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Common Errors in ABR Measurement and Analysis

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Common Errors in ABR Measurement and Analysis

Learner Outcomes: *As a result of this Continuing Education Activity, participants will be able to …*

1) List 3 technical mistakes audiologists sometimes make in ABR recording
2) Identify 3 rarely applied techniques for increasing efficiency of ABR recordings
3) List 3 factors influencing ABR findings are often NOT accounted for in ABR measurement

Common Errors in ABR Measurement and Analysis

- Introduction and historical perspective (0 – 5 minutes)
- Common errors or inadequacies in ABR measurement with simple solutions (6 – 20 minutes)
- Reasons for unacceptable delays and wasted time in pediatric ABR recordings (21 – 40 minutes)
- Factors that must be considered for accurate analysis of ABR findings (41 – 55 minutes)
- Questions and answers (55 – 60 minutes)

The First Comprehensive Description of the Auditory Brainstem Response (ABR) in Humans

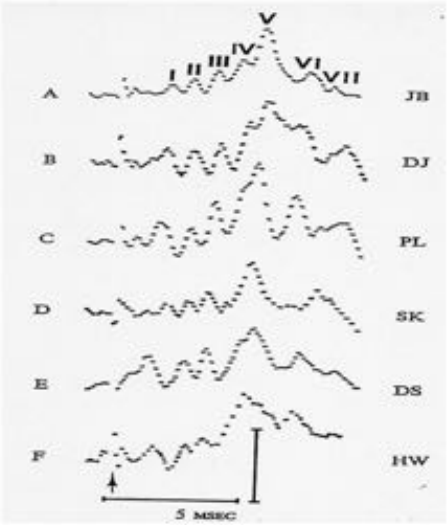
Jewett DL & Williston JS. Auditory evoked far fields averaged from the scalp of humans. Brain 4, 1971

Robert Galambos

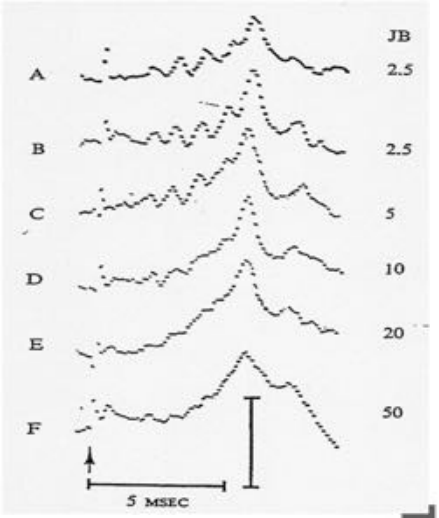
Don Jewett

Jewett & Williston (1971) … Ahead of Their Time

Inter-Subject Waveform Consistency

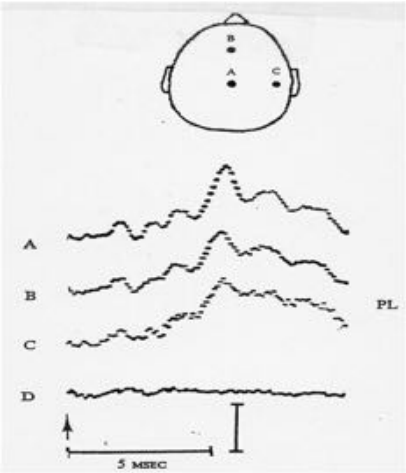


Effect of Stimulus Rate

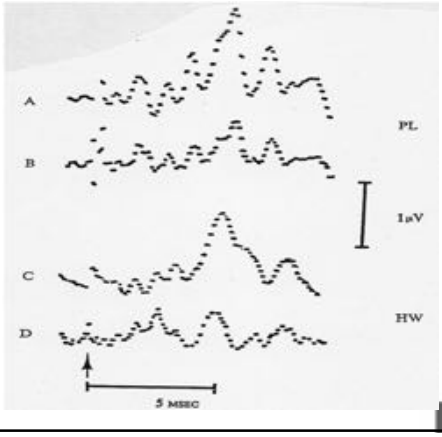


Jewett & Williston (1971) … Ahead of Their Time

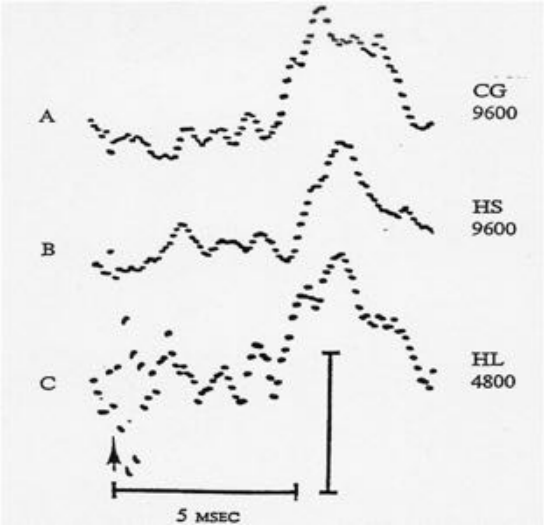
Non-Inverting Electrode Site



Inverting Electrode Site
A = ear canal inverting
B = mastoid inverting



Jewett & Williston (1971) … Ahead of Their Time
Tone Burst Signals



Common Errors in ABR Measurement and Analysis

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- Questions and answers (55 – 60 minutes)

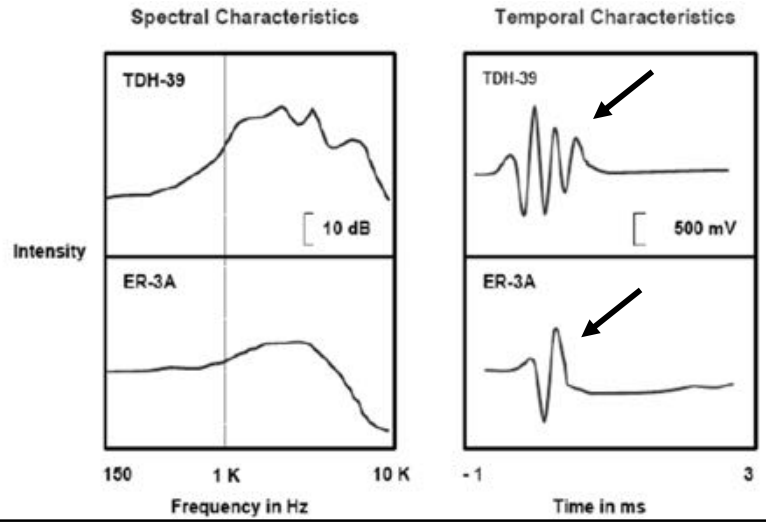
Common Errors in ABR *Measurement* and Analysis

- Common errors in or inadequacies in ABR measurement with simple solutions (6 – 20 minutes)
  - Failure to use insert earphones
  - Reluctance to use bone conduction stimulation
  - Insert ER-3A transducer near inverting electrode
  - Mastoid versus earlobe inverting electrode placement *(cite common electrode errors first)*
  - Problems related to stimulus intensity
  - Too short or too long analysis time
  - Inadequate display gain

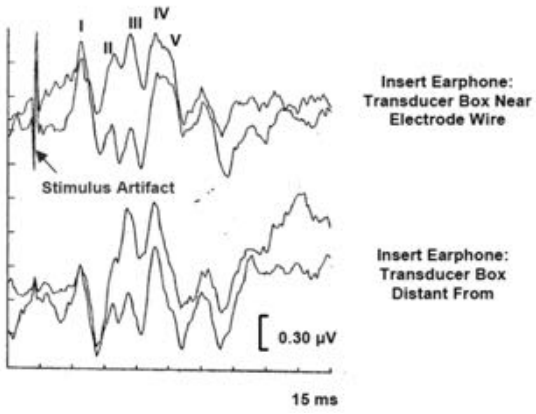
Common Errors in ABR Measurement and Analysis *Failure to use Insert Earphones*

- General
  - Increased inter-aural attenuation
  - Increased ambient noise attenuation
  - Elimination of ear canal collapse
  - Increased patient comfort
  - Improved aural hygiene
  - More precise placement (reliability). Use adaptor.
- ABR specifically
  - *Reduced transducer ringing*
  - *Reduced stimulus artifact with separation of transducer from inverting (earlobe) electrode*

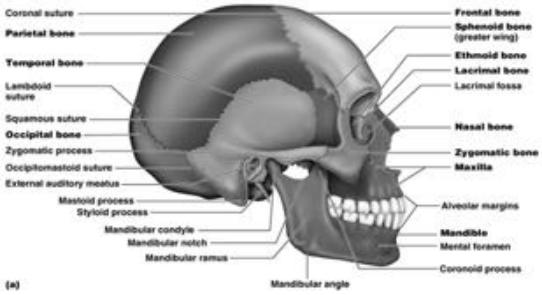
Advantages of Insert Earphones in ABR Measurement:
Less Ringing and Less Stimulus Artifact



Common Errors in ABR Measurement and Analysis
Insert ER-3A Transducer Near Inverting Electrode



Common Errors in ABR Measurement and Analysis
Reluctance to Use Bone Conduction Stimulation

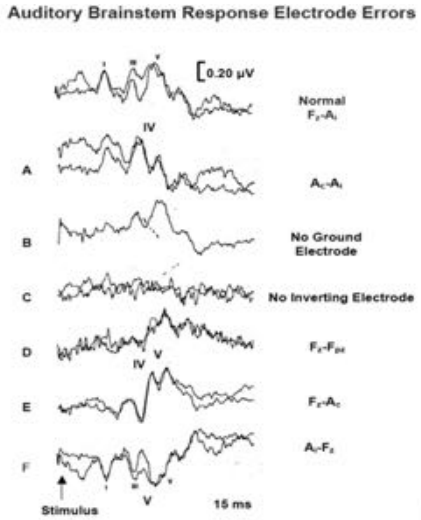


Common Errors in ABR Measurement and Analysis
Reluctance to Use Bone Conduction Stimulation

- Clinical Indications for BC ABR
  - Patient history of middle ear disease
  - Risk factor for conductive hearing loss, e.g., aural atresia or other craniofacial anomalies
  - Otological or other medical evidence of middle ear disorder, including placement of ventilation tubes (grommets)
  - Abnormal aural immittance findings, e.g., tympanometry
  - Air conduction ABR pattern (delayed wave I latency)

Common Errors in ABR Measurement and Analysis
Mastoid versus Earlobe Inverting Electrode Placement And Other Common Electrode Errors)

- Disadvantages of mastoid inverting electrode location
  - Smaller wave I amplitude
  - Close proximity to bone oscillator placement
- Advantages of earlobe inverting electrode location
  - 30% larger wave I amplitude (see Jewett & Williston, 1971)
  - Permits distance between electrode and bone oscillator
  - Ease of attachment with ear clip electrode design



Common Errors in ABR Measurement and Analysis
Avoiding Electrode Errors

Avoiding Electrode Errors

Electrode errors can be minimized with the following common-sense clinical steps and policies:

- Organize a set of electrodes well before preparing for an ABR recording and keep them in a handy location.
- It's good clinical protocol to braid together several sets of ABR electrodes using the color scheme described next.
- Electrode sets might be neatly kept near an ABR system or draped around a clinician's neck just before placement on a patient.
- Consistently assign specific colors to the wire of each electrode used in recording ABRs, such as yellow or white for the Fz electrode wire, blue for the left ear electrode (A1), red for the right ear electrode (A2), and black or gray for the ground electrode.
- Whenever possible always follow the same sequence in applying electrodes to the patient and plugging the wires into the pre-amplifier.
- Place the electrodes on the patient and plug the wires into the pre-amplifier in a well-lighted environment or at least verify proper placement with a flashlight or penlight in a poorly lit environment.
- Immediately suspect electrode errors if ABR appearance is not what was expected for the patient. Do not remove electrodes from the patient and discontinue ABR measurement without verifying correct electrode use.
- As soon at ABR measurement is complete, remove electrodes from the patient. Properly discard disposable electrodes or clean and dry re-usable electrodes.
- Return clean electrode sets or wires to their customary location.
- Regular inspect electrode wires and re-usable electrodes for damage.
- Never power the evoked response system on or off with the patient connected with electrodes to the pre-amplifier and to the system

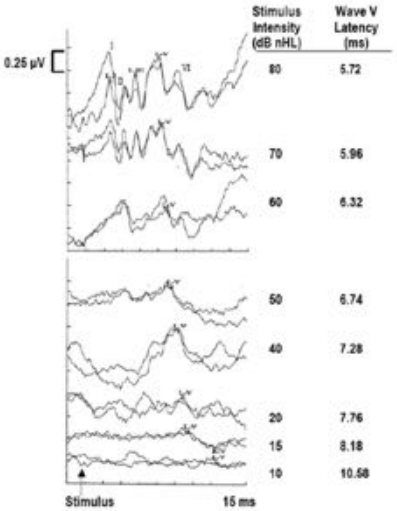
Source: eHandbook of Auditory Evoked Responses (Author: Hall. Available from Amazon)

Common Errors in ABR Measurement and Analysis *Ear Clip Electrode Design (Also Note Electrode Colors and Braided Cables)*

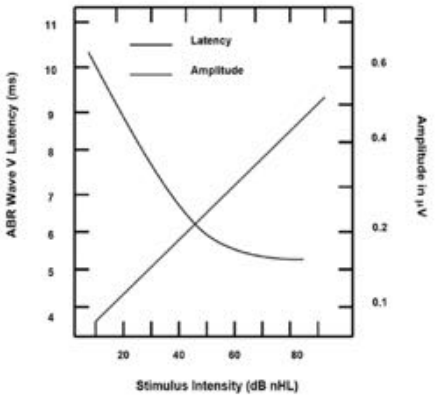
- Electrode Colors
  - Non-inverting (Fz) = **Yellow**
  - Inverting right ear = Red
  - Inverting left ear = Blue
  - Ground (common) = Gray or Green

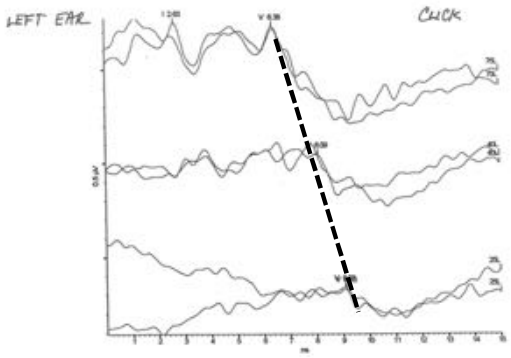
Common Errors in ABR Measurement and Analysis *Problems Related to Stimulus Intensity*

- For air conduction stimuli, failure to verify 0 dB nHL in ABR test environment (problem especially for lower frequency tone bursts)
- Failure to verify 0 dB nHL for bone conduction stimuli
- Small or absent wave I due to inadequate high intensity level
- Excessive number of intermediate intensity levels between clear ABR and threshold ABR (wastes test time)
- Failure to recognize and take advantage of predictable changes ABR waveform with changes in stimulus intensity levels



Common Errors in ABR Measurement and Analysis
Problems Related to Stimulus Intensity



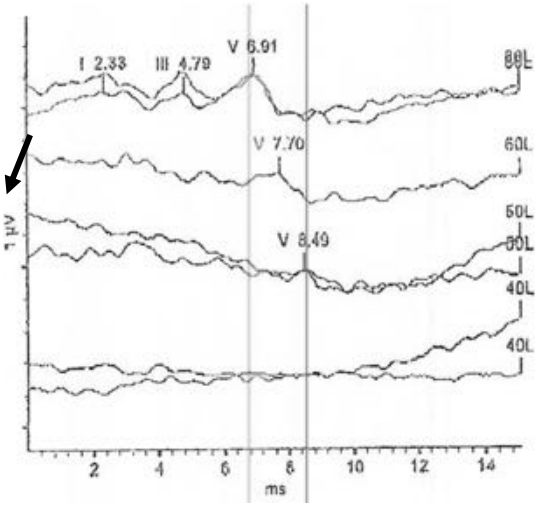


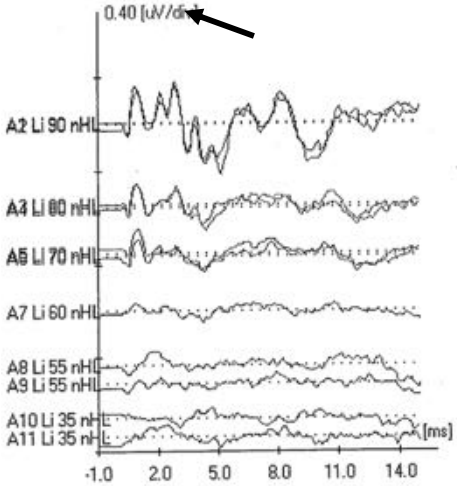
Common Errors in ABR Measurement and Analysis
Too Short or Too Long Analysis Time

- 10-ms = Too short
  - Wave V exceeds 10-ms under some subject and test conditions
- ≥ 20-ms = Too long
  - ABR crammed into first 25% of analysis time; poor resolution
  - Post-auricular muscle artifact can interfere with ABR recording
- 15-ms = Just Right

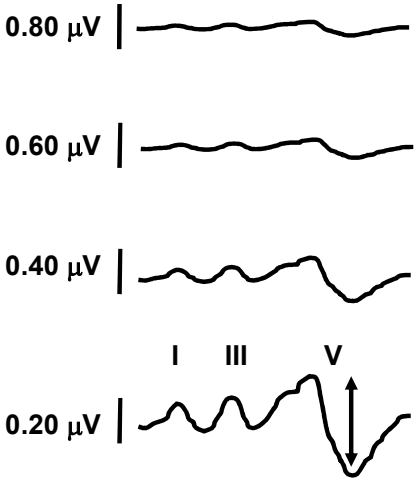
ABR wave V latency for click stimulus at 85 dB nHL	~6.0-ms
Decrease in intensity to 20 dB nHL	+3-ms
Conductive hearing loss component of 50 dB	+2-ms
Age related latency increase for term infant	+1-ms
Latency increase with hypothermia (4 degrees)	+1-ms
Pre-stimulus baseline	+1-ms
	Total = 14-ms

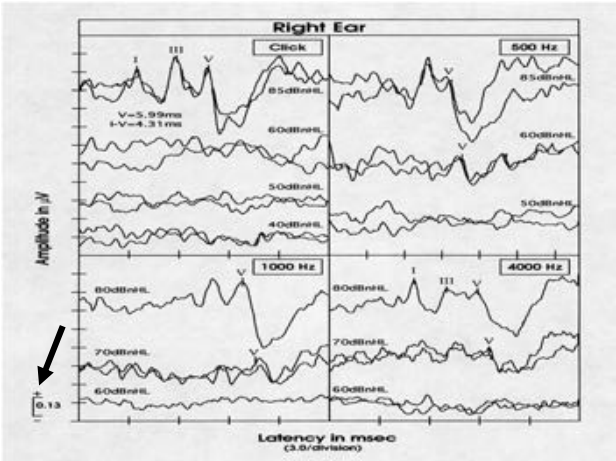
Common Errors in ABR Measurement and Analysis
Inadequate Display Gain (Not Amplification)





Common Errors in ABR Measurement and Analysis
Adequate Display Gain
Remember Wave V Amplitude is ≤ 0.5 microvolts





Common Errors in ABR Measurement and *Analysis*

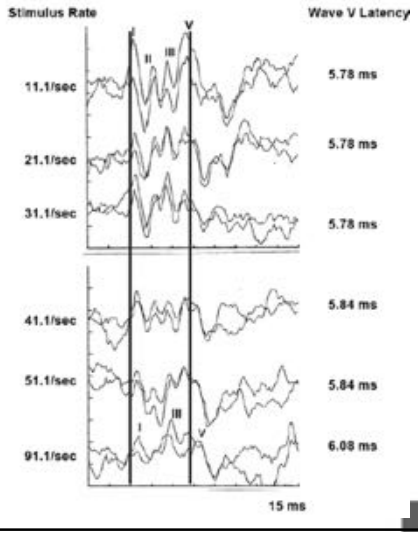
- Reasons for unacceptable delays and wasted time in pediatric ABR recordings (21 – 40 minutes)
  - Inappropriately slow stimulus presentation rate
  - Excessive signal averaging despite adequate SNR
  - Recording irrelevant ABR waveforms at numerous intermediate intensity levels
  - Reliance on traditional click and tone burst versus chirp stimuli
  - Failure to analyze waveforms during data collection
  - Not thinking ahead to the next step in ABR recording

Common Errors in ABR Measurement and Analysis
Inappropriately Slow Stimulus Presentation Rate

Objective: Present stimuli as fast as possible without producing a deterioration in ABR morphology or increase in latency. *Message: Go at least at the speed limit or 10% faster.*

Click: 21.1/sec

- **Reasonably fast data collection**
- **Predictable latency values**
- **Detectable wave I**
- **Tone Burst: 37.7/sec**
- **Faster data collection (less time)**
- **Not interested in wave I**



Common Errors in ABR Measurement and Analysis
Inappropriately Slow Stimulus Presentation Rate

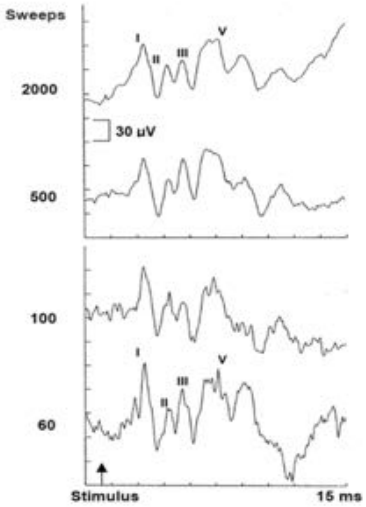
Data Collection in a Typical Pediatric ABR Assessment:

- **4 stimuli (click + 3 tone burst frequencies)**
- **4 intensity levels per stimulus**
- **2 replications per intensity level**
- **2 ears**
- **Total = 4 X 4 X 2 X 2 = ~ 64 separate ABR waveforms**

Calculated Data Collection Time

- **Assume 1000 stimuli (sweeps) per waveform = 64,000 sweeps**
- **Stimulus rate of 11.1/sec = 96 minutes**
- **Stimulus rate of 37.7/sec = 28 minutes**

Common Errors in ABR Measurement and Analysis
Excessive Signal Averaging Despite Adequate SNR



Signal-to-noise ratio (SNR) =

$$\frac{\text{Signal Amplitude X Number of Averages}}{\text{Noise Amplitude}}$$

where Signal = ABR

Adequate SNR = 3

(ABR wave V is 3 times larger than residual background noise)

Common Errors in ABR Measurement and Analysis
Excessive Signal Averaging Despite Adequate SNR

NHS
Antenatal and Newborn Screening Programmes

NEWBORN HEARING SCREENING AND ASSESSMENT

Guidance for Auditory Brainstem Response testing in babies

Version 2.1

March 2013

NHSP Clinical Group

Graham Sutton[1], Guy Lightfoot[2] (Co-editors)
Contributors: John Stevens[3], Rachel Booth[4], Siobhan Brennan[5], Rachel Feirn[6], Rhys Meredith[7]

Common Errors in ABR Measurement and Analysis
Excessive Signal Averaging Despite Adequate SNR
(NHS Guidelines, 2013)

The number of sweeps per waveform accepted should be varied depending on both the size of the response and the level of background activity. The aim is to achieve a clear response or response absence rating (see later). The number of sweeps required to achieve this will normally vary between 1500 and 3000, although it may be higher when the responses are small or the background noise is high. Typically a figure of 2000 sweeps is recommended (minimum of 1500) for ckABR & narrowband chirp ABR and 3000 (minimum of 2000) for tpABR.

Exceptionally there may be such a large ABR response or low background activity that fewer sweeps can be used (subject to a minimum of 1500 for tpABR and 1000 for ckABR & narrowband chirp ABR). Any waveform must still be judged against the full clear response (***CR***) criteria, described later.

Example of a clear response (*CR*), satisfying the 3 to 1 signal to noise criterion

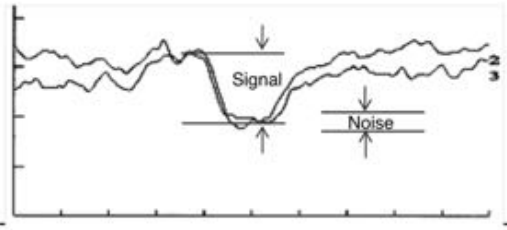


Figure 1

Scales:
150nV / div
2 ms / div

Common Errors in ABR Measurement and Analysis
Excessive Signal Averaging Despite Adequate SNR

Inefficient Data Collection in a Typical Pediatric ABR Assessment:

- 4 stimuli (click + 3 tone burst frequencies)
- 4 intensity levels per stimulus
- 2 replications for all waveforms
- 2 ears
- Total waveforms = 4 X 4 X 2 X 2 = 64
- 2000 stimuli (sweeps) per waveform = 128,000 sweeps

Calculated Data Collection Time

- Assume stimulus rate of 37.7/sec
- Data collection time = 57 minutes
- Only for air conduction ABRs … not including bone conduction

Common Errors in ABR Measurement and Analysis
Excessive Signal Averaging Despite Adequate SNR

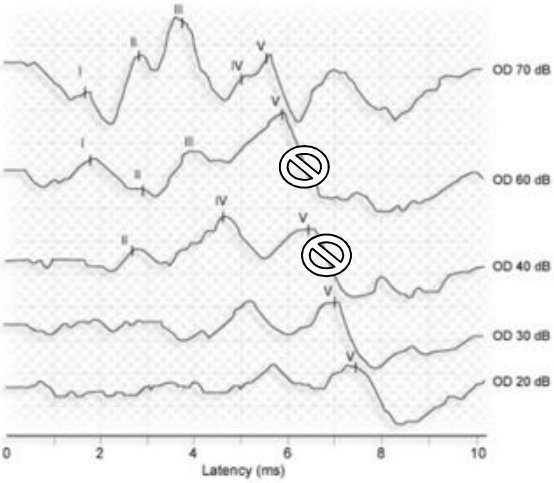
Efficient Data Collection in a Typical Pediatric ABR Assessment:

- 4 stimuli (click + 3 tone burst frequencies)
- 4 intensity levels per stimulus
- 2 ears
- 500 stimuli (sweeps) per waveform for 3 higher intensity levels
- 1000 sweeps for two replicated waveforms at threshold intensity level
- Total = 1500 + 2000 = 3500 sweeps per stimulus X 4 stimuli X 2 ears = 28,000 sweeps

Calculated Data Collection Time

- Assume stimulus rate of 37.7/sec
- Averaging of 500 sweeps requires only 13 seconds
- Data collection time = 28,000/37.7 = 12.5 minutes

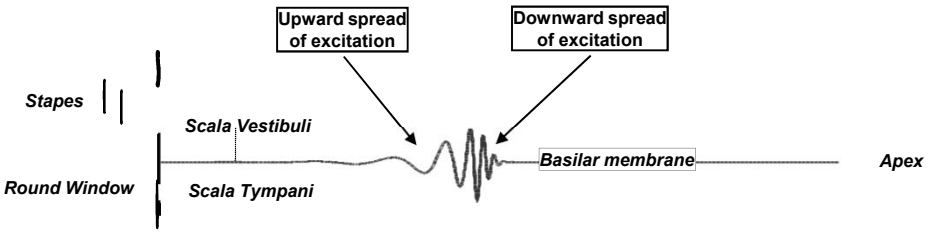
Common Errors in ABR Measurement and Analysis
Recording Irrelevant ABR Waveforms at Numerous Intermediate Intensity Levels



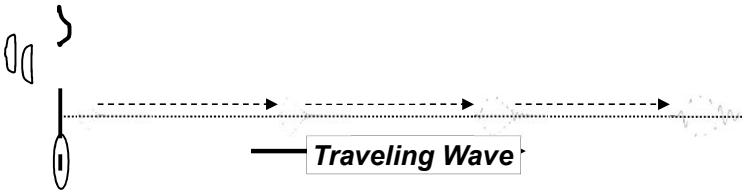
Recommended Changes in ABR Protocol (Figure from Internet)

- Higher maximum intensity level to better define wave I
- Analysis time of 15-ms
- Pre-stimulus baseline (-1-ms)
- Include amplitude description
- Eliminate intermediate intensity levels to save test time

Cochlear Excitation Patterns for Click versus Narrow Band Stimulation
Traditional Stimuli Waste Cochlear Activity



Continuous, narrow band stimuli



Transient, broad band stimuli

Kristensen & Elberling (2012). Auditory brainstem responses to level-specific chirps in normal-hearing adults.
***J American Aacademy of Audiology, 23,* 712-721**

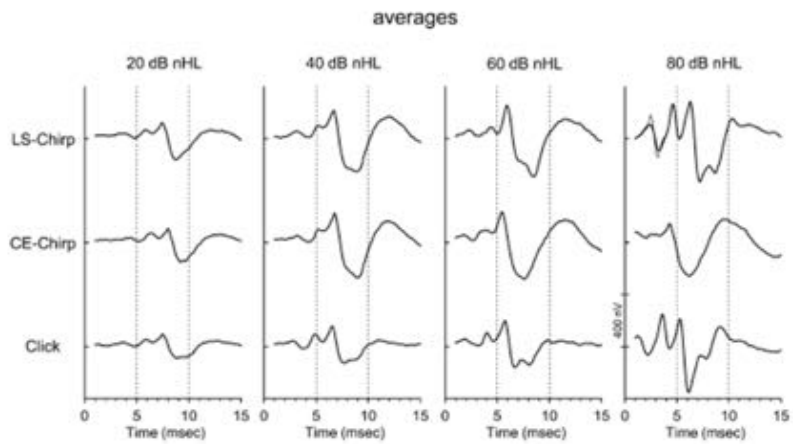
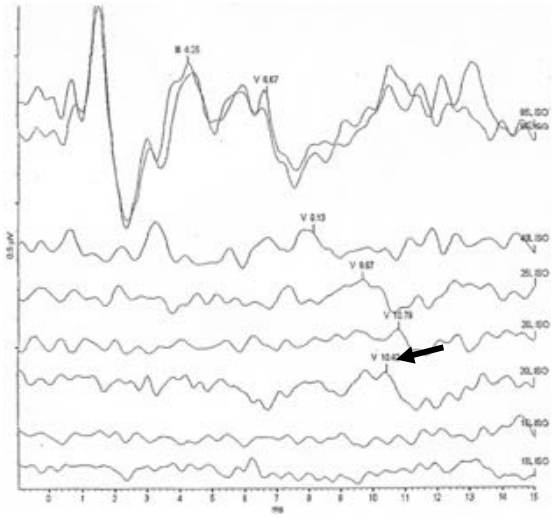


Figure 6. Grand Average ABR waveforms from N = 20 ears. The Grand Averages are obtained by time-shifting the underlying individual waveforms according the wave V latency. The thin line in the LS-Chirp/80 dB nHL condition shows a small part (corresponding to wave I) of the Grand Average obtained by using the latency of wave I instead of wave V for the temporal adjustment.

Conventional Click versus CE Chirp Evoked ABR

(1 year 4 month old boy with speech & language delay who failed hearing screening in nursery. Parents do not speak English)



85 dB nHL Click, rarefaction, 21.1/sec
I = 1.46 ms
V = 6.67 ms
I-V = 5.21 ms

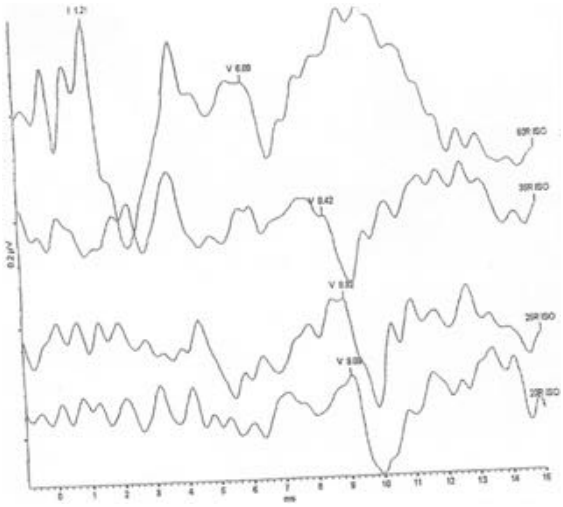
45 dB nHL Click

25 dB nHL Click

20 dB nHL Click

20 dB nHL CE Chirp

2000 Hz Chirp Evoked ABR
Stimulus rate = 37.7/sec
Total sweeps = 2318 ; Total test time = 61 seconds



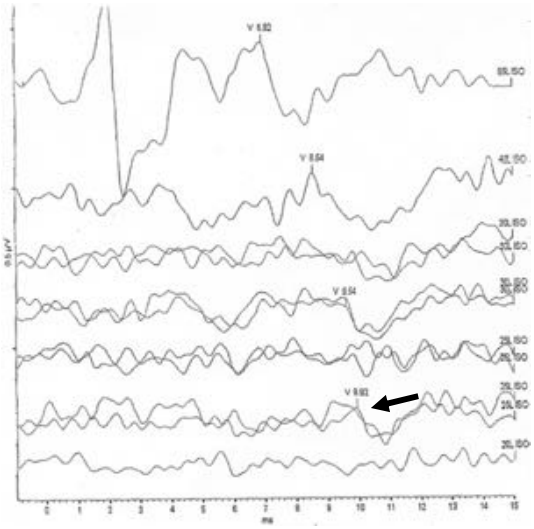
80 dB nHL
722 sweeps

35 dB nHL
570 sweeps

25 dB nHL
456 sweeps

20 dB nHL
570 sweeps

4000 Hz Conventional versus Chirp Evoked ABR:
Larger Wave V and Lower ABR Threshold



Left Ear
85 dB nHL
Tone Burst

40 dB nHL
Tone Burst

30 dB nHL
Tone Burst

30 dB nHL, Chirp Tone Burst

25 dB nHL, Tone Burst

25 dB nHL, Chirp Tone Burst

15 dB nHL, Chirp Tone Burst

Common Errors in ABR Measurement and Analysis

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  - Inappropriately slow stimulus presentation rate
  - Excessive signal averaging despite adequate SNR
  - Recording irrelevant ABR waveforms at numerous intermediate intensity levels
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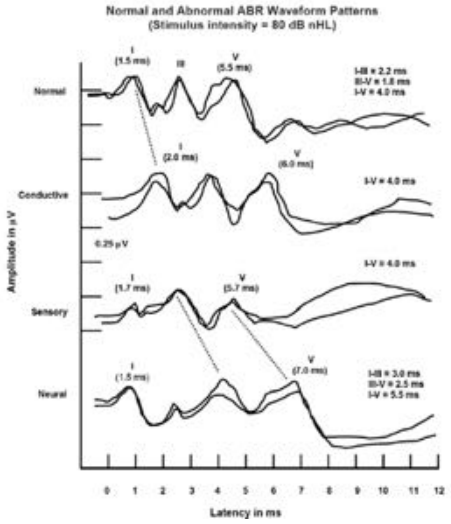
- Questions and answers (55 – 60 minutes)

Common Errors in ABR Measurement and Analysis

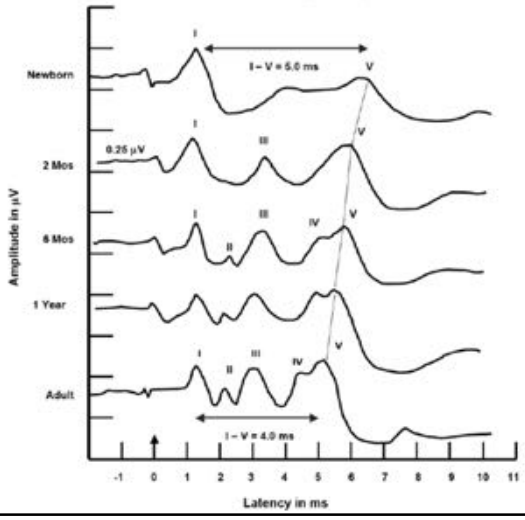
- Factors that must be considered for accurate analysis of ABR findings (41 – 55 minutes)
  - Stick with the click … it's a good use of test time
  - Consider non-pathologic subject factors
    - Age
    - Gender
    - Body temperature
    - Drugs, e.g., anesthetic agents
  - Other auditory test findings

Common Errors in ABR Measurement and Analysis
Stick with the Click … it's a Good Use of Test Time



Click Stimulus
85 dB nHL
Rate of presentation = 21.1/sec
Test time = < 3 minutes

Common Errors in ABR Measurement and Analysis
Consider Non-Pathologic Subject Factors: Age in Infants



Common Errors in ABR Measurement and Analysis
Consider Non-Pathologic Subject Factors: Others

- Age
  - Marked developmental changes
  - Modest changes with advanced age
- Gender
  - Significantly shorter latencies in females versus males
- Body temperature
  - Prolonged latency in *hypo*thermia (0.2 ms/1 degree)
  - Shorter latency in *hyper*thermia
- Drugs (medications)
  - Sedatives = no effect
  - Selected anesthetic agents = slight effect on latency

Common Errors in ABR Measurement and Analysis

- Introduction and historical perspective (0 – 5 minutes)
- Common errors or inadequacies in ABR measurement with simple solutions (6 – 20 minutes)
- Reasons for unacceptable delays and wasted time in pediatric ABR recordings (21 – 40 minutes)
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- Questions and answers (55 – 60 minutes)

Reference/Resource

eHandbook of Auditory Evoked Responses (Hall)

Topics include:

- Introduction to Auditory Evoked Responses
- Electrocochleography
- Auditory Brainstem Response (ABR)
- Auditory Steady State Response
- Auditory Middle Latency Response
- Auditory Late Response
- P300 Response and MMN
  - and more

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