Auditory Electrophysiology in Infants & Toddlers

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General Consideration for Using ABR

Stimuli
Signal-to-Noise/Averaging
Recording Parameters to Optimize Recordings
Expected Accuracy
Patient: ES  
Age at Test: 2 years, 9 months

**Infant ABR**

**4000 Hz Tone Burst**
- 60 dB
- 40 dB
- 20 dB

**Infant ABR**

**500 Hz Tone Burst**
- 60 dB
- 40 dB
- 20 dB

**Auditory Brainstem Response**

Stimulus: Click, 25/s, Insert Earphones  
Right Ear

- V = 7.9
- V = 8.9
- V = 9.0

Stimulus: 500 Hz Tone Burst, Insert Earphones  
Right Ear

- V = 13.1
- V = 11.9
- V = 12.7

Stimulus: 4000 Hz Tone Burst, Insert Earphones  
Right Ear

- No Response
- No Response
- No Response

Stimulus: 500 Hz Tone Burst, Insert Earphones  
Left Ear

- V = 200 nV

**Auditory Brainstem Response**

Stimulus: Click, 25/s, Insert Earphones  
Left Ear

- V = 200 nV

**Audiogram**

DOB: 198
Age at Audio Eval: 2 yrs, 8 mo.

Tympanogram: Right WNL, Left CNT

Ipsi Acoustic Reflex Thresholds: Right present at 500 & 1000 Hz, absent at 2000 Hz. Left CNT.
You MUST use Bone Conduction to determine the type of hearing loss if air thresholds are elevated!

Normal Tympanometry is not sufficient to rule out conductive loss!

Ossicular Fixation will show normal tymps and 40-60 dB air bone gaps.

Nape Electrode Placement may help reduce stimulus artifact.

Hearing Sensitivity in Newborns Estimated from ABRs to Bone-conducted Sounds
Barbara Cone-Wesson & Glendy M. Ramirez

Newborn ABR thresholds for BC stimuli were -5, -14, and 0 dB nHL (re adult psychophysical threshold) for click and 500 Hz and 4000 Hz tonebursts, respectively.
Bone-Conduction ABR Thresholds

- Place vibrator above and behind pinna with elastic strap (velcro closure) and 400-450 g pressure.
- Start with a mid frequency Air Bone comparison (1 or 2 kHz).
- If 500 Hz is used, an air bone gap is not significant unless it exceeds 20 dB!
- For spring scales see www.benmeadows.com
  PESOLA® Spring Scale with Hook, 1000g Capacity, 10g Graduations, 22cm L

What Factors Contribute to Accurate Hearing Assessment with ABR in Infants and Children?

Correct Filter Characteristics?
- Averaging Window
- Electrode Placement

Protocol for Infant ABR/Hearing Evaluation

Use High-Pass Filter settings 30 or 50 Hz
Low pass of 1000 Hz is great.

Protocol for Infant ABR/Hearing Evaluation

Use Filter settings:
- High Pass 30-50 Hz (no higher than 100)
- Low Pass 1000 Hz
- 6-12 dB/ octave
What Factors Contribute to Accurate Hearing Assessment with ABR in Infants and Children?

Filter Characteristics?
Averaging Window
Electrode Placement

Infant ABRs have extended latency

Wave V Latency is Later at Threshold

Traveling Wave Delays the Activation of Low Frequency Regions of the Cochlea

Infant ABR Threshold Identification

10 ms Window

25 ms Window
Protocol for Infant ABR/Hearing Evaluation

*Use Recording Window of 20-25 ms for Tone-Burst ABRs with Infants*

This limits the rep rate to about 40/sec but this is as fast as you should go!

What Factors Contribute to Accurate Hearing Assessment with ABR in Infants and Children?

- Filter Characteristics?
- Averaging Window
- Electrode Placement

Protocol for Infant ABR/Hearing Evaluation

Two Recording Channels if Possible (Vertex to nape, Vertex to mastoid)

Signal-to-Noise Ratio

Averaging
Averaging must increase with reduced sensation level of stimulus.
Rules for Averaging

- The more noisy a recording, the longer it will take to obtain a clear average.
- The lower the amplitude of the response, the longer it will take to obtain a clear average.
- Set Sweeps to high number (6000) and stop when response is clear.
- Average up to 6000 before determining a NR

Subject 5  8 Months Old
Averaging will be stopped when a positive response is detected by Fsp > 2.9, when background noise <= 18 nV or when 6000 sweeps have been averaged

Subject 11  2.5 Months
Averaging will be stopped when a positive response is detected by Fsp > 2.9, when background noise <= 18 nV or when 6000 sweeps have been averaged

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Subject 5  8 Months Old
Subject 11  2.5 Months

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Protocol for Infant ABR/Hearing Evaluation

Filter settings 50-1000 Hz
Rate <40 stim/second
Recording window of 20-25 ms
Sedation over 3-6 months of age(?)
Two channels if possible
Use a high-frequency then a low, alternate ears
Repeat only when questionable response
Increase sweeps at threshold (6000 max)
Verify with Behavior, OAE, Tymps and acoustic reflex

New Stimuli and Detection Methods Improves ASSR Performance

Yvonne S. Sininger PhD
Representing Interacoustics Corporation
ASSR vs. ABR for Threshold Estimation

- Urgent Need for FAST & ACCURATE threshold test for follow up of NBHS.
- Tone Burst ABR is accurate but slow.
- ASSR has been presented as the answer to this dilemma but questions remain.

![Slide courtesy of Dr. Terry Picton](image)

Food for Thought

- ABR and ASSR are derived from the same stimulus-generated brainstem neural activity.
- ABR extracts the time waveform and ASSR the spectral information in the neural activity.
- Detection of the activity is a valid method for assessing the sensitivity of the auditory system in infants and toddlers.
- Using spectral analysis has a HUGE potential time advantage by allowing simultaneous assessment of multiple frequency regions in both ears.
- To my mind, ASSR elevated threshold sensitivity is a technical issue that can/should be addressed thus rendering speed and accuracy.

Interacoustics ASSR (Eclipse)

- Claus Elberling and associates (Cebulla, Sturzebecher, Don) addressed two important issues and applied technology to the IA ASSR system.
  - 1) The stimulus was fashioned to enhance response amplitude.
  - 2) More information is used in the detection of the spectral information.
Response Amplitude is related to the Number of Neurons Active at any point in time!

**Response amplitude - 90 stimuli/second**
- Click - ASSR
- Freq-spec ASSR

**lower amplitude**  ➝  longer test time

**ASSR Amplitude Modulation - AMFR**

**Cochlea travel time**

**Stacked ABR**

- Derived-Bands (Actual timing)
- Derived-Bands Aligned (Shifted and summed)

**II. Input compensation** for traveling time

- Another way to compensate for the traveling time is to time-shifting the different frequency components of the click stimulus
- This is done by allowing the low-frequencies to appear before the high-frequencies
- Such a click with re-shuffled frequency components is called a Chirp
- A chirp ABR is significantly larger than a click ABR
Narrow-band ABR latencies (- 4.1 ms)

based on data from M. Don

Chirp (Don)

Chirp ABR

Grand Average ASSR temporal waveforms
30 dBnHL

Click

Chirp

50 dBnHL

Click

Octave-band delay-compensated stimuli

<table>
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<tr>
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<th>Detection Rate (%)</th>
<th>Detection Time [s]</th>
<th>SNR</th>
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<tr>
<td>Click 30 dBnHL</td>
<td>83.3</td>
<td>72</td>
<td>3.1</td>
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<td>N = 42</td>
<td>35/42</td>
<td>25 - 250</td>
<td>0.2 - 8.4</td>
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<tr>
<td>Chirp 30 dBnHL</td>
<td>97.7</td>
<td>30</td>
<td>6.0</td>
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<td>N = 43</td>
<td>42/43</td>
<td>14 - 227</td>
<td>1.5 - 17.8</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Detection Rate (%)</th>
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<tr>
<td>Click 50 dBnHL</td>
<td>85.7</td>
<td>46</td>
<td>5.2</td>
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<td>N = 42</td>
<td>36/42</td>
<td>16 - 207</td>
<td>0.8 - 10.7</td>
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<tr>
<td>Chirp 50 dBnHL</td>
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<td>23</td>
<td>7.4</td>
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<tr>
<td>N = 43</td>
<td>45/43</td>
<td>13 - 55</td>
<td>3.2 - 15.3</td>
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InterAcoustics Innovations

1) Phase compensate stimulate to enhance response amplitude

2) Evaluate more information components in response detection.

Amplitude and phase of one harmonic frequency with some added noise

Response Detection Algorithm

- Amount of information included
  - six harmonics
  - amplitude and phase

- The efficiency of the algorithm is documented in a series of publications:

**Hearing diagnostics with band limited stimuli**

**Materials and Methods**

- **Subjects**: 10 normal-hearing adults (≥10 dBHL; 20 – 40 y)
- **Stimuli**: Four one octave-band Chirps: 500, 1,000, 2,000 & 4,000 Hz
- **Stimulation**: On both ears simultaneously i.e. eight stimuli
- **Repetition rates**: Within the range: 86/s – 94/s
- **Stimulus level**: Start level 60 dBHL; lowered in 10 dB steps until no response is detected before time out then finally increased by 5 dB.
- **Application device**: EAR-3A (Surface electrodes, Vertex vs. each Mastoid with ground on Cheek, max. 360s measuring time)
- **Signal detection**: Modified Mardia’s q-sample test, Error level 5%
- **Equipment**: Interacoustics, Eclipse platform with ASSR software

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**An Estimated Audiogram is**

- Estimated Audiogram point
- ASSR Threshold

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**Detection of Auditory Neuropathy**

- Reference values (N = 131 ears)
  - D’haenens et al. (2007)
  - Dimitrijevic et al. (2002)
  - Kaf et al. (2006)
  - Werff and Brown (2006)

<table>
<thead>
<tr>
<th>Test frequency [Hz]</th>
<th>500</th>
<th>1,000</th>
<th>2,000</th>
<th>4,000</th>
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<td>Mean</td>
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<td>10.3</td>
<td>7.8</td>
<td>7.9</td>
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<tr>
<td>Stdev</td>
<td>7.1</td>
<td>7.1</td>
<td>4.8</td>
<td>4.1</td>
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Criteria for Auditory Neuropathy

- Absent or severely abnormal ABR
- Evidence of normal hair cell function by normal OAE and/or obvious CM
- Absent acoustic reflexes
- Some degree of hearing loss

**Auditory Neuropathy in Children < 2 Years of Age**

*Average Hearing Loss*

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<td>7</td>
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<td>9</td>
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</tr>
<tr>
<td>11</td>
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**Potential Sites of Lesion in AN Based on Symptoms**

- OAE (outer hair cells) Normal
- ABR Wave I Abnormal—(Peripheral Auditory Nerve Involved (?)
- Inner hair cell function or synapse could be involved.

**Timing and Auditory Evoked Potentials**

Cat ABR with stimulus trigger (top) and with jittered stimulus (bottom). Neural jitter will do the same thing, obliterate the ABR even if activity is present.
Auditory Brainstem Response in Auditory Neuropathy

Normal ABR

AN ABRs
CM Prominent
Neural peaks absent!

ABR with Residual V
Wave V can remain with prominent CM in Cases of ANSD

Large Cochlear Microphonic-
Some Waveform with Elevated Threshold

9 months old; behavioral thresholds WNL

ANSD Cannot be determined from poorly recorded ABR!

Child Incorrectly Diagnosed with ANSD
Poor vs Good Quality tracings

Interpretation of Present OAEs

- Represents normally functioning cochlear amplifier.
- Indicates presence of OHCs
- Unless neural conduction is impaired, usually indicates that hearing sensitivity should be 35-40 dB or better.
How to Interpret Absent OAE

- The CM is more reliable than OAE in AN diagnosis and should be the true test of Hair Cell Function
- A patient with an absent OAE who has a clear disconnect between hearing thresholds and ABR thresholds, and evidence of a CM should still be considered to have AN
- A small OAE at a few frequencies only should not be used alone as evidence of AN.

OAEs will disappear in up to 30% of cases?

- Middle ear disease (ear infections) ??
- Loss of neural input (??)
- Noise exposure from amplification (??)
- Change in OHC function ??

- HEARING LEVELS GENERALLY DO NOT CHANGE WITH OAE
- Presence or Absence of OAEs should not be considered regarding amplification.

Consensus Diagnostic Criteria

1. Tests of cochlear hair cell (sensory) function:
   b) Cochlear Microphonic

- 80-90 dB click response
- One rarefaction and one condensation average
- Insert earphones
- Clamp tubing to distinguish stimulus artifact

Hair cell depolarization with incoming sound is the source of the Cochlear Microphonic (CM).

Cochlear Microphonic

- Not a sign of abnormality, rather an expected response generated in functioning hair cells (both inner and outer).
- If seen in an otherwise normal ABR, the CM is not a sign of AN.

Normal Newborn ABR with CM
Auditory Neuropathy
To Distinguish CM from Stimulus Artifact or ABR

- CM will disappear when stimulus delivery tubing is clamped; stimulus artifact will remain.
- When using an insert phone the CM is later than artifact.
- ABR changes latency with stimulus level; CM does not.
- CM is visible only at high stimulus levels (+60 dB nHL).

Note: CM will be large and ring for up to 6+ ms in patients with AN. ABR in these recordings (the non-inverting potentials) will be poor or absent.

How to Record the Cochlear Microphonic

- Use insert earphones, stimulus artifact precludes effective recording of CMs when circum-aural earphones are used,
- Obtain separate recordings to high-intensity (e.g., 80–90 dB nHL) condensation vs. rarefaction click stimuli, and
- Leaving all other conditions the same (e.g., eartip/tube in ear, transducer in place), disconnect tube from transducer or pinch tube to prevent sound delivery to ear, and record ABR in this condition:
  - If the “response” is stimulus artifact, the “response” will be present in this tracing.
  - If the “response” is a true CM, there will be no “response” in this tracing.

CM vs stimulus artifact

Abnormal ABR with Present Cochlear Microphonic
Expanded time window

MEMR Abnormalities
From Berlin et al., 2010
International Journal of Audiology, Volume 49 Number 1

<table>
<thead>
<tr>
<th>Middle Ear Muscle Reflexes (number of subjects)</th>
<th>Absent MEMRs (all absent)</th>
<th>Total</th>
<th>Percent</th>
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<tr>
<td>Bilateral ANSD</td>
<td>125/148</td>
<td>132/148</td>
<td>84.46</td>
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<tr>
<td>Unilateral ANSD</td>
<td>7/148</td>
<td>4.73</td>
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<tr>
<td>Total Absent</td>
<td>132/148</td>
<td>89.19</td>
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<tr>
<td>Abnormal (combination of elevated and absent)</td>
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<tr>
<td>Bilateral ANSD</td>
<td>14/148</td>
<td>9.46</td>
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<tr>
<td>Unilateral ANSD</td>
<td>2/148</td>
<td>1.35</td>
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<tr>
<td>Total Abnormal</td>
<td>16/148</td>
<td>10.81</td>
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</table>

Middle ear muscle reflexes (acoustic reflexes) are absent or elevated in individuals with ANSD (Berlin et al., 2005). Because normative data on acoustic reflex thresholds in very young infants using high probe-tone frequencies (1000 Hz) have not been established, this procedure is not required to diagnose ANSD. Nevertheless, a complete test battery for ANSD should include middle ear muscle reflex testing whenever possible.

Consensus
Additional Tests Useful for Diagnosing Individuals with ANSD
Middle Ear Muscle Reflex in Neonates

Mazlan et al Ear & Hearing 2009 30(3), 295

Test-retest reliability of the acoustic stapedial reflex test in healthy neonates

Used 1k Hz probe to elicit 2k Hz AR from neonates.

This study demonstrated that ASRs could be consistently elicited from healthy neonates who showed a single-peaked configuration in the high-frequency tympanometry test and passed the automated auditory brain stem response and TEOAE tests.

DO NOT NEGLECT ACOUSTIC REFLEX TESTING IN THE TEST BATTERY.

How to Detect AN in the Audiologic Assessment of Newborns

- Start with HF Tone Burst (2 or 4k)
- If NR at highest level-
  - Switch to click 80 dB
  - Measure ABR with both polarities
  - Superimpose responses to inspect for CM
- If present CM in either ear- OAEs
- If not proceed with TB ABR for threshold.
- If using ASSR---Run high level click ABR first!

ASSR in Patients with AN

- May have responses at all frequencies at high (60-90 dB) levels.
- These responses are NOT related to the hearing levels and are probably reflecting the measure of the cochlear microphonic.
- Cortical EPs require less synchrony than ABR or ASSR. Can they be used to predict performance or sensitivity??

IMPORTANT

- HEARING THRESHOLDS CANNOT BE DETERMINED FROM ABR WHEN AN IS PRESENT.
- BEGIN EARLY INTERVENTION WITHOUT AMPLIFICATION AND WORK TO OBTAIN BEHAVIORAL THRESHOLDS AS QUICKLY AS POSSIBLE!

Thank you for listening

Questions??