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Feasibility of and adaptations for administration of auditory processing tests with children utilizing cochlear implants

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FEASIBILITY OF AND ADAPTATIONS FOR ADMINISTRATION OF AUDITORY PROCESSING TESTS WITH CHILDREN UTILIZING COCHLEAR IMPLANTS

by

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Abstract: The first goal of this study was to evaluate the feasibility for children with cochlear implants to complete three APD tests: Pitch Pattern Sequencing (Musiek, 1994), Duration Pattern Sequencing (Musiek et al, 1990), and Bamford-Kowal-Bench Speech-In-Noise Test (Etymotic Research, 2005). The second goal was to explore adaptations needed to administer the tests. The third goal was to provide preliminary normative data. The tests were administered to early implanted, orally educated children, ages 7-17. The results indicated that this population is able to complete each test, with adaptations.

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Approval from the Institutional Review Board at Washington University's Human Research Protection Office was obtained on November 19, 2015 (ID No. 201511056). Approval was also acquired on November 19, 2015 from the Moog Center Research Committee to recruit participants and conduct the study at the Moog Center for Deaf Education (Moog Center).

Throughout this project I have received an abundance of support and guidance from my two supervisors. Dr. Valente kindly shared her idea for this project with me and continued to help me navigate the project from beginning to end, while offering priceless encouragement and thoughtful editions along the way. Dr. Holstad provided valuable insights to the project and took hours out of her busy schedule to provide guidance and supervision for testing. This project would not have been possible without Dr. Valente and Dr. Holstad. I feel truly honored to have had the opportunity to work with and learn from them.

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ABBREVIATIONS

AAA	American Academy of Audiology
ASHA	American Speech-Language Hearing Association
APD	Auditory Processing Disorder
BKB-SIN	The Bamford-Kowal-Bench Speech-In-Noise
BTE	Behind the Ear
CI	Cochlear Implant
DPS	Duration Pattern Sequencing
dB	decibel
FPT	Frequency Pattern Test
Hertz	Hz
HL	Hearing Level
L	Left
m	month (s)
Moog Center	Moog Center for Deaf Education
R	Right
RNBHS	Referred Newborn Hearing Screening
SDT	Speech Detection Threshold
SNR-50	The Signal to Noise Ratio for a 50% correct key word score
SPL	Sound Pressure Level
y	year (s)

INTRODUCTION

Investigators have demonstrated the benefit of early cochlear implantation for language development (Cuda, Murri, Guerzoni, Fabrizi, & Mariani, 2014; Black, Hickson, Black, & Khan, 2014). Early enrollment in intervention has been shown to predict cochlear implant success (Moeller, 2000), as well as improved language development (Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998). Two other predictors include: age at which hearing loss was identified and at which a hearing aid or hearing aids were fitted. Yoshinaga-Itano et al. (1998) reported, “Significantly better language development was associated with early identification of hearing loss” (p. 1161). Sugaya et al. (2015) described the value of early hearing aid use. It is indicated, based on research, that a child will be a successful cochlear implant user if the following take place: early identification of hearing loss, timely fit with hearing aids, timely enrollment in early intervention, and early implantation (approximately 12 months of age). There are children who meet these criteria, but still have difficulties. This can be a source of frustration for these children and their families. Audiologists and parents have sought to determine what other factors could be coinciding with the hearing loss to cause additional challenges for the child in the classroom and in development of speech and language. One such factor is a possible Auditory Processing Disorder (APD).

According to the ASHA Working Group on APD, Auditory Processing Disorder “refers to difficulties in the perceptual processing of auditory information, auditory synthesis, comprehension and interpretation of auditory presented information in the Central Nervous System” (ASHA, 2005). APD testing evaluates skills such as: temporal processing, auditory discrimination, localization and lateralization, and auditory recognition in background noise or with a degraded signal. The signs and symptoms of children who have an APD can closely

resemble characteristics of children who are deaf or hard of hearing, who have attention deficit hyperactivity disorder (ADHD), learning disabilities, and/or language impairment (ASHA, 2005). Some of these signs and symptoms include: asking someone to repeat, difficulty hearing in noise, difficulty following multi-step directions, inattentiveness, not understanding, difficulty spelling and reading, and poor musical abilities. They may also have difficulty learning in a typical classroom and struggle to develop language. Academic delay with slow and inconsistent responsiveness may indicate hearing, processing and/or learning concerns. Distraction, restlessness, nervousness, and disruptiveness may indicate attention concerns.

In order to diagnose an APD, multiple auditory processing (AP) skills are evaluated through different test measures designed to evaluate: auditory discrimination, auditory temporal resolution and patterning, dichotic listening, monaural low-redundancy speech, binaural integration, and electrophysiology (ASHA, 2005). In order to identify processing deficits, a battery of tests is used (ASHA, 2005). Currently, no standardized APD test battery exists for patients who have typical hearing or hearing loss. There are normative data for different APD tests for children with typical hearing, but not for children with hearing loss. Consequently, there is a need for further information regarding the utilization of APD tests in populations with hearing loss; however, determining what tests are appropriate can present a challenge. The characteristics shared by those with hearing loss and those with APD make it hard to differentiate what problems are caused by the hearing loss versus AP deficits. The equipment set-up and test protocols may need to be modified to accommodate the person's severity, type, configuration, and cause of hearing loss, as well as his or her hearing aid(s) and/or cochlear implant(s). The presentation level of stimuli and mode of presentation may need to be adjusted. These variables must be considered when testing this population and when interpreting results.

In order to overcome these challenges, Musiek, Baran, and Pinheiro suggest utilizing tests, results of which are least influenced by hearing loss (1990).

Tests such as the Frequency Pattern Test (Musiek, 1994) and the Duration Pattern Sequencing Test (Musiek et al, 1990) are less linguistically loaded, utilizing only tones of varying lengths or frequencies as stimuli. The Frequency Pattern Test (FPT) involves the presentation of three tones, two of the same frequency and one of a different frequency. The stimulus is either an 1122 Hertz (Hz) tone or an 880 Hz tone, and the tones must be identified as ‘high’ or ‘low’. The Duration Pattern Sequencing test (DPS) involves the presentation of three tones of different durations, either 500 ms or 250 ms, and the tones must be identified as ‘long’ or ‘short’. The FPT is a frequency patterning test and the DPS is a temporal processing test. Both tests are temporal ordering or sequencing tasks which evaluate a person’s ability to assess acoustic events over a period of time (ASHA, 2005). Musiek and Pinheiro found the FPT to be “a very useful part of the central auditory test battery for the differential diagnosis of cerebral pathology” (1987). Musiek, Baran, and Pinheiro found no significant difference for duration pattern recognition between participants with normal hearing and participants with mild to moderate hearing loss (1990). To date, there is a paucity of information in the literature related to participants with more severe hearing loss. This is due to previously described challenges related to assessing and interpreting findings.

Another temporal processing test is the Gaps-In-Noise (GIN) Test (Musiek, 2005), where intervals of silence are identified amidst white noise in the monaural condition. Different studies have used the GIN to evaluate temporal processing abilities of cochlear implant users. One such study is a pilot study completed by Holstad (2010) and another is a capstone study completed by Leaders (2015). Holstad evaluated early implanted children with typical language scores, who

were enrolled in an oral school. She found that this population was able to reliably complete the GIN while wearing their cochlear implants. Leaders completed a similar study, but also included those with atypical language scores. She found that some participants from both the atypical and typical language groups were able to successfully complete the tests. Both studies suggested the need for further research on temporal resolution ability in children with hearing loss.

In an APD test battery, a speech-in-noise test is often completed (ASHA, 2005). Speech-in-noise tasks evaluate tolerance fading memory (Katz, 2007). Tolerance fading memory is characterized by difficulty understanding speech in noise, low tolerance to noise (Katz, 2007) and difficulty understanding degraded speech (Jerger & Musiek, 2000). The Bamford-Kowal-Bench Speech-In-Noise Test (BKB-SIN; Etymotic Research, 2005) is a speech-in-noise test for children, which presents sentences embedded in four talker babble at different signal-to-noise ratios (SNR). It has been normed for adult cochlear implant users, typically hearing adults, and typically hearing children (Etymotic Research, n.d.). It is advantageous to determine the SNR where children can comprehend speech stimuli. The BKN-SIN has been utilized to evaluate speech perception in cochlear implant users (Davidson, Geers, Blamey, Tobey, & Brenner, 2011; Robinson, Davidson, Uchanski, Brenner, & Geers, 2012). It has also been used as a screening tool for APD (Musiek, 2007). There is limited information regarding its use as an APD test for children with hearing loss and/or cochlear implants.

In children who wear cochlear implants, the following have been noted: the absence of normative data for APD tests, the lack of information regarding feasibility of implementing APD tests, challenges in interpreting results when obtained, and the call for further research on temporal processing abilities. There is also a need to study APD tests with children with hearing

loss, to determine if some children have additional processing deficits that impact auditory, speech and language development despite appropriate intervention.

Three main goals were the focus of this study. The first was to evaluate the feasibility for children with cochlear implant(s) to complete three APD tests: Frequency Pattern Test (Musiek, 1994), Duration Pattern Sequencing Test (Musiek et al, 1990), and BKB-SIN (Etymotic Research, 2005). The second goal was to explore adaptations needed to administer the tests. The third was to provide preliminary normative data.

METHODS

Participants

Approval from the Institutional Review Board (IRB) at Washington University's Human Research Protection Office was obtained on November 19, 2015 (ID No. 201511056). Approval was also acquired on November 19, 2015 from the Moog Center Research Committee to recruit participants and conduct the study at the Moog Center for Deaf Education (Moog Center).

In order to identify potential participants, the Moog Center's database was searched with a partial waiver of Health Insurance Portability and Accountability Act (HIPAA) authorization from the IRB. Participant inclusion criteria included: age of 7 to 17 years; age at identification of hearing loss less than or equal to two years (Range= 0 months- 14 months); age at cochlear implantation less than or equal to three years (Range= 10 months- 28 months); Advanced Bionics (AB), Cochlear Limited (Cochlear), or MED-EL cochlear implant device(s); consistent use of unilateral or bilateral cochlear implants during all waking hours; enrollment at the Moog Center for greater than or equal to three years; and an intelligence quotient score greater than or equal to average or between 90 and 109 (Range= 94- 123). Monaural aided warble tone

thresholds for 250 Hz to 4000 Hz and speech detection thresholds (SDT) were required to be between 0 to 25 decibels (dB) Hearing Level (HL) on the day of testing.

Thirty children were identified as possible participants. Each participant was invited to participate in the study via e-mail or telephone. Seven participants agreed to take part in the study. Ages ranged from 7 to 13 (mean=10.14, SD=1.86) years. Six were male and one was female. No payment was provided to participants; however, a prize, such as a small toy or candy, was given to participants upon completion.

Table 1 shows age, gender, ear(s) tested, device type, processing strategy, and age of implantation of participants. Table 2 shows age at hearing loss diagnosis, IQ test and score, and time in an auditory program by participant. Special considerations related to each participant, especially etiology of hearing loss, are also provided in Table 3.

Materials

The FPT and DPS stimuli were presented from the Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0 (1998), track 16, provided by the Department of Veterans Affairs.

The FPT consisted of 30 presentations of frequency pattern sequences. The “low” (L) frequency tone was 880 Hz. The “high” (H) frequency tone was 1122 Hz. The sequences included six different patterns by five randomizations (LLH, LHL, LHH, HLH, HLL, and HHL). Each pattern sequence had a 200 ms (millisecond) inter-stimulus interval with a 6 second inter-pattern interval. The high and low tones had a 150 ms duration with a 10 ms rise-fall time (cosine squared). The total time to present all 30 sequences was 198 seconds without stopping (Department of Veterans Affairs, 2011).

The DPS also contained 30 presentation sequences, but with varying tonal durations. There were six different patterns and five randomizations of the patterns (LLS, LSL, LSS, SLS, SLL, and SSL). The "long" (L) tone was 500 ms and the "short" (S) tone was 250 ms. All tones had a 10 ms rise and fall time and were 1000 Hz. The inter-stimulus interval was 300 ms, with an inter-pattern interval of six seconds. The total time to present all 30 sequences was 198 seconds without stopping (Department of Veterans Affairs, 2011).

For the BKB-SIN test, List Pairs 9 through 18 are recommended for cochlear implant users (Etymotic Research, 2005). List 17 was used for the left ear and List 18 was used for the right ear. Both lists included part A and part B, each of which consisted of 8 sentences, for a total of 16 sentences. For part A, sentences were presented at SNR +21, +18, +15, +12, +9, +6, +3 and 0 dB. The SNR sequence was repeated for part B, with different sentences. The verbal cue "ready" preceded each sentence. Each sentence contained key words used for scoring. The first sentence in each part had four key words, and the remaining seven sentences had three key words.

All testing was performed following calibration, using Dell Precision T 3500 computer-controlled presentation via a GSI AudioStar Pro Audiometer and a Radioear AP 70 Power Amplifier. All testing stimuli were presented into the soundfield through a GSI single cone speaker, which was mounted in a double wall sound-treated booth. The equipment utilized met current calibration standards. An SL-814 Digital Sound Level Meter was utilized to ensure appropriate presentation levels.

Throughout administration of the FPT and DPS, a score sheet was used to record responses (see Appendix A). The Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2 (1998) manual was referenced for calibration, set up, instructions, and

scoring for both the FPT and DPS. The BKB-SIN User Manual was referenced for calibration, set up, instructions, and scoring. A BKB-SIN score sheet was used to record responses and track key words correct (see Appendix B). Inclusion of the copies of the BKB-SIN materials in the appendices is with permission from Dr. Patricia A. Johnson, Director of Audiology at Etymotic Research, Inc.

Procedure

The procedure was explained to the participants and their parents before testing. Any questions were answered. All parents/guardians provided signed informed consent forms. Participants age 13 or older signed an assent form. Participants were tested following agreement to participate in the study.

Ear-specific aided soundfield thresholds were obtained in a sound-treated booth, with each participant wearing his/her cochlear implant(s) at user settings. If a participant had two cochlear implants, each ear was tested separately. Participants were seated at 0 degrees azimuth from the loud speaker. Aided detection thresholds were obtained for 500, 1000, 2000 and 4000 Hz utilizing frequency modulated tones. Speech detection thresholds were also obtained. If aided detection was poorer than 25 dB HL, and microphone covers appeared dirty, the covers were changed and testing repeated. If normal aided detection was not confirmed, the participant's role in the research study ended, and a recommendation was made for the family to contact the participant's audiologist. If the participant wore two cochlear implants and only one ear met the aided criteria, then only that ear was tested. Results were recorded on the participant's score sheet (see Appendix C). A total of seven participants, or thirteen ears, proceeded with the study.

The FPT (Musiek, 1994) and DPS (Musiek et al, 1990) were administered. If the participant did not have BKB-SIN results in his/her Moog Center database file within six months

of the day of testing, then the BKB-SIN was also administered. The tests were presented in a random order, alternating ear tested first. Before each test, the participant was instructed face-to-face on the procedure as indicated in the Tonal and Speech Materials for Auditory Perceptual Assessment, Disc 2.0, 1998 and BKB-SIN Manuals.

For the FPT, participants were instructed to say whether the tones were “high” or “low”. Participants could also use their hands to indicate “high” or “low” or could hum what they heard. For the DPS, participants were instructed to say whether the tones were “long” or “short”. Participants could also use their hands to indicate “long” or “short” or could hum what they heard. If the participant had any questions, these were answered. The test administrator provided practice “tones” by mimicking the tones while instructing the participant face-to-face, to confirm understanding.

An SL-814 Digital Sound Level Meter was utilized to set the stimulus presentation level at 70 dB SPL. Musiek (1994) compared presentation levels of 40 dB SPL and 70 dB SPL and found no significant difference in scores based on stimulus level. A stimulus level of 70 dB SPL was selected for the FPT and DPS tests for the current study. Channel 1 was used for the FPT and Channel 2 was used for the DPS. There were a total of 30 presentations. If the participant was slow to respond, then the CD was paused. Stimuli were repeated at the participant’s request. No more than one repetition was allowed. The test administrator recorded each response on a score sheet, noting any pauses or repetitions. It was also noted how the participant responded (i.e. by using hands, saying “long” or “short”).

For the BKB-SIN, participants were instructed that they would hear a man at a party with his friends. They were informed that sometimes the man’s friends could be loud and noisy. They were asked to repeat what the man said, even if they only knew one word or had to guess. If the

participant had any questions, these were answered. The calibration tone was set to peak at 0 on the volume unit (VU) meter. For the BKB-SIN, a 65 dB SPL presentation level in soundfield at 0 degrees azimuth was utilized to establish normative data for adult cochlear implant users (Etymotic Research, n.d.). For the purpose of the current study, a presentation level of 65 dB SPL was also used, and calibrated before administration. This likewise followed the Moog Center's protocol for test results obtained within the last six months. The test administrator recorded the response of the participant, as well as any repetitions.

Each test was completed at each ear (if the participant had two cochlear implants and aided thresholds which met the inclusion criteria). Breaks were given between tests if needed. Total test time was approximately 1 hour and 15 minutes for a participant with two cochlear implants. All testing occurred in one session.

After completion, each test was scored. For the FPT and DPS, the total number of correct responses was calculated out of the total number of presentations (30). A percentage was then determined. For the BKB-SIN, the total key words correct were counted for parts A and B. One point was assigned for each key word. Then the SNR for a 50% correct key word score (SNR-50) was calculated for parts A and B. The average SNR-50 was calculated by averaging the SNR-50 from parts A and B. Each score was recorded on a score sheet for each participant.

RESULTS

All participants' cochlear implants were manufactured by Cochlear Limited and all participants were bilateral implant users. As displayed in Table 1, all participants used ADRO, ADRO + ASC, or ADRO + ASC + background noise reduction in addition to the ACE programming strategy.

Aided Detection

Six participants exhibited acceptable aided SDT and warble tone thresholds at 500 Hz through 4000 Hz, per implanted ear. Participant 5 exhibited acceptable aided detection and speech detection solely at the right ear. As a result, testing was administered only in the right aided condition. The mean SDT was 10 dB HL (SD=4.47) for the left ear and 12.14 dB HL (SD=6.36) for the right ear. Mean average aided detection thresholds were 20.36 dB HL (SD=3.12) for the right ear and 19.17 dB HL (SD=2.92) for the left ear.

Frequency Pattern Test Results

For the FPT, the participants' results were compared to the normative data published by Teri Bellis (2011). The normative cut-off values indicate that these values are two standard deviations below the mean. Individual participant scores are displayed in Figure 1. Scores as compared with normative values may be viewed in Table 4, and the differences between these two values may be seen in Table 5. The difference between each participant score and the normative cut-off value for his/her age was calculated to determine if the mean difference between the participant and the normative cut-off score was significantly different from zero. Differences were calculated by subtracting the normative score from the participant's score. Positive scores indicated that the participant performed better than the normative value, negative scores indicated he/she performed more poorly, and a score of zero indicated performance equal to the normative value. Table 5 presents difference scores with standard error of the difference, indicating precision around the estimate of the mean difference. These values were used in calculation of the t-statistical values. The "total" value seen in Table 5 indicated a combined measure obtained from both the left and right ears. Multilevel modeling was used to compare the standard errors to account for the dependency between the measurements of the left and right

ears within the same participant while allowing use of all the data available. The research team chose to use a $p < 0.05$ level of significance.

For the FPT, the mean percentage scores were 76.67% (SD=6.3) for the left ear and 60.49% (SD=26.91) for the right ear. The mean difference was 8 (SE=5.97, t=1.34, p=0.21) for the left ear and -9.51 (SE=11.75, t=-0.81, p=0.43) for the right ear. The total mean, including right and left ears, was 67.95 (SD=21.19), with a mean difference of -1.43 (SE=9.18, t=-0.39, p=0.70). These findings indicated no significant differences at the $p< 0.05$ level, indicating no significant difference between the participants' scores and scores of their age-matched peers with typical hearing. As displayed in Table 4, two of the seven participants scored above the normative cut-off value for their age range for the right and left ears. Two participants scored above the normative cut-off value for the right ear only and one scored above the normative cut-off value for the left ear only.

Duration Pattern Sequencing Test Results

For the DPS, the participants' results were compared to the normative data published by Bellis (2011). Individual participant scores are displayed in Figure 2. The mean percentage scores, displayed in Table 5, were 43.88% (SD=27.11) for the left ear and 43.88% (SD=27.11) for the right ear. The mean difference score, displayed in Table 5, was -16.62 (SE=8.47, t=-1.96, p=0.07) for the left ear and -15.86 (SE=8.12, t=-1.95, p=0.07) for the right ear. These two scores indicated no significant differences at the $p< 0.05$ level. The total mean was 45.1 (SD=24.52). The mean difference was -16.21 (SE=7.93, t=-2.25, p=0.04). These results indicated a significant difference ($p< 0.05$) between participant total mean and the normative weighted mean cut-off score. As exhibited in Table 4, only Participant 1 scored above the normative cut-off value, at

each ear, for his age. The remainder of the participants scored below the normative cut-off value at the left and right ear.

BKB-SIN Test Results

For the BKB-SIN test, participant scores were compared to normative data published in the BKB-SIN User Manuel (Etymotic, 2005). The difference between the participants' SNR-50 and the normative SNR-50 by age was calculated by subtracting the normative value from the participant's score. A Degree of SNR Loss was then applied to each participant's score based on the difference between the participant score and the normative data for that participant by age. The SNR Loss was assigned based upon the test interpretation suggested in the BKB-SIN User Manuel. A lower score indicated a better performance.

Individual participant scores, normative values by age, and the Degree of SNR Loss are displayed in Table 6. As displayed, Participant 7's difference score was 2.7 for the right ear and 2.2 for the left ear. Difference scores between zero and three dB indicated a Normal/Near Normal SNR loss for both ears. Participant 2 also had a Normal/Near Normal SNR Loss for the left ear and a Moderate SNR Loss for the right ear. A Moderate SNR loss included a seven to fifteen dB SNR Loss. Participants 3, 4, and 6 had a Mild SNR Loss (or between three to seven dB) for both ears. Participants 1 and 5 received scores which indicated Severe SNR Loss, or above 15 dB.

DISCUSSION

In order for the participants to be tested while wearing their cochlear implant(s), all stimuli were presented via soundfield rather than via headphones or inserts. For the BKB-SIN test, Lists 17 and 18 were utilized in that List Pairs 9 through 18 are recommended for cochlear implant users (Etymotic Research, 2005). For the FPT, DPS, and BKB-SIN, visual as well as

verbal adaptations were made to ensure each child would understand the task. The visual method was used to explain the tests to the participants, (e.g. demonstrating high verses low pitch by pointing up or down, and demonstrating length of tone by changing the distance between two hands from narrow (short) to wide (long)). Some participants chose to respond in this way. Both types of responses were accepted, regardless of whether a verbal response was provided.

In addition, pauses and one repetition were allowed during each test. Pauses between presentations were utilized if a participant needed more time to respond. A singular repetition was provided upon request. Breaks between tests or before switching to test the opposite ear were provided based on the participants' attention and needs. At least one break was given for each participant. All of the participants demonstrated the ability to understand and complete the tasks required of the FTP, DPS, and BKB-SIN tests with these accommodations.

Best performance was noted on the FPT compared to the DPS and BKB-SIN tests. For the FPT, scores for five of the seven participants were above the normative cut-off value for their age-matched peers in at least one ear. Of the 13 ears tested, seven were above the normative cut-off value. Three of the seven ears were within 4.7% of the normative cut-off value of their age-matched peers. Participants 1 and 5 performed poorly at the right ear. Following the FPT, many participants indicated that the FPT seemed easier than the DPS. The lack of significant difference between the participant mean and the normative data cut-off values indicates these participants' scores are similar to their normal hearing, age-matched peers.

All participants were able to complete the DPS test. For the DPS test, only one of the participants scored above the normative cut-off value. The rest completed the test, but had poorer scores than their age-matched peers. The significant total mean, which incorporated scores from

each ear, indicated these participants' scores were significantly poorer than those of their age-matched peers.

Results of this study complemented findings of two other studies utilizing a different temporal processing test. Holstad (2010) investigated the ability of children with cochlear implants and typical language to provide reliable responses on the GIN test. Leaders (2015) demonstrated the ability of some children with cochlear implants with typical and atypical language to complete the GIN test. The findings from these two studies and the current study suggest that it is feasible to test children with cochlear implants with these temporal processing tests, but these participants are likely to perform poorer than their age-matched peers with typical hearing. Either temporal processing test could be incorporated into an APD test battery. If the FPT is incorporated, then it would be reasonable to use the DPS, in that tasks required for the two tests are very similar. Also, both the FPT and DPS are sold together.

For the BKB-SIN test, larger scores indicated more difficulty understanding speech in noise. One participant, Participant 7, had a Normal/Near Normal SNR Loss, indicating that she heard similarly to her age-matched peers in noisy situations. Participants 3, 4, and 6 had a Mild SNR Loss for both ears, indicating that they had more difficulty hearing in noise and required a larger SNR than their age-matched peers. Participant 2 had a Normal/Near Normal SNR Loss for his left ear and a Moderate SNR Loss for his right ear. This indicated that he would hear like his age-matched peers in his right ear, but had more difficulty than those peers in the left ear. Participants 1 and 5 both had Severe SNR Losses. This indicated they had a more challenging time understanding in noise and required a larger SNR than their age-matched peers. These results display a range of abilities from Normal/Near Normal to a Severe SNR Loss.

Two participants, Participants 1 and 5, completed the task but received a maximum possible average SNR-50 score of 24.4 dB for the right ear. It was interesting to note that Participant 1 scored above the normative cut-off value on the DPS, but poorly on the FPT for the right ear. Participant 1 scored above the normative cut-off value for the FPT and DPS, but received a high SNR-50 for the left ear. Participant 5 scored poorly on the FPT and the DPS. Although not allowed, Participant 5 requested to use a personal frequency modulation (FM) system during the BKB-SIN test.

When evaluating the participants who scored poorly on each test, it was noted that Participant 5 scored poorly on all three tests. After evaluating the demographic information, it was noted that the participant had been diagnosed with Auditory Neuropathy Spectrum Disorder, which may have contributed to the poorer test scores.

There are limitations to this study, including a small sample size, which likely contributed to the large standard deviations and standard errors. Determination of significant differences is also affected by the small sample size. Also, the variation of administrators of the BKB-SIN for the three participants (Participants 3, 4, and 6) who were tested prior to the study as opposed to during the investigation may have affected average SNR-50 scores, due to different interpretation of the participants' responses. It should be noted that Participant 6 was unable to complete the BKB-SIN test during the study due to scheduling conflicts; therefore, the BKB-SIN score utilized in the present study was obtained from records prior to six months before the beginning of the study. Another limitation of the current study is the challenge of determining what difficulties are caused by the hearing loss, what difficulties could be due to a processing deficit, or whether it is a combination of the two. Although the participants were able to quickly understand the tasks required for each test, participant artifact could also have

contributed. Even with breaks, focus on the task may have varied based on interest, motivation, and boredom level.

It is also noteworthy that each participant had a personalized cochlear implant map, with varying electrodes activated and different processing strategies. The FPT presents stimuli at 1122 Hz and 880 Hz. For those with deactivated electrodes, it is possible that the same electrode could have been stimulated for both tones, increasing the challenge for the participant. In the current study, it is unclear if the variety of maps had any effect on the results. Altering the frequencies tested or expanding the range between the frequencies would be two possible adaptations for the FPT. Although different processing strategies used by each participant were noted, the effect that the different strategies may have had on each test was not assessed. For example, some participants utilized a noise strategy to help decrease the effects of noise. Therefore, it is unclear if one strategy is more beneficial for one test than another. These concepts were not explored in the current study, but would be potential avenues for further investigation.

For the children who have met the suggested criteria for successful cochlear implant use, but still struggle beyond expectation when compared to similar peers, learning more about deficit areas can help to identify potential factors contributing to their struggle. Regardless of whether challenges are caused by a potential processing deficit, hearing loss, or a combination of the two audiologists can better collaborate with other professionals to find ways to better serve the child. One way is through seeking more information about the source of challenge, such as with this type of testing.

The findings from this study could allow for speech language pathologists, educators, and parents to know what areas to target for therapy. For example, if a child scored poorly on the FPT, then that child may experience difficulty with prosody and intonation. If a child performed

poorly on the DPS, then that child may have trouble with stress and rhythm in everyday communication. If the child's BKB-SIN scores indicated the need for a larger SNR, the child may struggle in noise and could benefit from use of a personal frequency modulation (FM) system or digital radio frequency system. This child could also benefit from other strategies for enhancing the SNR. Therapy could be tailored, as may classroom and home environments, to that particular child's needs. It also gives the audiologist helpful insights as to what adjustments may need to be made in the child's cochlear implant map.

The present study assessed the feasibility of children with cochlear implant(s) to complete the FPT, DPS, and BKB-SIN. Adaptations, including presenting stimuli via soundfield, were made in order for this population to complete the tests while wearing their cochlear implant(s). Results for each test were recorded in order to compile preliminary normative data. Other investigations could expand on this study with a larger number of participants, or could compare results of those with typical and atypical language for the same population. A potential area of future research would include establishing normative data for children with cochlear implants for the FPT, DPS, and BKB-SIN. Future investigations should include other APD tests which target different auditory skills for this population. In addition, a potential standardized test battery should be investigated for APD testing, regardless of hearing status.

CONCLUSION

Feasibility and adaptations required to test children with cochlear implants on the FPT, DPS, and BKB-SIN tests were evaluated. The results of the present study revealed the ability of all of the participants to understand the task and complete each test, given adaptations. The participants' scores on the FPT were closest to those of their age-matched peers. When evaluating the total mean, the participants scored significantly poorer than their age-matched

peers on the DPS. For the BKB-SIN testing most participants required larger SNR than their normal hearing peers. The participants displayed a range of abilities from Normal/Near Normal to a Severe SNR Loss. Future research with a larger sample size is required to confirm the results of the current study and to develop normative data for this population. The study should be expanded by incorporating tests which target other auditory skills. The results of this study can help audiologists, deaf educators, speech language pathologists, parents, and other professionals to tailor therapy or to provide support for children who are deaf or hard of hearing.

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TABLES AND FIGURES

Table 1

Demographics- age, gender, ear(s) tested, device type, processing strategy, and age of implantation of participants

Participant Number	Age (years)	Male/ Female	Ear	Device Internal/External	Program	Age Implanted
1	13	Male	R L	CI24RE(CA)/Freedom CI24R(CS=)/Freedom	ADRO ADRO	2 y 11 m 10 m
2	10	Male	R L	CI24RE(CA)/Nucleus 6 CI24RE(CA)/Nucleus 6	ADRO+ ASC ADRO+ ASC	1 y 5 m 2 y
3	11	Male	R L	CI24RE(CA) CI system/Nucleus 6 BTE CI24RE(CA) CI system/Nucleus 6 BTE	ADRO+ ASC ADRO+ ASC	27 m 19 m
4	10	Male	R L	CI24RE(CA) CI system/Nucleus 5 BTE CI24RE(CA) CI system/Nucleus 5 BTE	ADRO ADRO	2 y 4 m 2 y 10 m
5	11	Male	R	CI24RE(CA) CI system/Nucleus 5 BTE	ADRO+ ASC	2 y 9 m
6	9	Female	R L	CI24RE(CA)/Nucleus 6 CI24RE(CA)/Nucleus 6	ADRO+ASC ADRO+ASC	12 m 12 m
7	7	Male	R L	CI512/ CP 810 CI512 / CP 810	ADRO+ASC+ background noise reduction (SNR-NR) ADRO+ASC+ background noise reduction (SNR-NR)	12 m 12 m

Table 2
Demographics- age of hearing loss diagnosis, IQ test and score and time in an auditory program for all participants

Participant Number	Age HL Diagnosed	IQ Test	Non-Verbal IQ Score	Time in Auditory Program
1	RNBHS	WPPSI- III	119	5 y 3 m
2	11 m	WPPSI- III	119	4 y 6 m
3	14 m	WISC-IV	94	5 y 5 m
4	RNBHS	WISC- IV	117	3 y 5 m
5	12 m	PPS	107	4 y 9 m
6	14 m	WPPSI- III	123	4 y
7	RNBHS	CELF- P2	121	3 y

CELF P2- Clinical Evaluation of Language Fundamentals-Preschool
PPS- CID Pre-school Performance Scale
RNBHS- Referred Newborn Hearing Screaming
WISCK- Wechsler Intelligence Scale for Children
WPPSI- Wechsler Preschool and Primary Scale of Intelligence

Table 3
Demographics- special considerations

Participant Number	**Special Considerations**
1	Growth hormone deficiency, Diabetes Insipidus, polyuria/polydipsia, hypothyroidism, microopthalmia
2	Hypotonia
3	Connexin 26 (GJB2 mutation), Juvenile Rheumatoid Arthritis, Attention Deficit Disorder, Mixed receptive and expressive communication disorder
4	
5	Auditory Neuropathy Spectrum Disorder, Attention Deficit/Hyperactivity Disorder
6	Pulmonary stenosis/hypertension (currently asymptomatic)
7	2 copies of 35delG Connexin 26 (GJB2) mutation

Table 4
Participant FPT and DPS Scores by Ear Compared to Normative Value Cut-Off by Age

Participant Number	Ear	DPS	DPS Normative Value Cut-Off	FPT	FPT Normative Value Cut-Off	Age
1	R L	**96.70%** **93.30%**	73%	26.70% **83.30%**	80%	13
2	R L	43.30% 50%	70%	76.70% 73.3%	78%	10
3	R L	43.30% 40.005	71%	**86.70%** 76.70%	78%	11
4	R L	43% 30%	70%	**80%** 76.70%	78%	10
5	R	30%	71%	23.30%	78%	11
6	R L	46.70% 36.70%	54%	**80%** **83.30%**	63%	9
7	R L	20% 13.30%	25%	**50%** **66.70%**	35%	7

*bolded scores indicate the Participant scored above the Normative Value Cut-Off for their Age

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Table 5

Group Mean and Mean Difference for the FPT and DPS

Test	Ear	Mean (SD)	Mean Difference from Norm (SE)	*T* statistic	*p* value
Frequency	Left	76.67 (6.3)	8 (5.97)	1.34	0.21
Frequency	Right	60.49 (26.91)	-9.51 (11.75)	-0.81	0.43
Frequency	Total	67.95 (21.19)	-1.43 (9.18)	-0.39	0.70
Duration	Left	43.88 (27.11)	-16.62 (8.47)	-1.96	0.07
Duration	Right	46.14 (24.24)	-15.86 (8.12)	-1.95	0.07
Duration	Total	45.1 (24.52)	-16.21 (7.93)	-2.25	0.04

Table 6
Participant SNR-50 Score by Age and SNR Loss

Participant Number	Age	Normative Value	SNR-50 Score (dB)	Difference Between Normative Value and Participant Score (dB)	SNR Loss
1	13	-0.9	R: 24.4 L: 22.4	R: 25.3 L: 23.3	R: Severe (>15 dB) L: Severe (>15 dB)
2	10	0.8	R: 10.5 L: 4.3	R: 9.7 L: 2.2	R: Moderate (7-15 dB) L: Normal/Near Normal (0-3 dB)
3*	11	-0.9	R: 6.0 L: 3.0	R: 6.9 L: 3.9	R: Mild (3-7 dB) L: Mild (3-7 dB)
4*	10	0.8	R: 5.5 L: 5.0	R: 6.3 L: 5.8	R: Mild (3-7 dB) L: Mild (3-7 dB)
5	11	-0.9	R: 24.4	R: 25.3	R: Severe (>15 dB)
6	9	0.8	R: 4.3 L: 7.3	R: 3.5 L: 6.5	R: Mild (3-7 dB) L: Mild (3-7 dB)
7*	7	0.8	R: 3.4 L: 3.0	R: 2.7 L: 2.2	R: Normal/Near Normal (0-3 dB) L: Normal/Near Normal (0-3 dB)

*indicates the score was obtained from the Participant's Moog Center file

Figure 1. Frequency Pattern Test Results Compared to the Normative Cut-Off Value

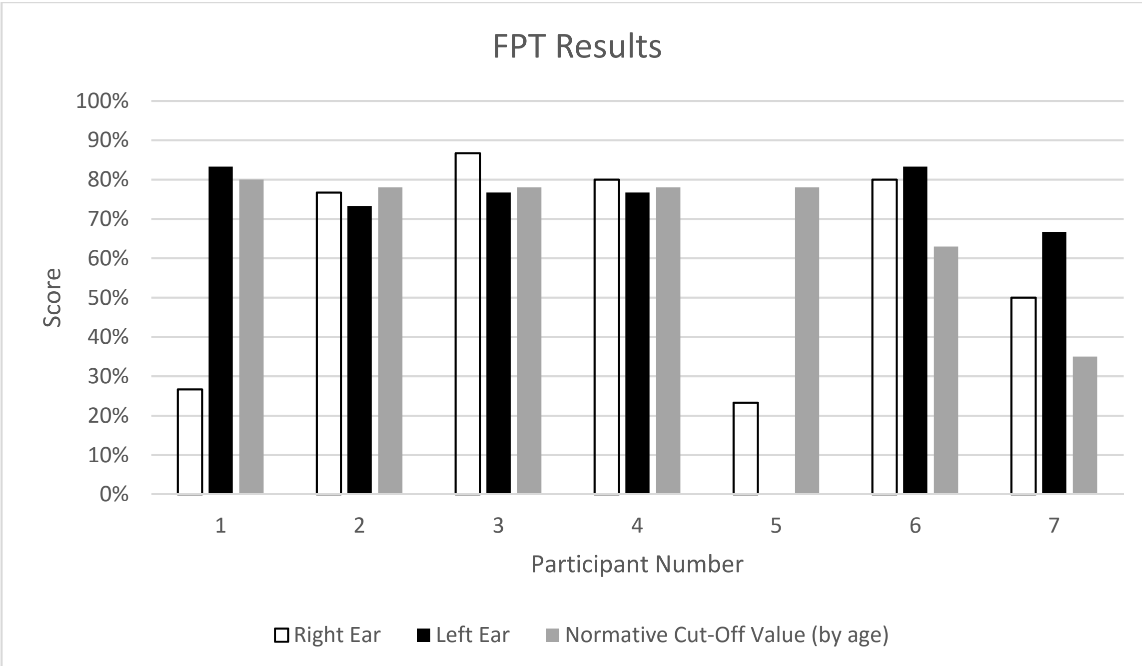

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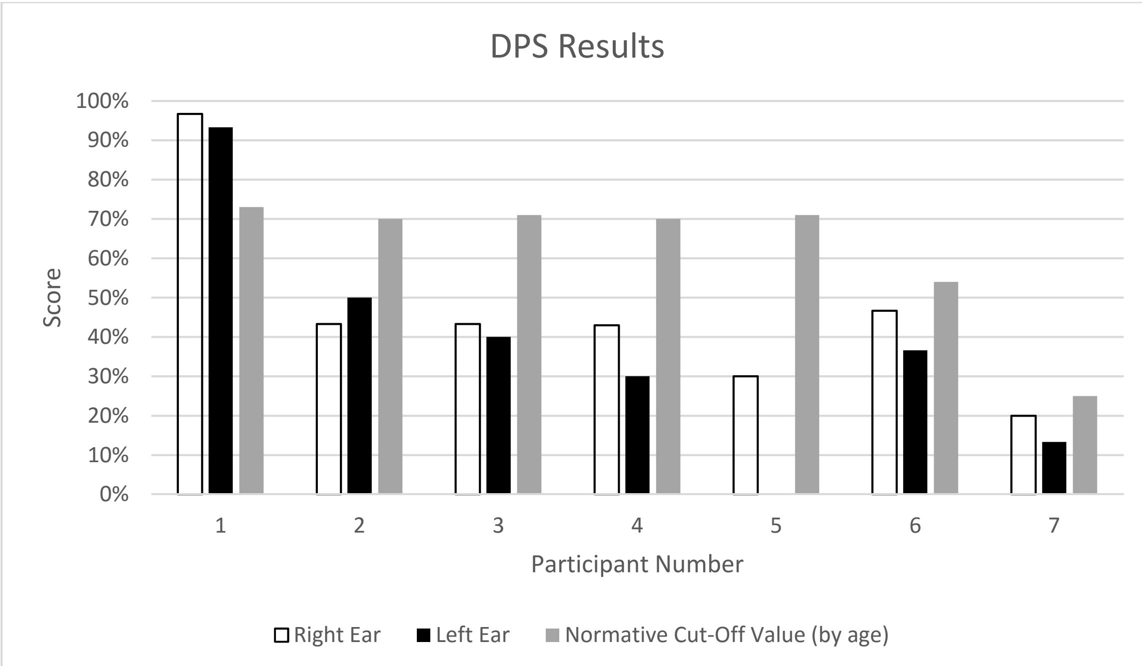
Figure 2. Duration Pattern Sequencing Test Results Compared to the Normative Cut-Off Value



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APPENDICES

Appendix A: FTP and DPS Form

Name:____________________________ **Date:**_______________________

TRACK 16											
Left Channel (1)						**Right Channel (2)**					
Frequency Tone Patterns						Duration Tone Patterns					
L = 880 Hz, 150 ms						L = 500 ms, 1000 Hz					
H= 1122 Hz; 150 ms						S = 250 ms, 1000 Hz					
1	LLH		**16**	LHH		**1**	LLS		**16**	LSS	
2	LHH		**17**	HLL		**2**	LSS		**17**	SLL	
3	HLL		**18**	LLH		**3**	SLL		**18**	LLS	
4	HHL		**19**	HHL		**4**	SSL		**19**	SSL	
5	HLH		**20**	LLH		**5**	SLS		**20**	LLS	
6	LHL		**21**	LHL		**6**	LSL		**21**	LSL	
7	LHH		**22**	HLH		**7**	LSS		**22**	SLS	
8	LLH		**23**	LHH		**8**	LLS		**23**	LSS	
9	HHL		**24**	HLL		**9**	SSL		**24**	SLL	
10	HLH		**25**	LLH		**10**	SLS		**25**	LLS	
11	LHL		**26**	HLL		**11**	LSL		**26**	SLL	
12	HLL		**27**	LHL		**12**	SLL		**27**	LSL	
13	HHL		**28**	LHH		**13**	SSL		**28**	LSS	
14	LHL		**29**	HHL		**14**	LSL		**29**	SSL	
15	HLH		**30**	HLH		**15**	SLS		**30**	SLS	
									Total Correct		

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Appendix B: BKB-SIN Form

Name:________________________
Date:______________

BKB-SIN™ Test

Ear: R L B
Device:
Level (dBA): 65 75
Mode: REC MLV

LIST PAIR 17

List 17A	Key Words	# Correct	SNR
1. They met some friends.	4	______	+21 dB
2. The bread truck is coming.	3	______	+18 dB
3. The picture came from a book.	3	______	+15 dB
4. The boy had a toy dragon.	3	______	+12 dB
5. They are playing in the park.	3	______	+9 dB
6. She argued with her sister.	3	______	+6 dB
7. He is cleaning his car.	3	______	+3 dB
8. The mouse found the cheese.	3	______	0 dB

Total Key Words Correct ______
SNR–50 = (23.5) - (# Correct) = ______dB

List 17B	Key Words	# Correct	SNR
1. They like orange marmalade.	4	______	+21 dB
2. The apple pie is baking.	3	______	+18 dB
3. He drinks from his mug.	3	______	+15 dB
4. The sky was very blue.	3	______	+12 dB
5. They knocked on the window.	3	______	+9 dB
6. People are going home.	3	______	+6 dB
7. The baby wants his bottle.	3	______	+3 dB
8. They had some chocolate pudding.	3	______	0 dB

Total Key Words Correct ______
SNR–50 = (23.5) - (# Correct) = ______dB

Average SNR–50, Lists 17A and 17B = ______dB

LIST PAIR 18

List 18A	Key Words	# Correct	SNR
1. The milkman drives a small truck.	4	______	+21 dB
2. The scissors are very sharp.	3	______	+18 dB
3. She is calling her daughter.	3	______	+15 dB
4. The girl ran along.	3	______	+12 dB
5. Mother read the paper.	3	______	+9 dB
6. The bakery is open.	3	______	+6 dB
7. She talks / talked to her doll.	3	______	+3 dB
8. The police helped the driver.	3	______	0 dB

Total Key Words Correct ______
SNR–50 = (23.5) - (# Correct) = ______dB

List 18B	Key Words	# Correct	SNR
1. They are pushing an old car.	4	______	+21 dB
2. He needed his vacation.	3	______	+18 dB
3. She is washing her dress.	3	______	+15 dB
4. The cow gave some milk.	3	______	+12 dB
5. The football game is over.	3	______	+9 dB
6. The bath water was warm.	3	______	+6 dB
7. The floor looked clean.	3	______	+3 dB
8. Some men shave in the morning.	3	______	0 dB

Total Key Words Correct ______
SNR–50 = (23.5) - (# Correct) = ______dB

Average SNR–50, Lists 18A and 18B = ______dB

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Appendix C: Participant Data Form

Device(s):

R Advanced Bionics Cochlear Limited MED-EL

____

L Advanced Bionics Cochlear Limited MED-EL

____

Bimodal **Unilateral** **Bilateral**

Age of implantation: 1st____________________________ 2nd ________________________________

Age diagnosed with hearing loss:________________ **Nonverbal Intelligence Quotient:**______________

Time in Auditory-oral program:____

Aided thresholds:

R: 500 Hz _______ 1000 Hz________ 2000 Hz_________ 4000 Hz________

L: 500 Hz _______ 1000 Hz________ 2000 Hz_________ 4000 Hz________

Average:______________

Speech Detection Threshold:

Score R ________ L ________

Duration Pattern Test:

Score R ________ L ________ Presentation Level R _______dB SPL; L _______dB SPL

Frequency Pattern Test:

Score R ________ L ________ Presentation Level R _______dB SPL; L _______dB SPL

Bamford-Kowal-Bench Speech-in-Noise Test (BKB-SIN):

Score R ________ L ________ Presentation Level R _______dB SPL; L _______ dB SPL

Adaptatations:____

____