

OPEN ACCESS GUIDE TO AUDIOLOGY AND HEARING AIDS FOR OTOLARYNGOLOGISTS



AUDITORY BRAINSTEM RESPONSE (ABR) IN CLINICAL PRACTICE

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Auditory Evoked Potentials (AEPs) are not measures of hearing per se, but are highly correlated with, and provide accurate behavioural pure tone thresholds¹⁻⁴. It is for this reason that the phrase ‘estimation of behavioural pure tone auditory thresholds’ is applicable.

With AEPs one identifies a pattern of waves, then to turn down the volume of the sound stimulus to find a threshold response, which is the lowest intensity at which a small response is present. This threshold, minus a small correction value, correlates with an individual’s hearing threshold¹.

Accuracy of AEP threshold estimation is dependent on neural synchrony. In Auditory Neuropathy Spectrum Disorder (ANS) neural synchrony is lacking. Hence AEP will not provide an accurate estimation of true behavioural hearing thresholds.

A discrepancy between behavioural pure tone thresholds and AEP threshold intensity (AEP indicating better hearing sensitivity) in a population suspected of nonorganic (exaggerated) hearing loss is strong evidence that behavioural pure tone threshold findings are inaccurate⁵. The clinical application of AEP for this purpose has been reported extensively^{1,3,5-13}. Consequently, AEPs play a critical role to assess hearing in individuals who cannot or will not participate actively in standard hearing assessment procedures (mentally retarded or malingering patients), as well as infants and young children².

Early AEPs occur at a latency of 0 - 20 ms, the most popular of which is the Auditory Brainstem Response (ABR) test. I like to

think of early AEPs as non-voluntary, automatic *hearing* functions – the ones one cannot switch off. These tests therefore can be done with the adult or child asleep or even under general anaesthesia. Participant attention to stimuli, or the lack thereof, has little or no effect on these short latency responses^{14,15}, resulting in robust, repeatable recordings despite differences in the participant’s state of consciousness. ABR does require that individuals lie still with minimal movement to reduce artefacts; sedation is sometimes required for uncooperative children or even adults. A two-year-old can barely sit still for two minutes let alone for the hour and half to two hours that is needed to complete neurological evaluation and threshold determination.

Despite this, the stability of these potentials over participant state, the relative ease with which they may be recorded, and their sensitivity to dysfunctions of the peripheral and brainstem auditory systems make them ideal for clinical use. This has led to the almost universal application of ABR for behavioural pure tone threshold estimation in children and infants too young to be tested using standard behavioural measures¹⁶. In addition to estimation of hearing sensitivity, ABR is used as an objective tool to assess auditory-neural integrity and synchrony. If one knows there is synchrony in the way in which the auditory nerve fires, then one knows that AEPs can be used to estimate hearing thresholds. That is the core reason why every AEP assessment needs to begin with a neurological, click-evoked ABR.

Each AEP, including ABR, has its own recipe for stimulus and acquisition parameters. Below I describe the recipes for

neurological ABR, and ABR for threshold determination and bone conduction ABR.

NOTE: Always attempt to manage patient, environmental and instrumentation considerations, as described in the chapter 'Auditory evoked potentials (AEPs) and underlying principles', so that you start testing with the EEG as quietly as possible before adjusting the recording parameters.

NEUROLOGICAL ABR

Stimulus parameters

- Duration: 0.1ms
- Type: Click
- Intensity: ≥ 80 dBnHL
- Rate: < 30 Hz
- Polarity: Rarefaction & condensation (separately)
- Repetitions / sweeps: ± 2000
- Masking: 50 dBnHL fixed

Acquisition parameters

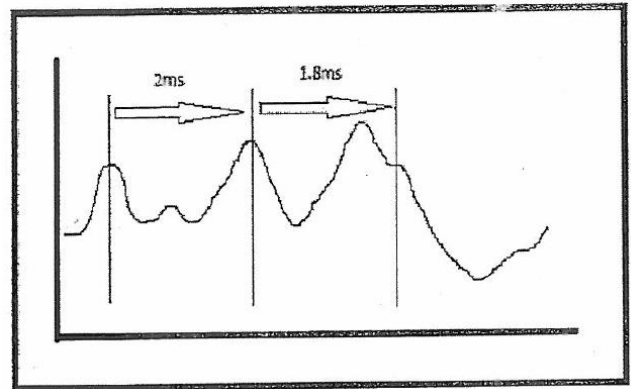
- Filter: HP = 100; LP = 3000 Hz
- Electrodes: Fz, A (ipsi & contra) or M (ipsi & contra)
- Analysis time: 10ms (adults); 15ms (children < 3 yrs)
- Gain: 100 000

Neurological ABR patterns

The neurological ABR is elicited with a click stimulus and provides a measure of auditory neural integrity. Four patterns of neurological ABR can be identified once one has completed a single trace rarefaction and a single trace condensation. Note that the latencies provided in this chapter is an approximation. Always consult your equipment manual for recommended normative values or set up your own normative values with a group of normal hearing young

adults. Use the reported mean latencies, plus two standard deviations.

Pattern 1



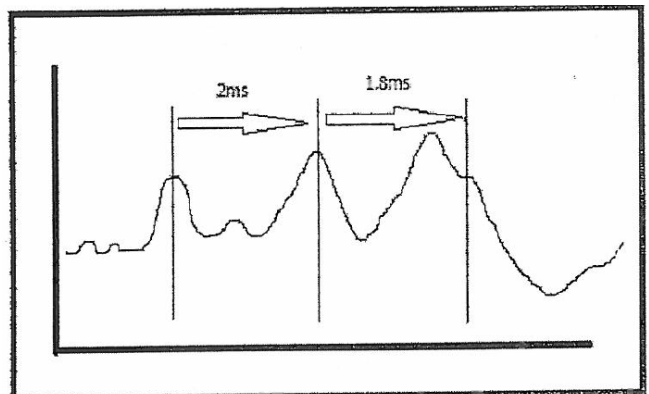
NORMAL ABR

In an adult or children of three years of age or older, one is likely to measure the following absolute and interpeak latencies:

- I = 1.5 ms
- III = 3.5 ms
- V = 5.5 ms
- I-III (interpeak latency) = 2 ms
- III-V (interpeak latency) = 1.8 ms
- I-V (interpeak latency) = 3.8 ms

This pattern will be found with a single trace rarefaction and single trace condensation.

Pattern 2

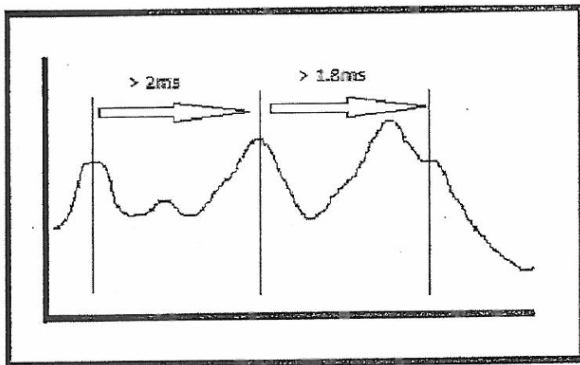


CONDUCTIVE PATHOLOGY / BLOCKED EAR TIP / EAR TIP FALLING OUT

Wave I is delayed, with Waves III and V consequently also delayed. However, the interpeak latencies of I-III and III-V still remain within normal limits.

- I = ≥ 1.9 ms
- III = > 3.5 ms
- V = > 5.5 ms
- I-III = 2 ms
- III-V = 1.8 ms
- I-V = 3.8 ms

Pattern 3

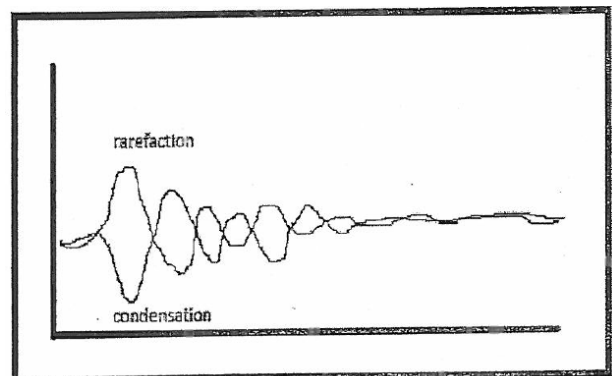


POSSIBLE BRAINSTEM PATHOLOGY / CHILD < 3 YRS

This pattern of waves begins with Wave I at a normal latency. However, either Wave III or Wave V, or both are delayed. This results in either a prolonged I-III interpeak latency, which would suggest a lower brainstem lesion, or an III-V interpeak latency, which would suggest an upper brainstem lesion.

- I = 1.5 ms
- III = > 3.5 ms
- V = > 5.5 ms
- I-III = > 2 ms
- III-V = > 1.8 ms
- I-V = > 3.8 ms

Pattern 4



COCHLEAR MICROPHONIC

With stimulus polarity reversal, *i.e.* one trace rarefaction and one trace condensation, no *repeatable* waveforms are present. Instead, with reversal of polarity, the waveform inverts. The resulting mirror image is a representation of residual (mainly) outer hair cell excitation and inhibition, known as the cochlear microphonic. If one identifies a cochlear microphonic, which continues past 2 ms at 90 and 80 dBnHL, with no repeatable waves thereafter, this *may be* indicative of ANSD (Auditory Neuropathy Spectrum Disorder). But it is also important to ensure that the residual hair cell function is not a product of good low frequency cochlear function with significantly poorer high frequencies (as evidenced by absence of waves using a click stimulus). Follow up this pattern of neurological ABR with 500 Hz tone burst ABR threshold estimation to determine whether there is good low frequency hearing thresholds.

Rule of thumb: If you find repeatable waveforms at any frequency and any intensity, you have evidence of neural synchrony. A cochlear microphonic (which provides evidence of residual hair cell function) in the absence of neurological waveforms using click and tone burst stimuli, with or without the presence of otoacoustic emissions, is enough evidence

to diagnose ANSD. In such cases the AEPs will not provide an accurate estimate of behavioural hearing sensitivity.

RATE STUDY

A rate study is part of the neurological workup. The aim is to increase the sensitivity of ABR to detect small intracanalicular tumours or neurological abnormalities such as multiple sclerosis. The minimal neural recovery time imposed by this technique significantly delays Wave V latency when the auditory nerve is compromised.

Ackley et al.¹⁷ suggest that a rate study with an increase from 31.1 to 61.1 Hz stimulus rate should use a Wave V latency of 6.25 ms or later for adults and children over the age of 3 years as positive for possible retrocochlear pathology. Do not use this latency as point of reference if Wave I is delayed, however – in other words if there is a conductive component to the hearing loss. If wave V is delayed to start with, use a maximum shift of 0.8 ms between wave V measured at low to high stimulus rates¹ A greater shift in wave V latency, or if wave V cannot be identified at the faster rate, implies that the rate study is positive for retrocochlear pathology and should be flagged as such, and further investigations should be instituted.

THRESHOLD ESTIMATION USING FREQUENCY SPECIFIC ABR

Stimulus parameters

- Type: Tone burst / NB chirp
- Rate: 33.3/sec / 37.1 – 49.1/sec
- Polarity: Rarefaction / alternating at higher intensities and for chirps
- TB ramping: 2-0-2 cycles

- Repetitions / sweeps: 700-2000 per recording
- Masking: 55 dBnHL fixed

Recording parameters

- Filter TB: HP = 30 Hz; LP = 1500 - 3000 Hz
- Filter chirps: HP = 30; LP = 1500Hz
- Electrodes: Fz, A (ipsi & contra) or M (ipsi & contra)
- Analysis time: 15 ms (adults); 20ms (children <3yrs)

DETERMINING NATURE OF LOSS USING BONE CONDUCTION ABR

Stimulus parameters

- Transducer: B71 / B81 bone conductor
- Type: Click / freq specific
- Intensity: < 65 dBnHL
- Rate: 13.1/sec
- Polarity: Alternating
- Repetitions / sweeps: +/- 2000
- Masking: 55 dBnHL

Recording / Acquisition

- Filter: HP = 150; LP = 2/3000 Hz
- Electrodes: Fz, A (ipsi & contra) or M (ipsi & contra)
- 2-channel recording recommended
- Analysis time: 10 ms (adults); 15ms (children <3yrs)

STANDARD VS. ALTERNATIVE PROTOCOL

You will follow one of two paths when you see a child or adult for AEP testing for threshold estimation. The following decision tree will help decide whether to follow the standard or an alternative protocol.

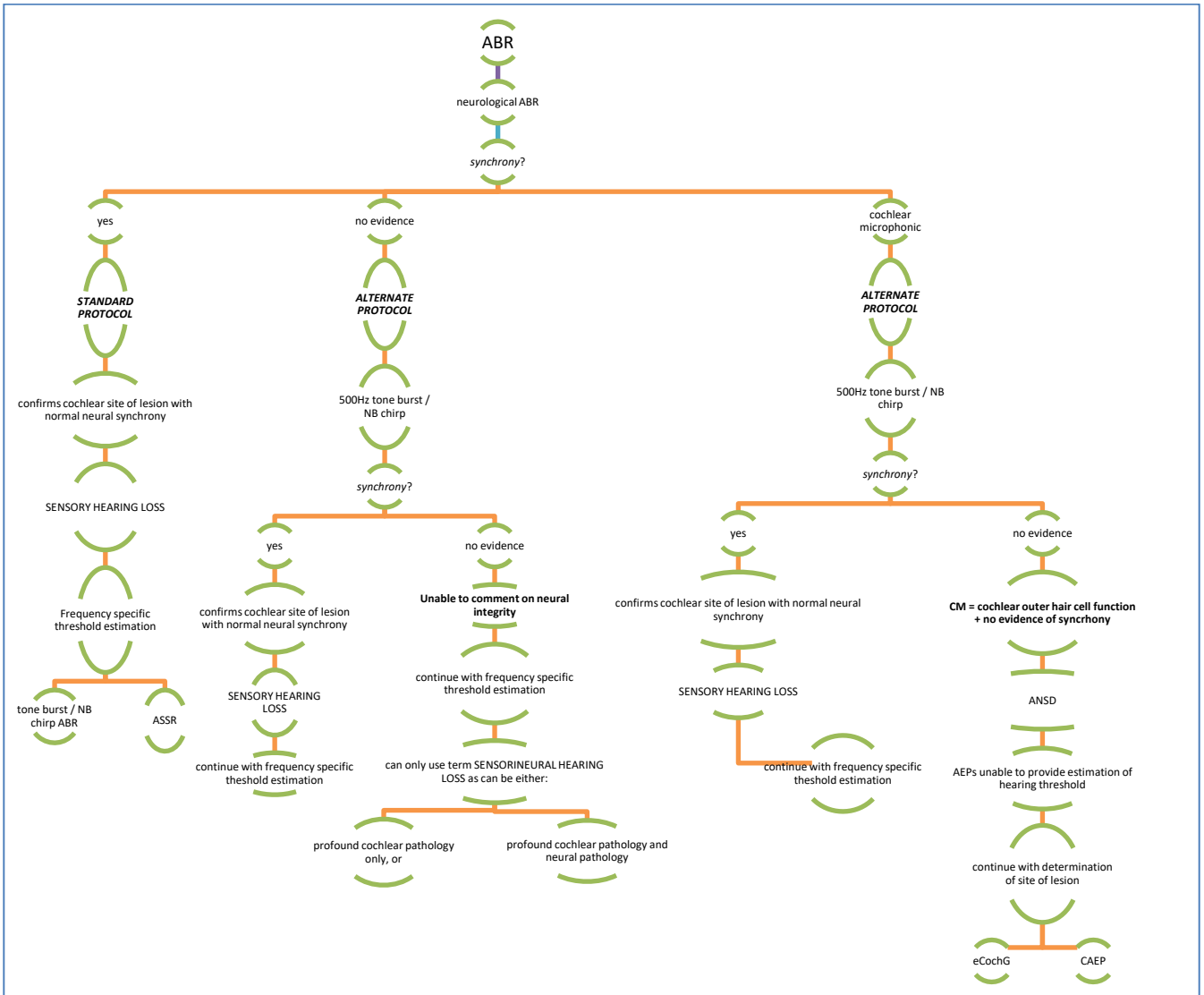


Figure 1. Decision tree of typical AEP testing

STANDARD PROTOCOL

Start the assessment with tympanometry and at least a broadband reflex. Distortion production otoacoustic emissions (DPOAE) using a 65:55 stimulus protocol should follow (this is the trickiest of DPOAEs). When OAEs are present, one immediately has excellent information. The presence of OAEs indicates that the outer hair cells at the relevant frequencies are functioning very well, and that there is no middle ear pathology. If OAEs are absent at high

frequencies but present at low frequencies, one should suspect high frequency sensory hearing loss. If OAEs are absent at all frequencies, this may be due to middle ear pathology and/or sensory pathology. Absent OAE therefore merely indicates that the hearing is not perfect and that one needs to do additional testing to determine the nature and degree of the loss. That one does using ABR.

Step 1: Neurological ABR

Why ALWAYS neurological first?

1. The neurological ABR confirms whether there is neural synchrony or not
 2. This confirms whether ABR can be used to estimate hearing sensitivity
 3. A delayed wave I suggests a conductive overlay / pathology that may require bone conduction ABR
 4. If wave I is within normal limits, then one knows that the ear tip is in the ear canal and not occluded
 5. If there is a marked asymmetry, the neurological ABR help determine whether masking is needed
 6. The neurological ABR will determine whether one follows the standard or alternative protocol
- Stimulus: 80 dB nHL click; 1 x trace rarefaction, 1 x trace condensation
 - If one is unable to identify waves I, III and V, increase the stimulus to 90 or 100 dBnHL
 - If one is able to identify waves III and V but not I, it may be helpful to reduce the stimulus rate to 11.1Hz
 - If necessary, one may also consider using an eCochG to confirm absolute latency of wave I

Step 2: Analyse and report on the neurological ABR

Comment on:

- Waveform morphology: *good/average/poor*
- Absolute latencies of waves I, III, V: are latencies *within normal limits or delayed?*
- Interpeak latencies I-III, III-V, I-V: are latencies *within normal limits or prolonged?*
- Symmetry of wave V absolute latency: Are interaural wave V latencies within

0.4 ms of each other? If yes, then neurological ABRs are symmetrical

Step 3: Continue with frequency specific ABR for threshold estimation

The following order is suggested although the case history and DPOAE results may guide one to do otherwise:

TB / NB chirp at:

- 4kHz R & L
- 0.5kHz R & L
- 2kHz R & L
- 1kHz R & L

At what intensity should one start?

- Where one expects to get a clear suprathreshold response. Repeat trace at least once.
- If one suspects normal or near-normal thresholds, then 60 dBnHL may be advisable. Once wave V is repeatedly identified, turn the volume down to minimum stimulus levels. If one is unable to confirm threshold at the minimum stimulus level, increase the volume in 10 dB increments
- If one suspects a hearing loss, begin at 80 dBnHL but turn the volume up or down in 20 or 30 dBnHL steps, depending on the amplitude of the wave V, if present
- A clear suprathreshold response provides one with a large, clear response. It will then be easier to identify a threshold response with the required increase in latency at the lower intensity
- One needs at the very least a threshold response and a “no” response if the hearing threshold is abnormal

General tips

- Use residual “noise” levels to determine how long to continue signal averaging. The ideal for adults would be < 40uV.

- If one can identify a clear response with good amplitude, continue for a minimum of 800 to 900 sweeps of accepted stimuli, stop and repeat the trace
- If one is testing near threshold or is completing a “no response” trace, continue to average much longer to reduce SNR, namely for 2000 to 4000+ accepted stimuli. Allow the residual “noise” levels to guide one.
- If one thinks someone will argue a marked response, do a 3rd or 4th trace to prove your point - or do a trace + 10 dBnHL.

Correction factors for threshold estimation

- Correction factors are specific to your equipment, your protocol and setting
- Therefore, your correction factors should be based on the mean of a group of young, normal hearing adults.
- Typical tone burst correction factors are:
 - 20 dB at 0.5 kHz
 - 15 dB at 1 kHz
 - 10 dB at 2/4 kHz
- Typical chirp correction factors are:
 - 15 dB at 0.5 kHz
 - 10 dB at 1 kHz
 - 5 dB at 2/4 kHz
- Typical click correction factor = 0-5 dB
- Typical broadband CE chirp correction factor = 0 dB

ALTERNATIVE PROTOCOL

Step 1: Neurological ABR

- 80 dBnHL click; 1 x rarefaction, 1 x condensation
- If unable to identify waves I, III and V, increase stimulus to 90 / 100 dBnHL
- If no waveforms can be identified, continue with the alternative protocol

- If with reversal of stimulus polarity, a cochlear microphonic and no repeatable neurological responses are identifiable, continue with the alternative protocol

Step 2: Frequency specific ABR for threshold estimation

- TB / NB chirp at 0.5 kHz R & L
- TB / NB chirp at 1 kHz R & L

What is the aim of threshold estimation if no waveforms could be identified during neurological ABR? It is to find evidence of neural synchrony. If there is evidence of neural synchrony, the site of lesion is the cochlea and the hearing loss is sensory in nature.

Step 3: ASSR

Use ASSR to determine threshold of hearing once you have excluded the possibility of ANSD or if you obtained no response during neurological ABR and 500 Hz ABR threshold estimation.

What is the aim of threshold estimation if there is a cochlear microphonic and no neurological responses? It is to determine if the patient has ANSD, or if the cochlear microphonic is a result of good residual low frequency hearing sensitivity. If one finds evidence of a repeatable wave V at any frequency or intensity, this provides evidence of auditory neural synchrony, and there is no dyssynchrony.

Step 4: In case of confirmed ANSD, the ideal would be to complete

- CAEPs using a click stimulus. A present CAEP predicts benefit from amplification
- eCochG with tympanic membrane contact electrode. The aim is to determine whether the ANSD site of lesion is

inner hair cells, synaptic or post-synaptic

- eABR (electrical ABR). A present eABR provides evidence that the auditory nerve is able to carry and relay an electrical stimulus and predicts significant benefit from cochlear implantation

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