The percentage of newborns screened for hearing loss prior to hospital discharge has dramatically increased across the United States from approximately 5% in 1993 to 95% in 2006. Secondary to the multiple benefits of universal newborn hearing screenings are increased referrals for diagnostic audiometric testing as well as increased hearing aid and cochlear implant fittings. A child’s ability to hear affects every aspect of education, psychosocial development, intelligence, cognitive ability, personality, and more. When children in school settings cannot clearly hear instructions, it undermines the entire premise of the educational system.

For appropriate candidates, amplification and aural habilitation (AH) should be initiated as soon as possible. Initiating AH before 6 months of age is preferable for maximizing the opportunity for normal or near-normal development of the auditory, speech, and language systems. In the U.S., successful newborn screenings are the reason that some 90% of children identified with hearing loss at birth will be mainstreamed.

Currently, the majority of all newborn hearing screenings are accomplished via auditory brainstem response (ABR) or otoacoustic emission (OAE) evaluation. Regardless of the screening technique, children who fail a newborn hearing screening are generally referred to an audiologist for diagnostic assessment, including otoscopy, tympanometry, OAEs, and ABR tests. The information from the diagnostic ABR evaluation can be used for the purpose of fitting hearing aids.

Auditory steady-state responses (ASSR) can also be used to estimate hearing thresholds in newborns and others unable or unwilling to participate in behavioral testing. But ABR and tone burst ABR are more commonly used for these purposes now, in part because norms for infants for ASSR measurements are not yet available. Therefore, this article addresses only converting ABR-derived data into hearing aid prescriptions. For more on ASSR see Beck, Speidel, and Petrak.

However, facilitating a smooth and efficient transfer of information (from ABR to hearing aid fittings) requires an understanding of the data-conversion process. This article will address the rationale and give step-by-step guidelines for converting ABR data into hearing aid fittings while using DSLv5.0a as implemented within the new Interacoustics Affinity 2.0 (also, see Bagatto et al.).

### Obtaining Thresholds via ABR

The ABR, an integral part of universal newborn hearing screening programs, is an efficient and effective protocol for evaluating hearing sensitivity in infants and young children. As with any method for measuring and defining hearing loss, test results are a reflection of appropriately calibrated equipment. Only recently have standards for electroacoustic calibration of ABR equipment been developed (ISO, draft international standard 389, part 6). The International Organization for Standardization (ISO) calibration standard uses a peak-to-peak equivalent SPL (dB ppeSPL) measurement to calibrate the acoustic stimulus used for ABR measurements.

It is important for the user of ABR equipment to know that threshold values can be defined in various ways, depending on the equipment selected and the procedure used for calibration. There are two ways in which the DSL Method implements ABR data: (1) allowing the user to enter data in normalized HL (nHL) or (2) allowing a behaviorally equivalent measure (HL). It is important for the clinician to know which thresholds are being defined, since the two (nHL and behaviorally equivalent HL) may differ by 20 dB. ABR thresholds defined in nHL are collected via equipment and calibration procedures that do not embed corrections to behavioral-equivalent thresholds. ABR thresholds defined in HL are collected using equipment and calibration procedures that do embed corrections, thus providing dB HL threshold data.

<table>
<thead>
<tr>
<th>Tone bursts in Hz:</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABR thresholds in dBnHL</td>
<td>80</td>
<td>75</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Correction dBnHL to HL</td>
<td>-20</td>
<td>-15</td>
<td>-10</td>
<td>-5</td>
</tr>
<tr>
<td>Estimated HL thresholds (dB eHL)</td>
<td>60</td>
<td>60</td>
<td>70</td>
<td>75</td>
</tr>
</tbody>
</table>
When ABR-derived information is applied to hearing aid prescriptions, ABR click stimuli (in isolation) are inadequate. Traditional ABR clicks best correlate with hearing thresholds from 2000 to 4000 Hz. ABR protocols should be enhanced and supplemented with tone bursts to approximate hearing thresholds across the speech spectrum and to allow approximation of the slope of the hearing loss.

If ABR thresholds are converted into a behaviorally equivalent format (dB eHL), further corrections are not necessary prior to moving to the hearing aid selection and fitting stage. However, if the ABR equipment does not automatically provide this correction, further corrections to arrive at the behaviorally equivalent dB HL threshold will be necessary. These corrections are equipment, stimulus, and procedurally specific.

Table 1 shows the nHL-to-estimated HL (eHL) correction values currently used in DSL v5.0 implementations. Applying these correction values to nHL thresholds (collected using the same procedures described in Bagatto et al.) provide behaviorally equivalent threshold values that can be used in the hearing aid selection and fitting process.

For the purpose of hearing aid selection and fitting, prescriptive methods such as DSL convert behavioral thresholds to define hearing threshold levels in dB SPL near the tympanic membrane (TM) in the ear canal (dB SPL TM). To define thresholds in terms of a dB SPL reference, we measure the infant or child’s real-ear-to-coupler difference (RECD) values as a function of frequency to be used with the HL threshold values to calculate ear canal threshold levels (in dB SPL). The interested reader is referred to Bagatto et al. for an in-depth discussion of the dB HL to dB SPL conversion process for ABR measurements. Further, the reader is advised to review Figure 1 ("Road Map") to better understand the conversions related to these protocols.

RECD MEASUREMENTS
Newborns and small children pose unique audiometric challenges. Their smaller ear canals essentially invalidate adult normative data for determining SPL threshold values. Indeed, if adult normative values are applied to pediatric fittings, overamplification is certain to occur.

To accommodate smaller ear canals and pediatric hearing aid fittings, real-ear-to-coupler-difference (RECD) measurement procedures have been developed to account for amplitude differences (in dB) across frequencies between the SPL measured in the newborn’s ear and the measurements determined in a 2-cc coupler using the same input signal. The child’s unique ear canal characteristics (their “acoustic fingerprint”) are measured via the RECD.

In the example shown in Figure 2, ABR thresholds have been acquired (black Xs) and are defined in dB nHL. Frequency-specific corrections for converting nHL to eHL were used to obtain a behavioral electroacoustic measurements performed on a 2-cc coupler. Thus, the RECD allows individualization of the hearing aid fitting for infants who cannot sit in front of a loudspeaker for repeated probe-microphone measurements.

The following case illustrates how hearing aid verification procedures can be performed with the Affinity 2.0 system when ABR tone burst data are combined with measured RECDs for an infant.

CASE STUDY
In the example shown in Figure 2, ABR thresholds have been acquired (black Xs) and are defined in dB nHL. Frequency-specific corrections for converting nHL to eHL were used to obtain a behavioral...
equivalent dB HL audiogram (see Bagatto et al.10 for the appropriate ABR set-up and correction values). Thus, the blue Xs are estimated behavioral equivalent threshold (eHL) values. These behaviorally equivalent HL threshold values will be used in subsequent stages of the hearing aid selection and fitting process.

For most REM systems frequency-specific “eHL” (behavioral-equivalent hearing thresholds) values can be manually entered or automatically transferred from the NOAH module.

**RECD MEASUREMENT PROCEDURE**

The RECD measurement procedure on the Affinity 2.0 system can be customized for the end user. The general RECD measurement procedure consists of two measurements: (1) the measurement of the SPL from a transducer delivered into a 2-cc coupler and (2) the measurement of the SPL of the same signal delivered into a patient’s ear. The Affinity 2.0 system provides step-by-step and visual instructions for both parts of the measurement (see Figures 3a and b). Unfortunately, there are times when these measurements are not accomplished due to behavioral or other issues. In those situations, average age-appropriate RECD values stored in the software can be applied.

**RECD VALUES AS A FUNCTION OF FREQUENCY**

Figure 4 illustrates the RECD values collected on a 3-month-old child. Notice that the RECD value at 2000 Hz is approximately 20 dB. Thus, sound delivered into this particular ear at 2000 Hz will be 20 dB louder than the same sound presented in a 2-cc coupler.

**DERIVING DSL V5.0A TARGET CRITERIA**

Figure 5 provides an illustration of an SPLogram. The ABR thresholds measured at the assessment stage have been converted to dB SPL thresholds to reflect what is happening in the ear canal. This is illustrated by the heavy dark red line in the lower section of Figure 5. The values associated with the upper limit of comfort (UCL) are automatically calculated using the DSL v5.0a algorithm because infants’ loudness discomfort levels (LDLs) cannot be measured. They are shown as the shaded gray region at the top of the SPLogram. The associated targets for setting the upper limit or maximum power output (MPO) of the hearing aid in order to avoid discomfort are shown by the red line just below the shaded UCL region. Once threshold values and UCL values have been defined, DSL v5.0a provides real-ear targets for various input levels selected by the audiologist. In the example above, we’ve selected 55 dB SPL (for soft speech), 65 dB SPL (for average speech), and 75 dB SPL (for loud speech).

**SELECTING AMPLIFICATION**

Decisions regarding amplification needs for children must be based on the diagnostic information available, the acoustic environments the child experiences (school, home, recreation, etc.), and the specific needs of the child and caregivers.21

In Figures 6a and 6b, Oticon Vigo Pro Power BTE hearing aids have been selected. The default fitting rationale for children is DSL 5.0, which permits electrophysiologic corrections and RECD data to be directly entered into the fitting software.

**FITTING AND VERIFICATION STEP BY STEP**

To ensure that the parameters in the hearing aid manufacturer’s and real-ear manufacturer’s software are matched for the child being fitted, the following steps are recommended for using the hearing aid fitting software (see Figures 7a and 7b):

1. **Step 1.** Open Genie through NOAH and detect the hearing instruments.
2. **Step 2.** In “Selection” verify the information stated under “Personal Profile” and “Acoustics.”
3. **Step 3.** Verify that “DSL v5a” is selected under “Program Manager.”
4. **Step 4.** Open the “RECD and REUR” screen. Enter the measurement data into the software (if it has not been imported via NOAH). Under the “Audiometry” tab, select “Tone Burst
ABR” for correction factors to be applied. If choosing “Other” (ASSR, click ABR, etc.), no correction factors are added.

**Step 5.** Navigate to “RECD” to take into account the measured individual RECD values. To automatically import the values measured on the Affinity 2.0, click “Import from NOAH.” The measured RECD will appear on the graph together with the predicted values and be taken into account in the “Fitting Step.”

It is important to ensure that each individual characteristic is entered correctly into the software. For example, if you measured ABR threshold values using equipment or a procedure in which nHL to eHL corrections are necessary, you note that at step 4 (above) by selecting the right measurement method in the software (tone burst ABR versus ASSR). If you do not make the correct selection, the threshold values you use for the fitting process will be incorrect.

After the hearing aids have been programmed using the DSL v5.0a target criteria coupled with the infant’s measured RECD values, the verification process begins. The Affinity 2.0 real-ear measurement (REM) system allows you to verify the electroacoustic characteristics of hearing aids via real-ear measurements or via predicted real-ear measurements based on performance measured in a 2-cc coupler. For verification purposes, the DSL Method recommends the use of speech stimuli. The system offers various speech signals shaped for use with DSL v5.0a target criteria, including the International Speech Test Signal (ISTS).

For predicted measures of hearing aid performance, the hearing aid is attached to the 2-cc coupler and appropriately positioned inside the test box. Speech signals are delivered into the test box and performance is measured on the 2-cc coupler for these signals as a function of frequency, using speech signals of appro-
For converting ABR tone burst data into a hearing aid fitting. Other technologies can be used to accomplish these goals. For example, Visible Speech can be used in the same predicted real-ear output approach (2-cc coupler measures with individual and personalized RECD values) to fit the child’s hearing aids. One of the primary advantages of the Visible Speech approach is that it allows the audiologist and the child’s family to see the speech spectrum outcome of their own voices to ensure audibility across the broadest frequency range possible. Visible Speech can also be used to examine the audibility and comfort of other sounds in the child’s environment, such as the child’s favorite music or toys.

Another diagnostic technology gaining momentum is the ASSR. The latest development in ASSR offers unique advantages over tone burst and click-evoked ABR. ASSR measures neurophysiologic responses across four frequencies in both ears simultaneously (at 500, 1000, 2000, and 4000 Hz). It may allow differentiation between severe and profound hearing losses, which may affect aural habilitation decisions such as power hearing aids versus cochlear implantation. When the Interacoustics ASSR is used as the diagnostic test it creates an “estimated audiogram,” which is transmitted directly into NOAH and can be retrieved on the Affinity 2.0 such that all corrections addressed above are automatically incorporated.

Fitting amplification to pediatric patients is an enormous responsibility with significant impact on children and their families. As noted above, some 95% of all newborns born in the U.S. receive hearing screenings prior to leaving the hospital. Secondary to the extraordinary success of newborn hearing screenings, referrals for diagnostic audiometric evaluations continue to increase. As pediatric diagnostic evaluations increase in quantity and sophistication, more children are expected to be fitted with hearing aids and cochlear implants. Therefore, protocols that integrate diagnostic and fitting information are desirable and pragmatic, as demonstrated above.

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REFERENCES


