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ABRs or ASSRs? The Application of Tone-Burst ABRs in the Era of ASSRs

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Although the newer auditory steady-state response (ASSR) test has solid applications in the field of diagnostic audiology, the auditory brainstem response (ABR) with click or tone-burst signals retains great importance. A tutorial on using and interpreting ABRs is presented, and the author shows why the ABR is most useful in the differentiation of types of auditory dysfunction, while the ASSR is uniquely valuable in estimating auditory thresholds of those with moderate to profound losses.

There is no doubt that the auditory steady state response (ASSR) technique will assume a valuable role in the pediatric audiology test battery, and perhaps even contribute to audiologic assessment of selected adult populations. However, the ASSR is not without its drawbacks, and the auditory brainstem response (ABR) as evoked with click or frequency-specific (tone-burst) signals retains great importance for diagnostic audiologists. Those involved in the auditory assessment of infants and young children will discover that the modest time and effort they expend to acquire skills in the measurement of tone-burst ABRs will yield valuable diagnostic dividends, and will contribute to the timely and effective audiologic management of children.

At the outset, I'll state my unequivocal enthusiasm for the auditory steady state response (ASSR). With the availability of FDA-approved instrumentation, the ASSR is quickly assuming a valuable and unique position in the current audiologic armamentarium. The ASSR is characterized by a number of clinical advantages, as summarized in Table 1. One clinical advantage alone—the capability of estimating electrophysiologically auditory thresholds of up to 120 dB HL in infants and young children—has guaranteed the ASSR a secure place in the pediatric test battery.

Potential advantages of ASSR

- Frequency-specific signals are employed for estimation of auditory sensitivity at audiometric frequencies.
- Frequency-specific auditory information can be obtained with air- or bone-conduction signals.
- Signal intensity levels can be as high as 120 dB HL. The ASSR is, therefore, useful for electrophysiologic assessment of severe to profound degree of hearing loss in infants and young children.
- Automated response detection and analysis (ie, experience in waveform analysis is not necessary).
- Clinical devices are available.

Potential disadvantages of ASSR

- ASSR recording requires a very quiet state from the patient. Movement artifact (interference) is likely to produce invalid results, or overestimation of actual auditory threshold levels. Sedation is required with infants and young children.
- The influence of deep sedation and anesthesia on the ASSR evoked by high modulation frequencies (eg, > 60 Hz) requires further investigation. Sedation and anesthesia clearly affect the ASSR for slow modulation

frequencies (eg, < 60 Hz).

With the advent of universal newborn hearing screening, and the requirement for hearing aid fitting of infants within months after birth, there is a clear clinical demand for objective (eg, electrophysiologic) estimation of hearing sensitivity as a critical step in prescriptive hearing aid fitting. Recent research on early intervention for childhood hearing impairment has demonstrated the dramatic benefits of providing within the first 6 months after birth adequate auditory stimulation.¹ Traditional behavioral audiologic techniques are insufficient for this purpose.

As reviewed in this article, it is certainly possible to estimate audiometric frequencies using frequency-specific ABR auditory thresholds. This threshold estimation information can then be incorporated into prescriptive fitting algorithms, such as desired sensation level (DSL), permitting a reasonably accurate initial hearing aid fitting for hearing-impaired infants. The ABR is evoked most effectively by transient (very brief) acoustic signals, with onset times on the order of a few milliseconds. The ABR consists of bioelectric activity that reflects synchronous firing of thousands of neurons in the auditory (8th cranial) nerve and auditory system pathways within the brainstem (pons and midbrain). Abrupt, transient signals must be utilized to produce this synchronous firing. The maximum effective intensity level of these signals is limited by their very brief duration. That is, due to their short duration, less energy is delivered to the auditory system.

A reduction in frequency-specificity—another potential problem associated with the very brief duration of the signal—is largely solved by the use of sophisticated equations (eg, Blackman) for ramping or shaping of the signal onset. As its name implies, the ASSR is generated with steady state (ongoing sinusoidal rather than transient) acoustic signals. The inherent limitation of maximum intensity associated with the transient signals does not, therefore, apply to ASSR signals.

When a new clinical technique is introduced, hearing care professionals have a tendency to ask whether the technique is better or worse than existing techniques. When, for example, clinical instrumentation for measurement of otoacoustic emissions (OAEs) became commonplace, there was almost immediately ongoing comparison among some audiologists of the merits of OAEs with pure-tone audiometry. I distinctly recall listening at professional meetings to conversations among concerned audiologists who wondered whether OAEs as a technique for hearing assessment would replace pure-tone audiometry and, taking this concern one (illogical) step further—whether automated OAE devices would minimize the need for audiologists!

There is now ample clinical evidence that, in comparison to pure-tone audiometry, OAEs provide more information on cochlear function. And, although OAEs are a very sensitive and site-specific measure of auditory function at the cochlear (outer hair cell) level, they are most certainly not a measure of “hearing”. Hearing, of course, involves a vast array of anatomic pathways and structures throughout the auditory system, especially at the cortical level.

Hearing also involves complex auditory functions and processes. Although the cochlea (and, of course, the outer hair cells), contribute importantly to auditory function, we essentially hear with our brains. During the late 1990s, as audiologists began to use OAEs in their clinical practice, audiometers were not discarded. In fact, before long audiologists realized that their work would not be supplanted by automated OAE devices. On the contrary, audiologists have discovered that their clinical assessment and management

of hearing loss is enhanced by the application of OAE techniques.

We are now discovering the clinical strengths of ASSRs and, inevitably, some weaknesses of this technique (see Table 1). Based on clinical experience with ABR for the past 30 years, and with ASSR during the past 2 years, I have formed some definite, albeit preliminary, perspectives on the likely role of ASSR in the audiologic test battery. My clinical experiences dispel some of the misconceptions or misunderstandings that are circulating about the comparative clinical pros and cons of ABR and ASSR.

One common misconception is that tone burst ABR assessment is excessively time-consuming, and that the ASSR requires relatively little test time. As an example, Ted Venema, PhD, in his informative May 2004 Hearing Review article on the ASSR noted that:

ASSRs hold the promise of delivering information similar to tone-burst ABR with much faster results. The tone-burst ABR can take some 2 hours to obtain ABRs to three or four frequencies from both ears. It is sometimes difficult for babies to remain calm for this length of time. The ASSR, however, can reduce this time dramatically—down to some 30-40 minutes!²

Actually, if a tone burst ABR went on for 2 hours, no one involved could possibly remain calm, particularly the anesthesiologist or whomever is responsible for sedating the child. Fortunately, tone-burst ABR assessments typically require less than 1 hour. Indeed, the day after reading this article about ASSRs, I performed sedated tone-burst ABRs (in the operating room) for estimation of hearing sensitivity with two children with language delay and suspected hearing impairment. Total test time for both of the ABR assessments combined was less than 40 minutes.

Using one of these cases for illustrative purposes, I present in this article a simple strategy for efficient and effective estimation of hearing sensitivity with a frequency-specific ABR protocol. A review of background information on measurement of ABR and ASSR is beyond the scope of this discussion. The reader is referred to a textbook for information on the ABR,³ and to two special editions of the Journal of the Academy of Audiology for a review of the ASSR technique.^{4,5}

Efficient ABR Test Protocols and Understanding ABR Printouts

ABR test protocol. Adherence to some practical guidelines will lead to reasonably accurate estimation of auditory sensitivity for selected audiometric frequencies in minimal test time. The primary, and most important, is reliance on a proven ABR test protocol. That is, the application of a set of stimulus and acquisition parameters effective in eliciting reliable frequency-specific ABRs from infants.

Thirty years ago, Hecox & Galambos⁶ described the application of ABR in auditory assessment of infants and young children. Since then, accumulated clinical experience with untold millions of children has produced ample evidence in support of specific measurement parameters that are effective for recording tone-burst ABRs. Experience has also clearly demonstrated that the use of improper test parameters will result in inaccurate threshold estimations or, in some cases, a false-negative ABR outcome error (ie, no detectable ABR in a child for whom an ABR should be present).

Space does not permit a full discussion in this article of detailed aspects of the ABR test protocol. An effective protocol for recording frequency-specific ABRs, summarized in Table 2, was used by the author to record frequency-specific ABRs for the case report described below. Clinicians are advised to create with their auditory evoked response system a similar protocol for measurement of tone-burst ABRs. The

protocol can be appropriately labeled, saved, and then retrieved as needed clinically.

FREQUENCY-SPECIFIC ABR MEASUREMENT PROTOCOL

Stimulus Parameters

Parameters	Suggestions	Comments
transducer	insert	Insert earphones offer many advantages in clinical ABR measurement, especially with infants and young children.
polarity	alternating	Instead of the usual rarefaction polarity, you may want to use an alternating polarity to minimize the possibility of a frequency-following type response.
ramping	Blackman	Ramping refers to how the rise/fall portions of the tone burst are shaped. Some non-linear ramping or windowing techniques reduce spectral splatter and increase frequency specificity of tone burst stimulation. Blackman windowing is the best, and most current AER systems include it in their stimulus package.
duration	variable	The rise/fall, and plateau, times for the tone burst stimuli vary depending on the frequency. As a rule, it's desirable to use longer times for lower frequencies so as to include more cycles. This increases the chances that the stimulus sounds like the desired frequency, and not a click. The most common approach of signal duration is to use 2 cycles rise time, 0 cycle plateau, and 2 cycles fall time or, in milliseconds: 1) 500 Hz: 4 ms rise/fall and 0 ms plateau; 2) 1000 Hz: 2 ms rise/fall and 0 ms plateau; 3) 2000 Hz: 1 ms rise/fall and 0 ms plateau; 4) 4000 Hz: 0.5 ms rise/fall and 0 ms plateau
intensity	variable	Keep in mind that the intensity levels "on the dial" for your ABR system will usually not be defined in dB nHL, as they are for a click. That is, you may select 95 dB on the dial, but the intensity range for the tone-burst frequency may go as high as 115 dB. Always get behavioral threshold data for each tone-burst stimulus you intend to use for ABR recording (with the earphones you'll use and in the ABR test room), and develop a "correction factor" for tone-burst intensity. For example, if your maximum dial setting for a 500 Hz tone burst is 115 dB, but your normal subjects have an average threshold of 30 dB for this stimulus, then at 115 dB on the dial you're really presenting an intensity level of 85 dB nHL. You may also want to actually record ABRs for this 500 Hz stimulus from a few of these normal-hearing subjects to estimate the lowest intensity level that produces an observable and reliable ABR wave V.

Acquisition Parameters

Parameters	Suggestions	Comments
electrode sites	Fz - Ai	Non-inverting (positive) electrode is located in the midline on the high forehead (Fz) and the inverting electrode is located on the earlobe ipsilateral to the stimulus ear (Ai). With a earclips electrode design, the earlobe electrode is easily applied, impedance is low, and the electrode is removed from the mastoid region. The earlobe electrode records a larger wave I than the mastoid electrode, and is associated with less stimulus artifact in bone conduction ABR recordings. The ground electrode can be located on the low forehead (Fpz) or the contralateral earlobe (limits recordings to a single channel).
filter settings	30-3000 Hz	It is essential that you keep the high pass filter cut-off this low (30 Hz) because the tone burst ABR is dominated by low frequency energy, especially in infants.
analysis time	15-20 msec	For click signals and higher frequency tone burst signals, an analysis time of 15 msec is adequate to encompass the wave V component even under

sweeps	variable	conditions associated with delayed wave V latency, eg, low signal intensity level, hearing loss, very young age (immaturity of the auditory pathways). For tone burst signals of below 1000 Hz, a 20 msec analysis time is recommended.
		The number of sweeps (stimulus repetitions or number of signal averages for an ABR recording) is dependent on the signal-to-noise ratio. When the signal (ABR amplitude) is larger (eg, at a high intensity level with a normal hearing patient) and/or when background noise is low (eg, the patient is sedated or anesthetized), then relatively fewer stimulus repetitions are needed. On the other hand, when ABR amplitude is smaller (eg, at lower signal intensity levels and/or in a patient with hearing loss) and noise is greater (a restless unsedated child), more signal averaging (more stimulus repetitions) will be needed. As a rule, less stimulus repetitions are required for the second (replication) ABR run when the goal is to simply verify that the response is reliable (and not just artifact).

Table 2. Protocol for frequency-specific auditory brainstem response (ABR) measurement. The conventional ABR protocol for air conduction click signals must be modified to successfully record ABRs for tone burst signals. The main differences between protocols for click versus tone burst ABRs are noted under comments.

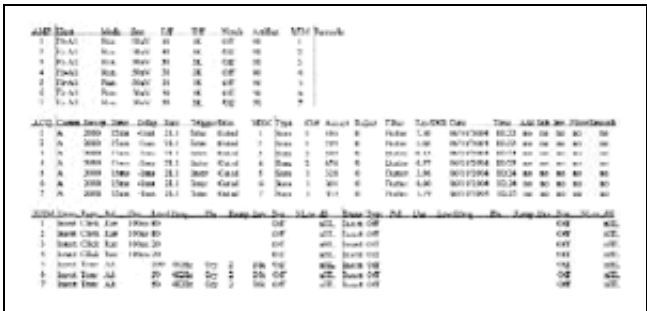


Figure 1. Printout of parameters used to record frequency-specific auditory brainstem response (ABR).

ABR printouts explained. To assist the reader in creating their custom tone-burst ABR protocol, the actual printout of the parameters used in recording ABRs for the case reported in this article is shown in Figure 1. A brief discussion of the parameters in this figure might be helpful to the reader. Beginning in the top left portion of

the parameter display, the electrode locations were Fz (high forehead) for the non-inverting electrode and A1 (left earlobe) for the inverting electrode. The “run” mode indicates that averaging was ongoing during data collection. Amplifier sensitivity (ie, gain) was ±0.50 mV. The high-pass filter setting (referred to with this system as low frequency filter or LLF cutoff) was 30 Hz, whereas the low-pass filter setting (high frequency filter or HFF cutoff) was 3000 Hz. The notch filter option was off (not used).

Sweeps and analysis time. Moving to the next grouping of parameters in Figure 1, the maximum number of sweeps per run (stimulus presentations or amount of signal averaging) was pre-set at 2000. However, this number of stimuli may be exceeded if necessary or, more commonly, signal averaging may be terminated sooner if a clear response is observed. For ABR measurement with click signals and higher frequency tone-burst signals, an analysis time of 15 msec is long enough for detection of ABR wave V under all possible conditions. That is, for young infants with ABR latencies that are delayed due to immaturity, for lower signal intensity levels, and/or with patients who have hearing loss producing longer latency responses. For the 500 Hz tone-burst signal, however, a 20-msec analysis time is needed to encompass ABR wave V under all potential measurement and subject conditions.

Lower frequency tone-burst signals activate more apical regions of the cochlea. For lower frequency tone bursts (eg, 500 Hz), the time required for the traveling wave to reach the more apical portion of the cochlea produces longer latencies for the ABR wave. Stimulus rate (the number of stimuli presented per

second) was 21.1. An odd number is utilized to minimize measurement interference between stimulus presentation rate and 60 Hz electrical noise. A somewhat faster rate of stimulation (eg, 27.3/sec or even higher) would also be appropriate for infant ABR measurement.

Signal acceptance/rejection. Two columns in Figure 1 describe the number of signal averages accepted (within the sensitivity limits noted above) or rejected (considered artifact because the voltages exceeded the sensitivity limits). Notice that, for some runs or averages, there were far fewer than the maximum number of stimulus presentations (sweeps). One of the most important ways to minimize ABR test time is to manually stop signal averaging as soon as a reliable response is detected. Often, at a high intensity level (eg, 80 dB nHL), a clear and well-formed ABR emerges after only a few hundred stimulus repetitions, whereas up to 2000 stimulus repetitions or more are required to detect a reliable response as threshold is approached.

In this example, movement artifact was not a problem because the patient was anesthetized. Therefore, there were no “artifact rejections”, as documented by the zeros under the “reject” column.

Filters and Fsp/SNRs. The term “Butter” in the column labeled “filter” is an abbreviation for the type of physiologic filter used by the evoked response system (Butterworth). The column to the right, labeled Fsp/SNR, contains statistical calculations of the Fsp (the F-statistic for a single point in the waveform). The Fsp is a statistical measure of the signal-to-noise ratio (SNR), and the presence versus absence of a response. Larger Fsp values correspond to larger SNRs. The Fsp is commonly applied in automated ABR systems used in newborn hearing screening.

Test time and date. The test date and time is displayed in the next columns. The reader will note in this and subsequent figures that stimulus presentation and signal averaging for the case began at 10:22 AM and ended at 10:38 AM. Although most current auditory evoked response systems have a variety of features for digital manipulation and analysis of waveforms (eg, adding or subtracting waveforms, and inverting, filtering, or smoothing waveforms after data collection), none of these options were used with this case.

Transducers and signal/tone-burst parameters. In the lower portion of the display of measurement parameters, the reader will note that the transducer was always an insert earphone. There are at least a dozen clinical advantages for the use of insert earphones in ABR measurement in infants and young children.⁷

A rarefaction (negative) polarity (abbreviated “Rar”) was used for the click signal, whereas alternating polarity (“Alt”) was used for the tone bursts. Although auditory responses can be elicited with single-polarity tone-burst signals, the result often consists of a series of periodic waves, whereas an alternating polarity signal tends to produce an ABR waveform with a typical appearance (eg, wave V and sometimes earlier latency components).

The conventional duration (Dur) for a click signal is 100 msec (or 0.1 msec). Duration of the tone-burst signals is shown in several columns to the right. The onset, or “Ramp”, consists of 2 cycles of the tone burst (in this example), whereas there is actually no plateau (“Pla”)—in other words, 0 cycles for the tone-burst signal frequency (“Freq”), which is 4000 Hz in this example.

Signal intensity, frequency, and shaping. The numbers in the column labeled “Level” refer to the intensity level of the signals. A brief explanation of the conventional approach for defining ABR signal intensity is

warranted at this point. For click signals, the intensity levels are given in dB nHL, representing decibels above the behavioral threshold for the click signal (or 0 dB nHL) in a group of normal-hearing persons. As a rule, the intensity levels displayed for tone-burst signals on the monitor screen of an auditory evoked system are not referenced to 0 dB nHL but, rather, are equivalent to dB SPL. Thus, before utilizing tone-burst signals in ABR measurement, the clinician should, for each signal frequency, obtain biologic normative data for a small number of normal-hearing persons.

The process of establishing biologic normative data (0 dB nHL or “dB normal hearing level”) for the tone-burst and bone-conduction click signals is quick and simple: Using the evoked response system and insert earphones in the typical test settings where ABRs will be recorded from patient populations (eg, a clinic room, a hospital room, and/or operating room), behavioral thresholds are estimated for each tone-burst signal for a handful of normal-hearing adults. It is not necessary to actually record an ABR in this process. The electrodes can be placed in a cup of water to prevent the equipment from constantly rejecting samples due to artifact, or the artifact reject feature on the evoked response system can be turned off during the normative data collection.

In a typical quiet (but not sound-treated) room, and with insert earphones, behavioral thresholds will be obtained at about 35 dB (the intensity level on the screen) for a 500 Hz signal, and about 20-25 dB (again, the intensity number on the screen) for higher signal frequencies. These behavioral threshold values are used as the reference, or as 0 dB nHL. Thus, returning to Figure 1, the intensity levels for the click signal are already in dB nHL, whereas dB nHL for the 4000 Hz tone-burst signal is actually the value shown (eg, 100 dB) minus the adjustment for behavioral normative data (eg, $100 - 25 = 75$ dB nHL).

The next column to the right, labeled “Env” (for envelope), indicates the mathematical equation used to shape the onset (ramping, windowing, or envelope) of the tone-burst signals. Consistent with accepted practice,³ I regularly use Blackman windowing (envelope) for tone bursts. Current evoked response systems all offer this and other onset envelope options.

Masking. Since no masking was used in the ABR recording, the word “off” appears in the Noise (“Noi”) column. An adequate discussion of indications for masking in ABR measurement is beyond the scope of this article. With the use of insert earphones, and close analysis of ABR waveforms and the latencies of waves, masking is rarely needed in recording ABRs.

For this particular case, a reliable ABR was recorded in the ipsilateral electrode condition (Fz to left earlobe) at a high intensity level (80 dB nHL) for click signals, and with all waves present and at normal latency values. This finding eliminates the possibility that the ABR was generated from crossover of the signal to the non-test (right) ear. Analysis of the initial ABR findings revealed that these criterion were met, and immediately confirmed that masking was not necessary. The remaining columns to the right side of the figure are reserved for stimulus parameters.

Putting It All Together

The practical application of the measurement parameters displayed in Figure 1, and summarized in Table 2, is discussed further in the following case report. Key parameters that can “make or break” successful and accurate ABR testing are appropriate calibration of stimulus intensity, the inclusion of low frequency electrophysiologic energy with appropriate high-pass filter settings (eg, 30 Hz), avoidance of the notch filter options, and an adequately long analysis time. When a proven test protocol is used to record a tone-burst ABR from an adequately quiet child, test time is minimal, analysis of the ABR is typically straightforward, and a valid and meaningful test outcome is almost always assured.

Saving test time without sacrificing test quality. With experience, most audiologists develop strategies for cutting corners and saving time when performing clinical procedures. The goal in diagnostic procedures is to obtain all the information needed to describe completely auditory function, without wasting time with the collection of irrelevant or unnecessary information. The following steps are useful for accomplishing this objective with frequency-specific ABR measurement:

n Always monitor ABR activity during recording, and continuously perform a visual analysis of ABR presence and reliability. Once a recording is complete (eg, during the replication recording), begin analyzing latency values for wave I (at a high intensity level) and wave V (at all intensity levels) relative to normal expectations. Remember to take into account in ABR latency analysis patient age for children under 18 months.

n Begin with a click-evoked ABR at a high intensity level (80 dB nHL or higher) that is likely to produce a clear and reliable response. If no clear ABR is readily apparent, then immediately move up to the maximum intensity level. There are at least three practical reasons for beginning the ABR assessment with a click signal: 1) A click signal is most likely to produce a clear and reliable ABR. A click-elicited ABR can serve as a guide in developing a strategy for recording a tone-burst ABR. That is, analysis of the ABR evoked by the click stimulus will facilitate decisions regarding the most appropriate initial tone-burst frequency and the starting intensity level; 2) Latency values are well-defined for click-elicited ABRs, and age-corrected normative data are available; 3) Analysis of click ABR latency values permits within a few minutes of ABR measurement the differentiation between reasonably normal auditory function and auditory dysfunction (see Table 3). If there is no click ABR at maximum signal intensity levels (usually 95 to 100 dB nHL), then ASSR measurement is indicated. The specific role of ASSR in pediatric auditory assessment is discussed later.

Auditory Condition	Typical ABR Result
Normal hearing	• Typical click ABR result. Latencies for all components and interwave latencies within normal limits.
Conductive hearing loss	• Clear wave I, but a delay in wave I latency and subsequent absolute latencies. Interwave latencies are normal.
Sensory hearing loss	• Little or no wave I and often poorly formed waveform.
Neural dysfunction	• Delayed interwave latency values (eg, wave I-III, wave III-V, wave (I-V) or the absence of a detectable wave.
ASSR indicated when:	• No click ABR at maximum intensity level (eg, 95-100 db nHL).

Table 3. Typical results of ABR measurement and implication relative to hearing status.

n Discontinue signal averaging (stimulus presentation) as soon as a clear response is detected. Immediately attempt to replicate the response to verify its presence, and stop the averaging as soon as it is clearly repeatable. It is a waste of valuable test time to stubbornly present the pre-set number of stimulus presentations (eg, 2000) with no regard to the presence or absence of an ABR (ie, without considering the SNR).

n If at a high stimulus intensity level there is a clear ABR and all major components (waves I, III, and V) present relatively normal latency values, it is reasonable to decrease intensity level by 40 dB or more before recording the next ABR waveform. I often drop stimulus intensity level immediately from 80 dB

nHL to 20 or 25 dB nHL under these conditions (see case study below).

n As signal averaging is ongoing, always think ahead to the next step in the ABR measurement process relative to your choice for the next stimulus intensity level, stimulus frequency, stimulus mode of presentation (air- versus bone-conduction) and/or test ear. If signal averaging (stimulus presentation) stops and you're still thinking about what step to take next, then precious test time is slipping away.

Illustrative Case Study

The patient was a 3-year-old boy who was severely delayed in language development. When behavioral audiometry was attempted, the child was very difficult to test (described as non-compliant in the report). He would not accept earphones (supra-aural or insert) for pure-tone or speech audiometry. Behavioral responses were observed to soundfield warble-tone signals as follows: 30 dB HL at 1000 Hz, 50 dB HL at 2000 Hz and 4000 Hz. A speech awareness threshold (SAT) was obtained at 40 dB HL in the soundfield condition. Response reliability was judged good.

My ABR experience with this child was typical. Both of the children I assessed with ABR on this test date were at risk for hearing impairment due to severe language delay, and the ABR findings for both were consistent with normal hearing sensitivity. The tone-burst ABR for each child required less than 20 minutes, including application of electrodes, earphone placement, and impedance verification.

Children who require sedation for ABR are most often between the ages of 4 months and 4 years. Administration of sedation is optimally carried out in a medical clinic setting in accordance with institutional guidelines for administration of conscious sedation (eg, chloral hydrate), or in an operating room with the patient lightly anesthetized with drugs, such as nitrous oxide in combination with propofol or sevoflurane. A review of over 100 sedated ABRs performed by the author under these conditions in the operating room showed that average test time per child was less than 30 minutes. Age is not a factor in ABR test time with sedated children.

The ABR protocol used by the author includes threshold estimations for click signals, and two or three tone-burst signals (eg, 500 Hz, 1000 Hz, 4000 Hz) for each ear. More test time (up to but never exceeding 1 hour) is required when hearing loss is identified—especially with the measurement of bone-conduction and air-conduction ABRs to define the degree of conductive or mixed hearing loss—whereas less time is needed for children with normal ABR findings. My review of sedated ABR patients revealed that final outcome was interpreted as normal for 54% of the children. This case report is an example of the brief test time characteristic of normal ABRs recorded from an adequately sedated child.

ABR measurement, analysis and interpretation. Previous behavioral audiologic assessment of this child suggested the possibility of a bilateral hearing loss. This suspicion was confirmed by the documentation of severe speech and language impairment.

There is no single correct strategy or step-by-step process for conducting a pediatric ABR assessment. That is, a clinician is not bound by any specific guidelines or convention in deciding how the ABR recording begins (eg, which ear is stimulated first, and at what intensity level) and what steps will be taken next in the ABR assessment of auditory function. I offer the following general guidelines, based on clinical experience acquired over the past 30 years. Mistakes will be minimized by adherence to a consistent test protocol and sequence. However, it is certainly appropriate and often necessary to vary from this sequence to obtain as quickly as possible the information on auditory function that is most important for audiologic management of a child. If a child is well-sedated and sleeping for an adequate amount of

time (ie, for at least 45 minutes), and if both ears for the child are always accessible (ie, the child is supine), then the exact sequence of data collection for each ear and each signal condition (click versus tone burst, air-conduction versus bone-conduction) is not critical.

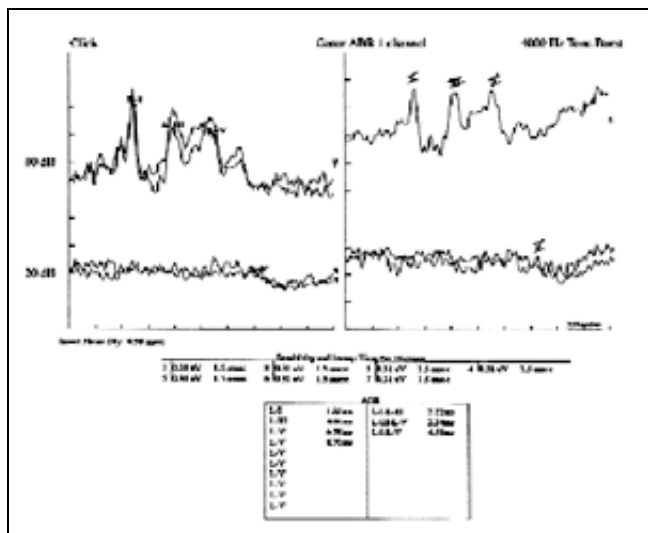


Figure 2. Case study, left ear: Auditory brainstem response (ABR) recorded with left ear air-conduction signals from 3 year-old boy under light anesthesia in the operating room. Waveforms for a click signal are shown in the left panel, and waveforms for a 4000 Hz tone burst are shown in the right panel. Measurement parameters are defined in Figure 1. The analysis time (X-axis) is 15 msec, including a pre-stimulus analysis time of -1 msec. Amplitude (Y-axis) is displayed with 0.31 mV per division (between sets of short horizontal lines). Absolute and interwave latencies for waves I, III, and V, are shown in the lower portion of the figure.

The initial ABR waveforms recorded for the child are shown in Figure 2. Test parameters for these recordings were reviewed in Figure 1. A well-formed and reliable ABR was recorded for a click signal presented to the left ear at 80 dB nHL. The reader will note, by reviewing closely the data in Figure 1, that relatively few signal repetitions were required to obtain these two replicated waves (see the documentation of 386 and 209 accepted sweeps at 80 dB nHL). Also, test time for recording the two waveforms was less than 1 minute (both were recorded at 10:22 AM).

Inspection of the latency data in the lower portion of Figure 2 shows that stimulation with an 80 dB nHL click signal produced an ABR wave I latency of 1.82 msec. This value is within normal limits, ruling out conductive hearing loss. Absolute latencies for later ABR waves and the interwave latencies (I-III, III-V, I-V) are at the upper limit of normal limits. Age must always be taken into account in interpreting ABR latencies for children less than 18 months old, as the pathways important in generating the ABR are not mature (fully myelinated) until that age. Since the patient is 3 years old, we can rule out age as a factor in ABR latencies.

However, two other factors must be considered. One is body temperature and the other is the anesthetic agent(s). In this case, body temperature was normal (within $\pm 1^\circ$ of 37° Centigrade) and, therefore, not a factor. Although conscious sedation (eg, chloral hydrate or versed) does not affect the ABR, some anesthetic agents may exert an effect (prolongation) on ABR latencies. The anesthetic agents used with this patient—sevoflurane and propofol—fall into this category. For this patient, it is possible that the effect of anesthesia increased the interwave latencies. We would expect, for example, a wave I to wave V latency interval of about 4.0 msec versus the 4.56 msec that was recorded. However, any possible effect of anesthetic agents in this patient was modest and did not alter the ABR interpretation.

Given the normal ABR at 80 dB nHL, I elected to decrease signal intensity immediately to 20 dB nHL. A reliable ABR wave V was again detected, albeit with a relatively lower amplitude. If the ABR at 80 dB nHL were not normal (eg, delayed latencies or some waves missing), then the signal intensity level would have been decreased by only 20-40 dB initially, to the level of 60 or 40 dB nHL. On the other hand, if at 80 dB nHL the ABR were absent or only wave V were recorded at a delayed latency, the signal intensity would have been immediately increased to maximum equipment limits (95 or 100 dB nHL). In this case, my decision to decrease the click signal intensity level from 80 dB nHL down to 20 dB nHL paid off by

yielding a normal threshold estimation in minimal test time.

The cautious clinician without ABR experience might, after inspecting the waveforms in Figure 2, question the presence of the ABR wave V for both the click and 4000 Hz tone-burst signals at the intensity level of 20 dB nHL. At least four steps could be taken to confirm the presence of the wave V. First, the display gain could be increased after ABR recording was completed, making the waveform appear larger on the screen. Second, a third replication could be obtained to verify that the deviation in the 8-9 msec portion of the waveform was really evoked by the stimulus, and not simply a random variation in voltage. Third, the two (or three) waveforms could be digitally added to highlight any replicable response (and to cancel out random activity). And, fourth, signal intensity level could be increased to 25 or 30 dB nHL to verify the presence of wave V. With a 5-10 dB increase in signal intensity, one would expect the wave V to be slightly shorter in latency and larger in amplitude.

Waveforms are numbered in Figure 2 (numbers 1 through 4 for the click signal presented to the left ear). The documentation shown for the four waveforms plotted in Figure 1 confirmed that estimation of normal auditory sensitivity with the click signal (waves 1 through 4) required only 2 minutes of test time (from 10:22 to 10:24 AM). Also, confirmation that auditory sensitivity was within normal limits at 4000 Hz in the left ear added only 3 minutes of test time (waves 5 through 7). Keep in mind that the presence of a reliable ABR wave V at 20 dB nHL for the 4000 Hz tone-burst signal estimates an audiometric threshold (hearing sensitivity) at 4000 Hz no worse than approximately 10 dB HL.

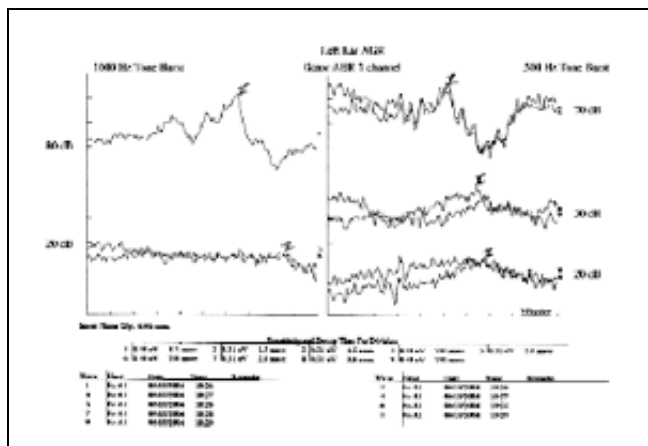


Figure 3. Case study, left ear: Auditory brainstem response (ABR) recorded with left ear air-conduction signals from 3-year-old boy under light anesthesia in the operating room. Waveforms for a 1000 Hz tone burst are shown in the left panel and waveforms for a 500 Hz tone burst signal are shown in the right panel. Measurement parameters are defined in Figure 1. For the 1000 Hz signal (left panel), the analysis time (X-axis) is 15 msec, including a pre-stimulus analysis time of -1 msec. For the 500 Hz signal (right panel), the analysis time (X-axis) is 20 msec, including a pre-stimulus analysis time of -1 msec. Amplitude (Y-axis) is displayed for all

signals with 0.31 mV per division (between sets of short horizontal lines).

Waveforms displayed in Figure 3 confirm that auditory sensitivity in the left ear was within normal limits also for 1000 Hz and 500 Hz. Tone bursts at each frequency produced a repeatable response at a high intensity level (70 dB nHL), and at 20 dB nHL. Note that a questionable response for the 500 Hz tone burst at 20 dB nHL was confirmed by a clearer response at 30 dB nHL. As expected, the latency for these two lower signal intensity levels was slightly greater than the latency at the higher (70 dB nHL) intensity level.

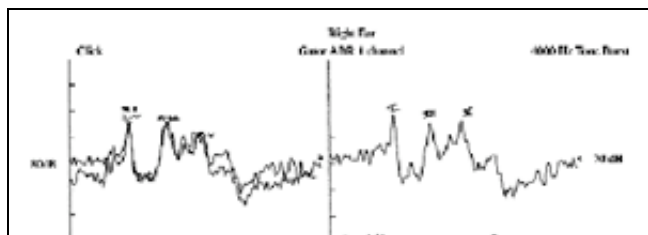
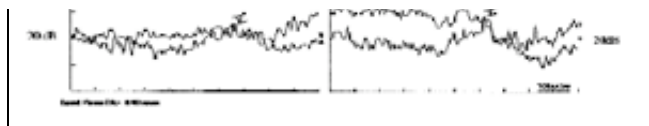


Figure 4. Case study, right ear: Auditory brainstem response (ABR) recorded with right ear air-conduction signals from 3 year-old boy under light anesthesia in the operating room. Waveforms for a click signal are shown in the left panel, and waveforms for a 4000 Hz tone burst are shown in the right panel. Measurement parameters



are defined in Figure 1. The analysis time (X-axis) is 15 msec, including a pre-stimulus analysis time of -1 msec. Amplitude (Y-axis) is displayed with 0.31 mV per division (between sets of short horizontal lines). Absolute and interwave latencies for waves I, III, and V, are shown in the lower portion of the figure.

Only 7 minutes of test time (from 10:22 to 10:29 a.m.) was required to confirm by the ABR auditory sensitivity within normal limits in the left ear for the speech frequency region (500 to 4000 Hz). Less than 10 minutes of total test time was needed for ABR assessment of the right ear (Figures 4 and 5), including analysis of wave I to rule out a conductive component (a wave I latency of 1.70 msec was within normal limits), confirmation that auditory neural function was normal (the wave I to V latency interval of 4.44 msec was within normal limits), and for verification that auditory sensitivity was within normal limits (Figures 4 and 5). Also for the right ear, an apparently replicable wave V at the lowest intensity level (20 dB nHL for the 1000 Hz tone burst and 30 dB nHL for the 500 Hz signal) was confirmed by replicating waveforms at a signal level 5 dB higher (see Figure 5).

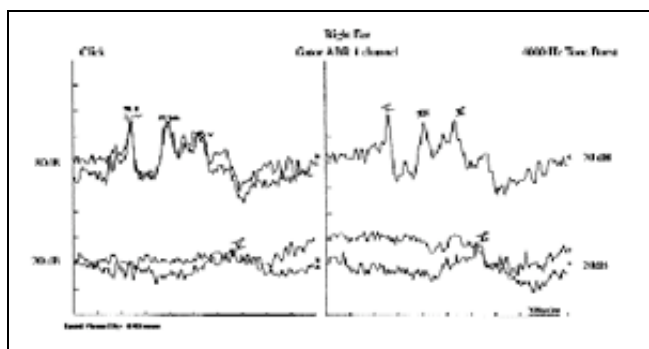


Figure 5. Case study, right ear: Auditory brainstem response (ABR) recorded with right ear air-conduction signals from 3 year-old boy under light anesthesia in the operating room. Waveforms for a 1000 Hz tone burst are shown in the left panel and waveforms for a 500 Hz tone-burst signal are shown in the right panel. Measurement parameters are defined in Figure 1. For the 1000 Hz signal (left panel), the analysis time (X-axis) is 15 msec, including a pre-stimulus analysis time of -1 msec. For the 500 Hz signal (right panel), the analysis time (X-axis) is 20 msec, including a pre-stimulus analysis time of -1 msec. Amplitude (Y-axis) is displayed for all signals with 0.31 mV per division (between sets of short horizontal lines).

the 500 Hz signal (right panel), the analysis time (X-axis) is 20 msec, including a pre-stimulus analysis time of -1 msec. Amplitude (Y-axis) is displayed for all signals with 0.31 mV per division (between sets of short horizontal lines).

In summary, this typical case illustrates the usefulness of a tone burst ABR technique for the electrophysiologic estimation with reasonable test time of auditory thresholds in infants and young children.

Complementary Roles

ABR and ASSR each contribute importantly to the pediatric audiologic test battery. In defining the most effective role of ASSRs in the audiologic test battery, we should be guided not by the question “Which procedure is better—ABR or ASSR?” but, instead, “How can I best exploit both ABR and ASSR clinically in the electrophysiologic assessment of auditory function?” In other words, the relationship between the two techniques is not competitive but, rather, complementary.

Auditory Dysfunction	ABR	ASSR
Normal Hearing	Accurate estimation.	Tends to over-estimate thresholds
Conductive HL	Ear-specific bone conduction threshold estimation is possible without masking.	Frequency-specific bone conduction threshold is possible, but masking is required.
Sensory HL	Accurate in estimating mild-to-moderate hearing loss, but not more severe losses.	Accurate from moderate to even profound hearing loss.

Neural/ Auditory Neuropathy	Neural dysfunction can be identified with analysis of interwave latencies and peripheral components (wave I and cochlear microphonics).	Cannot distinguish between profound sensory hearing loss and auditory neuropathy.
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Table 4. Selected relative contributions of auditory brainstem response (ABR) and auditory steady state response (ASSR) in pediatric audiological test battery for assessment of different types of auditory dysfunction.

The clinical strengths and weakness of the ABR and ASSR techniques for assessment of different types of hearing loss are summarized in Table 4. My clinical experience with these techniques in pediatric assessment suggests that the ABR is most useful in the differentiation of types of auditory dysfunction, whereas the ASSR is uniquely valuable in estimating auditory thresholds in infants and young children with moderate to profound sensory hearing loss.

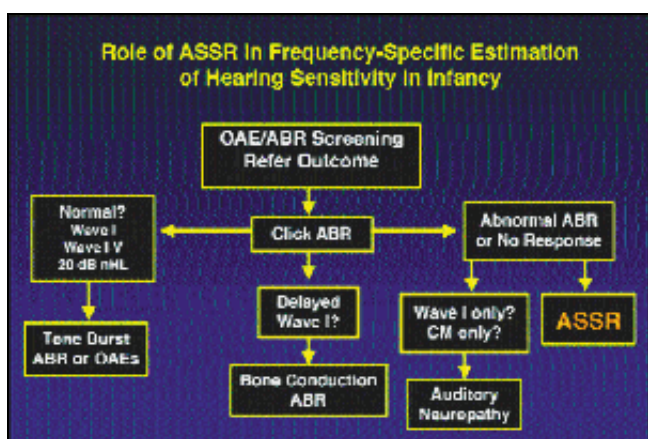


Figure 6. An approach for incorporating the auditory steady-state response (ASSR) into the pediatric test battery (see lower right portion of figure), along with otoacoustic emissions and the click- and tone-burst evoked ABR.

This observation forms the basis for the approach to incorporating the ASSR technique into the audiological assessment of infants that is illustrated in Figure 6. The diagnostic audiological follow up to an infant hearing screening failure begins with a simple click ABR. If the findings are entirely normal (ie, a reliable wave V at 20

dB nHL and a normal wave I to V latency interval), then either tone-burst ABR or otoacoustic emissions can be used to confirm normal peripheral auditory function. A finding of delayed ABR wave I latency with a click signal suggests the likelihood of a conductive hearing loss, and ABR measurement with bone-conduction stimulation can be used to confirm the conductive hearing loss, and to estimate the air-bone gap.

It should be pointed out that the ASSR technique could also be used for either of these diagnostic applications following the click ABR; that is, you could estimate normal auditory function within the speech frequency region or estimate air-bone gap. However, as noted above, the ABR technique has the advantage of more closely estimating normal hearing and the advantage of providing ear-specific bone-conduction information without masking.

The ASSR, in contrast, is most useful for estimation of auditory thresholds for patients with no evidence of auditory neuropathy by the click ABR, ECoChG, and OAEs, and who have an ABR only at high click intensity levels, or no ABR at maximum signal levels.

For Children, We Need Both

ABR and ASSR each can contribute importantly, and rather uniquely, to the diagnostic auditory assessment of children. My clinical experience with simultaneous measurement of ABR and ASSR indicates that test time is equivalent for the two techniques. Audiologists involved in the auditory assessment of infant and young children will discover that the modest time and effort they expend to

acquire skills in the measurement of tone-burst ABRs will yield valuable diagnostic dividends, and will contribute to the timely and effective audiologic management of this clinically challenging patient population.

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