What is an ABR?

The Auditory Brainstem Response is the representation of electrical activity generated by the eighth cranial nerve and brainstem in response to auditory stimulation.

ABR assesses the integrity of the peripheral auditory system and auditory brainstem pathway.

- Jewett & williston (1971)
- BSER (Brainstem Evoked Response)
- BAER (Brainstem Auditory Evoked Response)
- BAEP (Brainstem Auditory Evoked potential)
The scalp recorded potentials represent the "volume conducted" potentials generated by some anatomical structures deeply imbedded in the BS and up to the inferior colliculus.

The ABR is composed of 5 waves named by the roman numerals I to V. They are positive potentials when recorded from the scalp and referenced to a non-cephalic or cephalic electrode. The peak latencies are consistent within the same subject across trials and sessions. The components are not affected by the arousal state of the subject.

Wave I is mastoid negative & becomes positive only when recorded from the scalp. It appears close to 2 msec post stimulus onset.

Wave III appears 2 msec later than wave I and its morphology varies across subjects and may be single or double-peaked.

Wave V appears 4 msec later than wave I. It is the most prominent & consistent component.
Investigators agreed that the ABR is regarded as the volume conducted post-synaptic potentials (PSP) and not due to the all or none action potentials spreading along axons of the soma (cell bodies).

While PSPs allow temporal and spatial summations, the rapidly flying APs did not allow such summations and are therefore, can not be volume conducted.
ABR Generators

**Wave I:** the most distal fibers of 8th CN as it emerges from the cochlea.

**Wave II:** the most proximal fibers of the 8th CN as it enters the cochlear nucleus.

**Wave III:** The cochlear nucleus. Anteroventral cochlear nucleus as it projects to the superior olivary complex.

**Wave IV:** Ventral nucleus of the lateral lemniscus.

**Wave V:** Major contribution from the inferior colliculus of the mid brain.

Electrode placement

- Cz (at vertex) (recording electrode)
- Ipsilateral ear lobule or mastoid process (reference electrode)
- Contra lateral ear lobule (act as a ground)
Instrumentation

- **Averaging:** It is the main procedure utilized in evoked potential recording in order to enhance a low amplitude response on the expense of a relatively higher amplitude noise.

- The principle of averaging is that the response is time-locked to the stimulus (i.e. it happens exactly at the time in relation to stimulus onset), while the noise is random and does not have any time relation to the stimulus.

- With repeated measures, summing the responses will cause the noise to average out and thus get reduced in amplitude, theoretically to zero, while the response remains unchanged.

![Figure 8.1](image-url)

*Figure 8.1.* The principle of signal averaging to enhance a stimulus time-locked signal relative to random background “noise.” The signal is an electrophotographic light flash response recorded from the eyelid. N = number of responses averaged. Arrow labeled SYNC denotes the pulse which starts the A-D converter. Arrow labeled STIM denotes the pulse which triggers the light flash. The interval between the SYNC and STIM pulses is the prestimulus delay; the trace recorded during the prestimulus delay is often used to establish a baseline for amplitude measurement.
ABR Stimuli

1- Acoustic Click

• Commonly a click is used, by producing an electric pulse of 0.1 msec duration and sending it to the transducer.

• The click is calibrated in dB peSPL or in dBnHL.

• dBpeSPL means that e.g. a 70-dBpe SPL click is a click that when displayed on an oscilloscope will have the same amplitude as a 70 dBHL pure tone of 1000 Hz.

• dBnHL means you establish a zero level for behavioral click thresholds by determining the click behavioral threshold in a group of normal listeners.

• The correction factor between the dBpeSPL & dBnHL is usually 28 dB, the former usually assuming a higher number.

What does click-ABR represent?

Although the click excites the entire cochlear partition, it was found that the ABR thresholds obtained by clicks match the behavioral thresholds only at high frequencies (2000-4000). Why??

The explanation is derived from cochlear physiology. At the base of the cochlea (tuned for high frequencies) neurons are “crowded”. This crowdedness of neurons results in no time lag between excitation of neighboring neurons. As a result of that, synchronization of responses is only true at the base of the cochlea.

On the other hand, at the apex of the cochlea the neurons are scattered which results in significant time lags between excitation of neighboring neurons. As a result of this time lag, synchronization is lacking.

As a result of that, and despite the fact that the click excites the entire cochlear partition, the ABR as recorded from the scalp represents activity from the cochlear region 3000-4000 Hz with less contribution from 2000 Hz region.
Other stimuli to enhance frequency specificity

2- Tone bursts of 2-3-2 cycles

Tone Burst:
- Provides more frequency specific information
- High correlation between behavioral and TB responses
- Can diagnose low and high frequency HL
- 500Hz can be difficult!
- Repeatability is difficult because there is less synchronous activity at that region of the cochlea.
- Requires longer window
- Response can be 4-8ms later than a click.
3- Derived band ABR: 
Time consuming, masked ABR is not as clear as click-ABR

Figure 1. Model of the derived response technique. 
(A) Only the region designated \( W \rightarrow Z \) is contributing to the response, the rest of the cochlear partition is masked out. (B) The region designated \( X \rightarrow Z \) is contributing to the response (A-B). This is the waveform resulting from subtracting B from A. This response is evoked from the region designated \( W \rightarrow X \), and is considered the derived band response. The portion designated \( X \rightarrow Z \), being common to A and B, was excluded in the subtraction procedure and, therefore, did not contribute to the A-B response. 

Figure 2. Subject #3. Primary waveforms were obtained using a no masking condition and four conditions of high-pass maskers with cutoff frequencies at 5680, 2840, 1420, and 710 Hz. The derived band responses are the ones designated: 7500, 4000, 2000, and 1000 Hz and were obtained by sequential subtraction of the no masking condition and the aforementioned four high-pass masker conditions. Derived band responses are shown with twice the scale factor of the primary waveforms.
Clinical Applications of the ABR

- Estimation of Hearing Sensitivity thresholds in neonates, infants & difficult to test patients.

- Determination of site-of lesion (cochlear vs retrocochlear).

- Intra-operative monitoring.

Threshold Estimation

ABR versus behavioral hearing

- It is mandatory to stress that the only real test of hearing is the pure tone audiometry.

- Taking the ABR thresholds as estimates to behavioral thresholds is a mere approximation. The ABR is generated by a subgroup of auditory fibers that fire in response to the onset change of the stimulus (time keepers). Those time keepers may represent some aspect in the conception of hearing.

- The ABR itself may be regarded as a non-essential by-product (epiphenomenon) of the activity of a small portion of the auditory system.

- Evidences for the above contention can be derived from the contradictory results between the ABR & behavioral audiometry. Auditory neuropathy multiple sclerosis & cognitive disorders are examples of these paradoxical results.
Threshold Estimation

- Since low intensities may be applied, S/N ratio may be very low & quality of responses may be so much degraded to render interpretation difficult & may be erroneous.
### Frequency Response of Interfering Signals

<table>
<thead>
<tr>
<th>Signal</th>
<th>Frequency Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electro-dermal response</td>
<td>0.01 - 5 Hz</td>
</tr>
<tr>
<td>Electrode junction potential (polarized electrode) (DC)</td>
<td>0 - 5 Hz</td>
</tr>
<tr>
<td>EEG</td>
<td>0.05 - 30 Hz</td>
</tr>
<tr>
<td>Muscle potentials (EMG)</td>
<td>10- 5000 Hz</td>
</tr>
<tr>
<td>Power line</td>
<td>50 or 60 Hz</td>
</tr>
<tr>
<td>Stimulus artifact (square wave)</td>
<td>10- 20,000 Hz</td>
</tr>
<tr>
<td>Radiating electro-magnetic signals (FM stations, mobile stations)</td>
<td>10- 20,000 Hz</td>
</tr>
<tr>
<td>Internal amplifier noise</td>
<td>0 (DC) - ∞</td>
</tr>
</tbody>
</table>

### Tips for enhancing quality of ABR responses

- Electrode tips
- Recording tips
- Interpretation tips
Electrode Tips

- Ensure good grounding of the system.
- Good scrubbing.
- Ensure integrity of electrodes by putting them in a cup filled with water & measure impedance (should be less than 1 Kohm).
- Re-chloridize Ag Cl-coated electrodes by putting them in saline & connect electrode to be coated to a +ve pole of 1.5 V battery & another old electrode to -ve pole.
- Always braid active & ground electrodes to eliminate inductive current generated in the electrodes.

Recording Tips

- Always start with a higher intensity (guided by history) e.g. 80 dBnHL.
- Always obtain 2 runs per intensity.
- Calm down raw EEG:
  - Put child to sleep (natural or with 5% chloral hydrate)
  - Put pre-amp away from PC
  - Put child’s head in a restful position.
- Use condensation clicks to enhance wave V.
- Obtain no-stimulus run to have an idea about averaged noise. Display this run close to your proposed threshold.
- Use appropriate BP-filter 100-1500 Hz
Interpretation Tips

- Order traces from high to low intensity to have an idea about expected latency shifts.
- Be prepared for the expected latency of wave V for a particular intensity & age.
- Consider maturation effects:
  - Multi peaked III & V
  - Absolute & IPL prolongation (wave V shorten by 0.15 msec/3 months after birth).
  - Poor L/I shifts in anoxic & CP infants.

- Allow for CHL latency shifts: 0.15 msec/10 dB air-bone gap

Site-of-lesion Differentiation

- Although clear waves are important for interpretation as in threshold estimation, yet another problem appears here, which is the must to have all components of ABR waves particularly I & III.
- So all previous tips apply in addition to:
Tips for site-of lesion

- Use an intensity of 90 dBnHL to interpret results.
- Ensure that behavioral thresholds at 3-4 KHz is at least 15 dB less than stimulus intensity.
- Use appropriate BP-filter 100-3000 Hz to obtain clear definitions of waves.
- Enhance wave I by:
  - Rarefaction clicks, ear lobule reference & ipsilateral recording.
ABR Indices in Retro-cochlear Lesions

I. Latency Indices

1- Interpeak latencies (IPL): The most powerful index. I-V IPL is usually 4.0 msec (sd 0.2 msec). I-III IPL is slightly above 2.0 msec & III-V IPL is slightly below 2.0 msec (sd 0.1 to 0.2 msec). IPLs are not affected by conductive or cochlear hearing loss, and therefore no latency correction factor is needed to offset the loss.

2- Absolute latencies: If wave I is absent or ambiguous, one has to rely on absolute latency of wave V by comparing it with norms. The normative data should be stimulus-type, intensity level, rate-specific. One should first subtract the correction factor for the loss at 4000 Hz. If wave V latency is > 2 sd from the norms, one should diagnose retrocochlear lesion.
3- Interaural latency difference (ILD): it compares absolute wave V latencies between both ears, assuming normal value for one ear. Again hearing loss difference between ears should be offset before comparison. If ILD is greater than 0.4 msec, one should be concerned about retro-cochlear lesion.

II. Waveform Morphology

1- Total absence: 25 - 50% of tumor cases showed absent waveforms, depending on tumor size
2- Partial absence: Absent wave V or waves III & V in presence of wave I is indicative of low BS or CPA lesion.

III. Amplitude Ratio

It was found that in 50% of acoustic neuromata Amplitudes of V/I is less than one (normally should be more than one, since wave V amplitude is always bigger than wave I amplitude).
**IV. Repetition Rate**

The use of high RR stresses the auditory system and may uncover a hidden lesion. Normally 0.1 msec shift of wave V latency is allowed for every 10 pulse increase with sd of 0.2 msec. For example, pulse increase from 10 to 50/sec should yield no more than 0.6 msec delay.

**V. Opposite Ear effects**

Latency changes in non-tumor side with absent waveforms in the tumor side were found in big tumors with shift of neural structures to the other side.
ABR in Intra-operative Monitoring

- The merit of ABR here is that it is not affected by Anesthetics like halothane or by nitrous oxide, unlike all evoked potentials at 50 msec latency and up which were found to be affected by anesthetics.

- Hypoxia affects the ABR since it lowers the endocochlear potentials due to excessive influx of Na to the endolymph. This in turn affects all subsequent evoked potentials.