All cochlear implant evaluation protocols indicate that a child is a candidate for the device only after a trial period with appropriately fitted hearing aids indicates little or no benefit from amplification. It is therefore the audiologist’s responsibility to ensure that the child’s amplification provides speech audibility to the maximum extent possible before a decision is made regarding implantation. The case study presented here describes a 4-year-old child referred to an implant center whose hearing aids were not providing appropriate amplification and whose implant candidacy would have been inaccurately assessed without modifications to her hearing aids. Issues including hearing aid verification, difficult-to-test patients, and assessment considerations will be discussed.

Cochlear implantation of very young children is becoming increasingly common, with the lower age limit continuing to decrease (Cochlear Ltd. 1998; Osberger 1997). As younger and younger children are being implanted, the ability to accurately assess hearing aid use has become more of a challenge to the audiologist. As well, these young children often present with behavioral challenges, which may impede the ability to accurately verify hearing aid performance. However, despite the challenges these children present, the audiologist must ensure that a child is appropriately aided before recommending implantation. This case study discusses a young child referred to the Glenrose Rehabilitation Hospital (GRH) Cochlear Implant Service from an outlying community for an assessment of implant candidacy.

History

Jane Smith (a pseudonym) was born at 37+ weeks gestation weighing 3801 grams with Apgars of 8/9 at 1/5 minutes. She developed severe hyaline membrane disease and persistent pulmonary hypertension. Therapy included Surfactant, intubation and ventilation, and treatment with inhaled nitrous oxide. Routine audiologic testing at GRH through the Neonatal Follow-up Clinic (NNFC) at 6 months of age using behavioral observation audiometry indicated sound field responses to warbled pure tones and speech to be within normal limits. A strong startle was observed at 75 dB HL. No hearing concerns were reported by Jane’s parents. Given reduced static compliance for the right ear, audiologic review was recommended.

At 12 months of age a second evaluation at GRH during an NNFC visit indicated no consistent or reliable responses in sound field, although testing was done at nap time when Jane was tired and fussy. Jane’s parents reported they believed hearing to be normal. Reduced static compliance bilaterally was noted. Jane received treatment for otitis media, and audiologic review was recommended. Developmental testing indicated normal motor skills with average cognitive skills; limited verbal skills were noted.

At the time of the next audiologic assessment, at 16 months of age, Jane’s mother reported that she felt Jane was not hearing normally. Testing indicated essentially no responses in sound field, although again Jane was reported to be very distractible and tired. Normal middle ear function was indicated bilaterally; acoustic reflexes could not be interpreted due to noncompliance. Auditory brainstem response (ABR) testing was recommended.

Auditory brainstem response testing was conducted at 17 months of age in Jane’s outlying hometown. Utilizing click stimuli, wave V thresholds were reportedly obtained at 40 dB nHL for the right ear and 90 dB nHL for the left ear, although the waveforms were extremely noisy and the interpretation is questionable. Amplification was fitted within two weeks by a private clinic in Jane’s hometown based on the reported ABR thresholds. Aided
sound field testing at that facility one month later indicated responses in the 70 to 75 dB HL range, with no aided responses at 1000 Hz and 2000 Hz. Jane was reported to be difficult to test due to her activity level. More powerful amplification was recommended and fitted. Subsequent aided sound field testing at the same facility indicated responses in the 55 to 80 dB HL range using visual reinforcement audiometry. Jane was reported to be very active and almost impossible to test. Because Jane’s aided sound field responses continued to be depressed, a change in amplification was again recommended.

Following the fitting of new hearing aids, Jane’s aided sound field responses improved, although testing was quite limited due to Jane’s active and uncooperative behavior. At 23 months of age an attempt was made to condition Jane to play audiometry; she resisted the activity. At this time Jane was referred back to GRH for treatment through the Language and Speech Services for the Hearing Impaired (LSSHII) program where she was seen by Audiology and Communication Disorders on a regular basis. Management goals emphasized development of auditory skills and oral communication. Additional attempts were made to condition Jane to play audiometry, but Jane’s short attention span and behavior difficulties precluded reliable assessment. Because Jane’s aided results were not consistent with the ABR findings, a repeat ABR assessment was recommended. Wave V thresholds to click stimuli were obtained at 90 dB nHL for the right ear, and 95 dB nHL for the left ear. Wave V thresholds to 500 Hz tone pip stimuli were obtained at 80 dB nHL for the right ear, and 90 dB nHL for the left ear.

Further training in play audiometry was recommended.

Due to ongoing concerns regarding behavior as well as a lack of progress in oral/aural communication, it was suggested to the family that they consider adding sign language to the management goals. Because the family was not interested in using sign language with their daughter and because of difficulties they had encountered in traveling to Edmonton, they indicated that they felt Jane’s needs would be best met through auditory-verbal (AV) training at a different facility. She was therefore discharged from GRH programs at 2 years, 10 months of age.

At 4 years, 7 months of age Jane was referred back to GRH for consideration of cochlear implant candidacy based on audiologic results as well as clinical observations and parent report regarding progress. A treatment progress report from Jane’s AV therapist indicated that Jane had a mean length of utterance of 1.8; formal language testing could not be completed due to motivation difficulties. Jane’s speech skills were described as unintelligible to an unfamiliar listener, although often intelligible with context to a familiar listener. Behavioral concerns continued to be noted.

**Preliminary Implant Candidacy Assessment**

At the time of Jane’s referral for a cochlear implant candidacy assessment, complete audiologic evaluation results were unavailable due to Jane’s non-compliant behavior and the family’s lack of proximity to the treatment facility. Therefore, standard aided and unaided testing utilizing play audiometry was undertaken. Although Jane’s behavior difficulties did interfere with the testing procedure, consistent and reliable results were obtained through the use of two testers, frequent task changes, numerous breaks, and frequent and varied reinforcement. Pure-tone air- and unmasked bone-conduction thresholds are shown in figure 1 in dB HL. The air-conduction thresholds were obtained utilizing Etymotic Research ER-3A insert earphones. Results indicate a profound sensorineural hearing impairment bilaterally, worse for the left ear beyond 1000 Hz, with the exception of bilateral air-conduction thresholds at 250 Hz in the moderately severe hearing impairment range. Aided sound field warble-tone thresholds were obtained monaurally and are shown in figure 2 in dB HL. The aided

![Figure 1. Pure-tone air- and unmasked bone-conduction thresholds in dB HL. The air-conduction thresholds were obtained utilizing Etymotic Research ER-3A insert earphones.](image-url)
thresholds of 5 dB HL obtained at 250 Hz for both ears suggested some overamplification at this frequency.

Due to time constraints, only a superficial evaluation of Jane’s speech perception skills was conducted during the initial evaluation. Administration of the Test of Auditory Comprehension (TAC) (Audiologic Services 1981) and the Central Institute for the Deaf (CID) Early Speech Perception (ESP) Test (Geers and Moog 1989; Moog and Geers 1990) in the auditory-only condition was conducted. The TAC was designed for use with children who have hearing impairments, 4 through 12 years of age, to assess auditory functioning. The test consists of ten recorded subtests ranging in complexity from Subtest One, which assesses a child's ability to discriminate between linguistic and non-linguistic sounds, to Subtest Ten, where a child is required to recall five details of a story with a competing message. The ESP has three subtests used in a closed-set format to assess pattern and word discrimination in young children with profound hearing impairment. The ESP battery consists of two versions, the Standard Version utilizing a 12-item picture plate and the Low-Verbal Version utilizing 4 toy items. Based on the results, one of the four following categories of speech perception abilities is assigned to the child: 1—no pattern perception, 2—pattern perception, 3—some word identification, and 4—consistent word identification.

Jane’s assessment results can be found in table 1. On the TAC, administered at a recommended presentation level of 76 dB SPL, Jane obtained a passing score on Subtest One—Linguistic versus Non-Linguistic while she failed Subtest Two—Linguistic/Human Non-Linguistic/Environmental. Given Jane’s limited language skills, the Low-Verbal Version of the ESP was administered. In the live-voice condition at a presentation level of 70 dB SPL, she passed the Pattern Perception Subtest but failed the Spondee Identification Subtest. Based on her performance, a CID Speech Perception Category of 2–Pattern Perception was assigned.

The Meaningful Auditory Integration Scale (MAIS) (Robbins, Renshaw, and Berry 1991) was also administered. The MAIS is a parent-report scale administered in an interview format designed to assess a child’s spontaneous responses to sound in his or her everyday environment. It consists of ten probes with very specific scoring criteria that assess the following three main areas: (1) device bonding, (2) alerting to sound, and (3) deriving meaning from sound. Performance is scored in terms of the total number of points accrued out of 40 possible points. Each question has a potential of 0 (lowest) to 4 (highest) points. On this test a score of 29 was obtained.

Further assessments by medicine, speech-language pathology, education, psychology, and social work, in addition to a more extensive speech perception evaluation would have been required for a final determination of cochlear implant candidacy. However, Jane’s preliminary audiological and speech perception results reported above, in particular the CID Speech Perception Category of

Table 1. Preliminary speech perception results obtained with the initial hearing aid settings.

<table>
<thead>
<tr>
<th>Test of Auditory Comprehension (TAC)</th>
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<tr>
<td>Subtest Two</td>
<td>Spondee Identification</td>
<td>2/12</td>
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2–Pattern Perception, suggested she was a possible candidate for a cochlear implant (Osberger 1997; Waltzman et al. 1994). The only significant red flag based on the results presented thus far was that raised by the aided threshold of 5 dB HL for the right and left ears at 250 Hz suggesting over-amplification, and therefore the potential for significant upward spread of masking. Jane performed fairly well on the MAIS, but much of her success on the various probes could be accounted for by the audibility of speech information at 250 Hz.

**Evaluation of Amplification**

Jane’s hearing aid fitting was evaluated utilizing the desired sensation level (DSL) method (Seewald 1995; Seewald et al. 1996), specifically the computer-assisted implementation of version 4.1 (Seewald et al. 1997). The primary goal of this method is to provide children with amplified speech that is audible, comfortable, and undistorted across the broadest relevant frequency range possible (Seewald, Ross, and Stelmachowicz 1987).

A unique feature of the DSL method is that a common reference, dB SPL in the ear canal, is used for all variables. Since the procedures applied within a specific assessment situation will depend largely on the cooperation of the child, DSL has been designed to accept audiometric data that have been collected in a variety of ways. When audiometric characteristics are assessed in dB HL (re: the undisturbed field, 6cc or 2cc coupler), the program will apply the appropriate average transformation values based on the child’s age to derive predicted ear canal SPL values. If insert earphones are used to collect the audiometric data, the child’s own real-ear-to-coupler transform (RECD) can be measured (Moodie, Seewald, and Sinclair 1994) and will serve as the transfer function for the data in the program. The DSL method currently recommends a procedure where detection thresholds and RECDs are measured utilizing a child’s personal earmold attached to an ER-3A insert earphone (Seewald 1995; Sinclair, Moodie, and Seewald 1997).

To select the desired frequency-gain characteristics of a hearing aid, the program provides target levels to which the amplified long-term average speech spectrum (LTASS) should be delivered relative to a child’s thresholds across frequencies (Seewald 1995). The DSL method is currently using an operational definition of the LTASS that takes into account the average levels of the child’s own speech productions at the ear level position in addition to the average speech levels of potential conversational partners (Cornelisse, Gagné, and Seewald 1991). The one-third octave band levels in dB SPL of the University of Western Ontario LTASS are shown in table 2 (Seewald et al. 1997).

The DSL method offers the user a variety of options to verify that a child has been provided with appropriate amplification characteristics but strongly recommends the use of probe-tube microphone measures (Seewald 1995). Based on the measured/predicted ear canal levels at threshold, DSL prescribes target real-ear aided response (REAR) and real-ear saturation response (RESR) values across frequencies. In the case of a cooperative child, the probe-tube microphone system can be employed to measure REAR and RESR directly (Stelmachowicz and Seewald 1991). For the segment of the pediatric population with whom it is difficult to obtain valid and reliable measures of real-ear hearing aid performance, 2cc coupler-based measures can be used to predict real-ear hearing aid performance (Moodie, Seewald, and Sinclair 1994). In the DSL program the RECD values measured for the child are applied to derive 2cc coupler target values for gain and output limiting across frequencies. When RECD values have not been measured, the program will apply age-appropriate default values to derive the 2cc coupler target values (Seewald 1995).

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**Table 2.** The one-third octave band levels in dB SPL of the University of Western Ontario long-term average speech spectrum used in the DSL method (from Seewald et al. 1997). Reprinted by permission. ©1997. **DSL v4.1 for Windows: A software implementation of the desired sensation level (DSL [i/o]) method for fitting linear gain and wide-dynamic-range compression hearing instruments: User’s manual.** London, Ontario: University of Western Ontario.

<table>
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<th>2000</th>
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<th>2000</th>
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<td>60</td>
<td>55</td>
<td>50</td>
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et al. 1996). The procedure then allows for electroacoustic response shaping and verification to be performed in a 2cc coupler, significantly reducing the amount of measurement time and degree of cooperation required from the child (Moodie, Seewald, and Sinclair 1994). The DSL program utilizes an SPL-O-GRAM format to plot the variables in dB SPL within the child’s ear canal as a function of frequency. By presenting the results in this way, the relationship between the child’s thresholds, the predicted levels of amplified conversational speech, and the output limiting characteristics of the hearing aid can be evaluated.

For evaluation of Jane’s amplification the default transformations were used in the DSL program for converting data to dB SPL within the ear canal. An attempt to measure Jane’s RECD values was made; however, due to extremely noncompliant behavior, the measurements could not be completed. Since default RECD values were being utilized, Jane’s detection thresholds collected utilizing ER-3A insert earphones served as the assessment data entered into the DSL program. For the purposes of verification, 2cc coupler measurements of Jane’s Unitron US 80-PPL hearing aids were collected utilizing a FONIX 6500 electroacoustic analysis system. Coupler gain measurements were obtained utilizing pure-tone signals delivered at levels based on the LTASS incorporated into the DSL method (table 2). The specific values used in the measurements are shown in table 3 and reflect a slight modification in the levels due to limitations in the hearing aid test system (Moodie 1996; Sinclair, Moodie, and Seewald 1997). A 90 dB SPL pure-tone sweep was used to collect the maximum output data from the instruments in the coupler.

Figure 3 shows the DSL hearing aid verification results obtained with Jane’s initial user settings for the left ear in SPL-O-GRAM format. All variables including pure-tone air-conduction thresholds (a), maximum output and average amplified speech targets (b), maximum output measured (c), and average amplified speech measured (d) are plotted in dB SPL within the ear canal as a function of frequency.
quencies above 1500 Hz would indicate the residual hearing in this region is considered to be unaidable by the program. Figure 3(c) plots the maximum output actually measured from Jane’s left hearing aid relative to the threshold data and the targets for average amplified speech and maximum output. Figure 3(d) includes the average amplified speech measured. As can be observed in figure 3(d), there is significant overamplification of the average amplified speech targets for the left ear at 250, 750, and 1000 Hz. In addition average amplified speech approximates maximum output for Jane’s hearing aid at four frequencies, indicating saturation of the hearing aid for speech input. As a result of this analysis, Jane’s hearing aid settings were adjusted. Due to the degree of the hearing impairment, however, audibility of speech beyond 1000 Hz was not attained for this ear.

The verification results obtained with Jane’s initial user settings for the right ear are shown in figure 4 in SPL-O-GRAM format. As can be observed in figure 4(c), the maximum output of the hearing aid falls well below the targets for maximum output at 500 Hz as well as beyond 1000 Hz, severely limiting audibility at these frequencies. Average amplified speech approximates maximum output at five frequencies as shown in figure 4(d), resulting in saturation of the hearing aid for speech input. Also in figure 4(d), significant overamplification of the average amplified speech targets at 250, 750, and 1000 Hz is evident. Figure 5 illustrates a comparison of the dynamic range (dB difference between threshold and maximum output) as prescribed by the DSL method and that obtained with Jane’s right hearing aid at user settings as a function of frequency. For the frequencies above 1000 Hz an average dynamic range of 17.8 dB was prescribed by the DSL method while an average of only 5.3 dB was obtained with Jane’s user settings.

Given the limited dynamic range in the high frequencies, Jane has not been able to fully utilize the residual hearing in her right ear for the purposes of speech recognition with her current hearing aid fitting. Considering the difficulties reported with her earlier hearing aid fittings, this has likely been the situation since she was first diagnosed. In fact, the results of this assessment would sug-

![Figure 4](image-url). Initial DSL hearing aid verification results for the right ear in SPL-O-GRAM format. All variables including pure-tone air-conduction thresholds (a), maximum output and average amplified speech targets (b), maximum output measured (c), and average amplified speech measured (d) are plotted in dB SPL within the ear canal as a function of frequency.
gest that Jane has not had much more access to amplified speech for her right ear than she has had for her left ear despite the difference in unaid thresholds. In addition to demonstrating essentially no usable hearing beyond 1000 Hz, the analysis of Jane’s hearing aid fitting for both ears suggests significant overamplification at 250, 750, and 1000 Hz, as well as saturation of the hearing aid for speech input. Based on these findings, one might predict good access to pattern perception, but speech recognition beyond this level would be severely compromised, as in Jane’s case, due to hearing aid distortion and upward spread of masking.

Based on the initial DSL verification results, Jane’s right hearing aid settings were adjusted. The results are shown in figure 6 in SPL-O-GRAM format. As can be seen in figure 6(c), maximum output meets the targets from 500 Hz through 3000 Hz within 1 dB (2 dB at 1500 Hz) while the target at 250 Hz is exceeded. Average amplified speech matches the targets from 750 Hz through 3000 Hz within 1 dB as shown in figure 6(d). Limitations in hearing aid flexibility necessitated a compromise in the gain values obtained at 250 and 500 Hz. Although the average amplified speech target at 4000 Hz was not met, a significant portion of the long-term average speech spectrum remains audible at this frequency. Figure 7 compares dynamic range in dB obtained from Jane’s adjusted right hearing aid with that prescribed by

Figure 5. Dynamic range in dB for the initial hearing aid settings and that prescribed by DSL as a function of frequency for the right ear.

Figure 6. DSL hearing aid verification results for the right ear in SPL-O-GRAM format following adjustment of the hearing aid settings. All variables including pure tone air conduction thresholds (a), maximum output and average amplified speech targets (b), maximum output measured (c), and average amplified speech measured (d) are plotted in dB SPL within the ear canal as a function of frequency.
the DSL method. An average dynamic range of 16.0 dB was obtained for the frequencies above 1000 Hz as compared to 17.8 dB as prescribed by the DSL method. These results indicate that much of the amplified long-term average speech spectrum is accessible to Jane, contraindicating a cochlear implant at this time.

Discussion

The package insert for the Clarion cochlear implant device describes one of the indications for use with children as “lack of benefit from appropriately fitted hearing aids” (Advanced Bionics 1998). For the Nucleus 24 device, the package insert states that children should “demonstrate little or no benefit from appropriate binaural hearing aids” (Cochlear Ltd. 1998). Each package insert describes in detail the procedure for quantifying “limited benefit”; however, neither provides guidelines for determining the appropriateness of the hearing aid fitting. This is left to the discretion of the audiologist assessing the child’s audiologic candidacy for cochlear implantation.

Recent surveys of current practices employed by audiologists in the fitting and verification of hearing aids in young children give cause for concern. Hedley-Williams, Tharpe, and Bess (1996) reported the findings of a nationwide survey of pediatric audiologists in the United States designed to identify selection, fitting, and verification practices. On the basis of their findings these researchers concluded that few audiologists use any systematic approach for selecting and fitting amplification for young children, and many do not use current technologies in the fitting process. More recently Arehart et al. (1998) reported the results of a comprehensive survey of 16 states regarding the coordination and characteristics of universal newborn hearing screening, audiologic assessment, and intervention programs. For the sites using a particular method for fitting amplification in infants, these researchers found that sound field testing was the most common method reported (49% of the respondents) while a significantly fewer number of sites reported using probe-tube microphone testing (21%) or coupler testing with RECD corrections (10%). In the present case study, the concerns regarding the fitting of Jane’s amplification were not apparent in the aided audiogram with the exception of the suspected over-amplification of 250 Hz. Aided sound field testing does not provide any information regarding the relationship of output limiting to the gain characteristics of a hearing aid. It is imperative that audiologists involved in the assessment of pediatric cochlear implant candidacy have extensive experience with hearing aid fittings in this population, and follow hearing aid verification procedures as outlined by the Pediatric Working Group (1996). Unless such procedures are utilized, hearing aid performance cannot be accurately or adequately assessed, which may lead to inappropriate implant recommendations.

In this case study Jane’s behavioral challenges had a significant impact on the management of her hearing impairment, negatively affecting her initial diagnosis, aided assessments, and measurement of therapeutic progress. As a result only very limited information was available at the initiation of the implant candidacy assessment. Despite behavioral concerns it is the audiologist’s responsibility to obtain the most complete and accurate assessment results possible or risk implanting an inappropriate candidate based on an underestimation of performance. With the use of two audiologists experienced in pediatric hearing aid verification procedures, as is the GRH practice for difficult-to-test children, reliable and fairly complete assessment information was obtained from Jane. However, her behavior did preclude the measurement of an RECD having implications for the accuracy of the DSL results. Although the reported DSL findings suggest good speech audibility for the right ear following adjustment of the hearing aid, there is a potentially significant margin of error in these results as the lack of actual RECD values necessitated the use of the program’s default values.

Following Jane’s preliminary candidacy assessment, several recommendations were proposed. A priority will be the measurement of her RECD values for a more accurate assessment of her hearing aid performance. Additional hearing aid adjustments may be required, based on the actual RECD measurements. Jane will

![Figure 7](image_url)

**Figure 7.** Dynamic range in dB for the adjusted hearing aid settings and that prescribed by DSL as a function of frequency for the right ear.
need to utilize the new hearing aid settings for a period of six months, during which time speech-language management will continue. Following that time she will return to GRH for a reassessment of her speech perception abilities. In light of the reduced speech audibility in the left ear it may be determined that she is an implant candidate if she is unable to make adequate progress.

Summary

1. A standardized measurement of speech audibility beyond the sound field audiogram is required to adequately assess a hearing aid fitting.
2. For patients with noncompliant behavior it is critical that behavior modification be a treatment goal in order to obtain assessment data at appropriate developmental intervals to ensure the adequacy of the hearing aid fitting.
3. It is imperative that audiologists involved in the assessment of pediatric cochlear implant candidacy have extensive experience with hearing aid fittings with this population.

Acknowledgments

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References