Asking Some Clinical Questions About the Auditory Brainstem Response 50 Years After Its Discovery

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1. The first paper on the auditory brainstem response (ABR) was published in 1970, 50 years before publication of this 20Q article (Jewett, Romano & Williston, 1970). Therefore, it seems totally appropriate to focus here on some clinically-relevant questions about this valuable audiologic procedure. I'll begin with an electrode question. What are the advantages and disadvantages to using a high forehead versus vertex placement for the non-inverting electrode when recording ABRs from infants?

Long-standing evidence confirms no clinically significant differences in the amplitude of ABRs recorded with a vertex (Cz) versus high forehead (Fz) placement of the non-inverting electrode (Starr & Squires, 1982). The ABR is quite similar when recorded with a non-inverting electrode located anywhere along the midline of the scalp (electrode labels ending with "z"). There are, however, three distinct clinical advantages to the Fz site. As an aside, the "F" refers to frontal lobe.

First, electrode placement is more straightforward and secure for a forehead site than the typically hairy vertex site. The skin on the forehead can be easily prepared and electrodes securely placed. Disposable electrodes readily adhere to the skin and reusable metal electrodes can be taped to the skin. Second, vertex electrode placement is challenging or simply not possible for injured patients with head bandages and, in some cultures, with female patients who wear head coverings. Finally, vigorous preparation of the skin over the bony forehead with ABR recording from newborn infants poses no serious concern whereas the vertex site is located at the delicate fontanelle location where the skull bones are not yet firmly fused.

2. Speaking of electrodes, what's your recommendation for placement of the other electrodes in ABR measurement? Some audiologists are taught to use a mastoid site.

I strongly recommend an earlobe site for the inverting electrode in clinical ABR measurement rather than the mastoid. By the way, the term "inverting" is used because the electrical input detected with this electrode is inverted before it's combined with the input from the non-inverting electrode as the amplification process begins. There really is no reason for attaching an electrode to the mastoid for pediatric ABRs. In fact, ABRs can be recorded just as well from any location on the temporal bone.

There are at least three distinct advantages to using an earlobe versus mastoid placement for the inverting electrode. First, in the event that clinical findings (e.g., history, tympanometry, air conduction ABR pattern) indicate the need for ABR with bone conduction stimulation, the earlobe site creates some distance between the electrode and the bone oscillator, thus reducing stimulus artifact. Second, moving the electrode away from the mastoid reduces the chance of muscle artifact interference in ABR measurement. Two rather large muscles… the sternocleidomastoid and the post-auricular muscle… are in the mastoid area. Finally, amplitude of wave I is up to 30% larger for ABRs recorded with an earlobe versus mastoid location (e.g., Hall, 2015).

3. **That's a compelling argument for an earlobe location but how do you actually affix the electrode to the earlobe?**

First vigorously scrub both sides of the earlobes with the usual abrasive gel. After liberally applying the abrasive gel to a 2" X 2" gauze pad, I typically grasp the earlobe firmly before pulling downward two or three times. With reusable metal electrodes, I really like the spring-loaded double-electrode type that is specifically designed for earlobe placement. A set of two ear clip electrodes can be purchased for less than $10 from several vendors. You'll find them with an internet search. Disposable electrodes can also be affixed to either the front or back of the earlobe. Just be sure the small conducting gel portion of the disposable electrode is actually on the earlobe. The sticky part of the disposable electrode can then be pressed against other areas on the pinna. Inter-electrode impedance is typically quite low for either of these ear lobe electrode approaches.

4. **I just thought of another question about electrode location. What's your preference for placement of the ground or common electrode for routine clinical ABR recordings?**

The answer to that question is easy. When you prepare skin on the high forehead prior to placement of the non-inverting electrode at the Fz location, simply continue scrubbing about a 1-inch strip of the skin down almost to the nasion (the depression between the forehead and top of the nose). In a matter of just seconds you've simultaneously prepared more than enough area on the forehead for both the non-inverting (Fz) and ground electrodes. Disposable electrodes adhere firmly to the relatively flat hairless surface of the forehead, whereas a few short pieces of tape are needed to hold reusable electrodes in place.

5. **I recall that inter-electrode impedance values should be below 5k ohms. But I have also heard that the difference in impedance between electrodes should be small. Are both of these statements equally important or is one measure more important than the other?**

It is true that overall inter-electrode impedance should be less than 5000 ohms. Also, optimally, the impedance difference between any two electrodes should be less than 2000 ohms. These inter-impedance goals are usually achieved rather easily with good electrode site preparation technique. However, with some patients you may occasionally struggle to reach adequately low inter-electrode impedance values (< 5000 ohms), even after vigorously scrubbing the skin at all sites. In such cases, as a last resort, go ahead with an attempted ABR recording as long as there is reasonably good balance (< 5000 ohms) in impedance among electrodes.

6. **Should I ever use a two-channel set up for a pediatric, that is, a threshold search ABR, or is a single channel set up always adequate?**

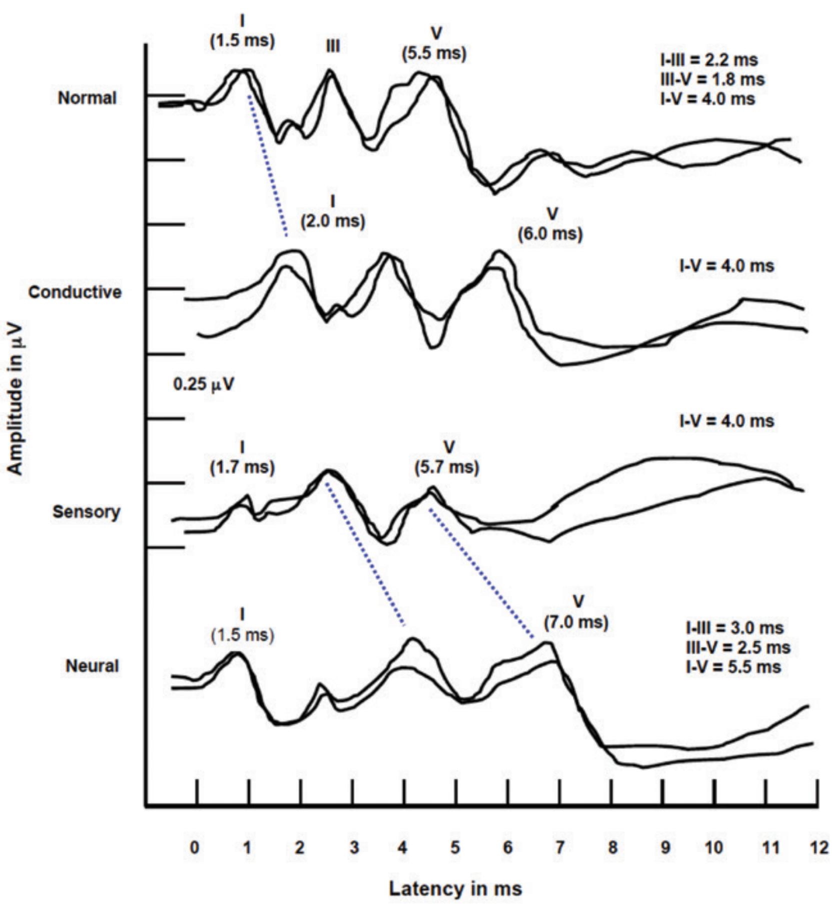
A single channel is adequate for recording an ABR from most patients and in most clinical settings. That one channel consists of a non-inverting electrode at the Fz site and an inverting electrode near the ear, preferably on the earlobe as already noted. Of course, a ground or common electrode is also needed. However, a two-channel protocol is occasionally helpful in recording pediatric ABRs with bone conduction stimulation. With a non-inverting electrode on the forehead and an inverting electrode on the ear, detection of a clear and reliable wave I for an ABR elicited with bone conduction stimulation confirms that the response is ear specific and from activation of the test ear. The wave I component is generated by activation of the distal (cochlear) end of the 8th cranial nerve that courses from the stimulus or test ear. To confirm the presence of wave I on the side of stimulation, it's sometimes helpful to examine the contralateral ABR waveform within the same latency region, that is, the response recorded with the same forehead (Fz) non-inverting electrode but an inverting electrode located on the contralateral ear. There should be no evidence of a wave I in the ABR recorded with the contralateral electrode array.

7. **When performing an ABR for hearing threshold estimation with an infant, what approach would you use? For example, do you begin with a high level click stimulus followed by threshold estimation with clicks and then tone bursts? Or, do you perform an ABR with tone burst stimuli only (no clicks)? Maybe you recommend some other approach?**

I'm pleased that you asked that question because the answer has important clinical implications. Fifty years of clinical research and experience has produced a substantial amount of information about click-evoked ABRs. The measurement of ABRs with click stimuli provides valuable clinical information in part because we are able to quickly differentiate normal versus abnormal findings. Long-standing normative data are available from children for expected latency values of wave I, Wave III, and wave V, and also for inter-wave latency values (e.g., wave I to V). Most ABR systems include published developmental latency data for ABRs recorded with click stimuli presented at different intensity levels (80 dB nHL down to 20 dB nHL) from normal hearing children ranging in age from premature infants to preschool years.

Also, there are also extensive normative data for click-evoked ABR latency values for male and female adults, including the upper limits of the normal region (mean + 2 standard deviations) for absolute wave I, III, and V, for inter-wave ABR latencies (I-III, III-V, and I-V), and also the upper limit for normal inter-aural latency symmetry (normal versus abnormal differences in latencies between ears). These extensive normative data, showing clear gender differences between males and females, are essential for analyzing neuro-diagnostic ABR findings in patients suspected of retrocochlear or neurological dysfunction.

There is another way we can take advantage of extensive normative data for click-evoked ABRs. Analysis of morphology and latencies for ABR waveforms elicited first with high intensity (e.g., 80 or 85 dB nHL) click stimuli and then lower stimulus levels yields valuable diagnostic information on type of auditory dysfunction and even the degree of hearing loss in the 2000 to 4000 Hz region. This point is illustrated in the figure.



8. **Is it really a good use of precious test time to record pediatric ABRs for click and tone burst stimuli? Also, please explain how analysis of click-evoked waveforms is used to distinguish among types of auditory dysfunction?**

Both questions are quite reasonable and definitely clinically relevant. Efficiency is always a top priority when recording ABRs in infants and young children. Let me begin by pointing out that the use of both click and tone burst stimulation is consistent with current standard of care for pediatric ABR assessment as defined in at least three peer-reviewed and evidence-based clinical practice guidelines (Joint Committee on Infant Hearing, 2019; Guidelines for diagnosis of auditory neuropathy spectrum disorder, 2010; Newborn Hearing Screening Program, 2013).

The primary rationale for incorporating click stimulation in an initial ABR assessment, in addition to using frequency-specific tone bursts, is to identify or rule out the likelihood of ANSD in infants at risk for hearing loss. ABR waveforms are recorded separately at a high intensity with rarefaction and condensation polarity click stimuli. If visual inspection reveals a relatively similar waveform for each stimulus polarity that is consistent in morphologies and latencies with an ABR, then ANSD is ruled out. However, cochlear microphonic rather than ABR is likely if each stimulus polarity produces a series of waves that doesn't resemble a typical ABR and if the polarity of waves (peaks and valleys) are inverted for each polarity. Presence of cochlear microphonic, and no ABR, is consistent with possible ANSD, Further investigation is warranted. A simple next step would be measurement of OAEs and acoustic reflexes. A finding normal OAEs in combination with absent acoustic reflexes in the ipsilateral and contralateral stimulus conditions would provide further evidence in support of ANSD.

Let's take a minute to look closely at the waveforms in the figure, all recorded from a patient age 2 years or older with a click stimulus presented at 80 to 85 dB nHL. The repeatable waveform at the top of the figure appears normal. Absolute and relative (inter-wave) latencies are normal and morphology is good. This pattern of findings is consistent with either normal hearing sensitivity or no more than a mild or moderate sensory hearing loss within the 2000 to 4000 Hz region (Gorga et al, 2006). Communicatively important hearing loss in this region could be ruled out by quickly recording a few more ABR waveforms at an intensity level of 20 to 25 dB nHL.

The second ABR waveform from the top is most consistent with a conductive hearing loss. All waves are well-formed and reliably recorded. Absolute latencies for waves, I, III, and V are all abnormally delayed but inter-wave latencies are within normal limits. The clear presence of wave I suggests normal cochlear function. The third waveform down is characterized by a very small and poorly formed wave I, or perhaps no wave I, small amplitudes and slightly delayed absolute latencies for each ABR component, yet normal inter-wave latencies. This ABR pattern would be most consistent with a moderate to severe hearing loss within the 2000 to 4000 Hz region (Gorga et al, 2006). The bottom waveform suggests the possibility of neural auditory dysfunction, assuming the patient is at least 18 months after term birth, body temperature is approximately normal (98.6 degrees F or 37 degrees C), and the patient was no under anesthesia during ABR measurement.

In a matter of a few minutes at the beginning of the assessment, analysis of click-evoked ABR waveforms for a high intensity level provides valuable diagnostic information. Findings for click stimulation are useful in determining the next steps in the ABR assessment, such which tone burst frequencies are likely to yield information on configuration of hearing loss, the need for bone conduction ABR measurement, or whether ASSR measurement at higher intensity levels is indicated. The diagnostic information also plays an important role in decisions about further audiological assessment, and appropriate referrals. In addition to enhancing the diagnostic accuracy of ABR assessment, the modest allotment of time required for recording these click-evoked ABR waveforms initially actually saves valuable test time as ABR measurement progresses.

9. **I didn't know another Joint Committee on Infant Hearing (JCIH) position statement was published in 2019. Thank you for the update. Does the position statement include any other new recommendations for ABR measurement?**

Yes, the 44-page 2019 JCIH statement offers plenty of new information about the identification, diagnosis, and management of infant hearing loss, including a number of recommendations not found in the previous 2007 version. The document refers to ABR as "the gold standard for threshold estimation for infants and children who cannot complete behavioral assessment" and necessary for defining "the type, degree, and configuration of hearing loss and provision of amplification" (Joint Committee on Infant Hearing, 2019, p. 12). The clinical contributions of air- and bone-conduction ABR measurement to infant hearing assessment are described in the document. The statement emphasizes the importance of OAEs and measures of middle ear function, including acoustic reflexes, as "key components" of the diagnostic test battery for evaluation of infants. In addition, the 2019 JCIH document describes in some detail timing of and protocols for hearing screening in the well-baby nursery, the neonatal intensive care unit (NICU), and in outpatient settings.

10. **What about chirp stimuli and the auditory steady state response. Are they recommended in the 2019 JCIH statement?**

The statement does address the potential benefits of chirp versions of narrow band (tone burst) and broadband click stimuli in infant hearing assessment, particularly the typically larger amplitude for chirp-evoked ABR and ASSR. However, the 2019 Joint Committee mentions the need for more investigations to provide data on "the relationship between behavioral hearing thresholds and chirp-elicited responses [ABR and ASSR] in infants with a variety of types and degrees of hearing loss" (Joint Committee on Infant Hearing, 2019, p. 14). In summary, chirp evoked ABR and ASSR are viewed as techniques that supplement more conventional ABR measurements and that might provide added diagnostic value in some infants, but at this time the JCIH does not endorse these techniques for routine audiological assessment of all infants suspected of hearing loss.

11. **That JCIH update was very helpful. Changing topics, I understand that audiologists need to estimate or verify behavioral hearing thresholds from a small group of adults for each of the ABR stimuli before using the stimuli in pediatric auditory assessment. How do I use this information? Are these average behavioral thresholds my nHL reference values? Do I need to check these thresholds in each environment I will be testing in, such as the sound booth, the neonatal intensive care unit, and an operating room (OR)?**

You've asked questions that are almost always on the minds of audiologists who perform infant hearing assessments with ABR. Let's begin with a step-by-step approach for establishing or confirming in your clinic setting intensity levels of the stimuli used to record ABRs from infants and children, specifically air conduction clicks, bone conduction clicks, and tone bursts at different frequencies.

- Identify 4 or 5 cooperative young adults with normal hearing sensitivity (e.g., hearing thresholds of < 15 dB HL from 250 to 8000 Hz, normal middle ear function, and normal OAE findings).
- With these normal subjects and using your ABR system in the clinical setting (s) where you will actually perform ABRs with children, estimate behavioral hearing thresholds in dB for each of these stimuli (air- and bone-conduction clicks and air conduction tone bursts). The subjects don't need to be hooked up with electrodes. Simply use your ABR system like an audiometer to find behavioral threshold for each stimulus type. With current ABR systems, the average intensity value on the screen for the thresholds estimated in your small normal group should correspond closely to 0 dB nHL. However, you may record slightly higher threshold levels in some clinical settings (e.g., the operating room or NICU) especially for low frequency tone bursts.

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- Document these slightly higher intensity deviations for 0 dB nHL so you can adjust or "correct" thresholds for ABRs recorded from infants in these setting, particularly when the thresholds are consistent with normal or nearly normal hearing sensitivity levels.
- Now you are ready to estimate behavioral auditory threshold from ABR threshold with infants and young children. With each stimulus type, find ABR threshold at progressively lower stimulus intensity levels. The first goal is to quickly determine the lowest intensity level where an ABR wave V can still be reliably detected. Then, estimate behavioral threshold for that stimulus type, that is, the 2000 to 4000 Hz region for click stimuli (Gorga et al, 2006) or the octave band frequency region corresponding to each of the tone burst stimuli.
- ABR threshold is usually 5 to 10 dB higher than behavioral threshold for low frequency stimuli for patients who appear to have normal hearing or only a mild sensory hearing loss. For patients with greater degrees of sensory hearing loss, ABR threshold is typically quite close to estimated behavioral threshold.

Audiologists who apply ABR in estimating hearing loss in infants and young children should take a little time to review this important topic in greater detail. There are several relatively recent references on the topic (Hall, 2015; McCreery et al, 2014; Norrix & Velenovsky, 2017).

12. I would like to collect my ABR information as quickly as possible, for obvious reasons. Is there a downside to using a faster stimulation rate, like 37 or even 39 stimuli per second?

Quick data collection and short test time is critical for pediatric ABR assessments. With highly efficient ABR data collection it is often possible to complete an entire neuro-diagnostic and frequency-specific threshold ABR assessment while a child is sleeping naturally. One of the most effective ways to minimize ABR test time is to use a relatively fast stimulus presentation rate that doesn't change the ABR morphology or latency. A click stimulus presentation rate of 21.1 to 27.7/sec is a good choice for quickly recording an optimal ABR for neuro-diagnostic purposes, that is, a reliable response with clear waves I, III, and V.

A faster stimulus rate of 37.7 or 39.7/sec is entirely appropriate for estimating auditory thresholds with tone bursts. The goal with tone-burst stimulation is simply to produce a reliable and easily-detectable wave V at the lowest possible intensity level. Detection of wave I is not important. These stimulus presentation rates in pediatric ABR assessment are consistent with evidence-based clinical practice guidelines (e.g., Newborn Hearing Screening Program, 2013).

13. Do you have any other tips for shortening ABR test time, in addition to using a faster stimulus presentation rate?

There is one other technique for minimizing test time without compromising the quality of the ABRs you are recording. Rather than presenting a fixed and constant number of stimuli (e.g., 2000) at each intensity level when averaging ABR waveforms, it's much more efficient to present only the number of stimuli that is required to produce an ABR to noise ratio of 3:1. The overall objective in ABR measurement is to detect a reliable signal (the ABR) in the presence of noise (all non-ABR brain activity plus myogenic or muscle activity). This rather straightforward objective is also emphasized in clinical practice guidelines (e.g., Newborn Hearing Screening Program, 2013).

Under certain test and patient conditions, a relatively modest number of stimuli or sweeps, such as 500 and certainly 1000, is needed to achieve this objective. The test and patient conditions include high stimulus intensity levels, relatively little background noise, and a child with normal hearing sensitivity. At lower stimulus intensity levels closer to auditory threshold and/or in less than optimal test conditions, maybe a restless baby and/or an electrically noisy test environment, considerably more stimuli are usually needed to produce a SNR of 3:1.

Two simple strategies for maximizing efficiency in pediatric ABR measurement, that is, minimizing test time while maximizing ABR quality: 1) Increase stimulus presentation rate within acceptable range and 2) Terminate stimulus presentation when the SNR (ABR to background noise) reaches 3:1.

Efficient Data Collection in a Typical Pediatric ABR Assessment:

- 4 stimuli (click + 3 tone burst frequencies)
- 4 intensity levels per stimulus
- 2 ears
- 1000 stimuli (sweeps) per waveform for 4 stimuli at 3 intensity levels for each ear including waveforms for rarefaction + condensation click stimuli at highest level = 26,000 sweeps
- 2000 stimuli X 2 replicated waveforms at 8 different lowest (threshold) intensity levels = 32,000 sweeps
- Total of 40 separate ABR waveforms
- Total of sweeps = 40,000
- Approximate data collection time = 40,000/37.7 = 1061 secs = 18-20 minutes

The table shows the reasonable test time when stimuli are presented at the rates we've discussed and the number of stimuli presented (sweeps) is sufficient to terminate stimulus presentation (averaging) when a SNR of 3:1 is reached. Actual ABR test time for each child varies depending on many factors but this simple two-step approach minimizes data collection time required for obtaining adequate information on auditory status with air conduction stimulation. Measurement of bone conduction ABRs typically extends test time by 12 to 15 minutes. Still, overall ABR test time of about half an hour (e.g., 20 minutes for AC + 15 minutes for BC) remains relatively brief and, in many cases, it's possible to complete the ABR assessment while an infant sleeps naturally.

I should add that there are several recent clinical studies confirming that the shortest test times, on average 20 minutes, are achieved with chirp-evoked ABRs, and ASSRs (e.g., Sininger et al, 2018). Chirp stimuli are designed to more effectively activate the cochlea, producing amplitudes for ABR waves that are sometimes with twice as big as ABRs elicited with convention stimuli.

14. **Insert earphones are certainly the preferred transducer – is there ever a reason to use headphones when performing an ABR on an infant?**

You are entirely correct. In comparison to conventional supra-aural earphones, insert earphones offer least a dozen practical advantages in ABR measurement (see Hall, 2015), such as:

- attenuation of ambient sound
- increased inter-aural attenuation
- increased comfort
- more precise delivery of the stimulus
- prevention of ear canal collapse
- minimization of stimulus electrical artifact
- aural hygiene (infection control)

The last advantage is very important in clinical settings, particularly with young infants. Of course, a supra-aural headset is necessary for conducting ABR assessments with the occasional child who presents with aural atresia. Audiologists in some clinics routinely perform audiological assessments of children with craniofacial anomalies, including syndromes or malformations that are associated with microtia or aural atresia (Jahrsdoerfer & Hall, 1986; Hall, 2015).

15. **Before we leave the topic of insert earphones, how do you squeeze the foam plugs into the ear canals of little babies? Even the pediatric size is too big for tiny infant ears. I've heard stories about audiologists trimming up the foam with scissors, but that would be time consuming and it doesn't seem very professional.**

I couldn't agree more. To be honest, I've never attempted to squeeze an oversize foal insert cushion into the tiny ear of an infant. And, I wouldn't even think about taking the time to trim foam ear tips while an infant and parents awaited an ABR assessment.

I strongly recommend a minor modification in the insert earphones used with an ABR system. Replace the little plastic "nipple" that is used to couple an insert cushion to the acoustic tubing with a slightly larger plastic adaptor that accepts the rubber tips used for tympanometry and sometimes OAE measurement. These black plastic adaptors are available from various vendors, including Oaktree Products (https://www.oaktreeproducts.com/), a well-known vendor focusing on audiology supplies. Searching among insert earphones, you'll find what is listed as "E-A-RTONE 3A single use ear tip adaptors". You can purchase them without or with the acoustic tubes. Then, it is simply a matter of keeping on hand an adequate supply of assorted sizes (and colors) of immittance ear tips, also available from Oaktree Products or manufacturers of devices for middle ear measurement.

16. **How should pediatric ABR results be reported? What information should the report include? For example, should I report absolute and interpeak latencies and comment on normal versus abnormal neural conduction? Should I mention interaural latency differences for Wave V? Do I specify that there is no evidence of ANSD? Do I describe all of the estimated thresholds at each frequency for tone burst stimuli in ABR recording or for ASSR stimuli? I really could use some guidance on what do include in my reports.**

Thank you for all of those clinically-relevant questions! There are no wide-accepted guidelines or conventions for reporting ABR findings. Here is the approach I've developed during my 40+ years of clinical experience with pediatric ABR measurements. I include four categories of information in my overall report including a:

- Print out of all the waveforms that were recorded in the ABR assessment clearly marked for test ear, stimulus intensity, and the absolute and relative latencies for each wave. We talked earlier about these two types of latencies
- Print out of the test protocol used for collection of all ABR data that provides details on stimulus and acquisition parameters used in recording each set of waveforms
- Audiogram-type graph that shows ABR thresholds and estimated hearing levels (eHLs) for each of the stimulus conditions, e.g., air- and bone-conduction click stimuli (plotted in the 2000 to 4000 Hz region on the graph) and tone burst frequencies. I also include on this graph plots of estimated thresholds from ASSR measurement if they are available.
- Signed narrative written report that consists of demographic information (patient name, birthdate, medical record number, referral source, test date, etc.), a two or three sentence history including the reason for an ABR assessment, Results (just the findings), Impressions (analysis and interpretation of the findings), and Recommendations for management, referrals, and follow up.

Some readers may wonder if this approach to ABR reports provides too much detail but it provides valuable information that is required to document auditory status at the time of the ABR assessment and to make important management decisions, such as the initial hearing aid fitting and whether medical referral is indicated. A detailed and well-documented report also reduces the risk of professional liability for the audiologist who performed the ABR assessment.

17. **I have read that a high pass filter must be set very low, at 30 or 50 Hz or some of the infant ABR response may be filtered out in the recording. But I notice that oftentimes, the high pass filter setting at 30 or 50 Hz leads to higher rejection and noisy responses. Is it acceptable to increase the high pass filter to 75 or 100 Hz as long as you see a clear response? Please explain.**

Research dating back to the 1980s confirms that infant ABRs consist of relatively more low frequency brain energy than older children and adults (see Hall, 2015 for review). This makes sense given the neurophysiological immaturity of infants. As you correctly noted, the optimal high pass (or low frequency cut off) for infant ABR measurement is 30 Hz (Hall, 2015; Newborn Hearing Screening Program, 2013). A high pass setting of 30 Hz is sufficient to remove most of the lower frequency brain EEG that doesn't contain any ABR energy while also preserving the dominant spectral energy within an infant ABR.

Sometimes, however, excessive measurement artifact is encountered when recording ABRs with a 30 Hz high pass setting. The artifact is usually related to myogenic (muscle) activity in a restless infant who is not sleeping soundly. The most effective solution for this problem is take whatever steps are necessary to quiet the infant and to enhance sleep. Another option is to increase the high pass setting a modest amount, perhaps to 75 Hz or 100 Hz. Although it might be tempting to use even higher settings to eliminate measurement artifact, the outcome is usually much lower ABR amplitude and the risk of either not detecting the ABR in the presence of background neurophysiological noise and/or estimation of an artificially elevated auditory threshold.

18. How important is waveform morphology and replication in pediatric ABR measurement? I have seen ABR recordings from children where is looks like a random peak was chosen for Wave V. What are some things an audiologist can do to ensure they are really seeing a response and they are marking the waves correctly?

Very perceptive observation and questions. There are two general ways you can increase the likelihood of recording a clear and reliable ABR waveform from an infant. One is to use an evidence-based test protocol that includes the most appropriate stimulus and acquisition settings or parameters. The other is to do everything possible to assure that the infant is sleeping quietly with minimal movement or muscle artifact. Replication of waveforms is one easy way to verify that you are really recording an ABR rather than background noise and muscle or electrical artifact. A safe strategy is to always replicate the first few waveforms recorded at the highest intensity to verify the presence of the ABR. Next, record a single (not replicated) waveform at each progressively lower stimulus intensity level until you reach threshold. Then, record replicated or even triplicated waveforms to confirm the ABR threshold.

Now I'll comment on how you can confidently identify ABR waves, including wave V. After almost 50 years of accumulated clinical experience and published research with pediatric ABR measurement, we have plenty of data on normal latency values for each major wave. The first step in accurately identifying an ABR wave is to visually inspect the waveform within an appropriate latency region for that wave, while accounting for type of stimulus (air or bone conduction click or a tone burst), the stimulus intensity level, and the patient's age (for children under about 18 months).

Let's take wave V as an example. For an adult or child older than 2 years, we would expect to see ABR wave V in the latency region of 5.5 to 6.0-ms for air conduction click stimulation at a high intensity level (about 80 to 85 dB nHL). However, normal wave V latency would be considerably longer for a lower stimulus intensity level, for younger infant, or for a lower frequency tone burst. Fortunately, many modern ABR systems have an option to display on the screen a shaded latency region indicating the most likely and logical location for wave V given these stimulus and subject factors.

19. Please tell me a little more about the differences in wave latency and waveform morphology for ABRs elicited with click versus tone burst, and for tone bursts of different frequencies.

That's a good follow up question. For most infants, morphology is best and latency values shortest for click stimulation. As you might expect, a tone burst stimulus of 4000 Hz usually produces an ABR with morphology and latency values that are comparable to click-evoked ABRs because both transient stimuli activate the same general region of the cochlea (Gorga et al, 2006; Hall, 2015). ABR latency progressively increases, and morphology of waves is less distinct, for lower tone burst frequencies because more travel time is needed for the stimulus to reach more apical places along the basilar membrane. The increase for wave V latency is approximately 5-ms for an ABR elicited with a 500 Hz tone burst stimulus versus a 4000 Hz tone burst or a click stimulus. I should point out that these observations do not necessary apply to chirp versions of tone burst and click stimuli.

20. **Since you mentioned normative data, I'd like to wrap up with a question about clinic-specific latency norms? Are they necessary and do we need them for click stimuli and tone burst stimuli at different frequencies? We use settings that are clearly referenced in the literature, and the normal range is typically + or – 2 SD.**

That's an appropriate topic to address as we conclude this stimulating Q/A session. Beginning as early as the 1970s, large normative data bases have been reported for latency values of ABRs recorded from infants and young children. Systematically collecting data from large numbers of children at different ages with confirmed normal hearing sensitivity and normal neurological function is a very time-consuming task.

Fortunately, most manufacturers now supply a collection of normative databases with their ABR systems, recognizing that clinical audiologists really can't collect normative data from an adequate sample of normal hearing infants. However, the unstated assumption is that the clinical audiologist who is analyzing ABR findings for a patient is using the same ABR test protocol as the researchers who collected the normative data. There is abundant evidence that altering stimulus parameters, such as presentation rate or polarity, or acquisition parameters (e.g., filter settings), is associated with changes in ABR latencies. Here's a straightforward and clinically feasible solution to this potential problem.

First the audiologist creates on the ABR system a number of separate and clearly named protocols for most commonly used test protocols, e.g., [clinic name] ABR AC click rare 21.1, [clinic name] ABR TB 4K Hz, etc. Next, the audiologist records ABRs with these different protocols from several infants who are confirmed to have normal hearing sensitivity, perhaps graduates from a well-baby nursery with no risk factors for hearing loss and who passed newborn hearing screening. Then, the audiologist marks ABR waves for different stimuli presented at different intensity levels.

Finally, the audiologist compares the latency values for the infants with normative data for comparable test conditions (e.g., same stimulus at the same intensity level for an infant of the same age). If the ABR latency values for the small sample of normal hearing infants are close to the mean latency value found within the normative database (which almost always is the case) then the audiologist can confidently analyze latency data for infants undergoing ABR assessment in the clinic using the large normative database

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