60	1.2	HiRes 90K Hi Focus Mid Scala	Naida Q70	7
C66	1.2	HiRes 90K Hi Focus Mid Scala	Neptune	3
C78	2.0	HiRes 90K Hi Focus Mid Scala	Neptune	(7) 14
C82	1.4	HiRes 90K Hi Focus Mid Scala	Naida Q70	7
F25	2.1	Freedom 24RE(CA)	Nucleus 6	(14) 26
N18	1.7	Nucleus CI512 Profile	Nucleus 6	1
M2	1.1	Synchrony Flex 28	Opus 2	14
M4	3.4	Synchrony Flex 28	Opus 2	13
C95	2.2	HiRes 90K Hi Focus Mid Scala	Neptune	2
C96	1.7	HiRes 90K Hi Focus Mid Scala	Neptune	9
N25	2.8	Nucleus CI522	Nucleus 6	9
C98	1.8	HiRes 90K Hi Focus Mid Scala	Naida Q90	1
C107	2.3	HiRes 90K Hi Focus Mid Scala	Neptune	1
C108	2.3	HiRes 90K Hi Focus Mid Scala	Neptune	1
M8	2.2	Synchrony Flex 28	Opus 2	7

Note. Values in parentheses in the last column represent the number of days from Visit 1 to Visit 2 for the three participants who required additional visits (and from Visit 1 to Visit 3 for C50).

As shown in the right panel of Figure 1, the video screen at the remote site was positioned behind the child to avoid distractions, but was visible to the test assistant for ease of communication with the audiologist. The web camera was positioned behind and to the right of the child (approximately 135° azimuth) for better viewing of behavioral responses by the programming audiologist.

Procedure

T Levels

At the start of each test session, electrode impedances were measured to ensure that all test electrodes were functioning within the manufacturer's normal range. Next, the audiologist created a blank program at the beginning of each test session. Prior to the first session, another lab member (not participating with data collection for the study) provided the audiologist with basic information from the child's current daily program, which included the processing strategy, stimulation rate, pulse duration, and approximate starting levels for each test electrode. This was done so that the programming audiologist was not biased by knowledge of the child's current program levels. The starting levels that were provided to the programming audiologist were determined arbitrarily between 40% and 60% of the child's existing map dynamic range for each electrode. This method ensured that the starting stimulation level would be audible enough to begin conditioning the child, but would not be too loud. In realistic applications of remote programming for routine follow-up visits, the audiologist would open the recipient's daily program and make adjustments from the existing levels. However, here we chose a pseudo-blinded method to ensure a more rigorous study design.

Standard VRA methods were used to condition the child and obtain thresholds. T levels were obtained for

three electrodes spaced across the basal, middle, and apical portions of the electrode array. Test electrodes were typically electrodes 13, 8, and 3 for Advanced Bionics; 3, 11, and 19 for Cochlear; and 10, 6, and 3 for MED-EL. Within each session, the test order for each electrode was randomized. In both the in-person and remote conditions, the test assistant was seated at a table across from the child, who was on the parent/caregiver's lap. The test assistant used neutral toys to center the child's attention toward the middle of the table. The visual reinforcer was located toward the left or right side of the table, corresponding to the ear with the CI. The reinforcer either was hardwired to a pancake switch or foot pedal on the floor under the table (operated by the test assistant) or was operated by a handheld remote control. In the remote condition, the volume on the laptop at the remote site was turned on so that the test assistant was aware of exactly when the stimuli were being presented. This feature helped to eliminate improper timing of reinforcement, which was an initial obstacle encountered in our CPA study (Goehring & Hughes, 2017). After the child was conditioned to look at the visual reinforcer when a sound was heard, a traditional bracketing procedure was used to find threshold. The same step sizes were used for bracketing as reported by Goehring and Hughes (2017), which were manufacturer specific. For Advanced Bionics recipients, the step size was 10 CU down and 5 CU up. For Cochlear recipients, the step size was 6 CL down and 2 CL up. For MED-EL recipients, the step size was a 3% change in charge, which was one arrow-key press up or down on the keyboard. Responses to the stimulus for conditioning and while seeking threshold were judged by both the play assistant and by the programming audiologist, who conferred verbally about response reliability. The same procedures were followed for both the remote and in-person sessions.

Figure 1. Illustration depicting the test setup for the remote condition. Left: The CI audiologist is seated in front of a computer that is used to gain remote access to the laptop at the recipient site (right panel). The videoconferencing system provides a two-way audio and video communication between the audiologist and the test assistant. Right: The child, caregiver, and test assistant are located at the remote site. The child sits with his or her back to the video monitor to avoid visual cues from the audiologist. The play assistant engages the child in the behavioral tasks to obtain thresholds. CI = cochlear implant.

Test Time

Test time (in minutes) was recorded by the programming audiologist using the start and end time for the behavioral tasks. Specifically, the start time commenced when the programming software was opened, and the end time was recorded when the last behavioral response was obtained. Because the primary purpose for recording the test time was to determine whether the remote procedure caused the testing to take longer (e.g., due to distractions, unfamiliar environment, or the need for additional communications between testers), the recorded test time excluded the informed consent process, equipment setup, and administration of the parent/caregiver questionnaire.

Measurement Success Rate

The rate of measurement success was calculated to determine whether the remote procedure hindered the ability to obtain reliable thresholds. For both the in-person and remote conditions, the measurement success rate was calculated as the number of electrodes for which reliable thresholds were obtained, divided by the number attempted. The initial goal was to measure each threshold twice at each session to ensure repeatability, with the final threshold for each electrode and session being the average of the repeated measures. However, with this young age group, this goal was often not possible. Therefore, the minimum requirement was to obtain at least one reliable behavioral threshold for each electrode at each test session (A, B, B, A),

which would result in a total of six thresholds (or "attempts") across the in-person conditions (three electrodes times two "A" sessions) and six thresholds across the remote conditions (three electrodes times two "B" sessions).

Questionnaire

Upon completion of the four test sessions (ABBA), a short questionnaire was given to the parent or caregiver. The questionnaire was the same as that used for the CPA group in our earlier study (Goehring & Hughes, 2017) and consisted of seven questions investigating how positively or negatively the remote testing procedures were perceived and how often the family would utilize remote services if they were available. Space was provided on the questionnaire to allow for open-ended elaboration for each question. The specific questions are listed in the Results section. The questionnaire was specifically designed for our studies and was therefore not a validated assessment tool.

Data Analysis

Thresholds for each child were converted to charge (nanocoulombs, nC) so that data from all manufacturers (who use different units) could be analyzed together. Threshold and test-time data were analyzed using a repeated-measures (RM) general linear model in SPSS (IBM SPSS). Greenhouse–Geisser corrections for degrees of freedom were used when sphericity was not met (Mauchly's test of sphericity). A Bonferroni correction was applied for

multiple comparisons. Individual signed-ranks tests (because data were not normally distributed) were used for the measurement success rate data.

Results

Behavioral Thresholds (*T Levels*)

As noted above, the goal was to obtain at least one reliable behavioral threshold for each electrode at each test session (A, B, B, A). For this age group, however, it was not always possible to obtain thresholds for all electrodes at both in-person (A) or both remote (B) sessions. This occurred for five participants: C50, C57, C78, F25, and M2. Therefore, thresholds for each participant were averaged across the two in-person visits (A) to obtain a mean threshold for each electrode for the in-person condition and across the two remote visits (B) to obtain a mean threshold for each electrode for the remote condition. Table 2 details the specific visits, conditions, and electrodes for which measures could or could not be obtained. The cells with asterisks represent successful measures, and the cells with an "x" represent unsuccessful measures. Three participants (C50, C78, and F25) required additional visits to obtain a minimum of one threshold for a given condition/electrode. For C50, a third visit was added to attempt to obtain the data that were missing from the first two visits. After three visits, the threshold for the middle electrode in the remote condition could not be obtained; therefore, a fourth visit was added, and the threshold was successfully measured (not shown in Table 2). A third visit was also added for F25 because data for the basal electrode in the in-person condition could not be obtained across the first two visits. Finally,

a third visit was added for C78 because thresholds could not be obtained for any electrode at Visit 1 in either the in-person or remote conditions or for the middle electrode at Visit 2 in the remote condition. The CI audiologist noted that VRA did not seem to hold her attention, but she was not quite ready for CPA. This participant was unable to return for another attempt to obtain a threshold for the middle electrode in the remote condition. Despite the addition of a third visit, this data point could not be obtained; therefore, threshold data from C78 were excluded from the analysis.

The top row of Figure 2 shows box-and-whisker plots representing group *T* levels in electrical charge (nC) from the 16 remaining participants (excluding C78). From left to right, each graph represents data from the basal, middle, and apical electrodes, respectively. Gray and white boxes represent data for the in-person and remote conditions, respectively. Box boundaries represent the 25th and 75th percentiles, and whiskers represent the 10th and 90th percentiles. The solid horizontal lines represent medians, and the dashed horizontal lines represent means. The black circles represent outliers.

A two-way RM analysis of variance (ANOVA) was conducted to assess the effects of condition (in-person, remote) and electrode (basal, middle, apical). Results showed no significant effect of condition, $F(1, 15) = 0.001$, $p = .98$, partial $\eta^2 < .001$, or electrode, $F(2, 30) = 0.261$, $p = .77$, partial $\eta^2 = .017$. There was also no significant interaction between these two factors, $F(1.4, 20.4) = 2.944$, $p = .09$, partial $\eta^2 = .164$. Mean thresholds for the in-person and remote conditions, averaged across electrodes, were 4.91 and 4.90 nC, respectively. Mean thresholds for basal, middle, and apical electrodes (averaged across conditions)

Table 2. Measurement success rate for individual participants.

Subject ID	VISIT 1						VISIT 2						VISIT 3					
	In-person			Remote			Remote			In-person			In-person			Remote		
	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A	B	M	A
C50	*	*	*	*	X	*	X	X	*	X	X	X	X	X	X	*	X	*
C57	*	*	*	*	*	*	*	*	*	*	X	*						
C60	*	*	*	*	*	*	*	*	*	*	*	*						
C66	*	*	*	*	*	*	*	*	*	*	*	*						
C78	X	X	X	X	X	X	*	X	*	*	*	*	X	X	X	X	X	X
C82	*	*	*	*	*	*	*	*	*	*	*	*						
F25	X	*	X	X	*	*	*	*	*	X	*	*	*			*		
N18	*	*	*	*	*	*	*	*	*	*	*	*						
M2	*	*	*	*	X	*	X	*	*	X	X	X						
M4	*	*	*	*	*	*	*	*	*	*	*	*						
C95	*	*	*	*	*	*	*	*	*	*	*	*						
C96	*	*	*	*	*	*	*	*	*	*	*	*						
N25	*	*	*	*	*	*	*	*	*	*	*	*						
C98	*	*	*	*	*	*	*	*	*	*	*	*						
C107	*	*	*	*	*	*	*	*	*	*	*	*						
C108	*	*	*	*	*	*	*	*	*	*	*	*						
M8	*	*	*	*	*	*	*	*	*	*	*	*						

Note. Cells with asterisks represent successful measures, and cells with an "x" represent unsuccessful measures. Blank cells under Visit 3 mean that no measures were attempted or that there was not a Visit 3 for that participant. B = basal; M = middle; A = apical electrode.

Figure 2. Top: Box-and-whisker plots for T-level data expressed in electrical charge (nC) for the basal (left), middle (middle), and apical (right) electrodes tested in all subjects. Boxes and whiskers represent the 25th–75th and 10th–90th percentiles, respectively. Filled circles represent outliers. Means and medians are indicated by the dashed and solid lines, respectively. Data for in-person and remote conditions are shown in gray and white, respectively. Bottom: Bland and Altman (1986) plots depicting the difference in T-levels (in nC) between the in-person and remote conditions (in person minus remote), plotted as a function of the mean T-level (average of in-person and remote conditions) for each individual. Data for basal, middle, and apical electrodes are plotted from left to right, respectively. Horizontal dashed lines represent ± 2 SDs around the group mean. T-level = threshold level; nC = nanocoulombs; Avg = average; IP-Rem = In-person minus Remote.

were 4.97, 5.02, and 4.73 nC, respectively. These results show that there was no significant difference in T levels between the traditional in-person and remote programming conditions.

The bottom row of Figure 2 shows the difference in T-levels (in nC) between the in-person and remote conditions (in person minus remote), plotted as a function of the mean T-level (average of in-person and remote conditions) for each individual. These plots (Bland & Altman, 1986) serve to evaluate the agreement between results obtained in the two conditions. In each panel, the solid horizontal line represents the mean difference between the in-person and remote conditions, averaged across all participants. These differences were 0.09, 0.32, and -0.29 nC for basal, middle, and apical electrodes, respectively. The dashed horizontal lines represent ± 2 SDs. These values were ± 1.48 , ± 1.01 , and ± 1.92 for basal, middle, and apical electrodes, respectively. As can be seen in these plots, one data point for each electrode region fell outside ± 2 SDs, and these occurrences were for three different participants: C78, F25, and M2 for the basal, middle, and apical regions, respectively.

Test Time

Figure 3 shows the amount of time spent obtaining behavioral thresholds for each condition and visit. These results do not include data from the additional visits for

the three participants who required extra test sessions (C50, C78, and F25). The outlier in the remote condition for Visit 1 was Participant C50, who was the first participant for this study and who also required additional visits (see Tables 1 and 2). A two-way RM ANOVA was performed to determine whether there was a significant difference in test time between in-person (gray boxes) and remote (white boxes)

Figure 3. Box-and-whisker plots for test time (in minutes) for in-person and remote conditions. Data are plotted similar to the top row of Figure 2.

conditions. Results showed no significant effect of condition, $F(1, 16) = 0.34, p = .57$, partial $\eta^2 = .021$, or visit, $F(1, 16) = 1.50, p = .24$, partial $\eta^2 = .085$, and no significant Condition $\times$ Visit interaction, $F(1, 16) = 1.77, p = .20$, partial $\eta^2 = .10$. The mean duration for in-person and remote conditions, averaged across visits, was 12.4 and 13.0 min, respectively. The mean duration for Visits 1 and 2, averaged across conditions, was 13.2 and 12.1 min, respectively. These results show that the remote testing procedure did not take significantly longer than the average in-person procedure.

To determine whether demographic factors, such as age or CI experience, affected the overall test time, Pearson correlation analyses were conducted. Because the RM ANOVA results showed no significant effect of visit or condition, test time was averaged across all four combinations of visit and condition (again, excluding the additional visits). There was no significant correlation between age and overall test time ($r = .04, p = .89, N = 17$) or between the duration of CI use (the time from initial stimulation to the first test session of the study) and overall test time ($r = -.06, p = .81, N = 17$). The average test duration for the five children for whom at least one measurement was unsuccessful (C50, C57, C78, F25, and M2; see Table 2) was approximately 5.5 min longer than for the remaining children (16.55 vs. 11.04 min, respectively). This difference was statistically significant (t test, $t = -4.97, df = 15, p < .001$).

Measurement Success Rate

The left panel of Figure 4 shows the mean number of electrode thresholds obtained, missed, and total attempted for the in-person (gray bars) and remote (white bars) conditions. Bar height represents the mean data, and whiskers represent $+1$ SD. Individual signed-ranks tests showed no significant differences between in-person and remote conditions

Figure 4. Bar graphs depicting measurement success for in-person (gray bars) and remote (white bars) conditions. Left panel: Data showing the mean ($+1$ SD) number of electrode thresholds obtained, missed, and total attempted for each test condition. Right panel: The measurement success rate was calculated for each individual as the number of electrode thresholds obtained divided by the number attempted. Bar height represents the mean measurement success rate across all participants.

for the number of measures obtained ($Z = 0.82, p = .5, df = 16$), missed ($Z = 0.26, p = .8, df = 16$), or total attempted ($Z = 1.09, p = .3$). For each participant, an individual measurement success rate was calculated by dividing the number of thresholds obtained by the total number attempted. The right panel shows the mean ($+1$ SD) measurement success rate for in-person (gray bars) and remote (white bars) conditions. A signed-ranks test indicated no significant difference in measurement success rate between conditions ($Z = -0.17, p = .9$). As noted above, Table 2 details the individual measurement success for each electrode, condition, and visit. For the five children who had unsuccessful measurements at the first two visits (C50, C57, C78, F25, and M2), 13 of these occurred for the in-person condition, and 10 occurred for the remote condition.

To determine whether demographic factors, such as age or CI experience, affected the measurement success rate, Pearson correlation analyses were conducted. There were no significant correlations between age and measurement success rate for either the in-person ($r = -.14, p = .60, N = 17$) or the remote ($r = -.18, p = .49, N = 17$) conditions. Likewise, there were no significant correlations between duration of CI use and measurement success rate for either the in-person ($r = -.21, p = .42, N = 17$) or the remote ($r = -.29, p = .25, N = 17$) conditions.

Questionnaire

Questionnaire results are summarized in Table 3. All seven questions are listed in the left column. In each cell, the number of respondents are listed (total across rows = 17), along with the percentage of the total in parentheses. All respondents reported that the efficiency and test environment for the remote condition were the same or better than in the in-person condition (Q1 and Q2). The one respondent that viewed the remote test room as “much better” than the in-person room (Q2) did not elaborate regarding what factors mediated this opinion. For Q3, 14 of the 17 respondents (82%) said that they would take advantage of remote programming some or all of the time. Three respondents said that they would never take advantage of this service if it were available. Two of those respondents lived in the same metropolitan area as the CI center, but only one elaborated to explain that their proximity to the CI clinic would require no need for their utilization of telepractice. These responses might also be influenced by the fact that approximately half of the respondents felt that it is not a hardship to attend clinical visits (Q5). In general, the technology was viewed positively (Q4, Q6, and Q7).

Discussion

The primary goal of this study was to evaluate the feasibility of using telepractice to obtain behavioral T levels for pediatric CI recipients using VRA techniques. The results showed that the process is feasible and was generally well received by participants and caregivers. T levels obtained in the remote condition were not significantly different from

Table 3. Questionnaire results.

Questions	Much worse	Slightly worse	The same	Slightly better	Much better
Q1. How smooth or efficient were the remote procedures compared to the in-person procedures?	0 (0%)	0 (0%)	16 (94%)	1 (6%)	0 (0%)
Q2. How did the remote test room compare to the in-person room?	0 (0%)	0 (0%)	16 (94%)	0 (0%)	1 (6%)
Q3. How often would you take advantage of remote options if they were regularly available for clinical appointments close to your home?	Never 3 (18%)			Some of the time 7 (41%)	All of the time 7 (41%)
Q4. Would you feel comfortable speaking with your child's clinician through videoconferencing technology?	0 (0%)		3 (18%)		14 (82%)
Q5. Do you feel it can be a hardship to attend clinical CI programming appointments for your child (e.g., travel, cost, time off work/school)?	8 (47%)		7 (41%)		2 (12%)
Q6. Did you feel overwhelmed by the distance technology?	Not at all 17 (100%)			Somewhat 0 (0%)	Yes 0 (0%)
Q7. Do you feel your child was distracted or not engaged due to the distance technology?	15 (88%)			2 (12%)	0 (0%)

Note. Number of responses is listed in each cell, with percentage of the total given in parentheses. CI = cochlear implant.

those obtained in person. Furthermore, the remote testing procedure did not lengthen the test time significantly, nor did it interfere with the success rate of obtaining behavioral responses. In summary, the results from this study suggest that VRA can be used successfully to program CIs for young children via telepractice.

The results for programming levels from the present study are consistent with those reported for adults using conventional audiometric methods (Eikelboom et al., 2014; Hughes et al., 2012; Ramos et al., 2009; Wesarg et al., 2010) and for children using CPA techniques (Goehring & Hughes, 2017). For adults, the findings that programming levels obtained remotely do not differ significantly from those obtained in person are not surprising. Typical adult CI recipients have considerable experience interacting with hearing health professionals and, as such, tend to be well versed in providing the behavioral feedback necessary for determining a threshold. In these cases, using videoconferencing as a substitute for in-person communication and using distance technology to remotely control the programming software add only a relatively minor challenge to a typical programming appointment. With young children, however, the timing between the programming audiologist and the test assistant is critical, which adds another layer of complexity to remote testing. Improper timing can lead to ineffective reinforcement and a subsequent lack of success in obtaining thresholds. In our earlier study with the CPA group (Goehring & Hughes, 2017), we experienced some initial challenges with timing between the audiologist and test assistant in the videoconference link versus the remote execution of commands to the programming software. This complication was easily remedied by turning on the sound of the remote-site computer so that the test assistant could hear beeps representing the delivery of each pulse-train stimulus to the child's CI (Goehring & Hughes, 2017; Hughes, Goehring, Miller, & Robinson, 2016). Because

the CI processor microphone is disabled when the programming cable is connected, the child cannot hear the sound from the computer's sound card. If a recipient has residual hearing, this solution might require the test assistant to use an ear bud to privately hear the audible notifications from the software. However, CIs are presently only approved in the United States for children with bilateral profound sensorineural hearing loss in the age range studied here.

Very few studies have empirically evaluated the use of teleaudiology for children under the age of approximately 3 years. Krumm, Huffman, Dick, and Klich (2008) compared hearing screening results for infants that were obtained remotely versus in person. Hearing screens were conducted using otoacoustic emissions or automated auditory brainstem response testing, and results showed similar outcomes for both in-person and remote testing. We are unaware of any studies that have specifically evaluated the use of VRA in young children, whether with normal hearing or with hearing loss. One study with CIs (Wesarg et al., 2010) compared programming levels obtained remotely versus in person and reported that participants ranged in age from 1 to 72 years at the time of testing ($M = 35.6$ years). However, no additional information was provided about the number of young children tested or the specific procedures used to obtain thresholds for the youngest participant(s). Another study (Franck, Pengelly, & Zarfoss, 2006) described remote CI programming for children who were "experienced" CI users, but the study was not empirical in nature, nor did it detail ages of the children or the methods used to obtain programming levels. The results from the present study, therefore, provide a first empirical evaluation of the use of telepractice for obtaining behavioral thresholds in young children with CIs using VRA.

The results from the present study showed that the mean difference in T-level between the in-person and remote conditions was 0.09, 0.32, and -0.29 nC for basal, middle,

and apical electrodes, respectively. To put these values into clinical perspective, the step size for the Advanced Bionics programming software (SoundWave) is 1 nC. For MED-EL devices, the step size in the clinical programming software (Maestro) corresponds to a 3% change in charge when utilizing the up and down arrow keys on the keyboard. Cochlear devices use current-level units, or CL, which is a log-based unit of current delivered at a fixed pulse duration. Because of the log scaling, a 1-CL step is a smaller difference in charge at low CLs and a larger difference at high CLs. For example, a difference of 0.3 nC would be similar to the difference between 120 and 124 CL (a typical approximate T-level value) or between 200 and 201 CL (a typical approximate C-level value) for a pulse duration of 25 μ s. When programming a Cochlear device, a step size of 2–3 CL is typically used. Therefore, the average difference between in-person and remote T-levels was about one to two clinical steps across device manufacturers.

Results from the questionnaire revealed that 18% ($N = 3$) of caregivers would never use remote programming if it were an option (Q3). This finding was in contrast to our recent study using CPA, in which none of the respondents reported “never” to Q3 (Goehring & Hughes, 2017). This result may have been influenced by the respondents’ view of the burden of attending CI programming visits (Q5). In the CPA study, all but one (18/19) respondent reported that it can be a hardship to attend programming appointments. This group might therefore be more likely to use telepractice if it were available because there is a greater need to reduce that hardship. In contrast, results from the present study indicated that only approximately half of the respondents (eight/17) reported that attending programming visits can be a burden. Respondents were not required to elaborate using the space for open-ended comments, so it is difficult to determine what factors influenced the difference in the degree of hardship viewed between caregivers of the two age groups. It may be that because many of the children in the CPA group were school aged, scheduling and traveling to programming visits can be more difficult to coordinate without accumulating school absences. The VRA group was younger (not yet school aged), so it is possible that schedules were more flexible to accommodate programming visits. It is important to point out, however, that our questionnaire was not a validated assessment tool, so one should be careful not to overinterpret these results.

Study Limitations

As with our earlier study using CPA (Goehring & Hughes, 2017), this study was designed to use the same test assistant for both the in-person and remote visits. This, of course, would not be the case for clinical applications of remote programming for young children. Clinically, the remote-site test assistant might be the child’s school audiologist, speech-language pathologist, or early interventionist. However, the present design was used to control

for any potential differences in tester bias between conditions and was necessary for a rigorous study design.

Second, like our CPA study, the present investigation was not designed as an equivalence study or a noninferiority study (Greene, Morland, Durkalski, & Frueh, 2008; Hahn, 2012; Lesaffre, 2008). Equivalence studies are two sided and are designed to show that a difference between two treatments is not clinically important. Noninferiority studies are one sided and are designed to show that the experimental treatment is not worse than the control treatment (typically the standard of care). Our study goal was simply to determine whether there was a difference in T levels between the two conditions.

Last, children in this study had at least 3 months of device use and had attended several clinical programming visits by the time of participation in this study. As a result, it is unclear whether the present results would apply to the use of remote programming for an initial activation. Because other aspects of an initial activation require clinician-to-patient contact, such as choosing the appropriate magnet strength, evaluating cord length, and physically providing the external equipment to the family to take home, we recommend that the initial activation be conducted in the traditional in-person condition. However, adaptations could be made to overcome these potential obstacles, and future studies could demonstrate the feasibility of using remote service delivery for initial activations.

One limitation with telepractice for audiology in general is that reimbursement for audiologic services is often not covered by insurance. However, there has been increasing emphasis on improving access to health care nationwide, so this problem is likely to change. As empirical research accumulates and continues to demonstrate the feasibility and efficacy of telepractice, it is likely that insurance coverage for telepractice services will continue to expand.

Another general limitation with many research studies is selection bias. Individuals who have the time and resources to be able to participate in a research study might have certain characteristics that affect the outcomes. For example, socioeconomic limitations could limit an individual’s ability to attend regular programming visits and affect their ability to participate in research. Although we did not collect demographic data pertaining to socioeconomic status for our participants, it is possible that the results of the questionnaire might differ for more diverse groups.

Conclusions

The results from this study suggest that telepractice can be used successfully—and without additional test time—to set T levels for young children with CIs using VRA. Communication and accurate timing between the audiologist and test assistant are critical, but our experience is that these aspects can be easily achieved with minimal training. Results from this study support the expansion of remote CI programming from adults and older children to include even the youngest CI recipients.

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