

Electrophysiological Threshold Estimation and Infant Hearing Instrument Fitting

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Abstract

This paper addresses the use of hearing thresholds derived from auditory brainstem response (ABR) testing when fitting hearing instruments to infants. Stimulus calibration and the difference between the electrophysiologic hearing threshold (nHL) and a behavioral threshold (HL) will be addressed.

These matters complicate the application of correction factors to the ABR thresholds (nHL) in the estimation of behavioral thresholds (eHL). Finally, the application of the real-ear-to-coupler difference (RECD) to estimated behavioral thresholds is addressed. This is done to compensate for individual ear canal acoustics in infant hearing instrument fittings.

Introduction

Universal Newborn Hearing Screening (UNHS) programs continue to be implemented worldwide. Detecting hearing loss early allows audiologists to support communication development by fitting hearing instruments to infants early. But these instruments must be adjusted appropriately to give the pre-lingual listener full and consistent access to sound, with no risk of discomfort for loud sounds. This requires an accurate assessment of their hearing.

Tone Burst ABR

A proper diagnostic assessment includes, at the very least, obtaining ear-specific thresholds for air-conducted stimuli in the 500 to 4000 Hz audiometric frequency region. This region contains the frequencies important for speech recognition. When combined with the type and configuration patterns of the hearing loss, these thresholds provide detailed specifications for a fitting.

Behavioral pure-tone audiometry is suitable for ear-specific testing using insert earphones or own earmolds in children aged six months and older. For infants younger than five to six months of age, electrophysiological methods have proven to be acceptable (JCIH, 2007; ASHA, 2004). One such method is the tone-burst evoked ABR. This widely accepted clinical method is effective for estimating frequency-specific hearing thresholds in infants (Gorga et al., 2006; Stapells, 2000).

Arriving at an Accurate Gain Prescription

Prescriptive formulas for fitting infants and young children, i.e. NAL-NL1, DSL $m[i/o]$ v5.0a, utilize behavioral thresholds to calculate the gain prescription. Because of the inherent discrepancies between ABR and behavioral thresholds it is essential to use frequency-specific correction factors to estimate behavioral hearing levels.

Another factor worth considering when handling ABR data is that calibration of the equipment may vary from clinic to clinic (Bagatto et al., 2005). Despite the standardized protocols currently available (IEC 60645-3, 2007; ISO 389-6, 2007; ISO 389-9, 2009), ABR thresholds may not be comparable between clinics, as the reference threshold may differ.

Producing accurate gain prescriptions from ABR thresholds requires addressing any sources of variance to arrive at the best estimate of the pure-tone audiogram. This paper examines some of the sources that can result in incorrect threshold estimations. This paper also addresses the incorporation of individual ear canal

acoustics for correcting the audiogram as recommended by current best practice guidelines (AAA, 2003; JCIH, 2007). To ensure that the amplification levels are appropriate for the infant in question the RECD can be used.



Newborn ready for screening with ABR

Attention to Stimulus Calibration

Standardised methods for calibrating audiometers are available and used in most clinics (ANSI S3.6-2004; ISO 389-x). This ensures that thresholds obtained at different clinics will be almost equivalent. Unfortunately, the same consistent use of a standardized method for calibration of the ABR system does not take place. Consequently the reference threshold cannot unequivocally be considered a gold standard, making the comparison of ABR thresholds from different clinics problematic (Poulsen & Legarth, 2008). New ISO and IEC standards (IEC 60645-3, 2007; ISO 389-6, 2007; ISO 389-9, 2009) have been made readily available to facilitate a uniform calibration of short duration signals.

Calibration reference values, i.e. $peRETSPL^1$, for clicks and tone-bursts specified in IEC 60645-3,

are standardized in ISO 389-6 for various transducers (earphones, bone vibrators and loud-speakers) and for different acoustic calibration couplers (ear simulators)².

The reference values specify the acoustical peak-to-peak equivalent sound pressure level, dB $peSPL$ of short duration signals at the normal-hearing threshold (0 dB nHL), when the signals are presented with alternating polarity at a rate of 20/s. The peak-to-peak equivalent sound pressure level, dB $peSPL$, is defined in fig. 1.

Thus the stimulus levels of the tone bursts, and the obtained thresholds, can be given equally well in either dB $peSPL$ or dB nHL.

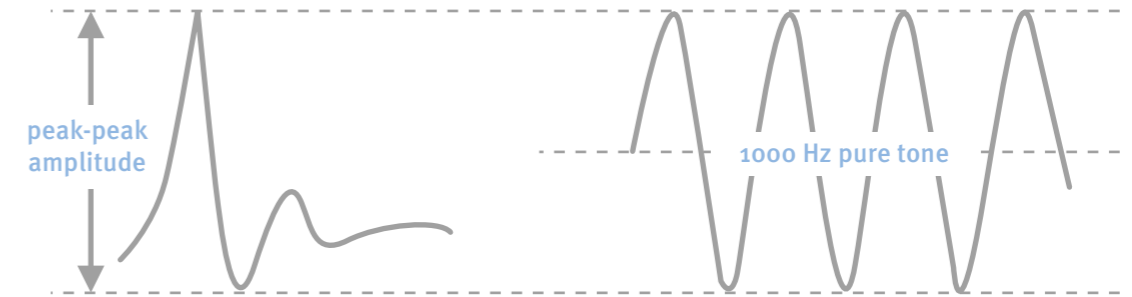


FIG. 1. Adopted from IEC 60645-3, Fig. 2b. The level of a 1000 Hz pure tone (for click calibration) is adjusted to give the same peak-to-peak amplitude as the short duration stimulus (e.g. a click, left). In this condition, the dB $peSPL$ of the short duration stimulus equals the dB SPL of the tone.

Note 1: When alternating polarity is used it is still the peak-to-peak amplitude of the single stimulus that is used to define the dB $peSPL$.
Note 2: For tone-burst calibration the pure tone frequency should correspond to the tone burst itself.

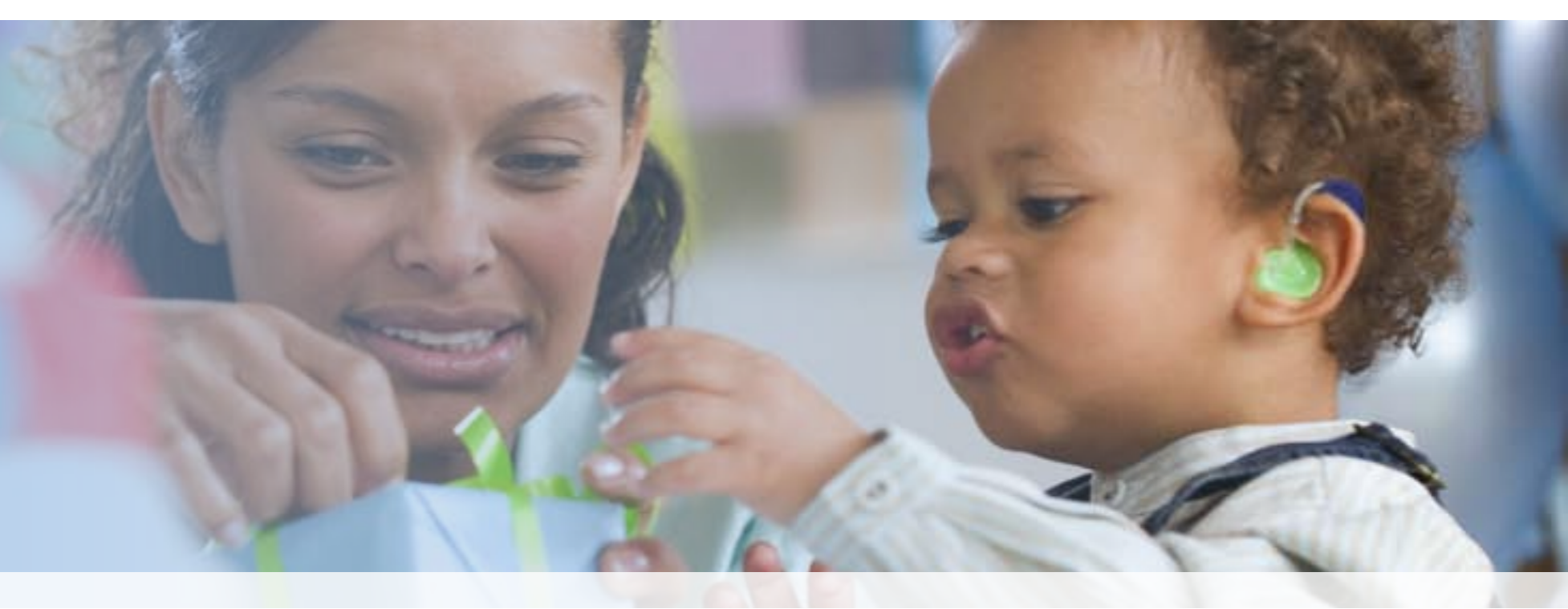


Preparation of baby for ABR testing

¹ $peRETSPL$: Peak-to-peak reference equivalent sound pressure level in dB re. 20 μPa .

² According to ISO 389-6, calibration of the insert earphones (ER-3A and ER-2) should be performed with the 711-occluded ear simulator (IEC 60318-4).

Discrepancies between Behavioral Pure-tone and ABR Evoked Thresholds



Behavioral measures of hearing level have a complex relationship to electrophysiological measures. Both measures evaluate auditory sensitivity, but the thresholds are determined on different premises (Elberling & Don, 1987; 2007). As discussed in the introduction, tone-burst ABR offers an objective means of assessing hearing levels. These can be used to predict the pure-tone audiogram and, in turn, to prescribe the gain.

Auditory Perception and Auditory Evoked Potentials

The inherent discrepancies between the results of behavioral and electrophysiological methods are partly due to the assessment of different parts of the auditory system. While behavioral thresholds reflect a perceptive response in relation to the function of the entire auditory system, auditory-evoked potentials elicit electrophysiological information up to the level of the brainstem (Elberling & Don, 1987; 2007).

Stimulus Duration

Another reason for discrepancies between the outcomes of the two measures of auditory thresholds is the duration of the stimuli. Pure tones used for behavioral audiometry are long-lasting compared to the brief tone bursts used for ABR. Temporal integration has less effect for shorter signals, which will yield higher thresholds in the dB peSPL-scale compared to the dB SPL-scale (Zwislocki, 1960; Elberling & Don, 1987). Moreover, higher stimulus levels reduce the effect of temporal integration. With sensorineural hearing loss, tone bursts are presented at higher levels, which in turn yield higher ABR thresholds (Elberling & Don, 1987).

Correction Factors

There are many variables besides those described above, which affect the relationship between ABR thresholds and behavioral hearing levels. The level at which an ABR is detectable depends on several factors: EEG noise levels, filter bandwidths, averaging parameters,

and response detection criteria, to name but a few (Elberling & Don, 2007). Besides the various procedural variables, analyses of empirical data (Stapells et al., 1995) and clinical practice are involved when attempting to derive correction factors that compensate for the discrepancy between ABR and behavioral thresholds (Ontario IHP, 2008).

Compensation in the Pediatric Fitting

For infants and young children with sensorineural hearing loss, ABR thresholds have been demonstrated to be from 5 to 30 dB higher than their behavioral thresholds (Stapells, 2000; Bagatto et al., 2005). This discrepancy must be compensated for when fitting infants. The consequence of failing to compensate for this is likely to be over (or under) amplification, which could have a substantial impact on the infant's hearing and language development.



Baby in natural sleep for ABR testing

Application of Correction Factors

The best possible approximation of a true behavioral threshold can be achieved by applying a frequency-specific correction factor to the ABR threshold (Bagatto et al., 2005). This only applies to thresholds referenced in nHL. Some ABR systems have correction factors pre-embedded into the derivation of thresholds. In this case the thresholds are referenced in the HL-scale and should be regarded as similar to the thresholds referenced in the 'eHL'-scale (see Terminology).

Terminology

The unit 'eHL' stands for estimated hearing level. This is not a standard term, but a term found in prescriptive software such as DSL v5.0a, and in UNHS programs such as the Ontario Infant Hearing Program (2008), to indicate a corrected ABR threshold. This precaution ensures two things: 1) That the corrected ABR threshold is not mistaken for a true behavioral threshold, and 2) that correction factors are not applied twice to the same threshold.

It is important to distinguish between the ABR thresholds in nHL and the estimated behavioral threshold in eHL. Often the clinician obtaining the ABR thresholds will not be the same as the one fitting the hearing device. This stresses the need for terminology that clearly indicates whether correction factors have indeed been applied to the ABR threshold or not. Implementing standardized terminology indicating whether a behavioral correction has been applied as the estimated HL, eHL, or if not, as the normalized HL, nHL, could be the solution to this problem (Bagatto et al., 2005).

Frequency Specific Correction Factors

It is important to apply correction factors to thresholds obtained through ABR. Generally, the correction factors can be said to be larger for low frequencies than for high frequencies. In practice, the correction factors are subtracted from the ABR threshold in order to account for increased thresholds and derive a best estimate of a behavioral threshold (table 1, fig. 2).

General ABR-to-behavioral correction factors are available in some fitting software such as DSL v5.0a and Oticon's fitting software, Genie (table 1). These offer a solution for the audiologist when the hearing thresholds supplied to them are not corrected (see the appendix for more information about the application in Genie).

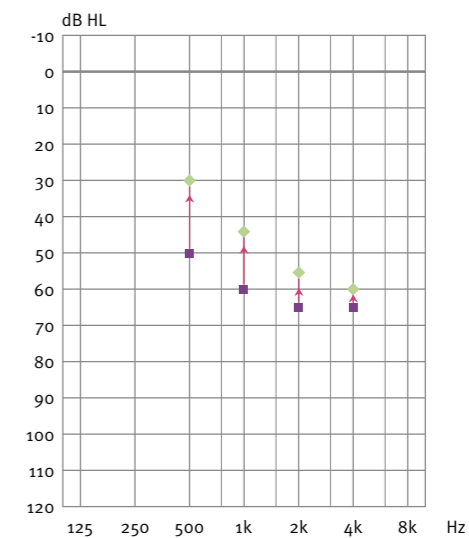


FIG 2. The purple squares represent the nHL values, while the green diamonds represent the eHL values.

TABLE 1. Showing correction of nHL threshold to eHL.

	500 Hz	1000 Hz	2000 Hz	4000 Hz
dB nHL	50	60	65	65
Correction (dB)*	- 20	- 15	- 10	- 5
dB eHL	30	45	55	60

* Frequency-specific ABR correction factors used with the DSL *m[i/o]* v5.0a prescriptive formula for air conduction thresholds. The same corrections are applied in the Genie fitting software, when selecting 'Tone-burst ABR'.

Individual Ear Canal Acoustics

Individual ear canal acoustics have an effect on the differences between the frequency-specific ABR threshold (nHL) and the behavioral thresholds (HL). Some of the infant-to-adult differences observed between ABR threshold and behavioral thresholds can be accounted for merely by the large ear canal resonance associated with small infant ear canals (Sininger et al., 1997).

This matter is even more critical when helping infants and younger children as their ear canals are not only anatomically smaller than those of adult's but they are also growing. Additionally, the size of the ear canal varies greatly for children at the same age. These circumstances make predictions of the acoustic properties of children's ear canals a mere approximation (Bagatto, 2005). In practice, action should be

taken to ensure that any change in sensitivity cannot be attributed to a change in individual ear canal acoustics (AAA,2003; JCIH, 2007).

Real-ear-to-coupler Difference

To compensate for the adult-child differences in hearing level, the RECD can be applied (Moodie et al., 1994; Seewald et al., 1999). The RECD is the difference between the SPL measured in an occluded ear canal and the SPL in a 2-cc coupler, measured across frequency. The coupler measurement is made with an insert earphone transducer. Then, the same stimulus is delivered into the patient's ear with the insert earphone coupled to a foam tip or a personal earmold.

To obtain the RECD, the SPL values from the coupler are subtracted from the values measured from the real ear. These values are typically positive and they climb as the frequency increases.

A study performed at the University of Western Ontario (Bagatto et al., 2005) examined the relationship between ABR and behavioral thresholds when ear canal acoustics were accounted for. In addition to subtracting the correction factors, the individually measured RECD and insert earphone RETSPL (reference equivalent threshold SPL) were added to the eHL threshold in order to convert from dB eHL to dB SPL. The results showed good accuracy in the prediction of behavioral thresholds.



Summary

To ensure accurate gain prescription for infants diagnosed with tone-burst ABR, multiple factors must be considered. It is essential that hearing thresholds measured in one clinic are comparable to thresholds measured in another clinic. To achieve this, standardized methods are available to ensure that the level of the tone burst is calibrated to the same reference, and that the duration and shape are uniform.

ABR thresholds are measured in dB nHL, or normalized hearing level, for a short duration signal. But since gain prescription is based on behavioral thresholds in dB HL, obtained through pure tone audiometry, the electrophysiological thresholds must be converted to resemble the equivalent behavioral threshold. This is achieved by applying frequency-specific correction factors that account for the discrepancies between the two measures of hearing sensitivity. The relationship between the meas-

ures is complex, however, as the procedures differ from one another distinctly. While one elicits an electrophysiological response from the auditory system to the level of the brainstem, the other elicits a perceptual response, which reflects the involvement of the entire auditory system. Furthermore, the stimuli have different acoustic properties, and so the estimation of behavioral thresholds from ABR thresholds must take multiple factors into account.

Converting ABR thresholds to estimated behavioural thresholds is important for the gain prescription, but it is just as important to ensure that correction factors are not applied twice. This risk does exist because the terminology for distinguishing the different threshold units is inadequate. Certain infant hearing programs as well as the DSL v5.0a prescriptive formula use the unit dB eHL to signify an estimated behav-

ioral threshold. This can affirm that the threshold is not a true behavioral threshold and also that correction factors have already been applied.

Finally, accounting for differences in individual ear canal acoustics is still relevant when fitting hearing instruments to infants based on ABR thresholds. Application of the RECD continues to be a feasible method for ensuring the appropriate amplification for the infant in question.

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Appendix A: How to Implement Hearing Thresholds Measured with Tone-burst ABR in Genie 2009.2



Genie 7.5 and later versions offer frequency specific correction of nHL thresholds obtained with tone-burst ABR (table 2). You can access these under “RECD, REUR and Audiogram” in the right-hand task pane in the *Selection* or *Fitting* step. To apply the corrections to the audiogram; first select *Tone Burst ABR* as the method and then specify that the measurement is reported in *dB nHL*. The frequency specific correction factors are then subtracted from the nHL threshold. This is visualized in the graphs displayed in the *Audiogram* tab, so that the

entered thresholds are grey while the corrected audiogram is coloured; red or blue according to the ear (fig. 3).

It is important to note that the unit, dB nHL, should only be selected when an estimated behavioral audiogram has not already been calculated. Reporting *Tone-burst ABR* in *dB nHL* will in that case apply the corrections a second time. This will result in ‘better’ hearing levels than what is actually the case and too little gain will be prescribed. If an estimated behavioral

audiogram has been calculated before hand, leave the measurement reported in *dB eHL*.

By default *Headphones* are set as the transducer used to present the test signal. If appropriate, change the transducer used for the ABR measurement. When *Insert earphones* are

selected for children in the age 0 to 7 years, Genie automatically applies predicted, age-specific RECDs, to account for the adult-to-child differences in ear canal acoustics. If individual RECDs are entered or imported from Noah in the *RECD* tab, these values are used to correct the audiogram.

Air conducted thresholds	500 Hz	1000 Hz	2000 Hz	4000 Hz
Correction for ABR measure	-20 dB	-15 dB	-10 dB	-5 dB

TABLE 2. Frequency-specific correction factors applied in Genie to audiometric thresholds obtained with Tone-burst ABR for estimation of the behavioral audiogram.

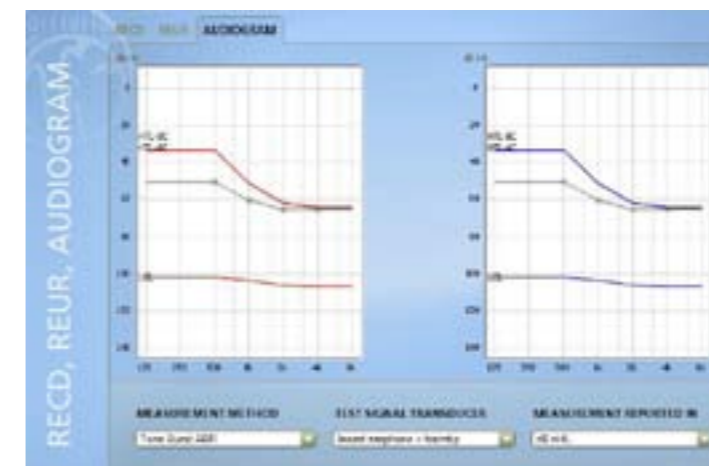


FIG 3. Screenshot from Genie 2009.2, Pediatric Fitting Mode. Tone Burst ABR has been selected as method, Insert earphone + foamtip as transducer, and finally the measurement is reported in dB nHL. The entered and the corrected audiogram are depicted in the graph as a grey and a coloured line respectively. In this case, the entered audiogram represents the nHL thresholds (50 dB @ 500 Hz, 60 dB @ 1 kHz, 65 dB @ 2 and 4 kHz). The corrected audiogram represents the adult eHL thresholds, i.e. the frequency-specific correction factors have been applied and the child’s ear canal acoustics have been accounted for.

Appendix B: How to Implement Hearing Thresholds Measured with Tone-burst ABR in Genie

Genie 7.5 and later versions offer frequency specific correction of nHL thresholds obtained with tone-burst ABR (table 2). When you have audiometric data in nHL, select *Tone-burst ABR* in the *Audiometry* tab. You can access this tab by pressing *RECD and REUR* in the right-hand task pane in the *Selection* step. The frequency-specific correction factors are then subtracted from the nHL threshold (fig. 4).

Furthermore, Genie automatically applies predicted, age-specific RECDs in a pediatric fitting, i.e. up to eight years of age, to account for the adult-to-child differences in ear canal acoustics. When individual RECDs are entered or imported from Noah, these values are used instead.

It is very important to note that *Tone-burst ABR* should only be selected when an estimated behavioral audiogram has not already been

calculated. Selecting *Tone-burst ABR* will in that case apply the corrections a second time. This will result in ‘better’ hearing levels than what is actually the case and too little gain will be prescribed. If an estimated behavioral audiogram has been calculated before hand then rather

select *Other (ASSR, click ABR, etc.)* so the correction is not applied twice. If appropriate, select the transducer used for the ABR measurement to account for the adult-to-child differences in ear canal acoustics. *Tone-burst ABR* should only be selected for tone-burst ABR thresholds (nHL).

Air conducted thresholds	500 Hz	1000 Hz	2000 Hz	4000 Hz
Correction for ABR measure	-20 dB	-15 dB	-10 dB	-5 dB

TABLE 2. Frequency-specific correction factors applied in Genie to audiometric thresholds obtained with Tone-burst ABR for estimation of the behavioral audiogram.

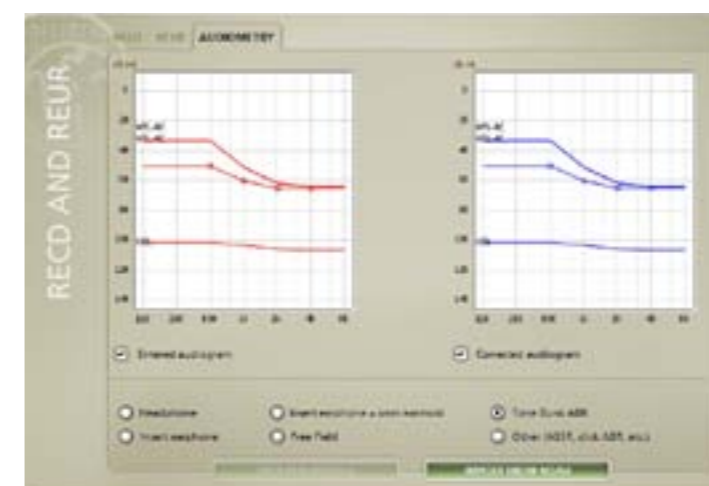


FIG 4. Screenshot from Genie 2009.1. Tone-burst ABR has been selected. The entered and the corrected audiogram are depicted. In this case, the entered audiogram represents the nHL thresholds (50 dB @ 500 Hz, 60 dB @ 1 kHz, 65 dB @ 2 and 4 kHz). The corrected audiogram represents the adult eHL thresholds, i.e. the frequency-specific correction factors have been applied and the child’s ear canal acoustics have been taken into consideration.



It takes a truly dedicated approach to help children with hearing problems achieve their full potential. That's why we deliver the solutions and services professionals and caregivers need to provide children the opportunities they deserve. This is what *child friendly hearing care* is all about.