Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

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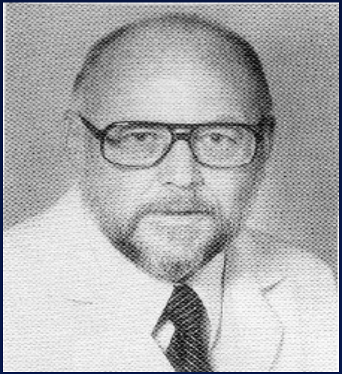
Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

- Welcome and Overview of Workshop Objectives
- The Crosscheck Principle: A 40-Year Perspective
- Auditory Brainstem Response (ABR)
  - Test Protocol and Analysis
  - Clinical Applications in Children
- Electrocochleography (ECochG)
  - Test Protocol and Analysis
  - Clinical Applications in Children
- Cortical Auditory Evoked Responses
  - Test Protocol and Analysis
  - Clinical Applications in Children

My Clinical Experience with ABR Measurement: *1974 - Present*



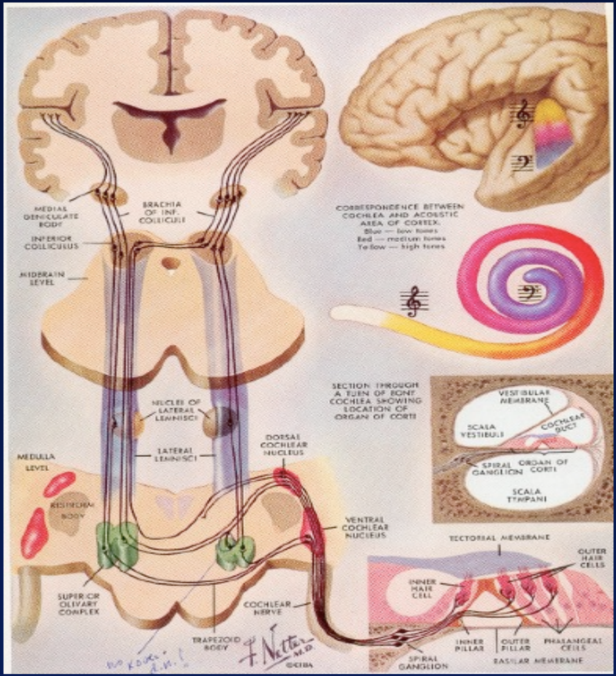
James Jerger

James Hall
(Circa 1975)

Thousands of ABRs in Children and Adults

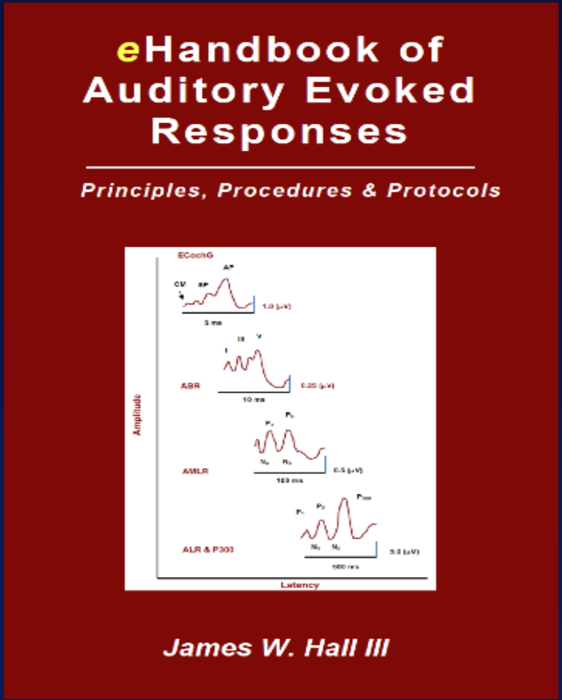
Auditory Evoked Responses:
Cochlea to Cortex

- P300 response and other cognitive evoked responses
- Auditory late response (ALR)
- Auditory middle latency response (AMLR)
- Auditory steady state response (ASSR)
- Auditory brainstem response (ABR)
- Electrocochleography (ECochG)



eHandbook of Auditory Evoked Responses
Available from Amazon.com
http://www.amazon.com/dp/B0145G2FFM

- Chapter 1. Introduction to Auditory Evoked Responses
- Chapter 2. Introduction to Electrocochleography
- Chapter 3. ECochG: Clinical Populations
- Chapter 4. Introduction to Auditory Brainstem Response (ABR)
- Chapter 5. ABR: Stimulus Parameters
- Chapter 6. ABR: Acquisition Parameters and Test Protocols
- Chapter 7. ABR: Analysis and Trouble Shooting
- Chapter 8. ABR: Clinical Applications and Patient Populations
- Chapter 9. Auditory Steady State Response
- Chapter 10. Auditory Middle Latency Response
- Chapter 11. Auditory Late Response
- Chapter 12. P300 Response and MMN



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- Workshop Objectives
  - List 2 specific clinical applications of ECochG in children
  - Describe electrode options for ECochG measurement
  - Explain rationale for the application of frequency-specific ABR in infants
  - Define chirp stimuli used in recording frequency-specific ABRs
  - Identify 3 distinct pediatric applications of cortical auditory evoked responses

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The Cross-Check Principle in for Diagnosis of Hearing Loss in Children

(Jerger J & Hayes D. Arch Otolaryngol 102: 1976)

The Cross-Check Principle in the Diagnosis of Hearing Loss in Children

(Jerger J & Hayes D. Arch Otolaryngol 102: 1976)

Reprinted from the Archives of Otolaryngology
October 1976, Volume 102

The Cross-Check Principle in Pediatric Audiometry

James F. Jerger, PhD, Deborah Hayes, MA

• We discuss a method of pediatric audiologic assessment that employs the "cross-check principle." That is, the results of a single test are cross-checked by an independent test measure. Particularly useful in pediatric evaluations as cross-checks of behavioral test results are impedance audiometry and brain-stem-evoked response audiometry (BSER). We present five cases highlighting the value of the cross-check principle in pediatric audiologic evaluation.
(Arch Otolaryngol 102:614-620, 1976)

kind of response they will give, the deviation of the deaf child will become patently evident.

We are not so sanguine. We have found that simply observing the auditory behavior of children does not always yield an accurate description of hearing loss. In our own experience, we have seen too many children at all levels of functioning who have been misdiagnosed and mismanaged on the basis of behavioral test results alone.

The mishandling of children based on the results of behavioral audiom-

techniques, uniquely suited to the evaluation of young children, have been made available to clinicians. The first, impedance audiometry, is not only sensitive to middle ear disorders, but in the case of normal middle ear function permits quantification of sensorineural level. The second technique, brain-stem-evoked response (BSER) audiometry, is an electrophysiologic technique that permits the clinician to estimate sensitivity above 500 hertz by both air and bone conduction.

Test Battery:

- Behavioral audiometry
- Immittance (impedance) measurement
  - ✓ Tympanometry
  - ✓ Acoustic reflexes (contralateral onl with SPAR)
- Auditory brainstem response (brainstem-evoked response audiometry or BSER)
  - ✓ Click stimulus air conduction
  - ✓ Click stimulus bone conduction

The Cross-Check Principle Pediatric Audiology
(Jerger J & Hayes D. Arch Otolaryngol 102: 1976)

"We have found than simply observing the auditory behavior of children does not always yield an accurate description of hearing loss"…

"The basic operation of this principle is that no result be accepted until it is confirmed by an independent measure."

"As long as audiologists are willing to accept the results of a single test measure they will continue to misdiagnosis and mismanage some children."

The Cross-Check Principle in Audiology Today
40-Years of Clinical Experience

- ❑ Behavioral Audiometry
- ❑ Otoacoustic Emissions (OAEs)
- ❑ Aural Immittance Measurements
  - Tympanometry
  - Acoustic Reflexes
- ❑ Auditory Brainstem Response (ABR)
  - Air- and Bone Conduction Stimulation
  - Click, Tone Burst and Chirp Stimulation
  - ❑ Auditory Steady State Response (ASSR)
- ❑ Electrocochleography (ECochG)
- ❑ Cortical Auditory Evoked Responses

The Cross-Check Principle in the Diagnosis of Hearing Loss in Children: A 40-Year Perspective

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REVIEW
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Crosscheck Principle in Pediatric Audiology Today: A 40-Year Perspective

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The crosscheck principle is just as important in pediatric audiology as it was when first described 40 years ago. That is, no auditory test result should be accepted and used in the diagnosis of hearing loss until it is confirmed or crosschecked by one or more independent measures. Exclusive reliance on only one or two tests, even objective auditory measures, may result in a auditory diagnosis that is not clear or perhaps incorrect. On the other hand, close and careful analysis of findings for a test battery consisting of objective procedures and behavioral tests whenever feasible usually leads to prompt and accurate diagnosis of auditory dysfunction. This paper provides a concise review of the crosscheck principle from its introduction to its clinical application today. The review concludes with a description of a modern test battery for pediatric hearing assessment that supplements traditional behavioral tests with a variety of independent objective procedures including aural immittance measures, otoacoustic emissions, and auditory evoked responses.

J Audiol Otol 2016;20(2):59-67

KEY WORDS: Auditory brainstem response · Auditory steady state response · Aural immittance measures · Crosscheck principle · Otoacoustic emissions.

Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

Advantages of Objective Tests

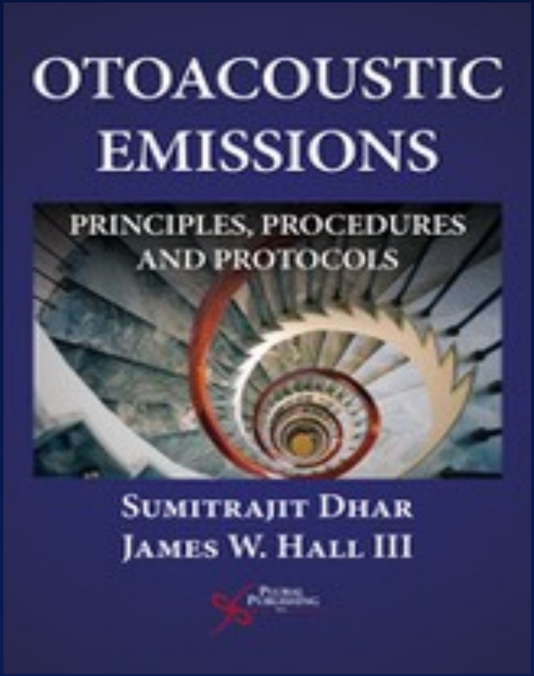
- Clinically feasible and valid measures of auditory function in
  - Newborn infants and young children
  - Difficult-to-test children
  - Sick patients
  - Sleeping, sedated, or anesthetized patients
  - Comatose patients
  - False or exaggerated hearing loss
- Automated technology
- Greater sensitivity than behavioral audiometry
- Greater specificity than behavioral audiometry

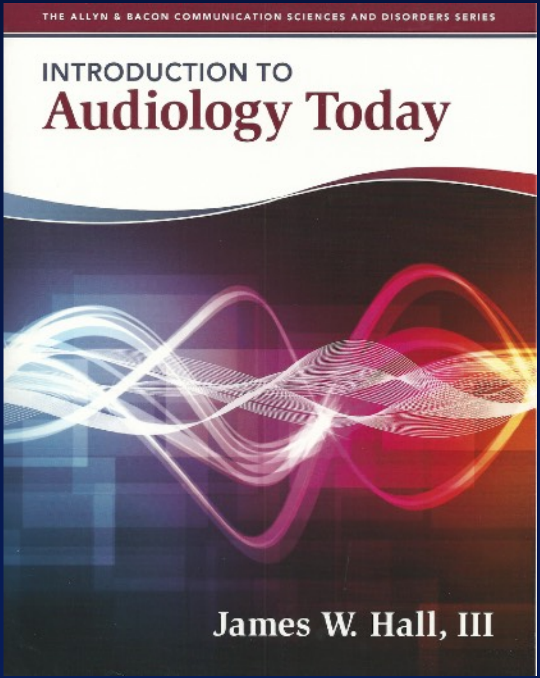
Year 2007 Joint Committee on Infant Hearing (JCIH) Position Statement Protocol for Evaluation for Hearing Loss In Infants and Toddlers from Birth to 6 months

- ❑ Child and family history
- ❑ Evaluation of risk factors for congenital hearing loss
- ❑ Parental report of infant's responses to sound
- ❑ Audiological assessment
  - Auditory brainstem response (ABR)
    - ✓ Click-evoked ABR with rarefaction and condensation single-polarity stimulation if there are risk factors for auditory neuropathy
    - ✓ Frequency-specific ABR with air-conduction tone bursts
    - ✓ Bone-conduction stimulation (as indicated)
    - ✓ Auditory steady state response (ASSR) is optional
  - Otoacoustic emissions (distortion product or transient OAEs)
  - Tympanometry with 1000 Hz probe tone
  - "Clinical observation of infant's auditory behavior. *Behavioral observation alone is not adequate for determining whether hearing loss is present in this age group, and is not adequate for the fitting of amplification devices."*

Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

More Information on Objective Auditory Procedures





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eHandbook of Auditory Evoked Responses
Practical Information About ABR
www.audiologyworld.net *jwhall3phd@gmail.com*

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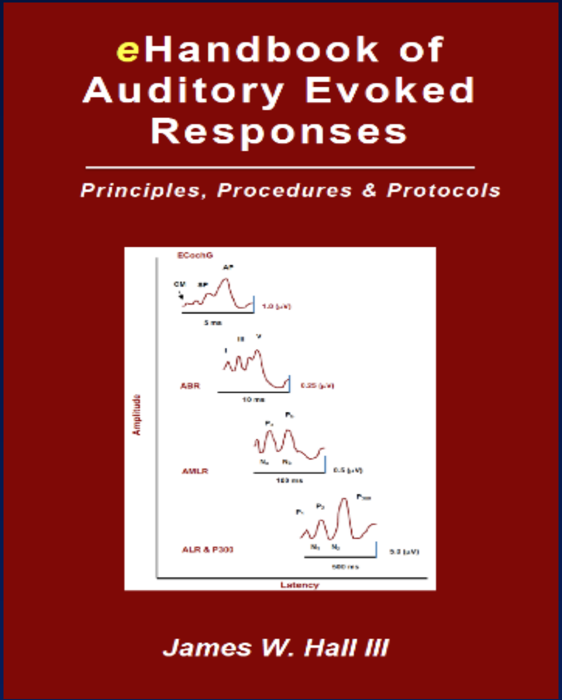
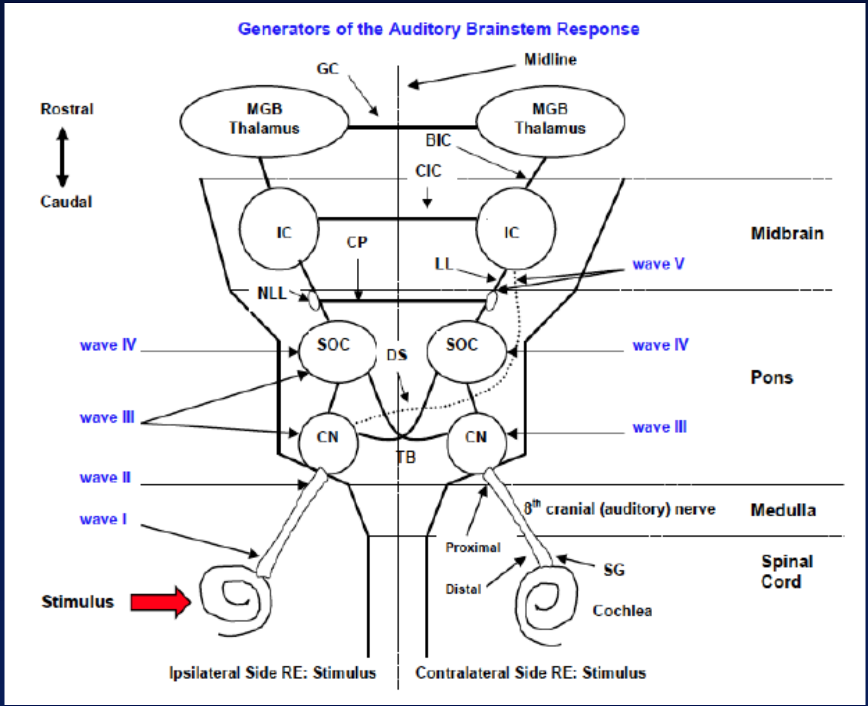


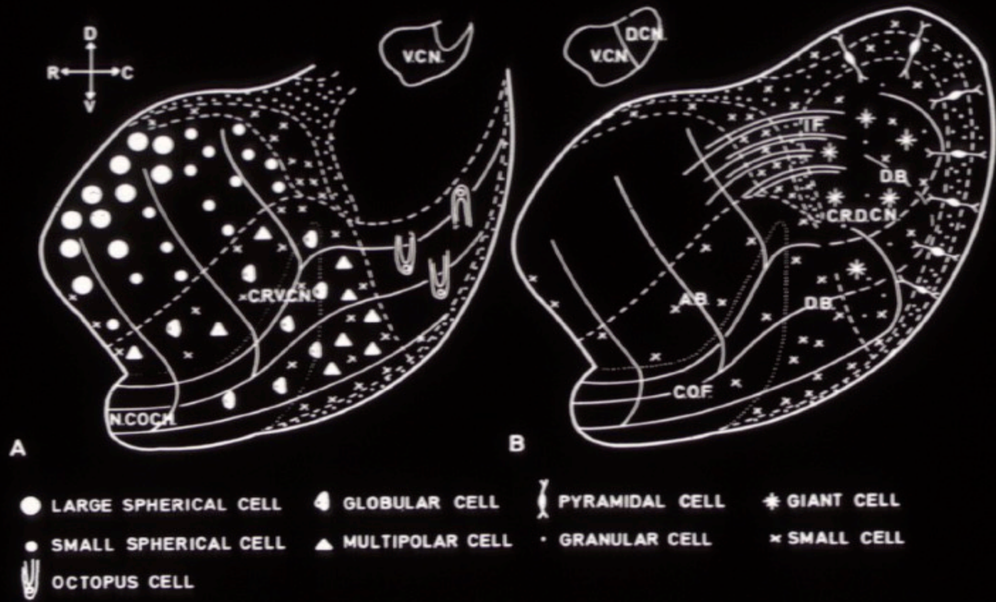
Don Jewett "Discoverer of ABR"
Robert Galambos (His Mentor)

Jewett D and Williston J. Auditory evoked far fields averaged from the scalp of humans. Brain 4: 681-696, 1971

Anatomy & Physiology of ABR:
Generators of ABR Waves
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



Anatomy & Physiology of ABR: Neural Generators (Onset neurons = Octopus Cells)



Schematic outline of the cochlear nucleus. VCN, ventral cochlear nucleus; DCN, dorsal cochlear nucleus. (From Osen, 1969.)

Anatomy & Physiology of ABR: *Why the ABR is Not a Test of Hearing*

- Generated only by "onset" neurons (octopus cells)
- Highly dependent on synchronous firing of these neurons
- Does not assess auditory cortex
- Can be recorded from persons who are:
  - Comatose
  - Sedated
  - Anesthetized persons
- Elicited with simple and non-speech signals, e.g., clicks

Auditory Brainstem Response Measurement: *Preparation and Precautions*

- What is the patient's age and gender?
- Why is an ABR being recorded?
- What is the tentative or possible diagnosis?
- Are other test results available?
- Is the patient taking any medications?
- Does the patient have any allergies?
- Can the patient understand instructions?
- For young children, has the ABR testing been explained to the parents?

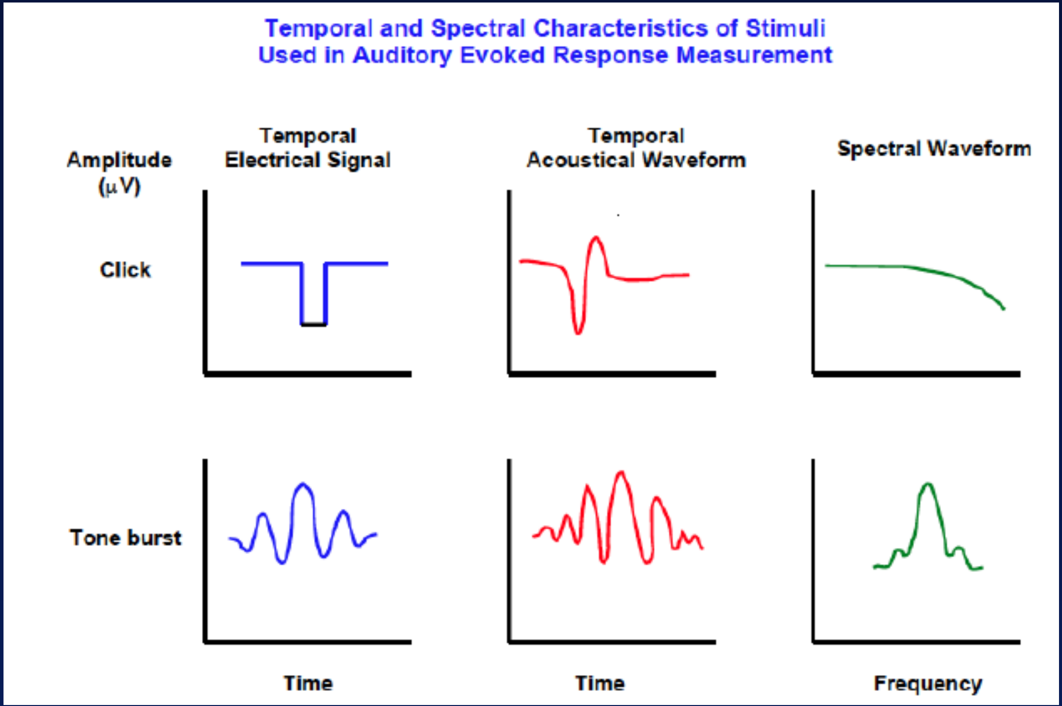
Evidence-Based Protocol for Basic ABR Measurement: *Stimulus Parameters*

Parameter	Selection	Comment
Transducer	Insert earphone	A dozen good reasons
	Bone oscillator	BC ABR is often necessary
Type	Click or tone burst	Click for diagnosis
		Tone burst for threshold estimation
Duration	Click = 0.1 ms	Transient (synchronous firing) onset
	TB = 2-0-2 cycles	Tonal but transient
Polarity	Rarefaction	Larger amplitude; change as indicated
Rate	Click = 21.1/sec	Faster rate saves time; slow if necessary
	TB = 37.7/sec	Faster rate saves time; only need wave V
Intensity	Variable in dB nHL	High for neurodx; low for thresholds
Repetitions	Variable	Whatever is needed for good SNR
Masking	Rarely needed	Only if ABR is abnormal and no wave I

ABR: Advantages of Insert (ER-3A) Earphones

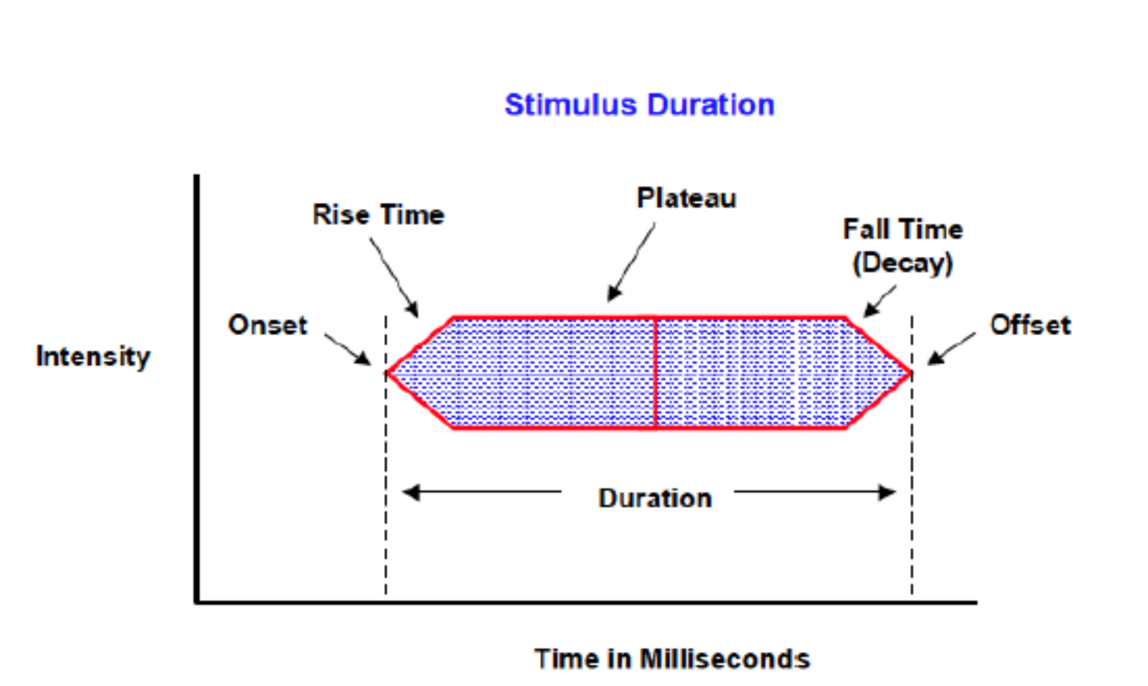
- General
  - Increased inter-aural attenuation
  - Increased ambient noise attenuation
  - Elimination of ear canal collapse
  - Increased patient comfort
  - Improved aural hygiene
  - More precise placement (reliability)
- ABR specifically
  - Reduced transducer ringing
  - Reduced stimulus artifact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

Auditory Brainstem Response Measurement:
Type of Stimulus
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



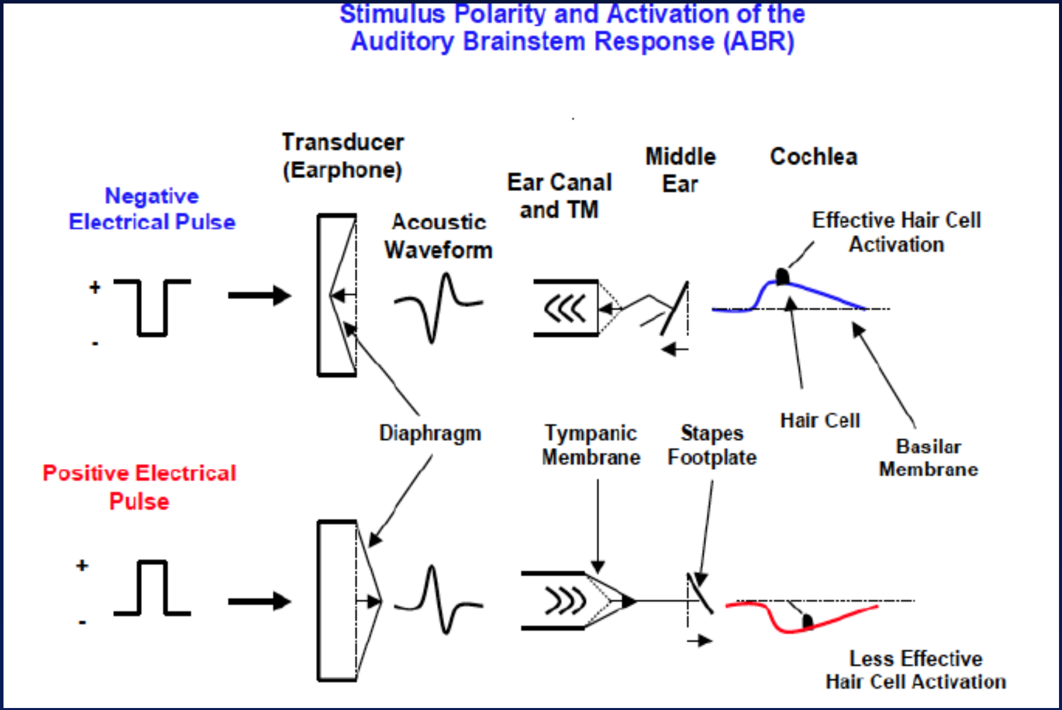
Auditory Brainstem Response Measurement:
Stimulus Duration for Tone Bursts

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

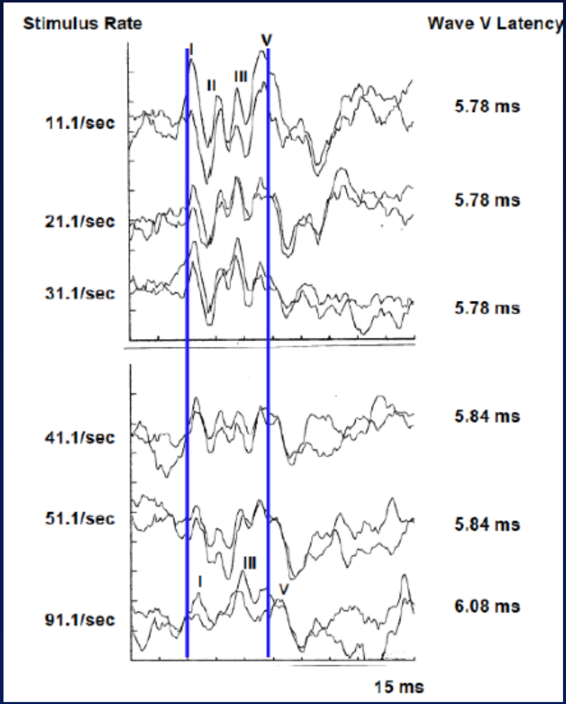


Stimulus Factors in ABR Measurement: *Stimulus Polarity*

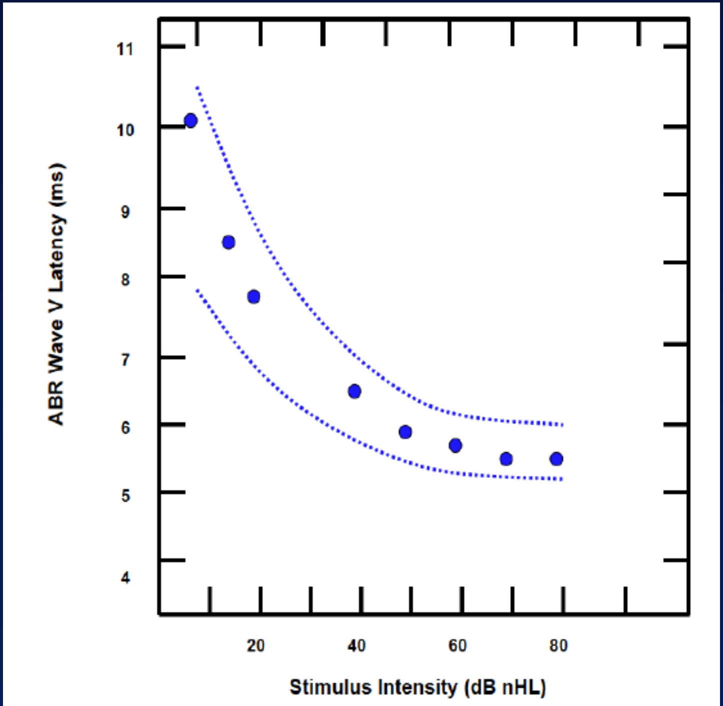
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



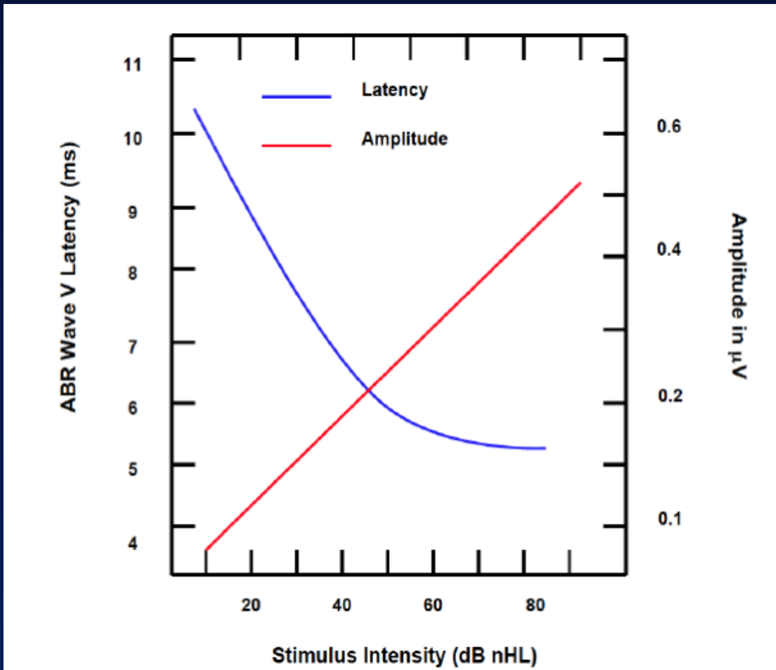
Auditory Brainstem Response Measurement:
Stimulus Rate
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

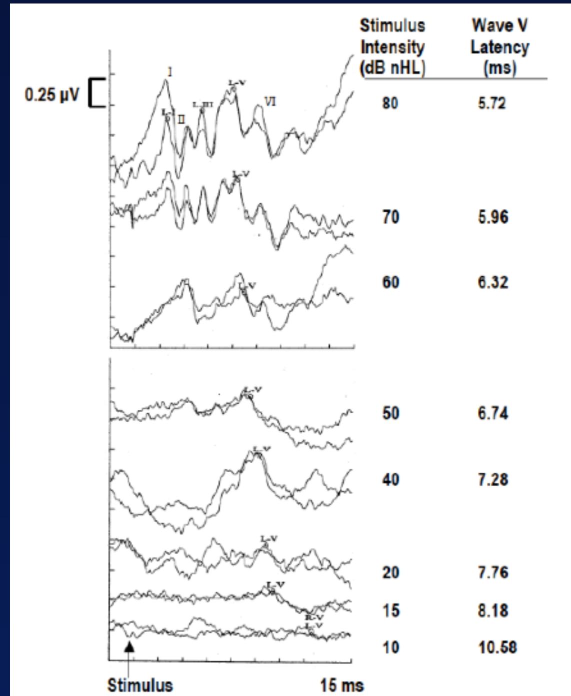


Effect of Stimulus Intensity on ABR Wave V Latency:
Latency/Intensity Function
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



Effect of Stimulus Intensity on Auditory Brainstem Response Wave V
Amplitude versus Intensity Differences





Evidence-Based Protocol for Basic ABR Measurement: *Acquisition Parameters*

Parameter	Selection	Comment
Electrodes		
Noninverting	Fz	High forehead preferred to vertex
Inverting	Ai	Ipsilateral earlobe; TIPtrode also O.K.
Ground	Fpz	Low forehead for common electrode
Filters (HP)	30 Hz	Low freqs in ABR, especially infants
(LP)	3000 Hz	1500 Hz O.K. if high frequency artifact
Notch	None	Removes critical low frequency energy
Amplification	100,000	Or sensitivity of +/- 25 or 50 μV
Analysis time	15 ms	Encompasses ABR in all cases (see TB)
Pre-stim baseline	- 1 ms	Information on response quality
Sweeps (# stimuli)	Variable	Whatever yields adequate SNR

Electrode Terminology and Amplifiers
(+ = noninverting; - = inverting)
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

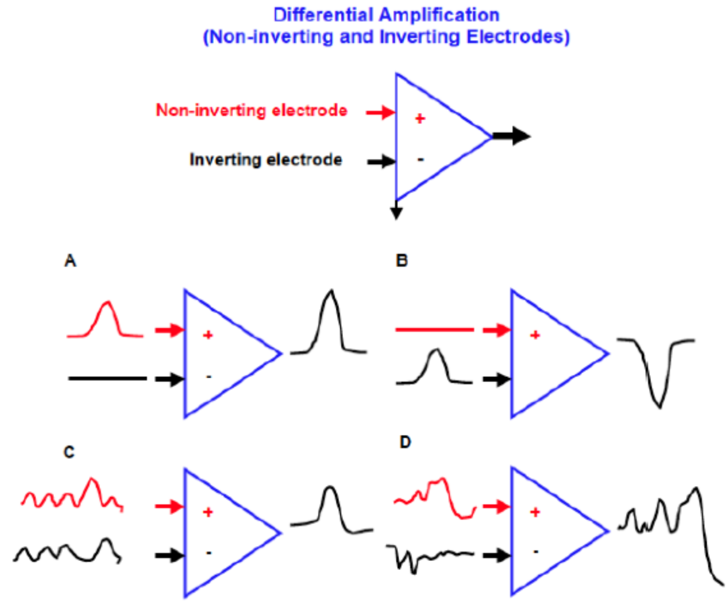
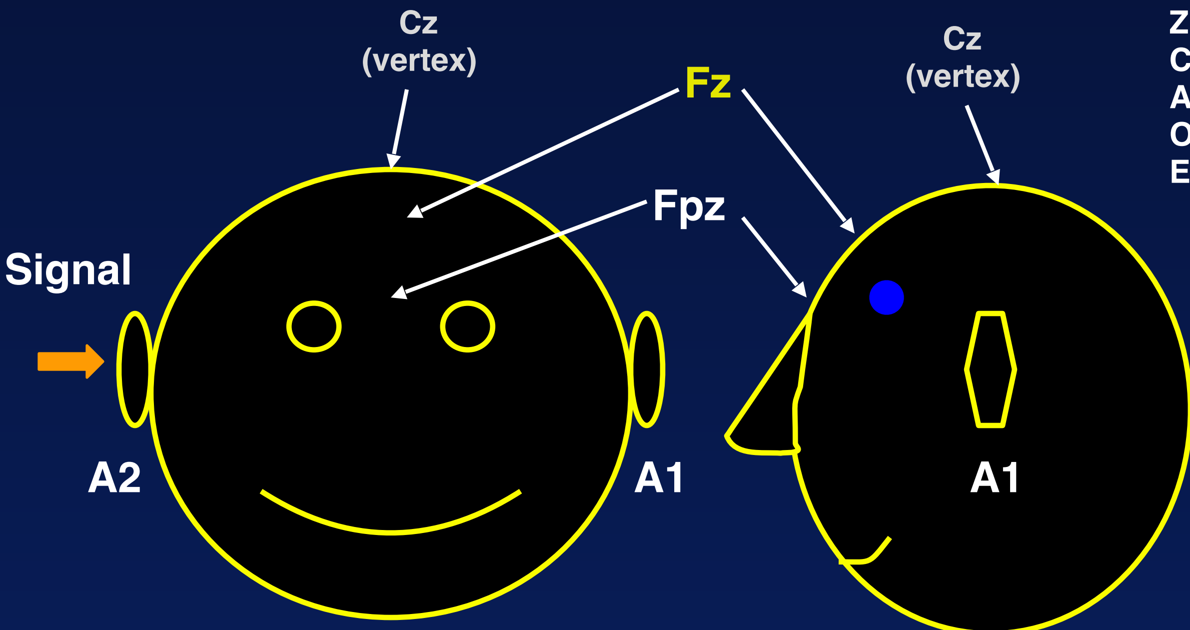


Figure 1.15. Illustration of the conception of differential amplification and common mode rejection (CMR)

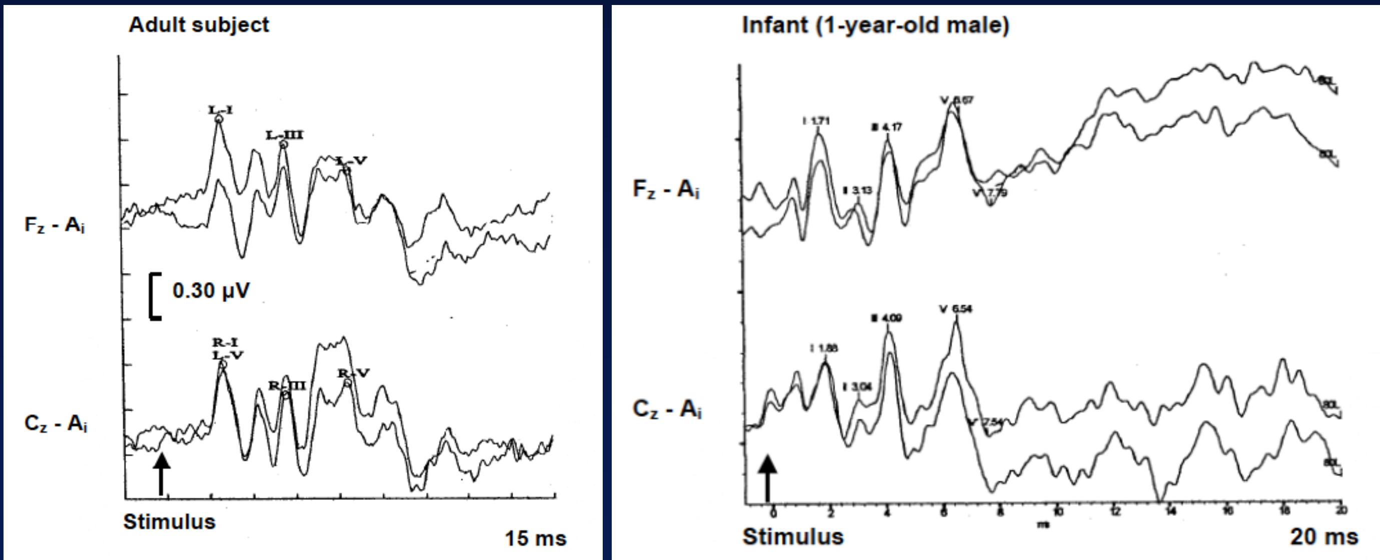
Electrode Locations in ABR Measurement
(10-20 International System)



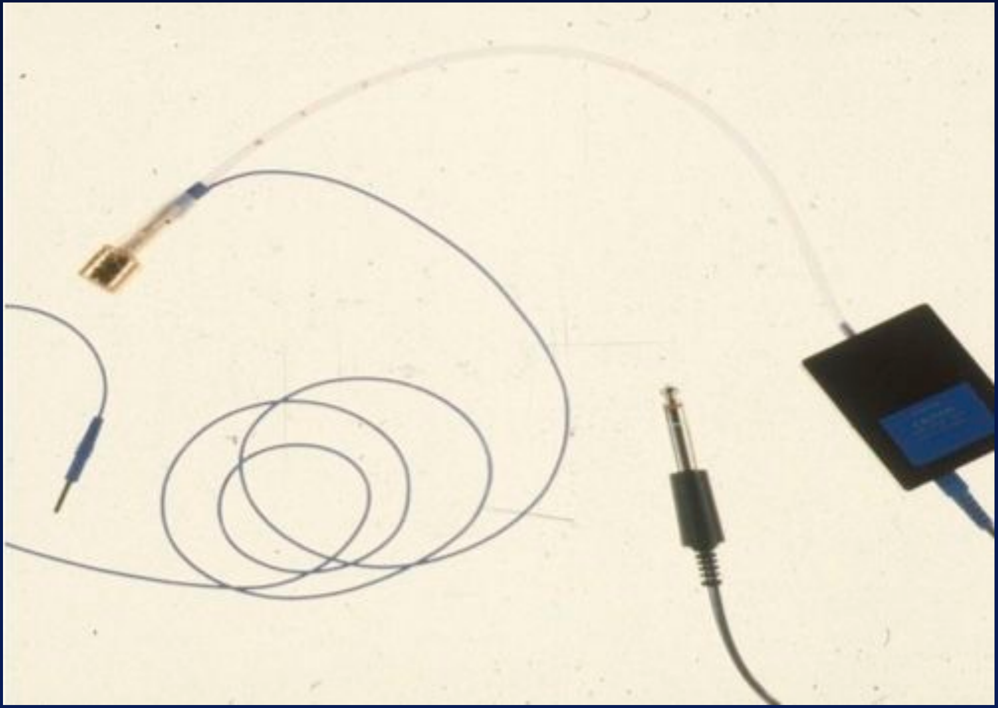
Z = midline
C = coronal
A = auris
Odd #s = left
Even #s = right

ABR Measurement
Electrode Locations and Arrays

ABR Measurement:
Impact of Fz versus Cz Electrode Site
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

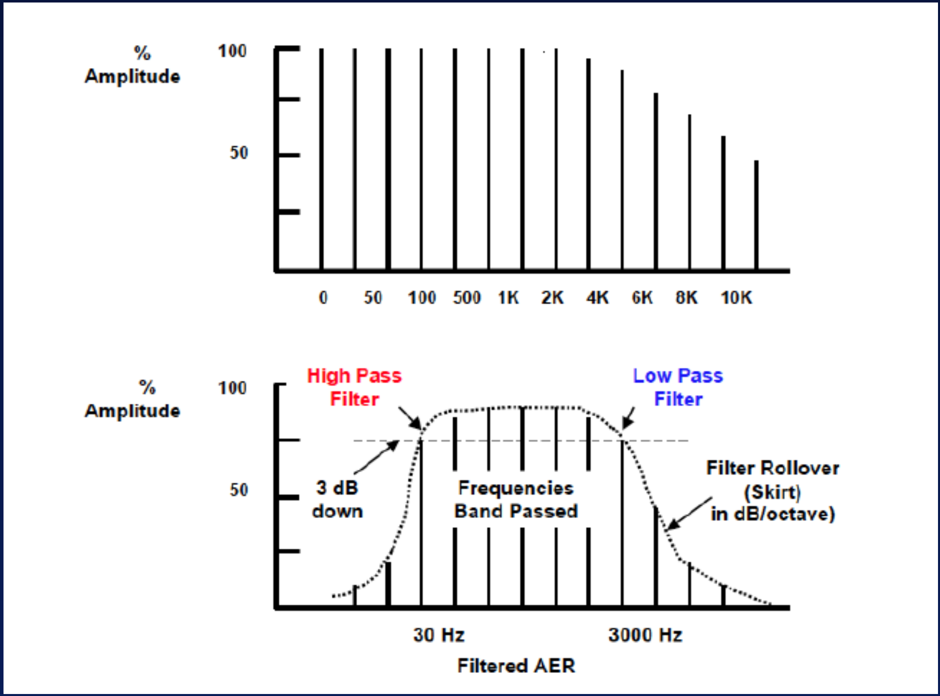


TIPtrode Electrode Type: Combination Transducer and Electrode



ABR Measurement:
Preparation for TIPtrode Placement

ABR Filter Settings:
Spectrum of ABR is About 100 Hz – 1000 Hz
High Pass = 30 Hz; Low Pass = 3000 Hz



Auditory Brainstem Response Measurement: *Factors Affecting Decisions About Analysis Time* (Table from Hall JW III. eHandbook of Auditory Evoked Responses)

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

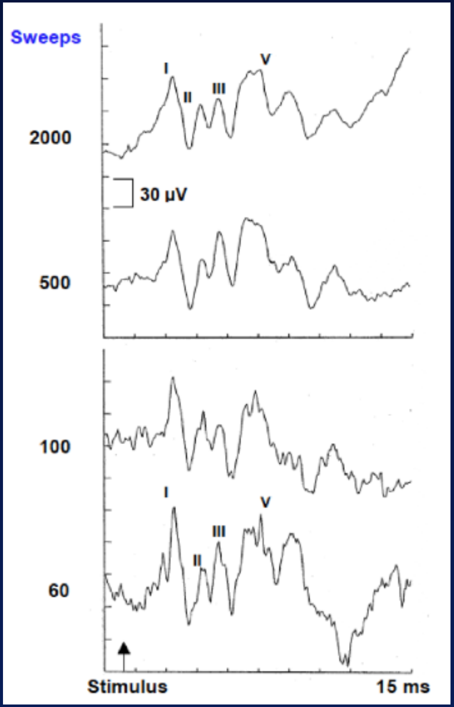
Auditory Brainstem Response Measurement: *Signal Averaging (Number of Sweeps)*

Signal-to-noise ratio (SNR) =

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

ABR Measurement: Saving Test Time and Preserving Valuable Data: *Signal Averaging or Number of Sweeps*

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



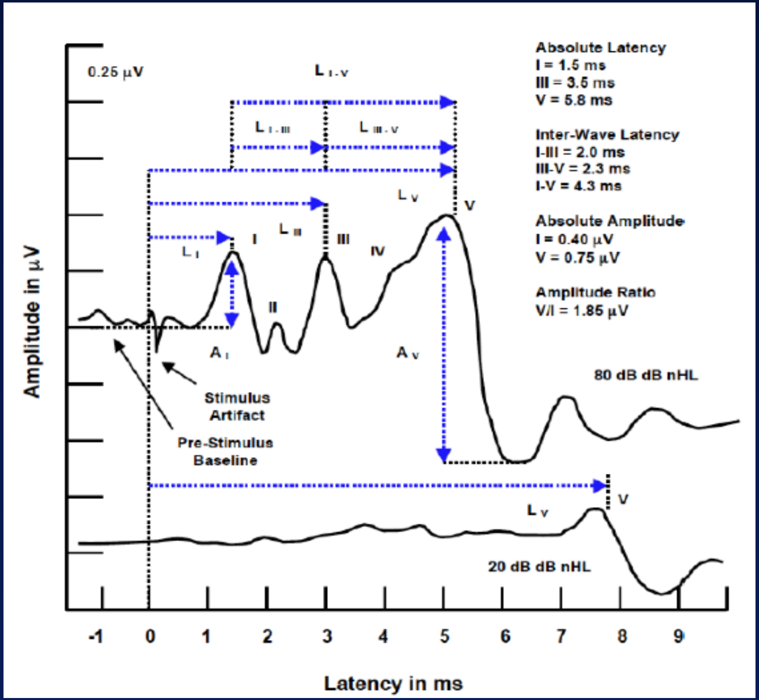
Introduction to ABR Analysis:
Formula for Successful ABR Measurement and Analysis

Evidence-Based Test Protocol + Quiet Patient = Optimal ABR

Optimizing Patient State for ABR and ASSR Measurement: *Clinical Options*

- Sleep deprivation
  - Detailed instructions for parents/caregivers
  - Atypically late bedtime for child
  - Extra adult during transportation to clinic
  - Schedule ABR for first appointment in morning
  - Prepare for ABR immediately upon patient arrival at clinic
  - Record ABR after feeding
- Melatonin
  - Over-the-counter substance
  - Research supports effective sleep enhancement (Schmidt et al, 2007)
- Conscious sedation, e.g.,
  - Chloral hydrate (no longer an option in USA)
- Anesthesia, e.g.,
  - Propofol

Introduction to ABR Analysis:
Latency and Amplitude
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



ABR Waveform Analysis: *Initial Steps*

- Is wave I reliably detected at a high level (85 dB HL)?
  - Delayed wave I latency with good waveform morphology --> conductive component
  - Small or absent wave I --> high frequency sensory hearing loss
- Are inter-wave latencies WNL or abnormally prolonged?
  - Unilateral or bilateral?
  - Wave I-III, wave III-V, and/or wave I-V latencies?
- Initial objective = differentiation among
  - Conductive hearing loss
  - Sensory hearing loss
  - Neural auditory dysfunction

ABR Analysis:
Enhancing Waveform Morphology
(Table from Hall JW III. eHandbook of Auditory Evoked Responses)

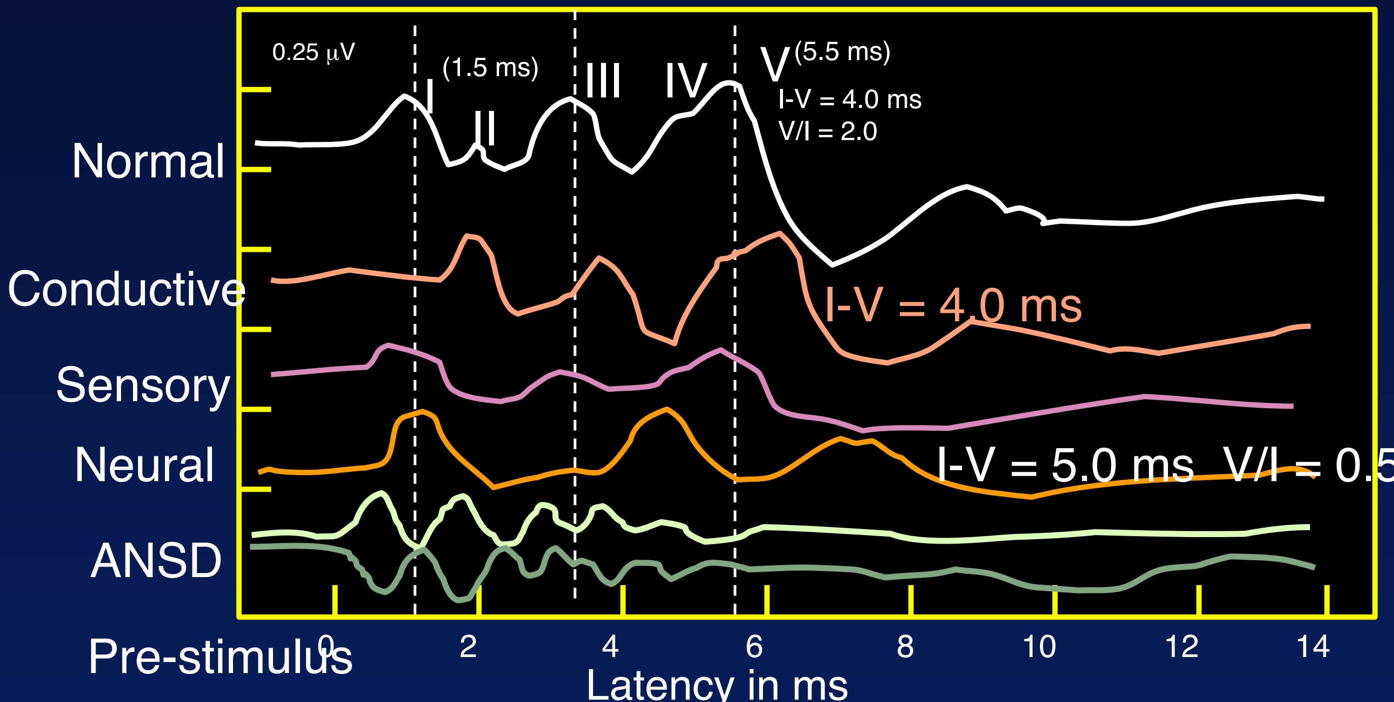
Enhancing ABR amplitude:

- Increase stimulus intensity
- Use non-cephalic non-inverting electrode (ABR wave V)
- Use inverting electrode closer to the cochlea (ABR wave I)
- Slow stimulus presentation rate (ABR wave I)
- Change to another stimulus polarity
- Record ABR with chirp stimuli

Minimizing measurement noise:

- Increase number of sweeps (signal averaging)
- Use weighted averaging option
- Sum replicated waveforms
- Alter filter settings as necessary
- Take steps to minimize patient movement and physical activity

Diagnostic Value of the Click-Evoked ABR: Differentiation Among Types of Auditory Dysfunction



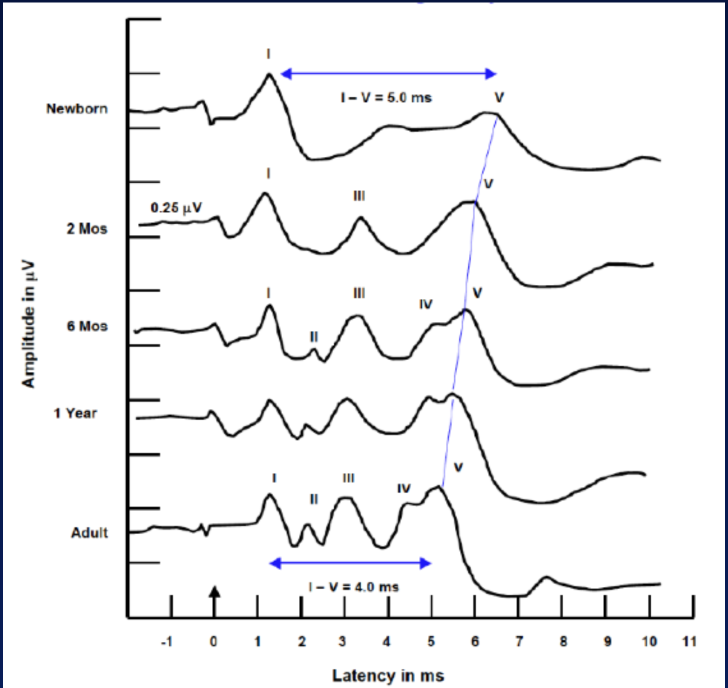
Diagnostic Value of the Click-Evoked ABR: Differentiation Among Types of Auditory Dysfunction

- Recommend beginning an ABR assessment with click stimuli
- Only requires a few minutes of test time
- Analysis permits differentiation among types of hearing loss
- Waveform analysis indicates test ear (presence of wave I)
- Identification of auditory neuropathy spectrum disorder
- Findings help to determine next steps in the assessment, e.g.,
  - Bone conduction ABR
  - Tympanometry
  - ASSR
- Recommended by the:
  - 2007 Joint Committee on Infant Hearing (USA)
  - International clinical guidelines (e.g., UK, Canada, Australia)

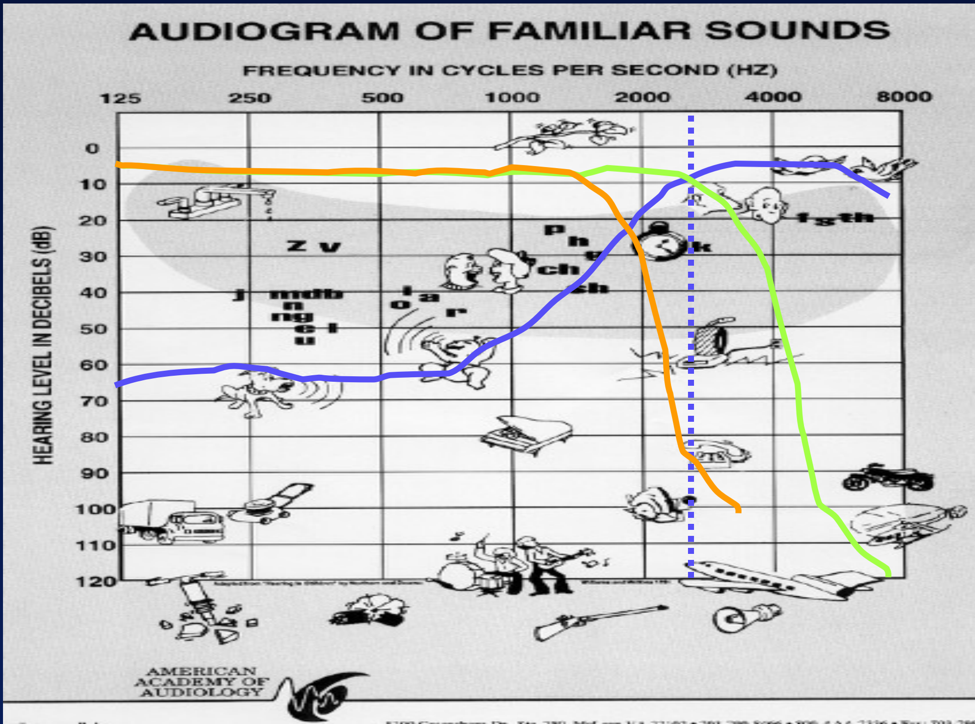
Introduction to Non-Pathologic Factors Influencing ABR Analysis

- Age
  - Marked developmental changes (< 18 months)
  - Modest changes with advanced age
- Gender
  - Shorter latencies in females versus males
- Body temperature
  - Prolonged latency in *hypo*thermia (0.2 ms/1 degree)
  - Shorter latency in *hyper*thermia (0.2 ms/1 degree)
- Drugs (medications)
  - Sedatives = no effect
  - Selected anesthetic agents = slight effect on latency

Introduction to Factors Influencing ABR Analysis: *Maturation of ABR … Developmental Factor*



Strengths and Weaknesses of Click-Evoked ABR: Diagnostically Useful but Limited Frequency-Specificity



Normal click ABR

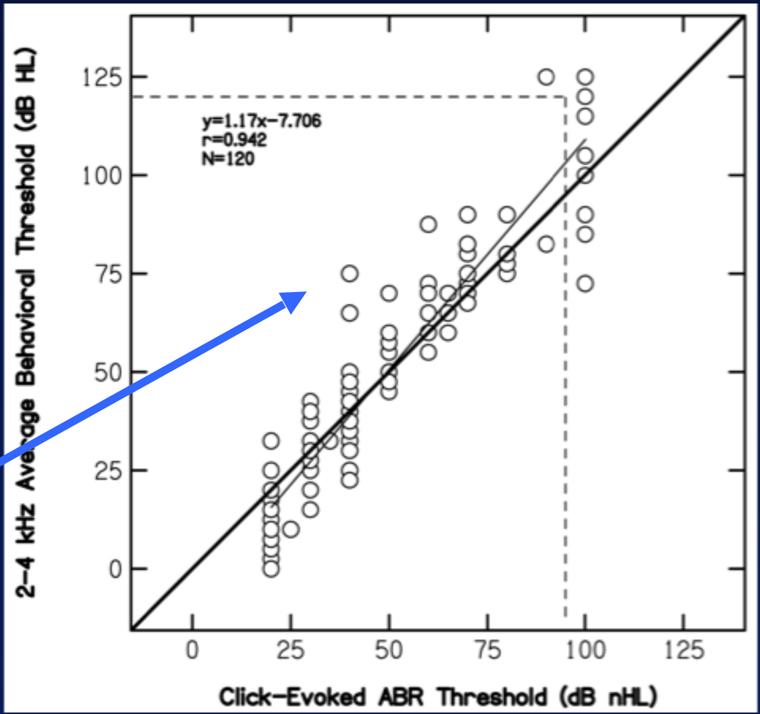
Abnormal or no click ABR

Gorga et al (2006). Using a combination of click- and toneburst evoked auditory brainstem response methods to estimate pure-tone thresholds. *Ear & Hearing, 27, 60-74*

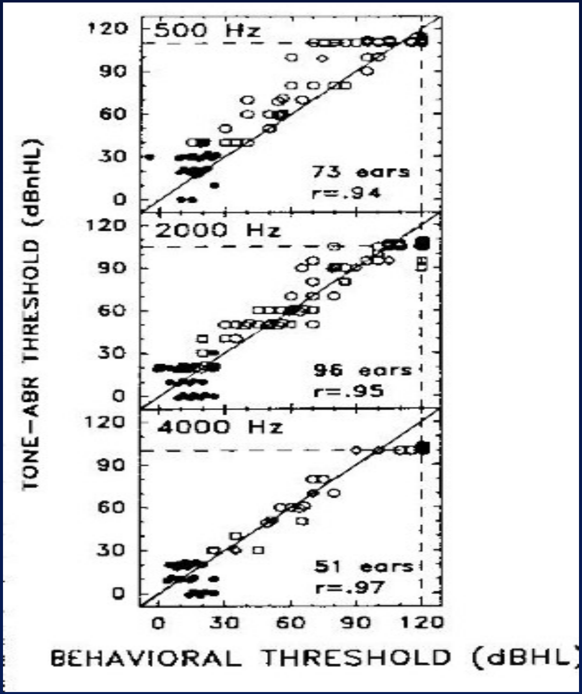
Click ABR Threshold versus Pure Tone Hearing Threshold (2 to 4 K Hz)

N = 77
71 = < 5 years

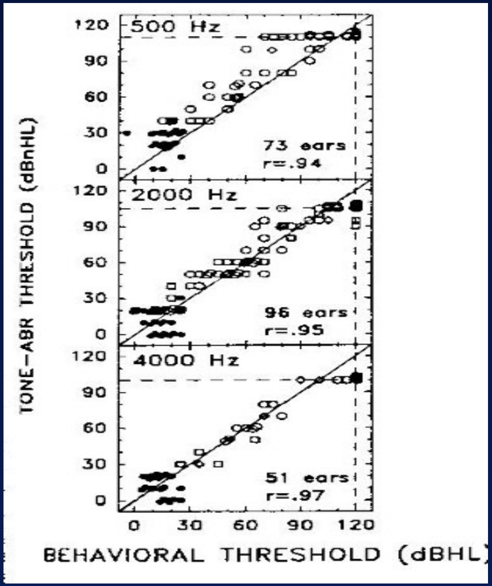
Click ABR Threshold Better Than Pure Tone Threshold

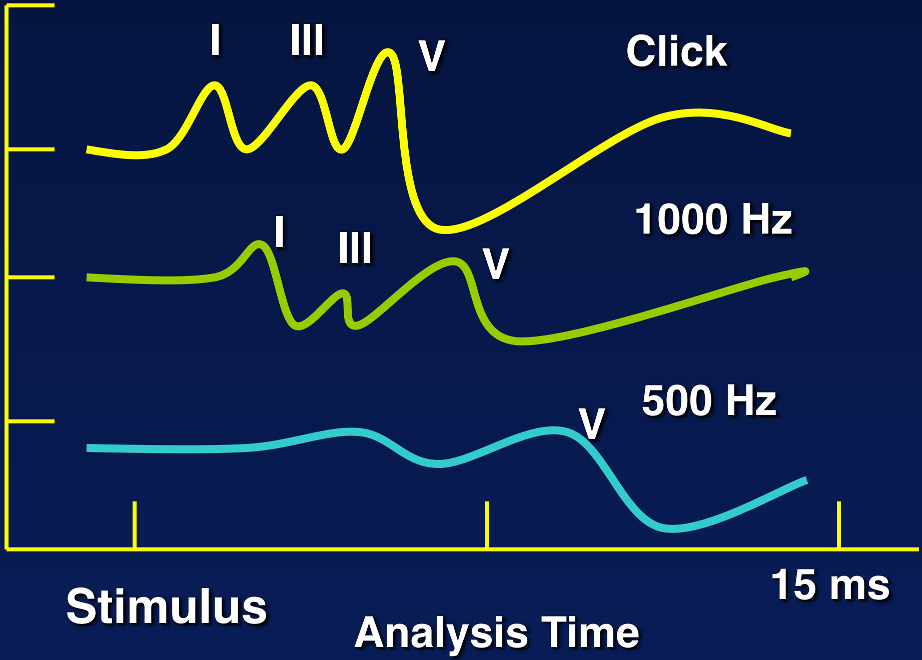


Tone Burst ABR:
Relation to Audiogram
(Oates & Stapells, 1998)

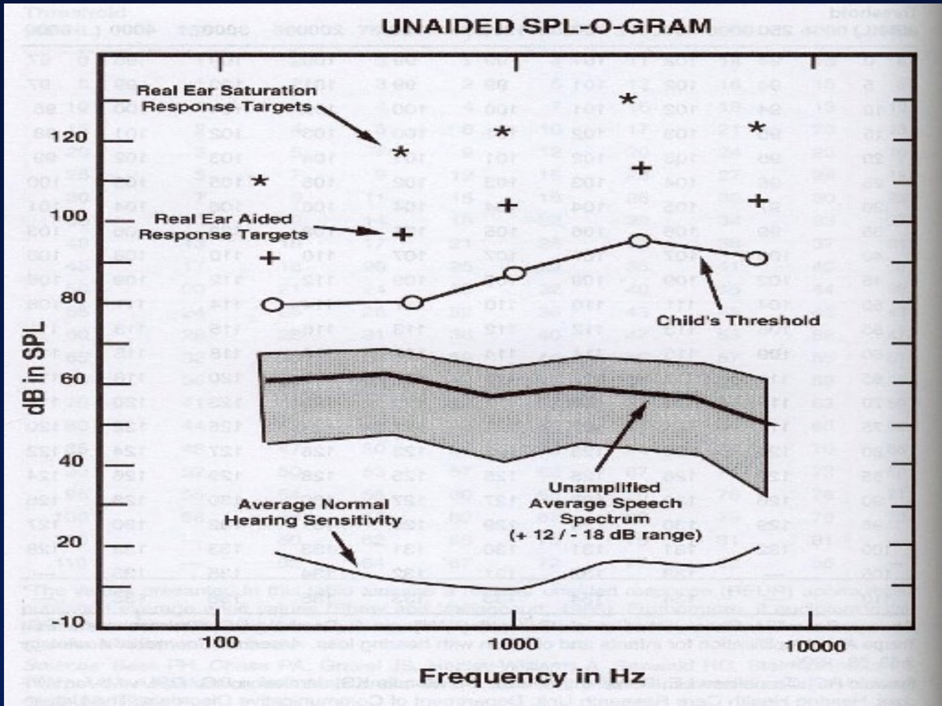


Waveform Analysis: Click versus Tone Burst ABRs
(Oates & Stapells, 1998)



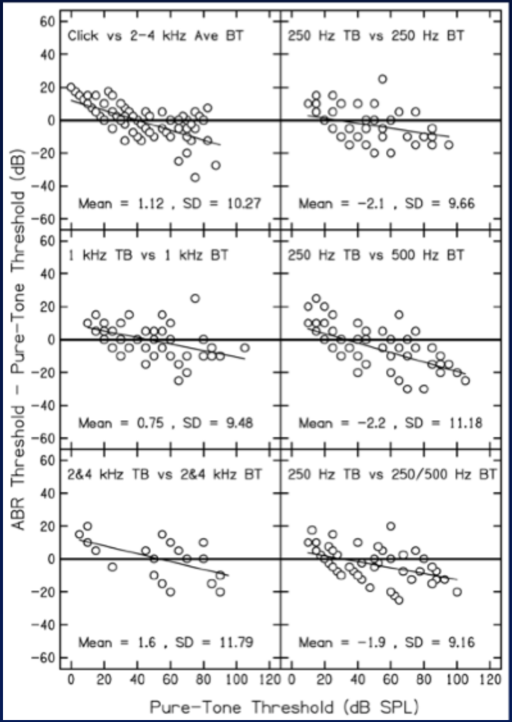


Estimation of Frequency-Specific Auditory Thresholds with Tone Burst ABRs: *Initial Data Points for Hearing Aid Fitting or Cochlear Implant Candidacy*



Gorga et al (2006). Using a combination of click- and toneburst evoked auditory brainstem response methods to estimate pure-tone thresholds. *Ear & Hearing, 27, 60*-74

N = 77
71 = < 5 years



Correction Factors for Converting ABR Thresholds in dB nHL to Estimated Behavioral Thresholds in dB HL (or EHL)
Normal Hearing Patients

Source	500 Hz	1000 Hz	2000 Hz	4000 Hz
BCEHP	-15 dB	-10 dB	-5 dB	0 dB
Bagatto (2006)	-20 dB	-15 dB	-10 dB	-5 dB
Hall (2007)	-15 dB	-10 dB	-10 dB	-10 dB

Note: According to Stapells (2000), ABR thresholds "overestimate" behavioral thresholds by 10 to 20 dB for normal hearers and 5 to 15 dB for patients with sensory hearing loss

Air Conduction Tone Burst ABR Thresholds Minus Behavioral Thresholds in Infants and Young Children with Hearing Loss

Adapted from Stapells (2011)

Study	500 Hz	1000 Hz	2000 Hz	4000 Hz
Stapells (2000)	+6 dB (+/-14)	+5 dB (+/-14)	+1 dB (+/-11)	-8 dB (+/-12)
Lee (2008)	+5 dB (+/-5)	0 dB (+/-5)	-5 dB (+/-8)	-5 dB (+/-8)
Vander Werff et al (2009)	+13 dB (+/-12)		0 dB (+/-9)	-3 dB (+/-14)

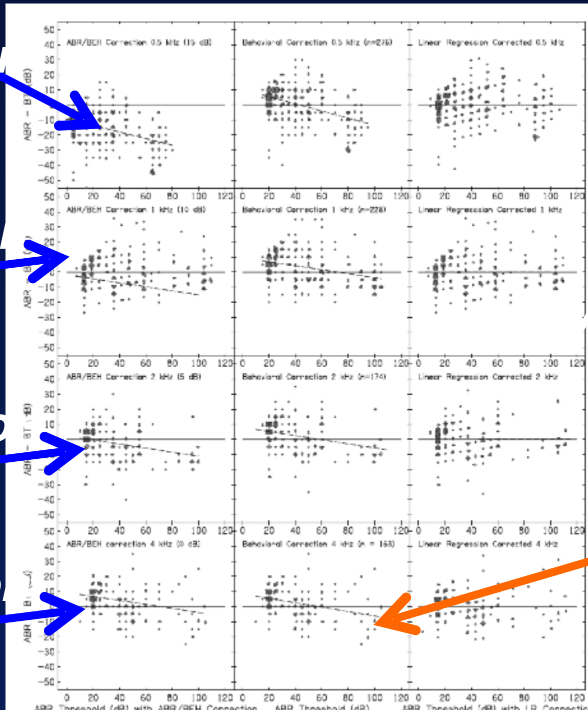
McCreery et al (2014). The impact of degree of hearing loss on auditory brainstem response predictions of behavioral thresholds. *Ear & Hearing*

ABR to eHL correction 15 dB at 500 Hz

ABR to eHL correction 10 dB at 1000 Hz

ABR to eHL correction 5 dB at 2000 Hz

ABR to eHL correction 0 dB at 4000 Hz



N = 177 (309 ears) Average age at ABR = 24 months)

ABR thresholds underestimate hearing levels for > moderate hearing loss

Simple Techniques for Saving Valuable Time in Frequency-Specific Estimation of an Audiogram with Tone Burst ABRs *(Test time of 30 minutes or less)*

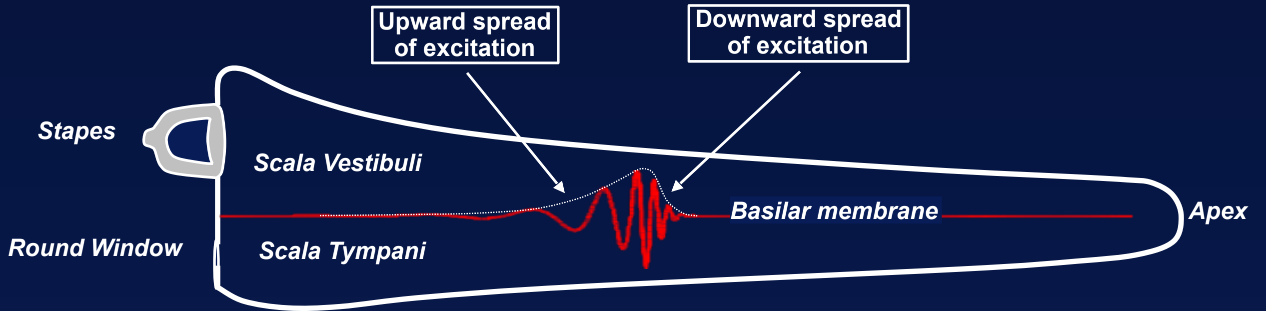
- Be prepared to begin ABR as soon as the child is asleep
  - Equipment is set up with patient information
  - Electrodes are handy with electrode gel or paste
  - Tape is cut
  - Insert earphones are ready with proper size tips
- Record ABR in conditions that optimize the SNR
  - Sleeping, sedated, or anesthetized child
  - Low and balanced electrode impedance
  - Little or no electrical artifact
  - Deep fitting insert earphone (minimize acoustic noise)
- Use a stimulus presentation rate of about 37.7/sec Immediately trouble-shoot if the ABR findings are different from what you expect

Simple Techniques for Saving Valuable Time in Frequency-Specific Estimation of an Audiogram with Tone Burst ABRs *(Test time of 30 minutes or less)*

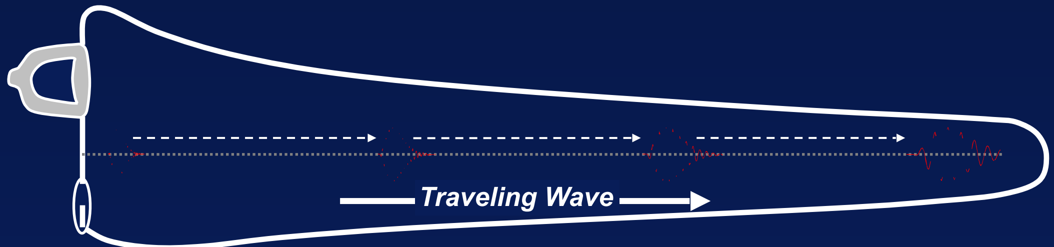
- Think ahead to the next step in the assessment while signal averaging … *don't* do your thinking between periods of data collection
- At high stimulus intensities
  - Discontinue signal averaging as soon as a clear response is detected (< 500 stimuli or sweeps)
  - Immediately replicate with even fewer averages
  - Calculate latencies and amplitudes while also collecting data at the next intensity level
- Drop the stimulus intensity level as quickly as possible to near threshold (e.g., from 80 dB nHL down to 40 dB nHL if the ABR has a wave I and wave V)
- After hearing thresholds are estimated with click stimuli, begin presenting subsequent tone burst stimuli at intensity levels 20 to 30 dB above anticipated ABR threshold
- Don't replicate "flat" ABR tracings

Chirp Stimuli in ABR Measurement:
A Valuable Supplement to Traditional Stimuli

Cochlear Excitation Patterns for Click versus Narrow Band Stimulation

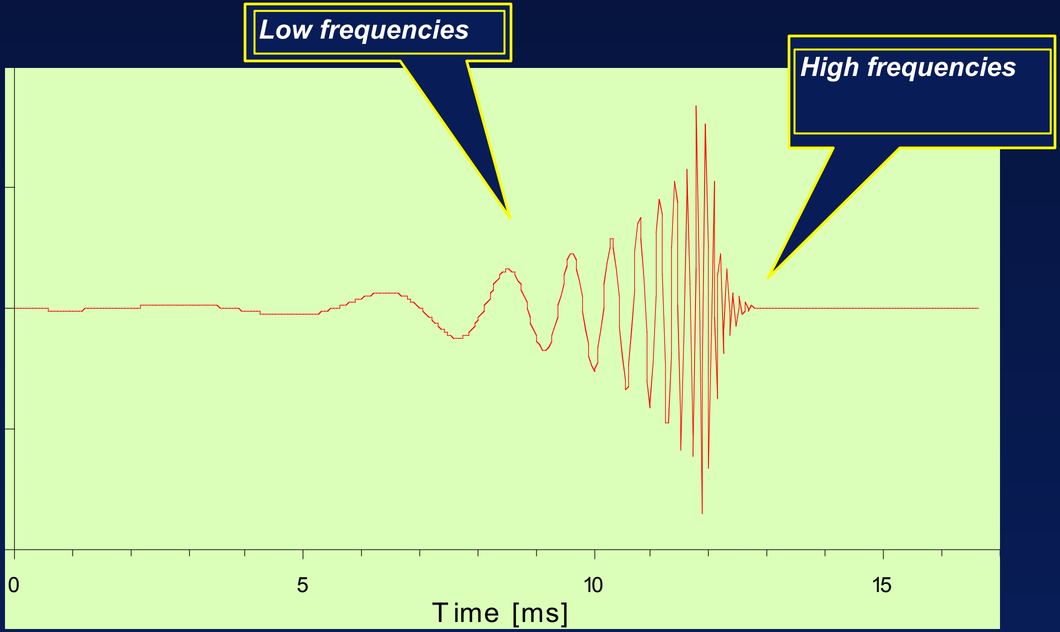


Continuous, narrow band stimuli

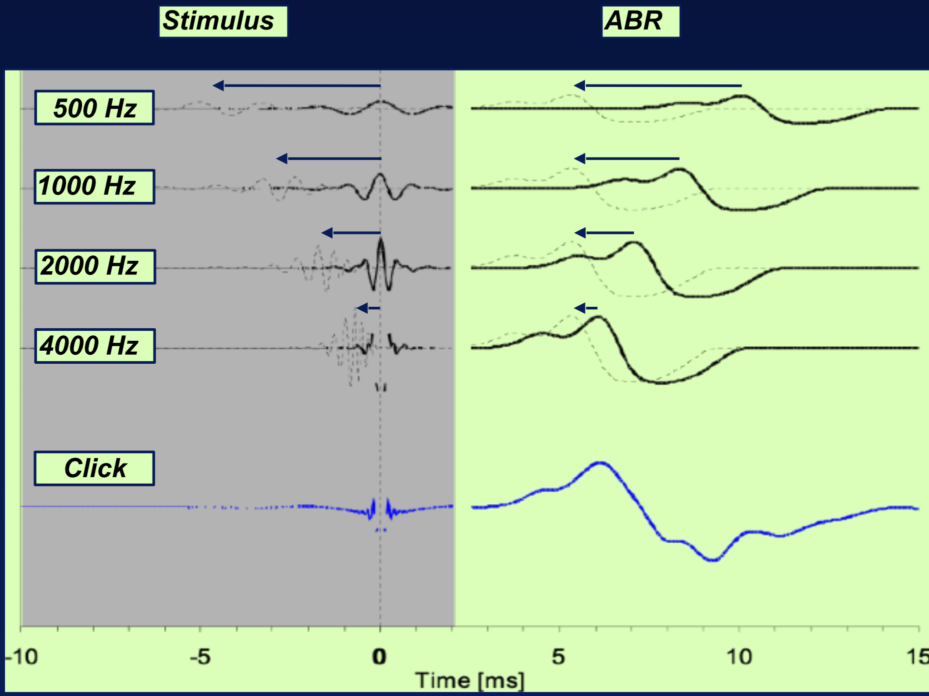


Transient, broad band stimuli

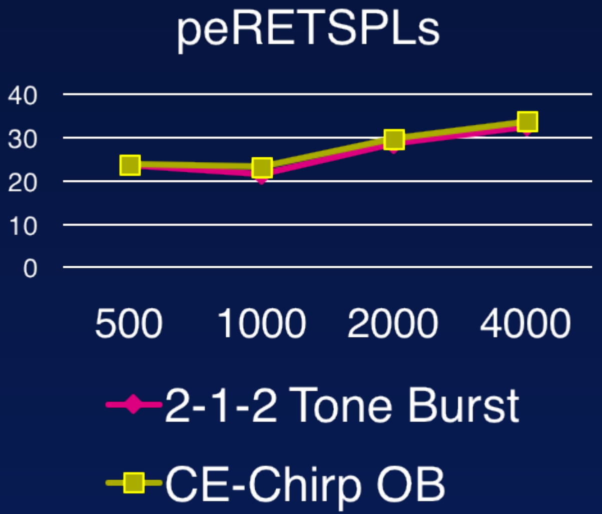
Chirp Temporal Waveform



Temporal Compensation via Input Compensation
(Courtesy of Claus Elberling)



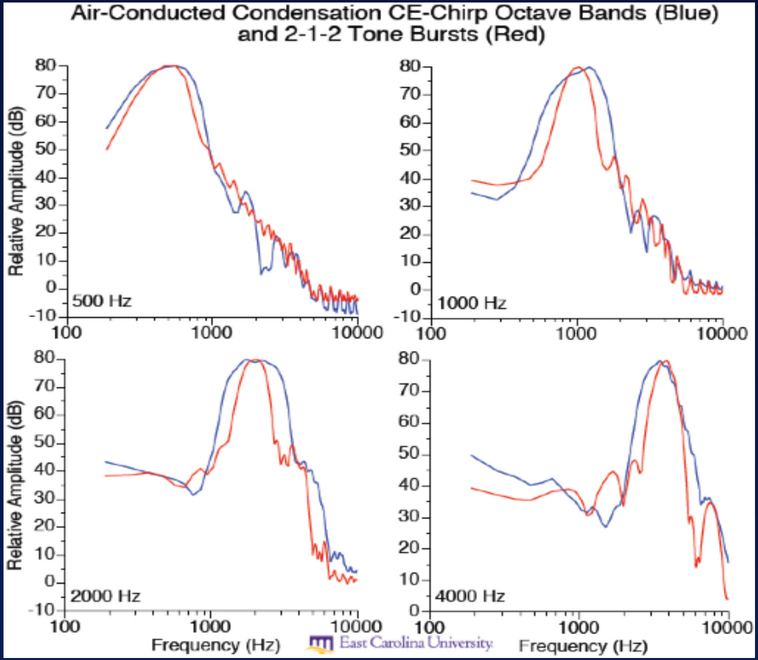
peRETSPLs: CE-Chirp Octave Bands vs. Tone Bursts



- ISO 389-6: 2-1-2 Tone Burst peRETSPLs (blue = tone bursts)
- 3A Insert Earphones using 711 ear simulator
- Range of 0.4 to 1.8 dB difference

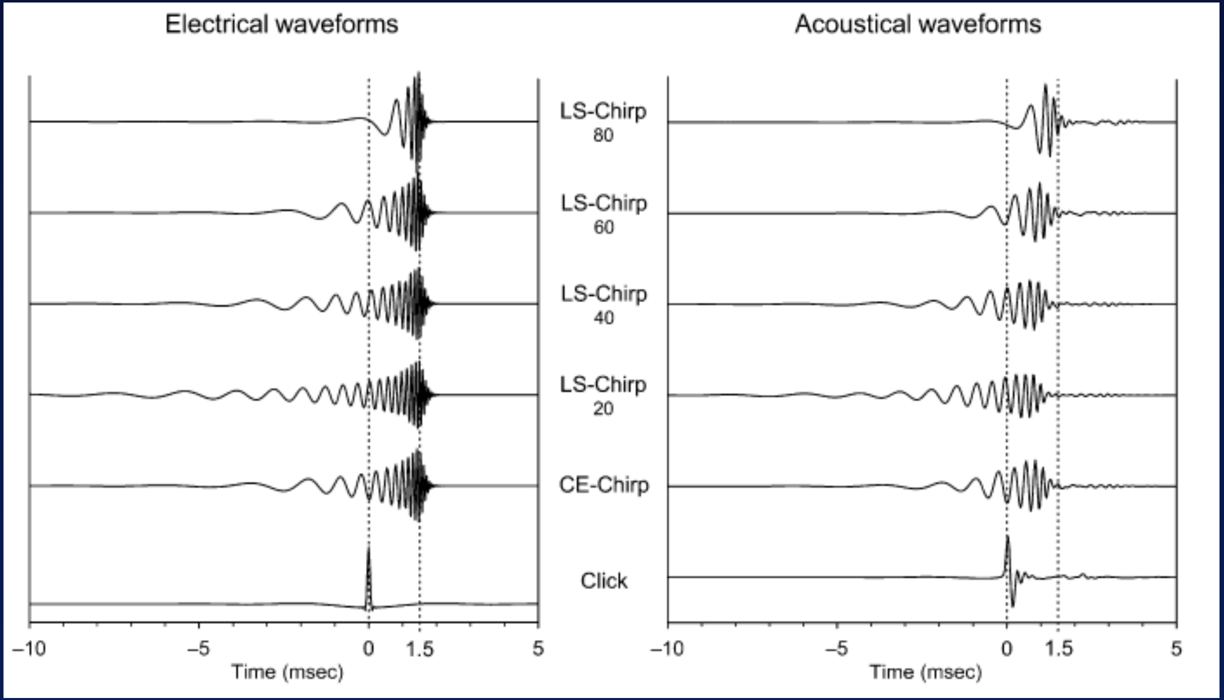
Reference: Gotsche-Rasmussen, Poulsen, Elberling, Reference Hearing Threshold Levels for Chirp Signals Delivered by an ER-3A Earphone, International Journal of Audiology, 2012, Early Online: 1-6

Acoustic Spectrum:
CE-Chirp Octave Bands vs. Tone Bursts



Courtesy of East Carolina University

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



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

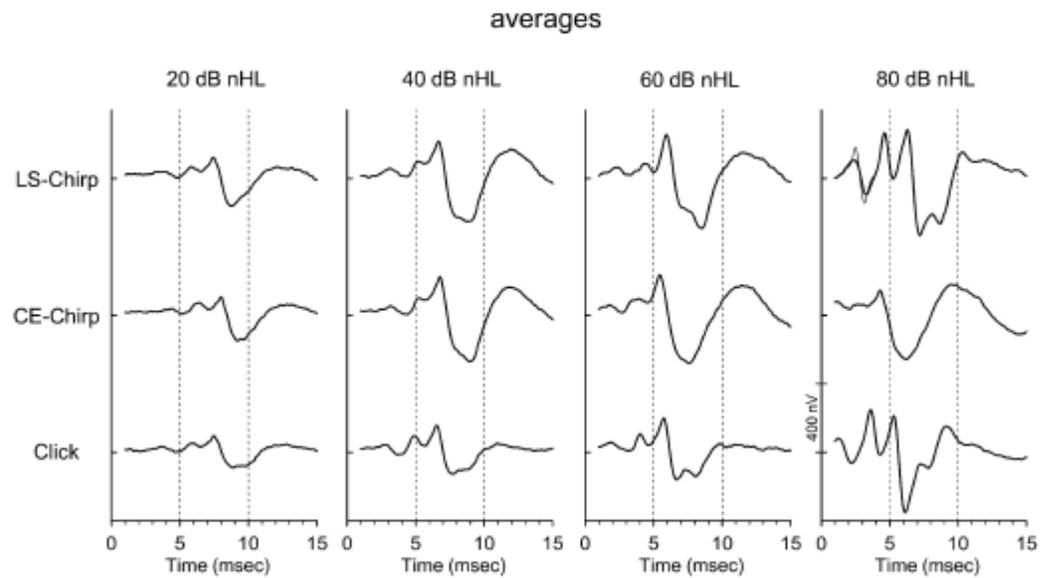
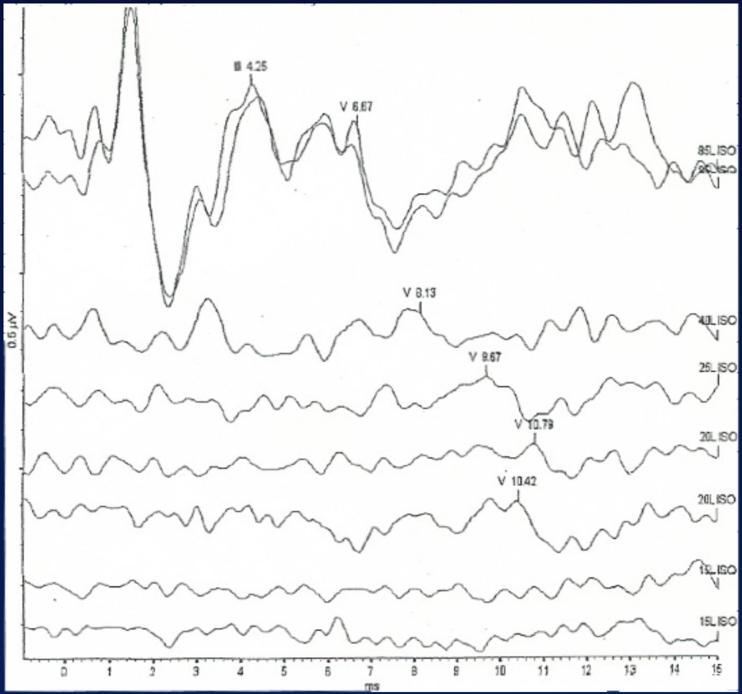


Figure 6. Grand Average ABR waveforms from N = 20 ears. The Grand Averages are obtained by time-shifting the underlying individual waveforms according the wave V latency. The thin line in the LS-Chirp/80 dB nHL condition shows a small part (corresponding to wave I) of the Grand Average obtained by using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

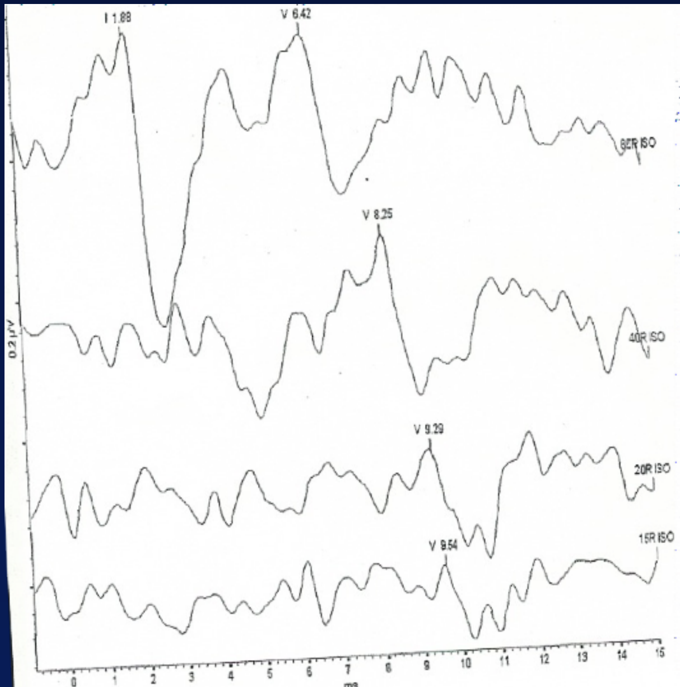
15 dB nHL Click

15 dB nHL CE Chirp

4000 Hz Chirp Evoked ABR

Stimulus rate = 37.7/sec

Total sweeps = 2622; Total test time = 69.5 seconds



Right Ear
80 dB nHL
684 sweeps

40 dB nHL
456 sweeps

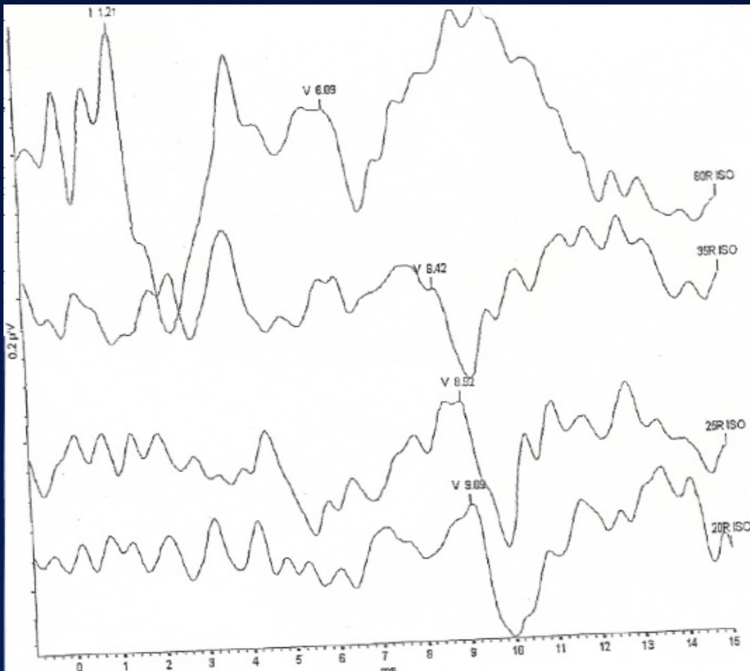
20 dB nHL
570 sweeps

15 dB nHL
912 sweeps

2000 Hz Chirp Evoked ABR

Stimulus rate = 37.7/sec

Total sweeps = 2318 ; Total test time = 61 seconds



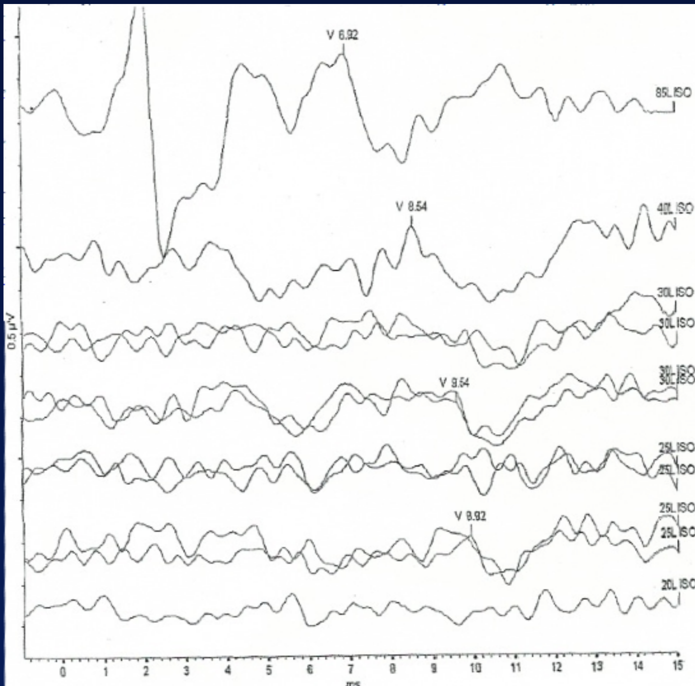
80 dB nHL
722 sweeps

35 dB nHL
570 sweeps

25 dB nHL
456 sweeps

20 dB nHL
570 sweeps

4000 Hz Conventional versus Chirp Evoked ABR



Left Ear
85 dB nHL
Tone Burst

40 dB nHL
Tone Burst

30 dB nHL
Tone Burst

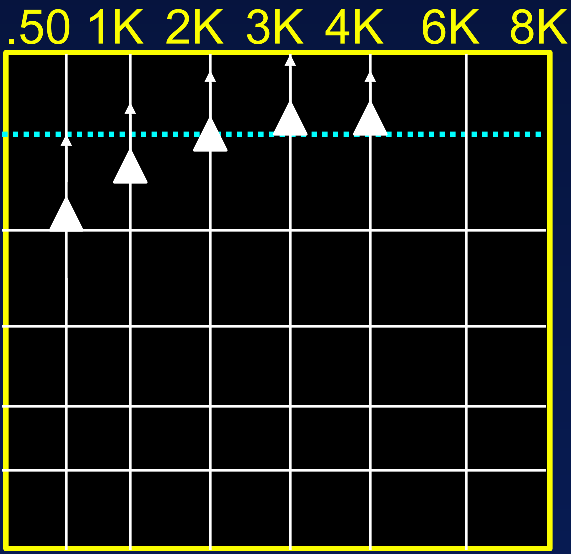
30 dB nHL, Chirp Tone Burst

25 dB nHL, Tone Burst

25 dB nHL, Chirp Tone Burst

15 dB nHL, Chirp Tone Burst

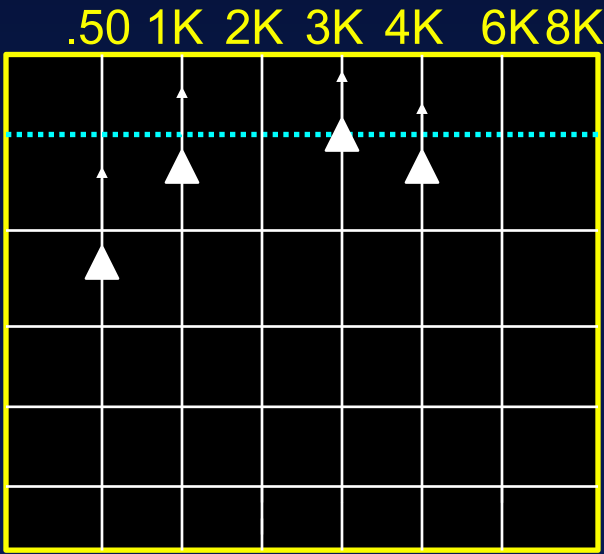
Electrophysiologic Estimation of the Audiogram:
One year 4 month boy



Right Ear
Frequency in Hz

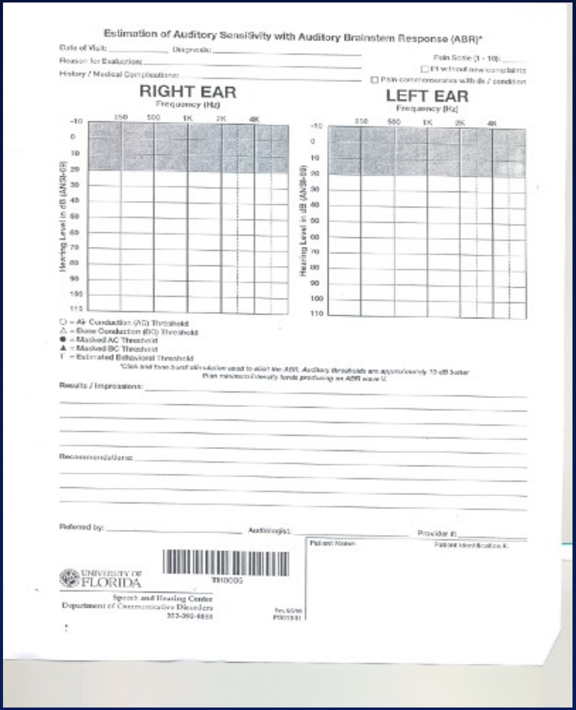
dB
HL
20
40
60
80
100

PT
ABR
ASS



Left Ear
Frequency in Hz

Plotting ABR Thresholds and Estimated Behavioral Hearing Levels



Advantages of CE-Chirp Stimulation of the Auditory Brainstem Response (ABR): *Advantages of Chirp Stimulation*

- ABR amplitude is up to two times larger for chirp stimulation
- Larger amplitude contributes to:
  - More confident identification of wave V
  - Shorter test time is needed to identify wave V
  - Reduced test time for each stimulus frequency permits more complete estimation of auditory threshold in speech frequency region
  - More accurate thresholds are sometimes possible with chirp stimulation

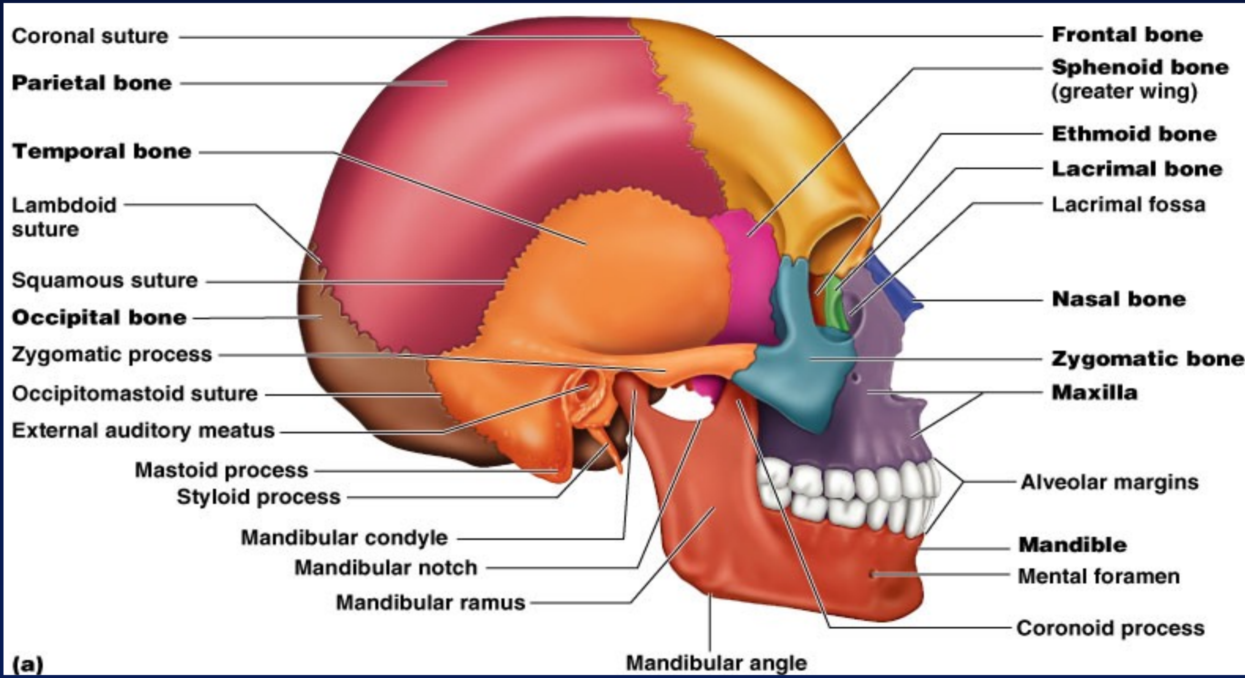
Keys To Confident Analysis of ABR Waveforms: *Click and Tone Burst Stimulation*

- Minimize background (residual) noise in ABR measurement
  - Quiet preferably sleeping patient (low myogenic noise)
  - Lowest possible electrical artifact
- Maximize the ABR (the signal)
  - High stimulus intensity level
  - Optimal stimulus characteristics
- Confident identification of a clear response
  - SNR of 3:1
  - Replicability
  - "… as well as meeting the 3:1 signal to noise criteria the waveforms must show the expected characteristics in terms of amplitude, latency, and morphology (NHS, 2013)."

Year 2007 JCIH Position Statement: Protocol for Evaluation for Hearing Loss In Infants and Toddlers from Birth to 6 months

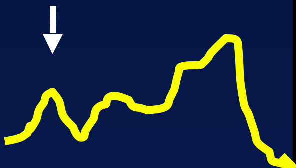
- Child and family history
- Evaluation of risk factors for congenital hearing loss
- Parental report of infant's responses to sound
- "Clinical observation of infant's auditory behavior. *Behavioral observation alone is not adequate for determining whether hearing loss is present in this age group, and is not adequate for the fitting of amplification devices."*
- Audiological assessment
  - Auditory brainstem response (ABR)
    - ✓ Click-evoked ABR with rarefaction and condensation single-polarity stimulation if there are risk factors for auditory neuropathy
    - ✓ Frequency-specific ABR with air-conduction tone bursts
    - ✓ Bone-conduction stimulation (as indicated)
  - Otoacoustic emissions (distortion product or transient OAEs)
  - Tympanometry with 1000 Hz probe tone
  - Supplemental procedures, e.g.,
    - ✓ Electrocochleography (ECochG)
    - ✓ Auditory steady state response (ASSR)
    - ✓ Acoustic reflex measurement (for 1000 Hz probe tone)

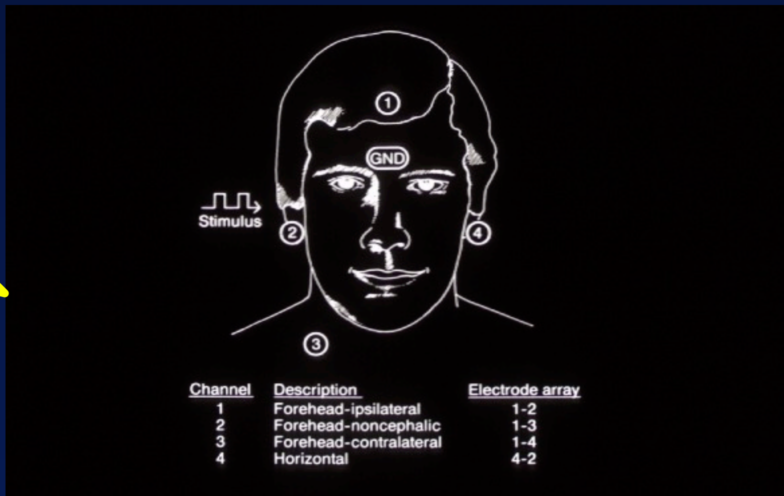
Ear Specific Bone Conduction Auditory Assessment with is Feasible and Often Clinical Necessary



Two-Channel Bone Conduction ABR Recording: Applying ECochG Principles to Verify the Test Ear

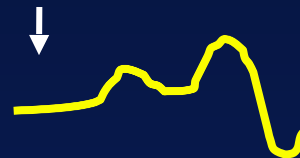
Ipsi Channel
Wave I





Channel	Description	Electrode array
1	Forehead-ipsilateral	1-2
2	Forehead-noncephalic	1-3
3	Forehead-contralateral	1-4
4	Horizontal	4-2

Contra Channel
No Wave I



ABR: Protocol for Bone Conduction

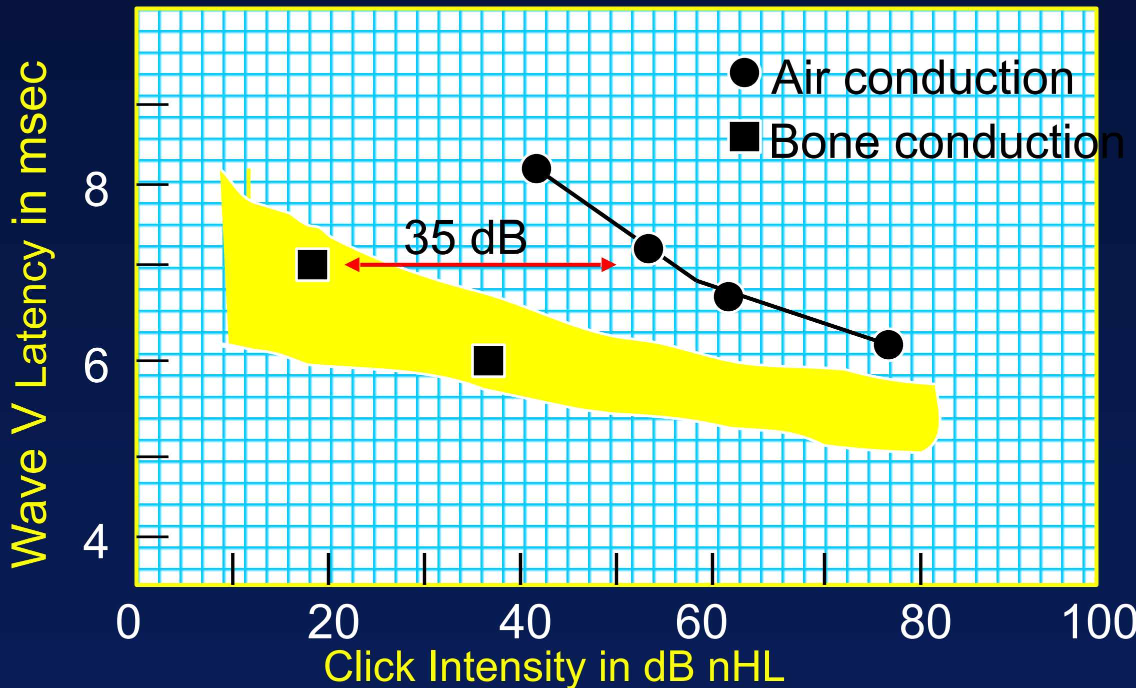
- B-70 or B-71 bone vibrator
- Mastoid placement
  - 10 dB increase in intensity
  - Less electrical interference with recording electrodes
- Leave insert earphones in ear canals for BC ABR
- Distance between inverting electrode and transducer
- Alternating click stimuli to minimize stimulus artifact
- Slower rate (e.g., 11.1/sec) as needed to enhance wave I
- 30 to 3000 Hz (low frequencies enhance amplitude)
- Begin near maximum intensity level (about 50 dB nHL)
- Identify wave I in ipsilateral array to verify test ear
- Plot latency/intensity function for wave V for BC vs. AC

Bone Conduction:
Head Band Placement for Infants

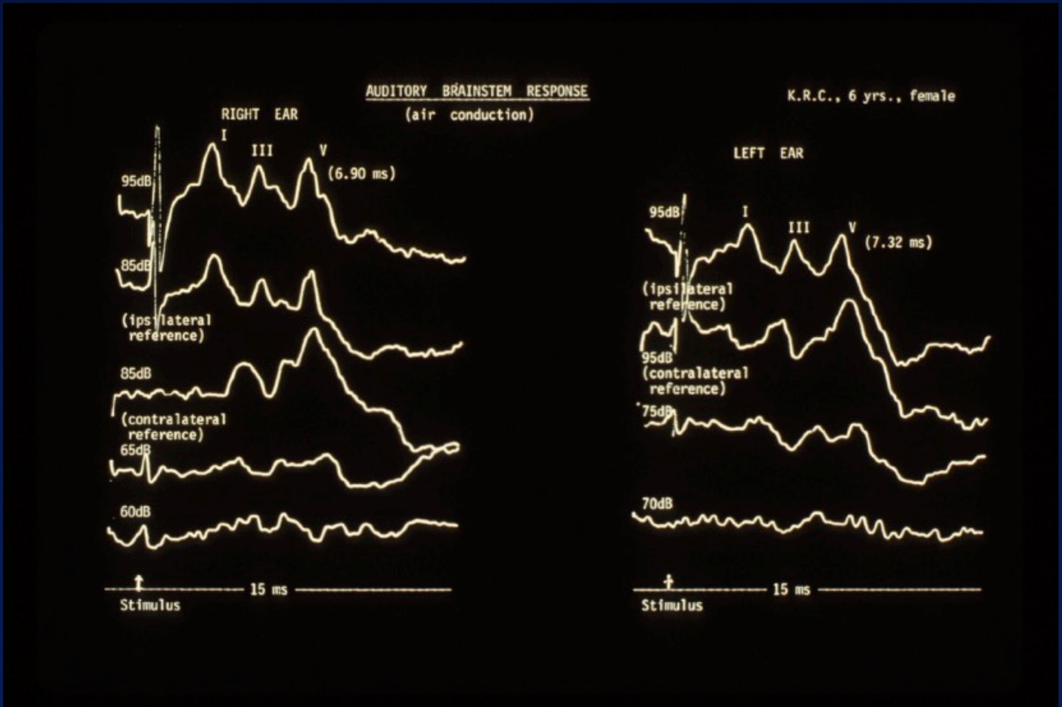
Posterior Placement Away from Electrodes

Adjusting the Head Band for Infants

Example of Estimation of Air-Bone Gap with ABR



Case Report: 6-Year Old Girl with Treacher Collins Syndrome and Bilateral Aural Atresia
(Air Conduction ABR)



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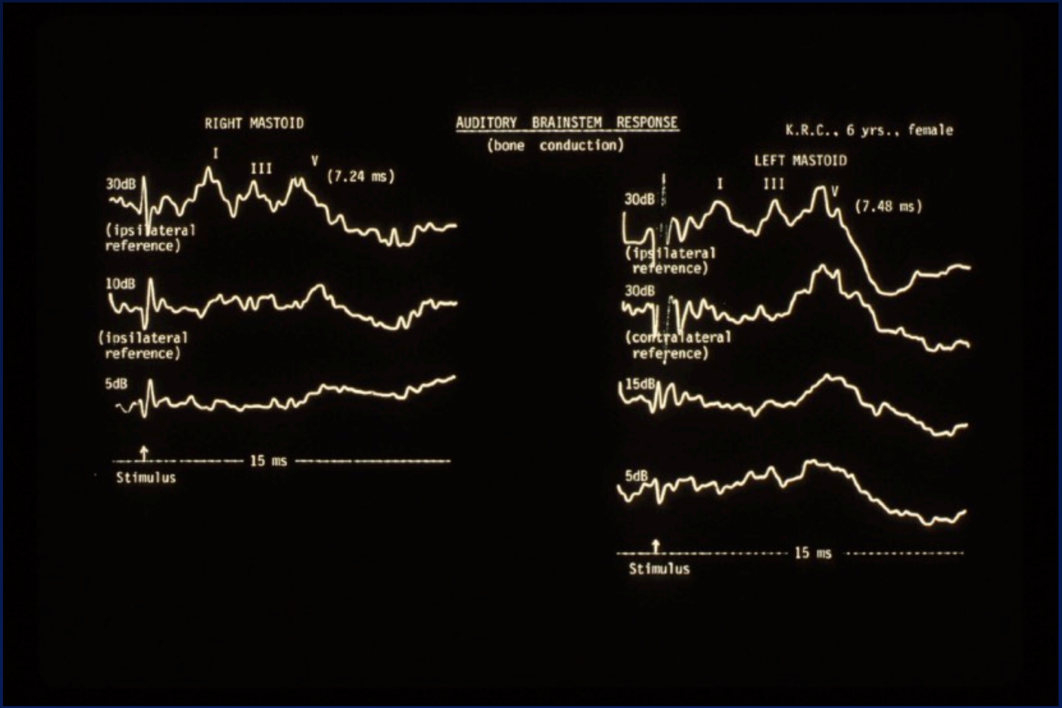
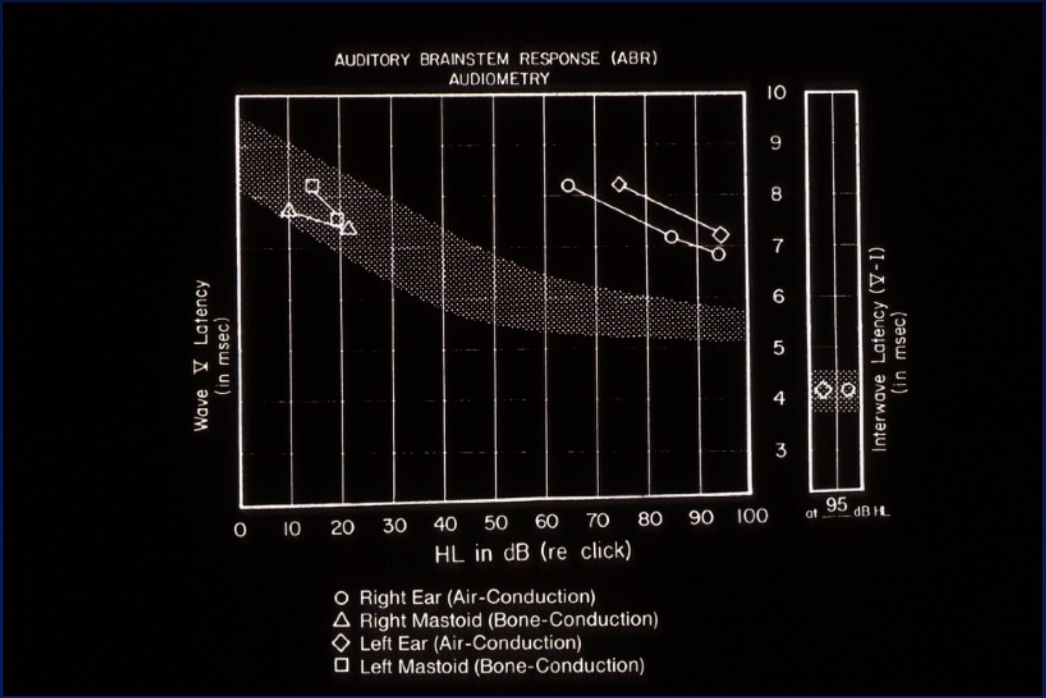
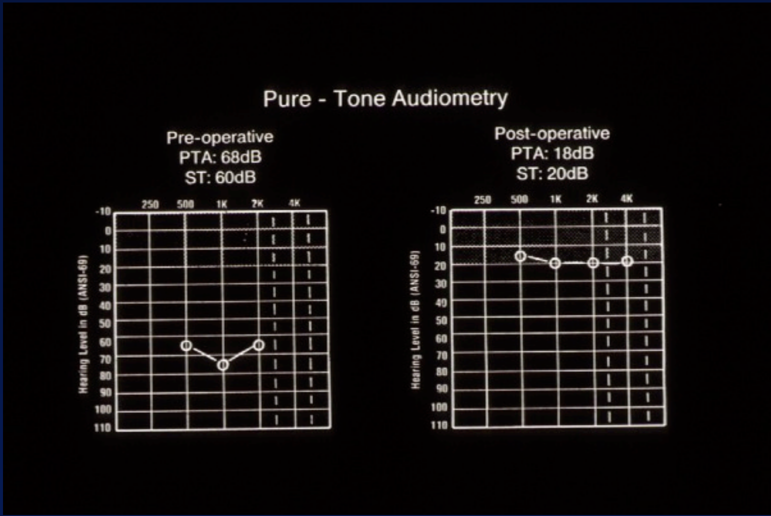


Case Report: 6-Year Old Girl with Treacher Collins Syndrome and Bilateral Aural Atresia

Estimating Air Bone Gap from Wave V L-I Function



Case Report: 6-Year Old Girl with Treacher Collins Syndrome and Bilateral Aural Atresia
Normal Hearing Following Surgical Repair

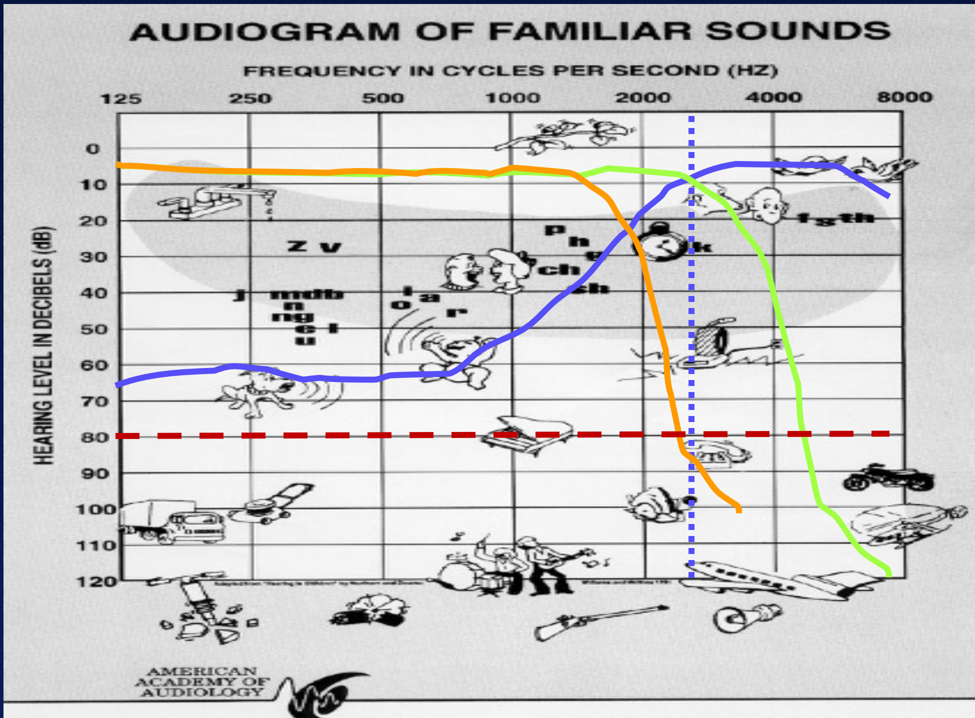


Robert Jahrsdoerfer, MD

Clinical Measurement and Applications of Bone Conduction ABR: Click or Tone Burst Bone Conduction Stimulation

- Rationale for click only
  - Air conduction tone burst information is most useful
  - Test time is unacceptably lengthy with addition of tone burst bone conduction recordings
  - Confident identification of ABR is more likely with click versus tone burst stimulation
  - Provides information needed for management decisions
- Rationale for tone burst stimulation
  - Consistent with protocol for behavioral audiometry
  - Click stimulation may underestimate conductive component
    - ✓ Only estimates air-bone gap in the high frequency region
    - ✓ Conductive hearing loss is usually greatest in low frequency region

Limitation of Click-Evoked ABR: Lack of Frequency-Specificity

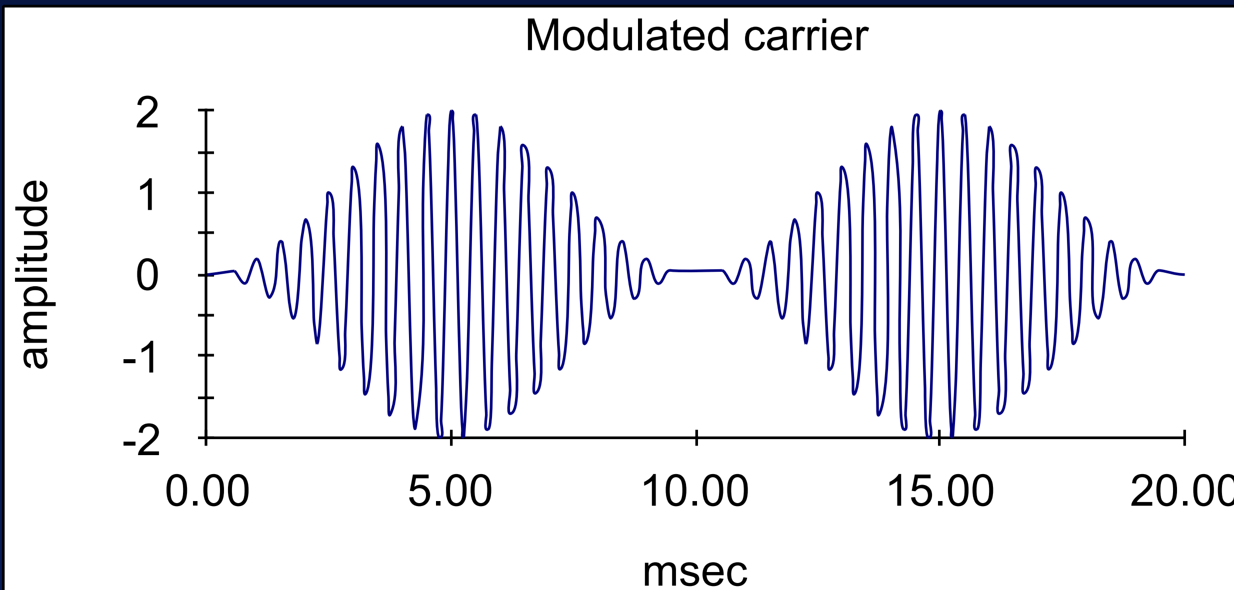


Normal click ABR

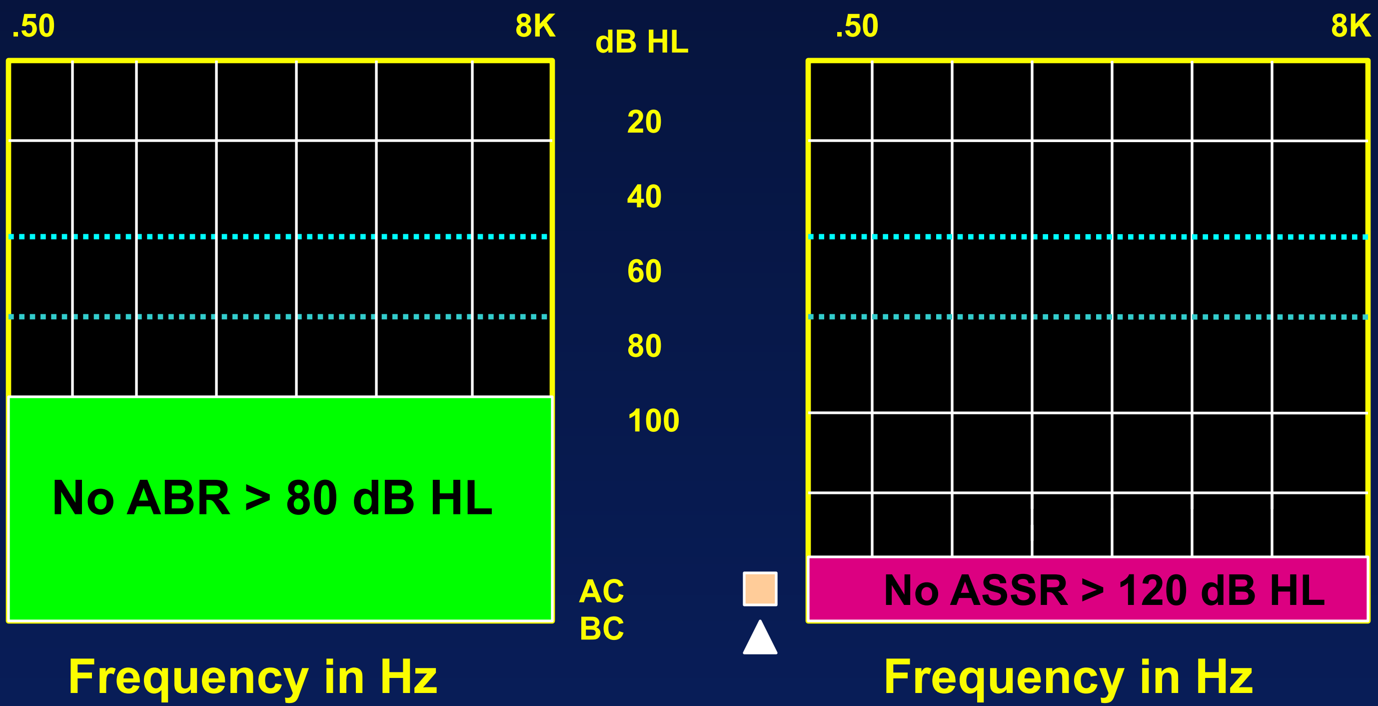
Abnormal or no click ABR

Upper Intensity Limit for Recording ABR

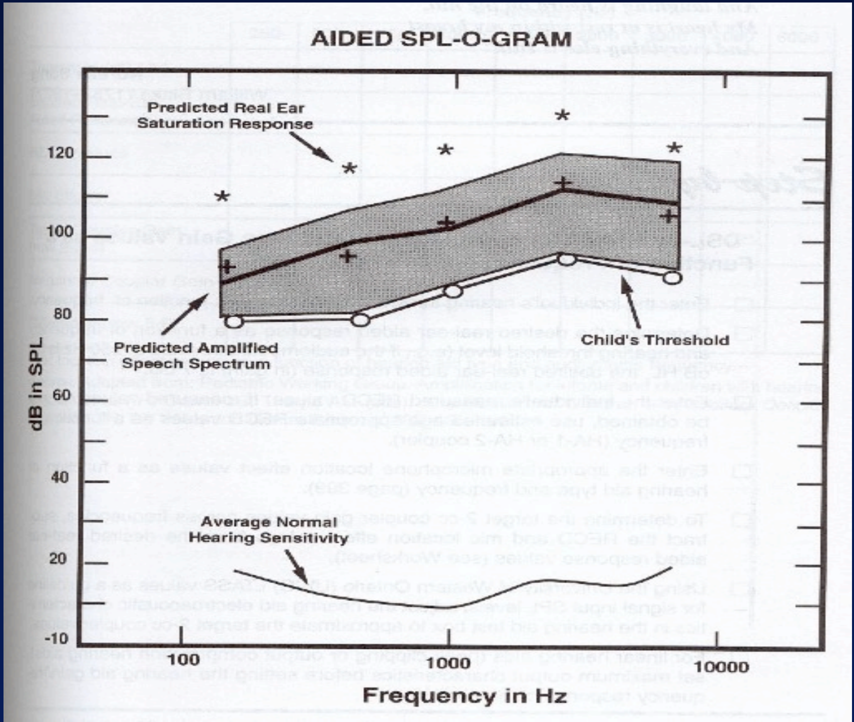
ASSR:
2000 Hz tone modulated at rate of 100 Hz



Limitation of Tone Burst Evoked ABR in Severe-to-Profound Hearing Loss



Estimation of Frequency-Specific Auditory Thresholds with Auditory Electrophysiology: An Essential Step in Prescriptive Hearing Aid Fitting in Infants



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  - Auditory brainstem response (ABR)
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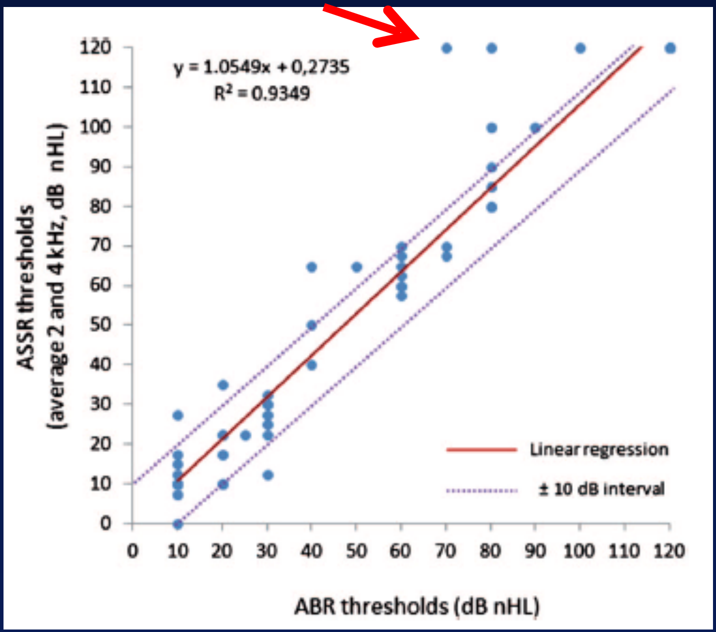
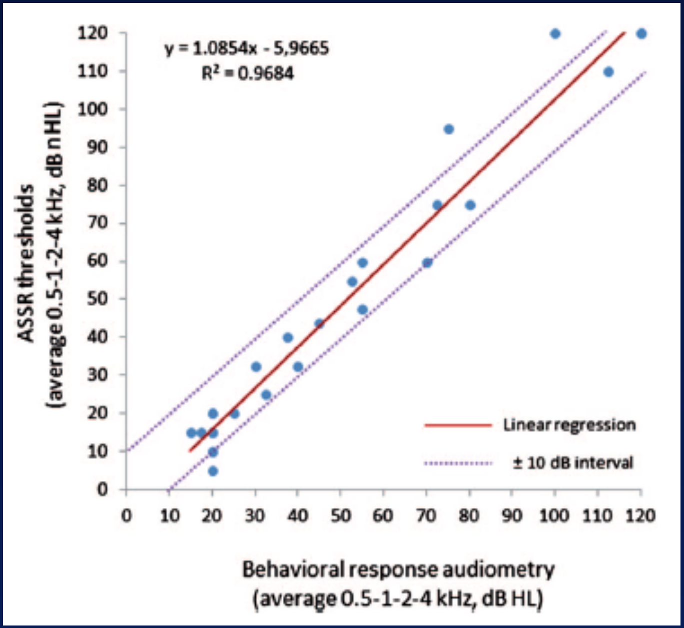
    - ✓ Frequency-specific ABR with air-conduction tone bursts
    - ✓ Bone-conduction stimulation (as indicated)
  - Otoacoustic emissions (distortion product or transient OAEs)
  - Tympanometry with 1000 Hz probe tone
  - Supplemental procedures, e.g.,
    - ✓ Electrocochleography (ECochG)
    - ✓ Auditory steady state response (ASSR)
    - ✓ Acoustic reflex measurement (for 1000 Hz probe tone)

Chirp-Evoked ASSR: Shorter Test Time and More Accurate Threshold Estimation

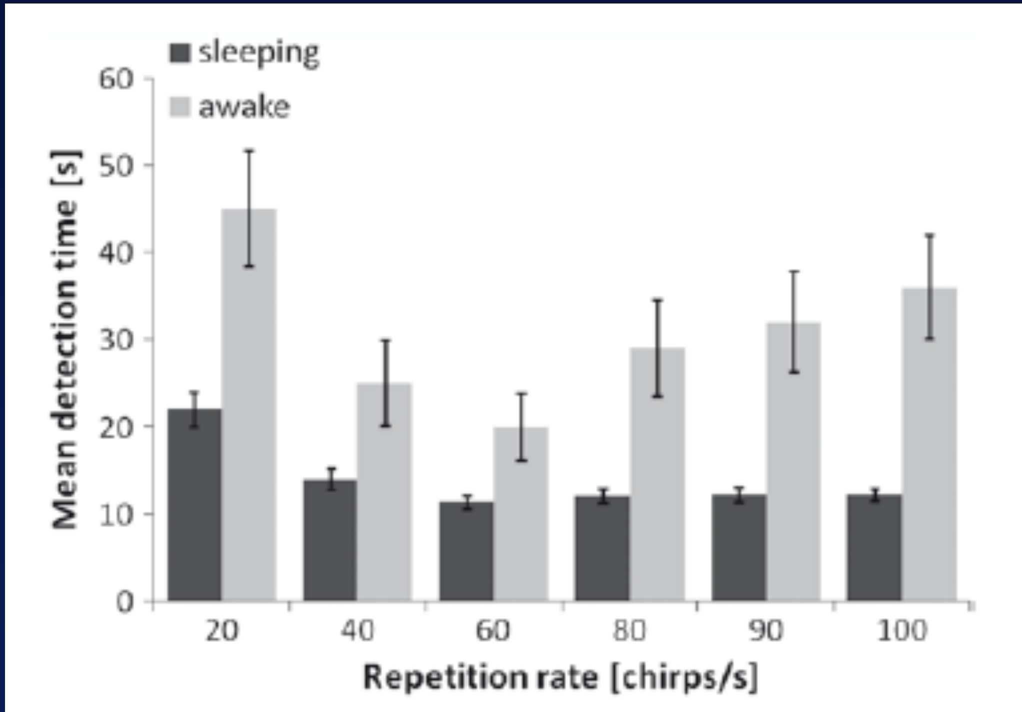
- Muhler et al (2012). Fast hearing-threshold estimation using multiple auditory steady-state responses with narrow-band chirps and adaptive stimulus patterns. *The Scientific World Journal*
- Rodrigues et al (2014). Establishing auditory stead-state response thresholds to CE-chirps in full-term neonates. *Int J Pedi ORL, 78* 238-243
- Venail et al (2015). Refining the audiological assessment in children using narrow-band CE-Chirp-evoked auditory state responses. *Int J Audiol, 54*, 106-113

Venail et al (2015). Refining the audiological assessment in children using narrow-band CE-Chirp-evoked auditory state responses. *Int J Audiol, 54*, 106-113





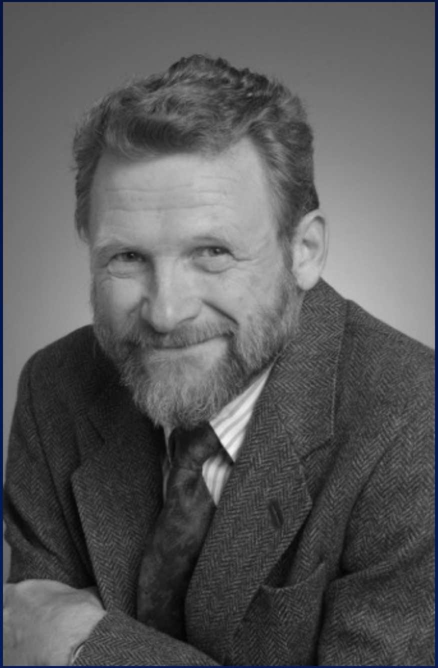
Cebulla M & Sturzebecher (2013). Detectability of newborn chirp-evoked ABR in the frequency domain at different stimulus rates. Int J Audiol, 52, 698-705



Conclusion of ABR Presentation
Questions?

Don Jewett

ABR



Terry Picton

ASSR

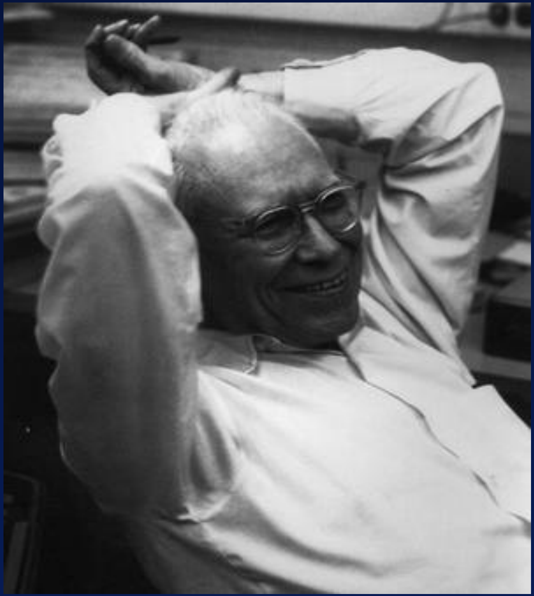
Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

- Welcome and Overview of Workshop Objectives
- The Crosscheck Principle: A 40-Year Perspective
- Auditory Brainstem Response (ABR)
  - Test Protocol and Analysis
  - Clinical Applications in Children
- Electrocochleography (ECochG)
  - Test Protocol and Analysis
  - Clinical Applications in Children
- Cortical Auditory Evoked Responses
  - Test Protocol and Analysis
  - Clinical Applications in Children

Original Description of Electrocochleography (ECochG)

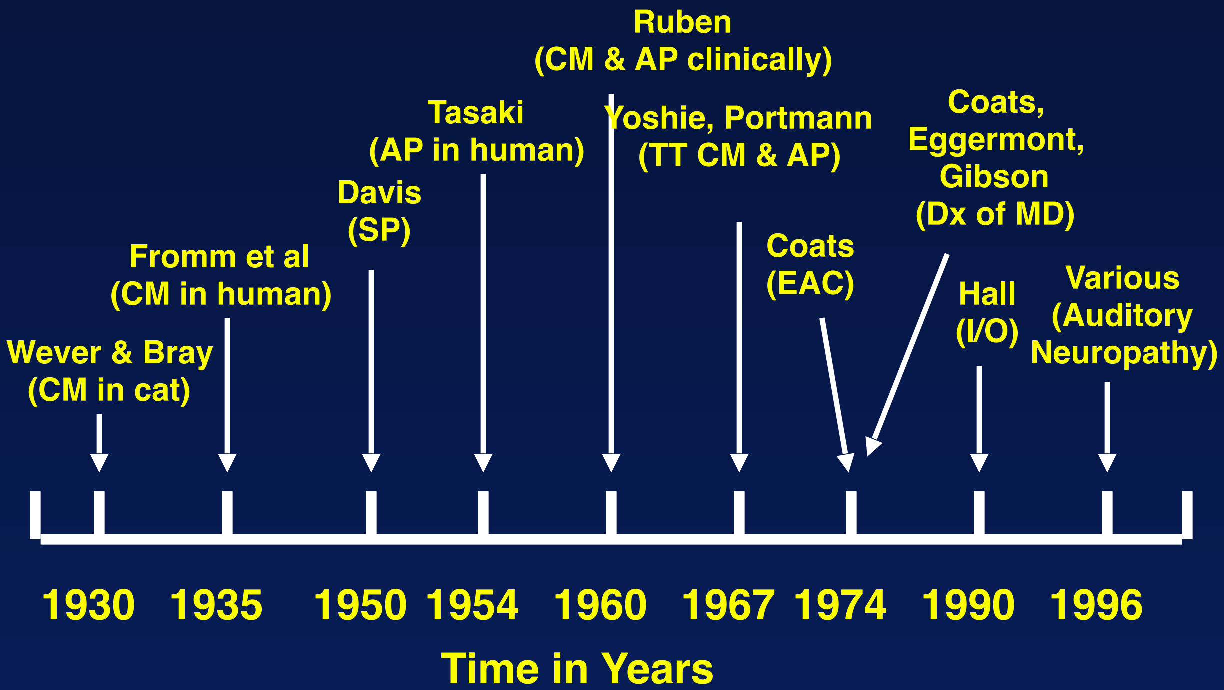
Wever EG and Bray CW. 1930.
Action currents in the auditory nerve in response to acoustic stimulation. Proceedings of the National Acad of Science (USA) 16: 344-350.

Wever EG and Bray CW. 1930.
Auditory nerve impulses. Science 71: 215.

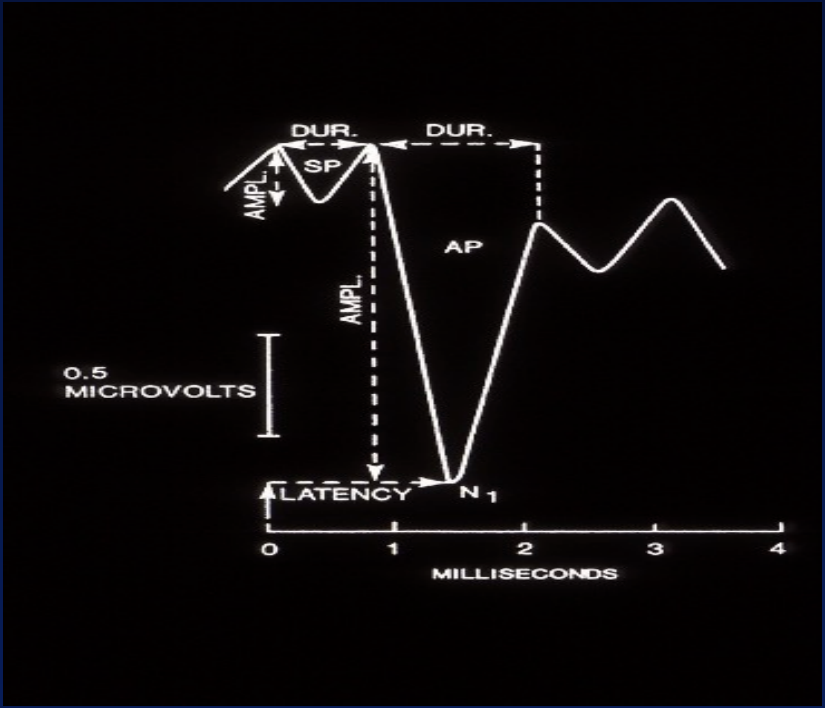


E. Glen Weaver, Ph.D.
(October 16, 1902 — September 4, 1991)

Electrocochleography:
87 Years Old and Still Clinically Important!

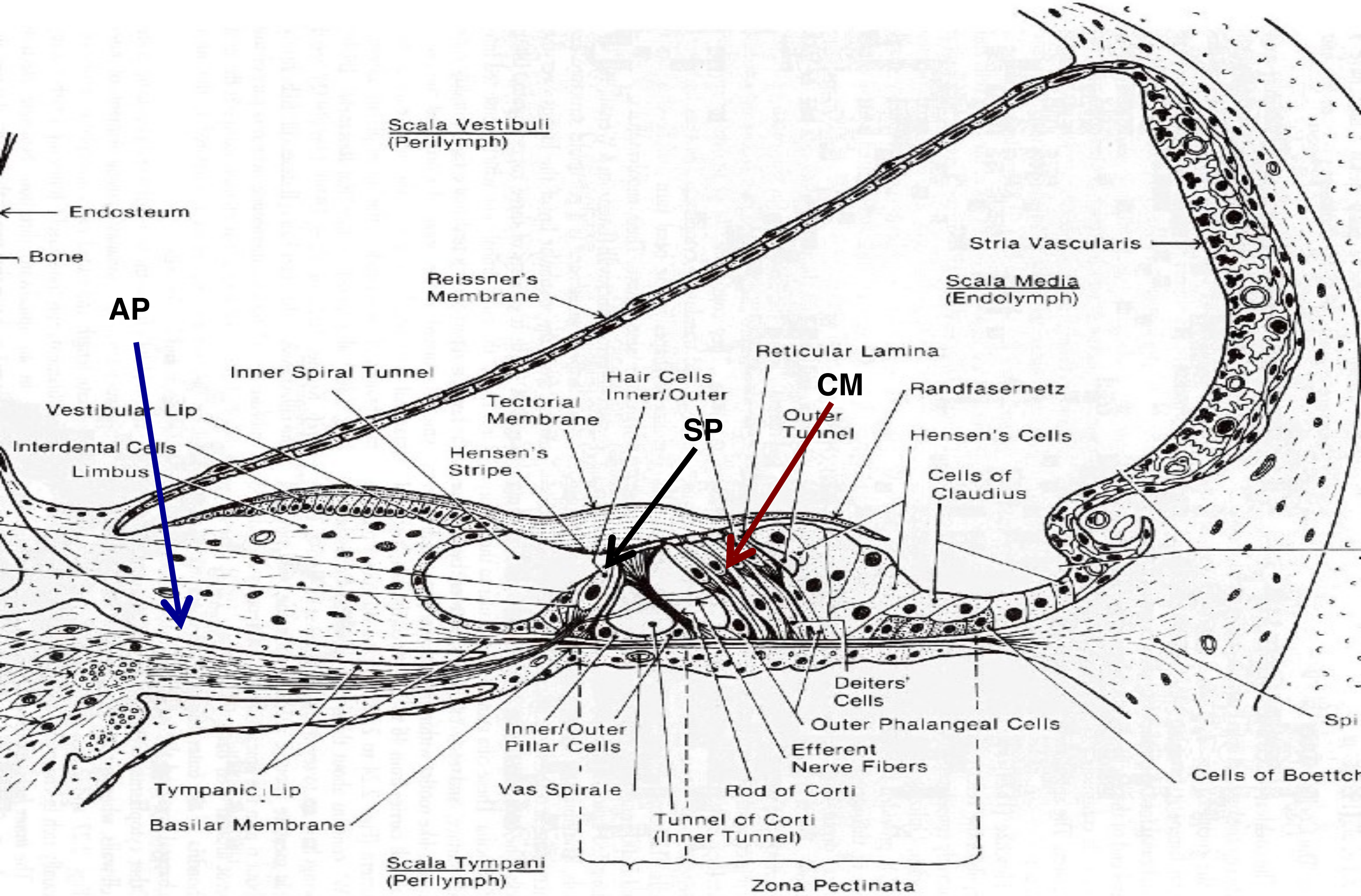


Electrocochleography:
Classic Recording



Electrocochleography:
Generators

- Cochlear microphonic (CM)
  - Outer hair cells
  - Receptor potentials
- Summating potential (SP)
  - Inner hair cells (> 50%)
  - Outer hair cells
  - Organ of Corti
- Action potential (AP)
  - Afferent fibers in distal 8th cranial nerve
  - Spiral ganglion


Scala Vestibuli
(Perilymph)
Endosteum
Bone
Reissner's
Membrane
Stria Vascularis
Scala Media
(Endolymph)
AP
Reticular Lamina
Inner Spiral Tunnel
Hair Cells
Inner/Outer
CM
Randfasernetz
Tectorial
Membrane
Vestibular Lip
SP
Outer
Tunnel
Interdental Cells
Hensen's
Stripe
Hensen's Cells
Limbus
Cells of
Claudius
Deiters'
Cells
Outer Phalangeal Cells
Inner/Outer
Pillar Cells
Efferent
Nerve Fibers
Cells of Boettch
Spi
Tympanic Lip
Vas Spirale
Rod of Corti
Basilar Membrane
Tunnel of Corti
(Inner Tunnel)
Scala Tympani
(Perilymph)
Zona Pectinata

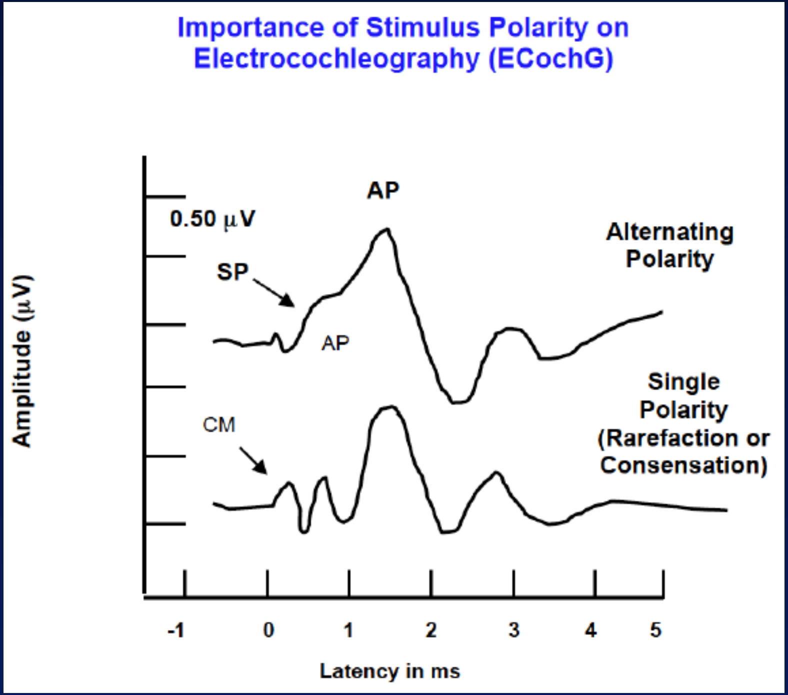
ECochG Test Protocol (1)

Stimulus Parameters

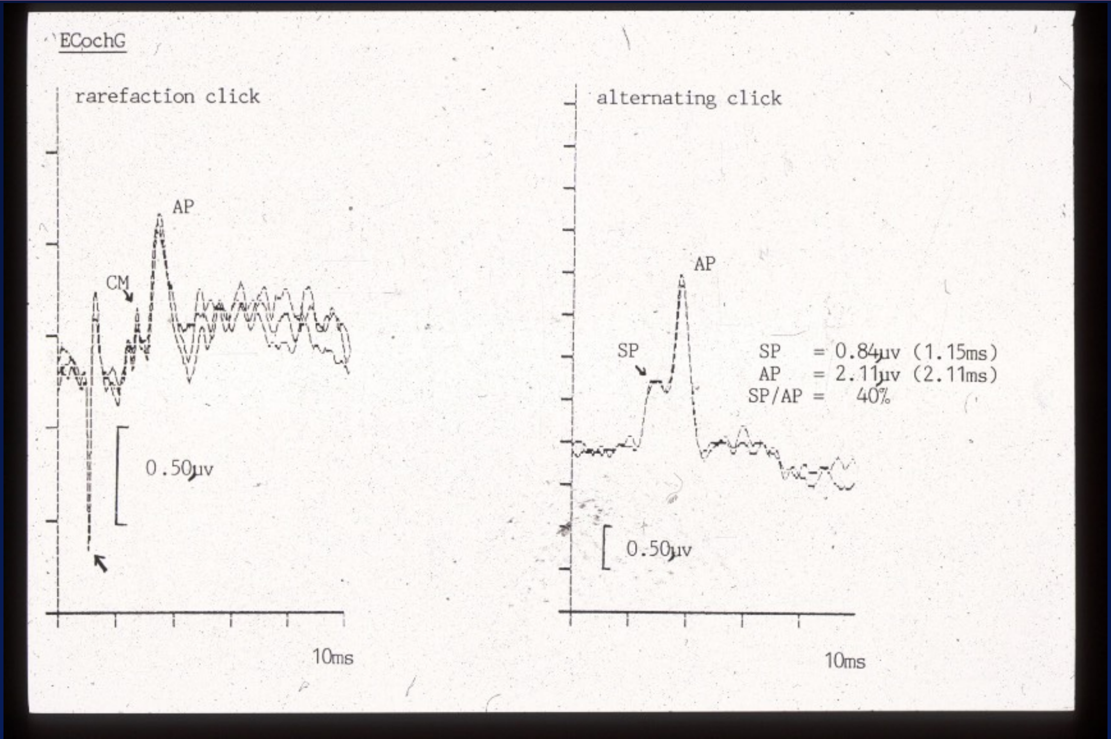
Type	Clicks or tone bursts
Duration	0.1 ms
Rate	7.1/sec; slower if needed or faster if possible
Polarity	Alternating (for SP and AP)
	Rarefaction and condensation (for CM)
Intensity	Maximum or lower
Transducer	Insert
Masking	Never needed (Components are biological markers for ear-specific response)

ECochG Recording: Manipulating Stimulus Polarity to Detect CM versus SP Component

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

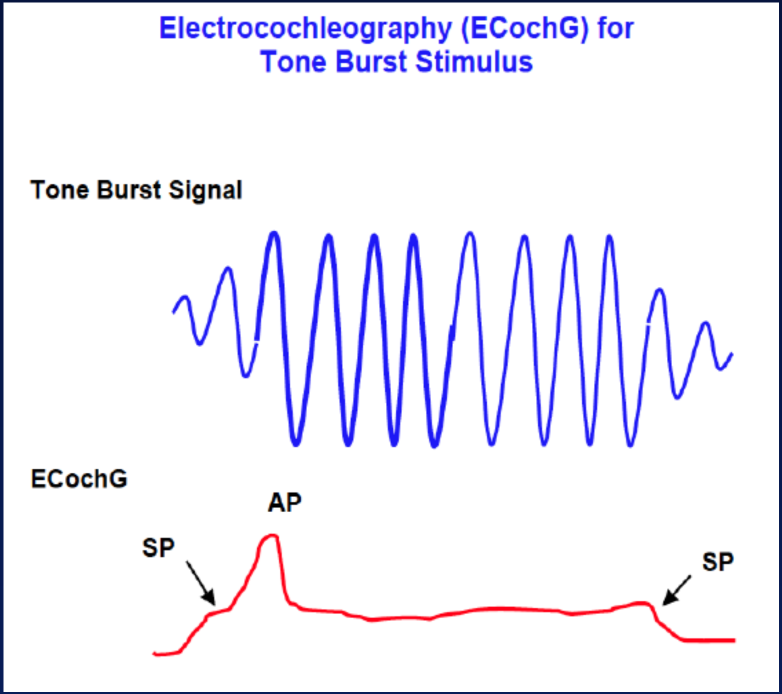


Electrocochleography:
Effect of Stimulus Polarity
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



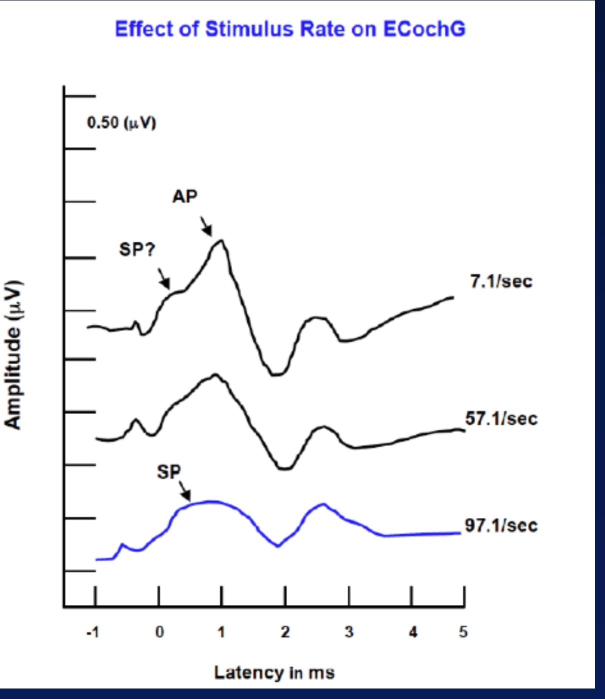
ECochG Recording: Manipulating Stimulus Duration to Confirm the SP Component

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



ECochG Recording: Manipulating Stimulus Presentation Rate to Confirm the SP Component

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

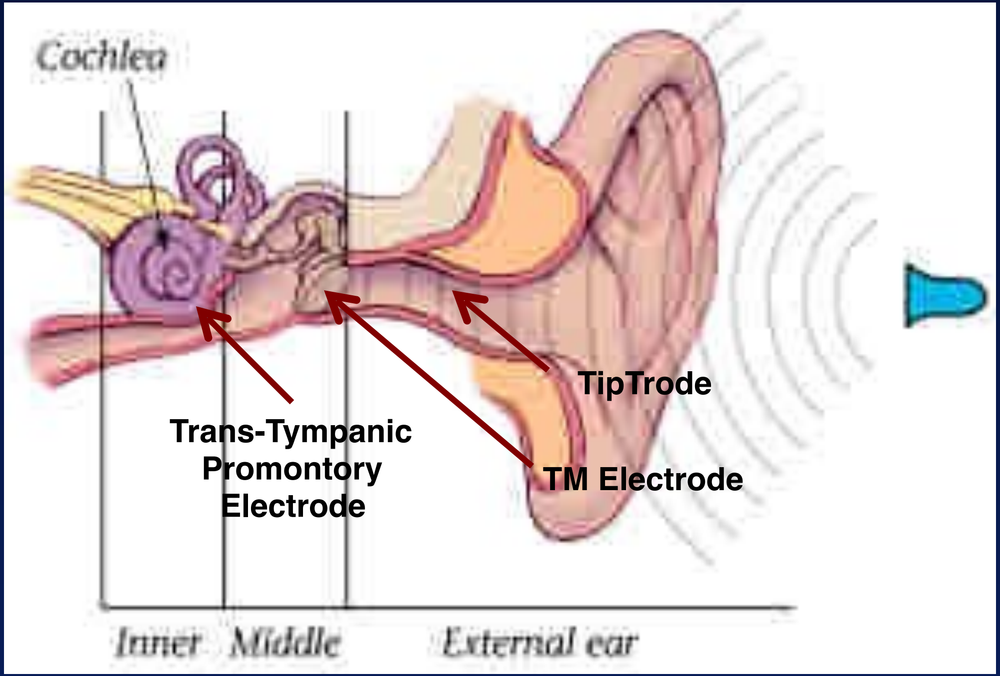


ECochG Test Protocol (2)

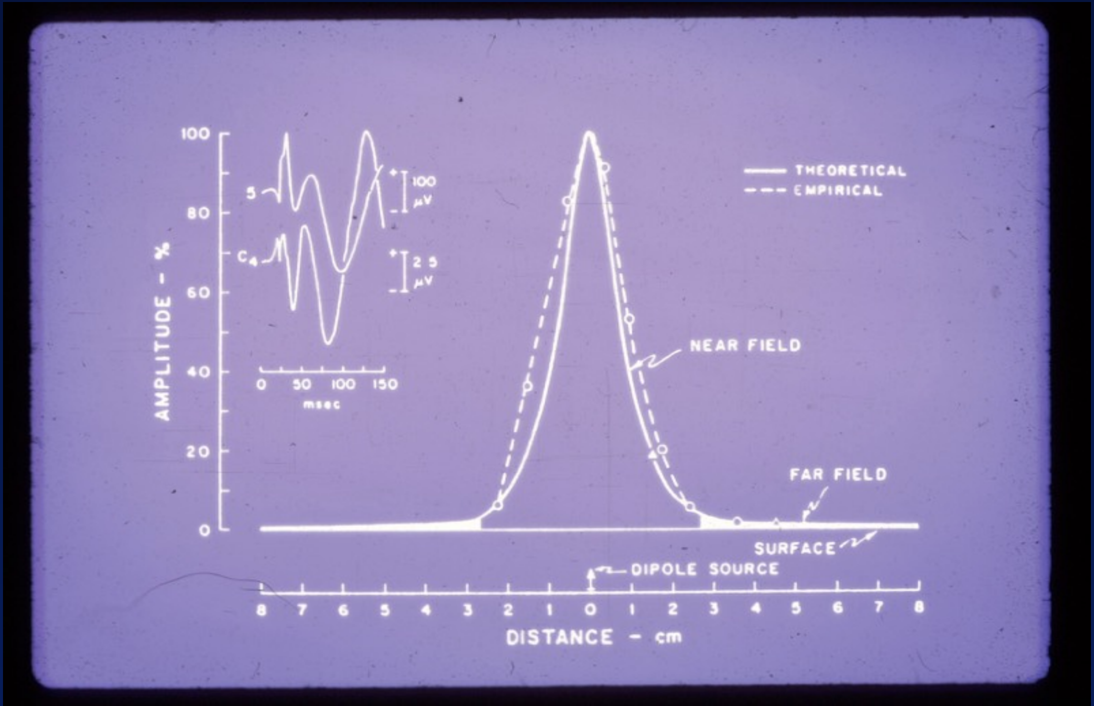
Acquisition Parameters

Amplification	75,000 or less
Analysis time	5 or 10 ms
Sweeps	500 or less (depends on SNR)
Filters	10 to 1500 Hz
Notch filter	Never
Electrodes	
Option 1	Fz to trans-tympanic needle
Option 2	Fz to tympanic membrane
Option 3	Fz to Tiptrode

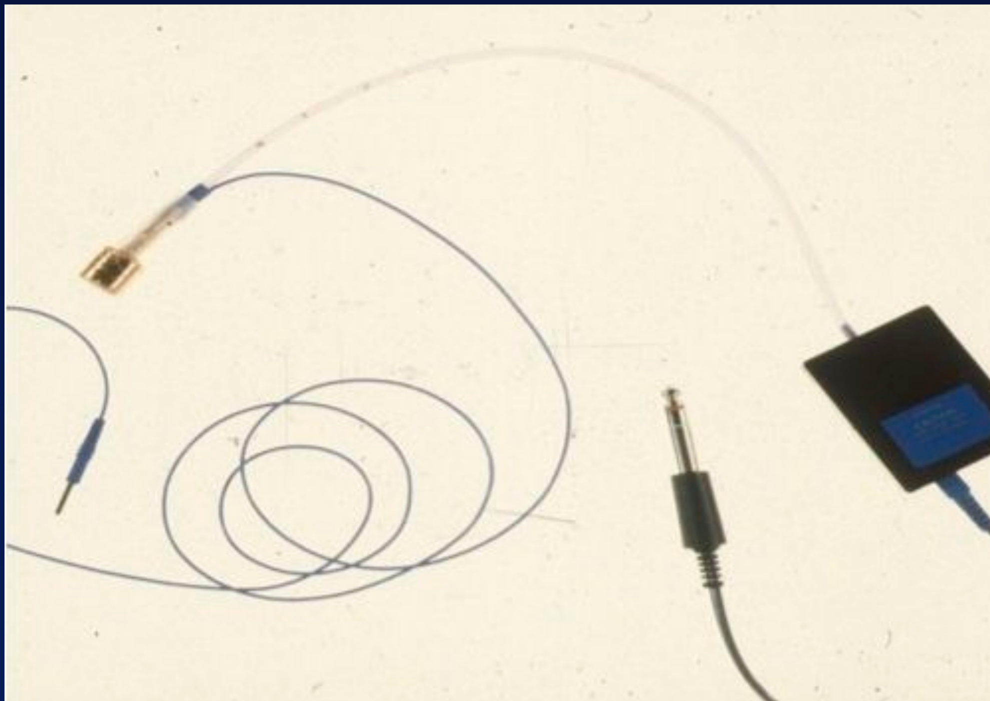
ECochG Electrode Options:
The Closer to the Cochlea, the Better



ECochG is a Near Field Response



TIPtrode:
Part Transducer and Part Electrode



Tympanic Membrane Electrode:
A Non-Invasive Option for Audiologists

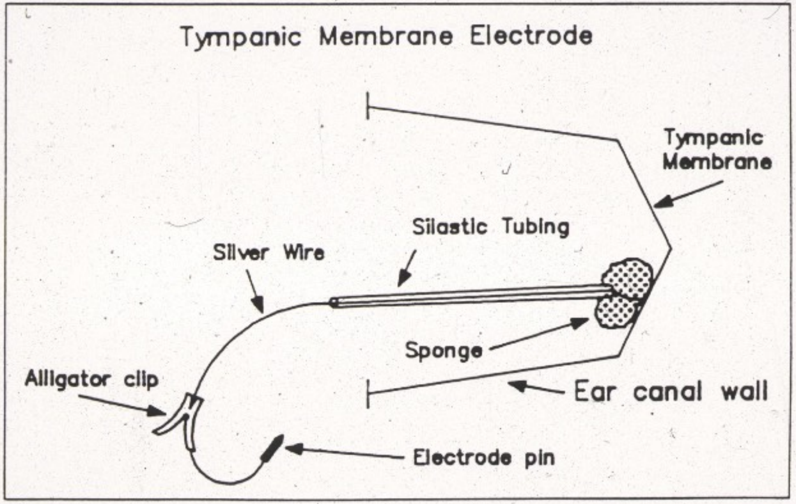
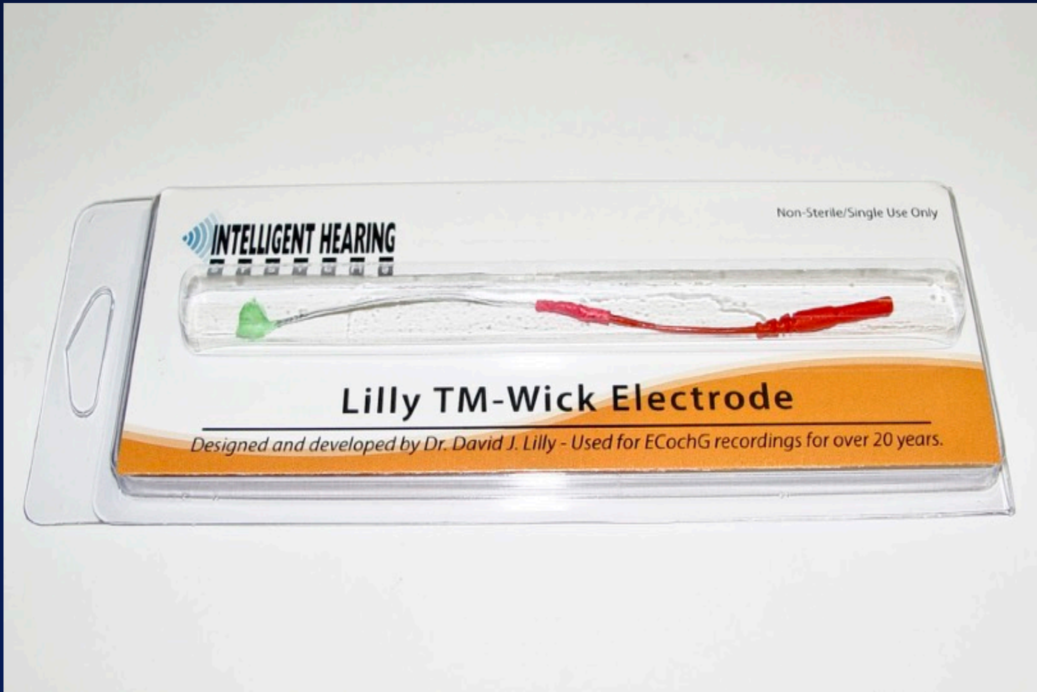


Figure 5–3. TM electrode design (sometimes called a "tymptrode"). Silver wire runs through a flexible plastic tube and connects with sponge or cotton at the tip. When the tymptrode is inserted into the ear canal, the tip makes contact with the lateral surface of the TM.

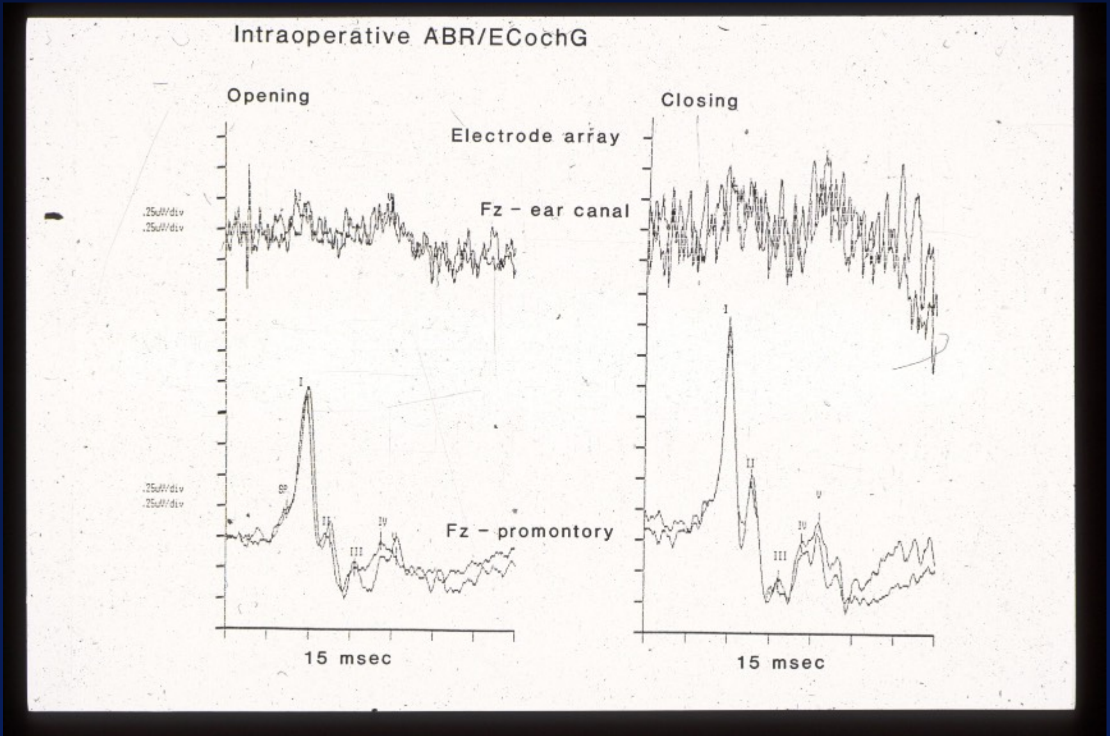
Tympanic Membrane Electrode:
A Non-Invasive Option for Audiologists



Tympanic Membrane Electrode:
A Non-Invasive Option for Audiologists

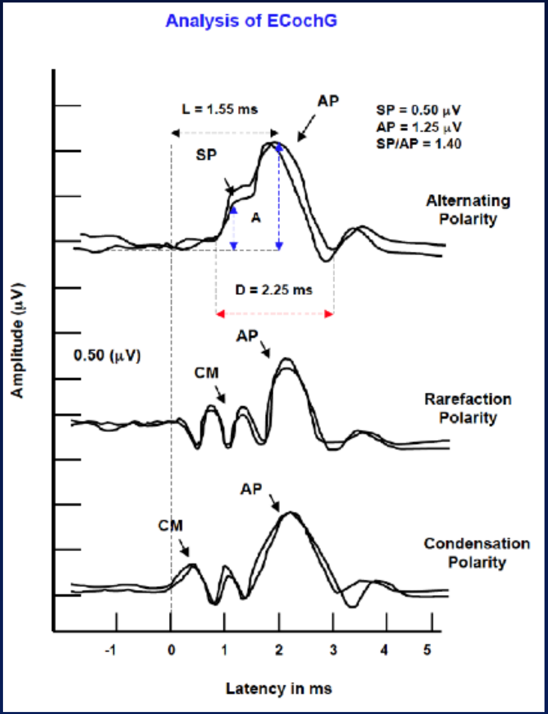
Sub-Dermal Needle Electrode for Trans-Tympanic Promontory ECochG Recording

Advantages of a Sub-Dermal Needle Electrode for Trans-Tympanic Promontory ECochG Recording



Electrode Analysis

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

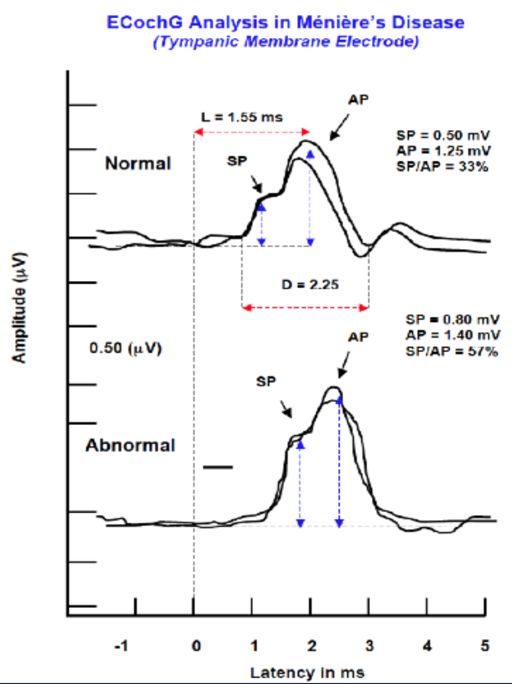


Electrocochleography (ECochG):
Clinical Applications in Adults

- Enhancement of wave I in ABR measurement with air- and bone conduction click stimulation to:
  - Enhance inter-wave latency analysis
  - Confirm ear-specific test findings (biological marker)
  - Minimize the need for masking non-test ear
- Intra-Operative Neurophysiological Monitoring
  - Prompt documentation of cochlear status
  - Enhance inter-wave latency analysis
  - Minimize interference of electrical artifact
- Diagnosis of Meniere's disease

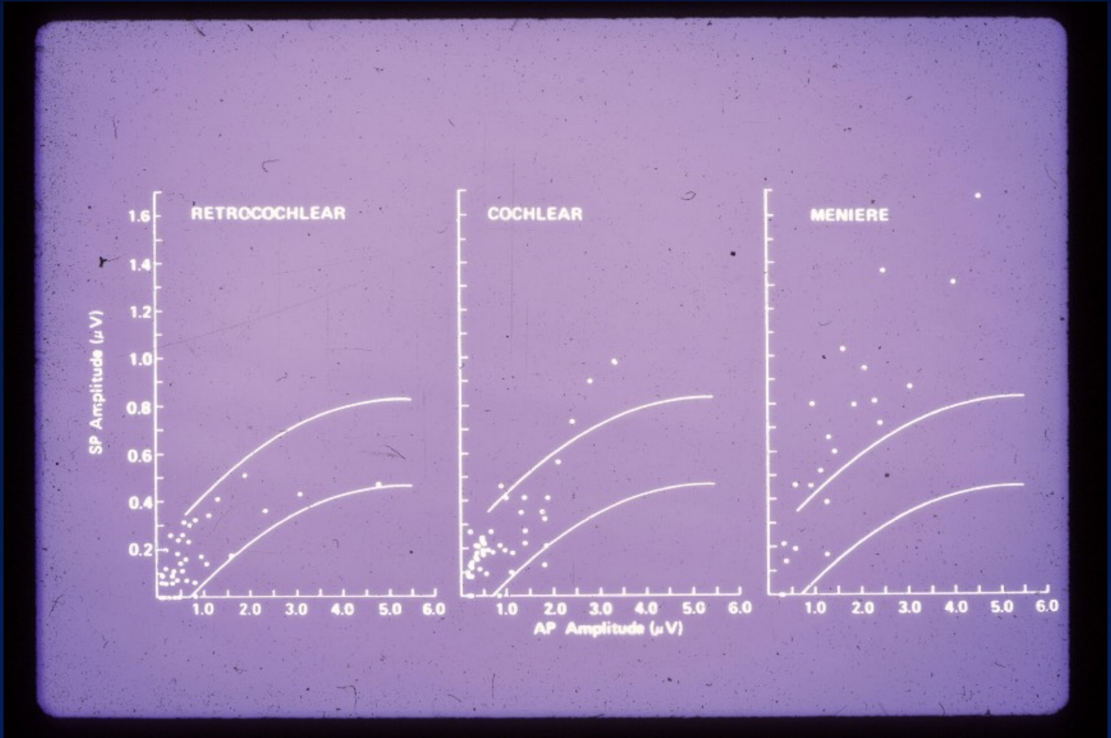
ECochG in Diagnosis of Meniere's Disease: *Abnormally Large SP/AP Ratio*

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



ECochG in Diagnosis of Meniere's Disease: Abnormally Large SP/AP Ratio

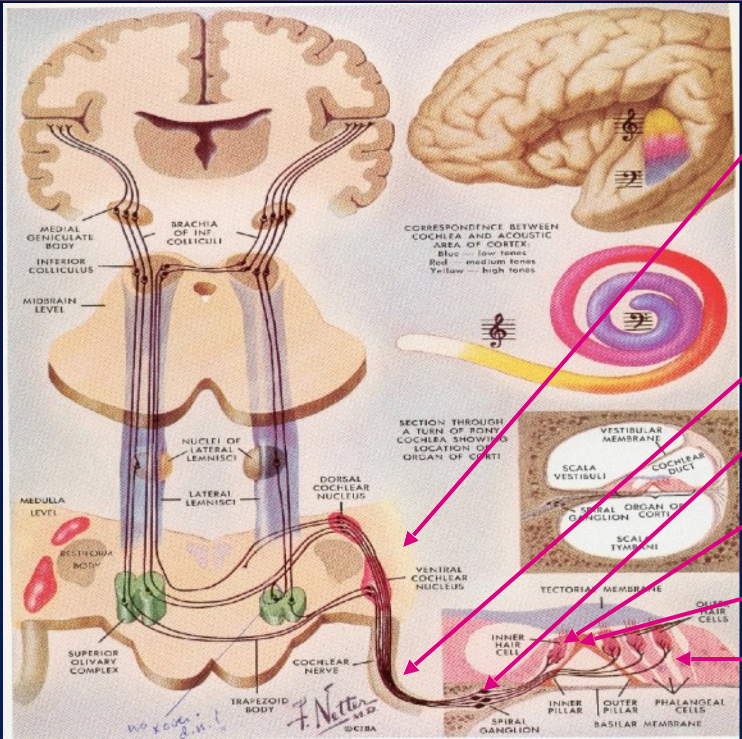
Coats AC (1981). The summating potential in Meniere's and non-Meniere's ears. Archives of Otolaryngology, 107, 199-208



Electrocochleography (ECochG):
Clinical Applications in Children

- Enhancement of wave I in ABR measurement with air- and bone conduction click stimulation to:
  - Enhance inter-wave latency analysis
  - Confirm ear-specific test findings (biological marker)
  - Minimize the need for masking non-test ear
- Auditory neuropathy spectrum disorder (ANSD)
  - Diagnosis
  - Management

Essential Role of Electrocochleography (ECochG) in the Diagnosis and Management of Auditory Neuropathy Spectrum Disorder (ANSD)



Cerebello-pontine angle (CPA)

Internal Auditory Canal
(Auditory Nerve)

Spiral ganglion cells

IHC - 8th CN Synapse
(glutamate)

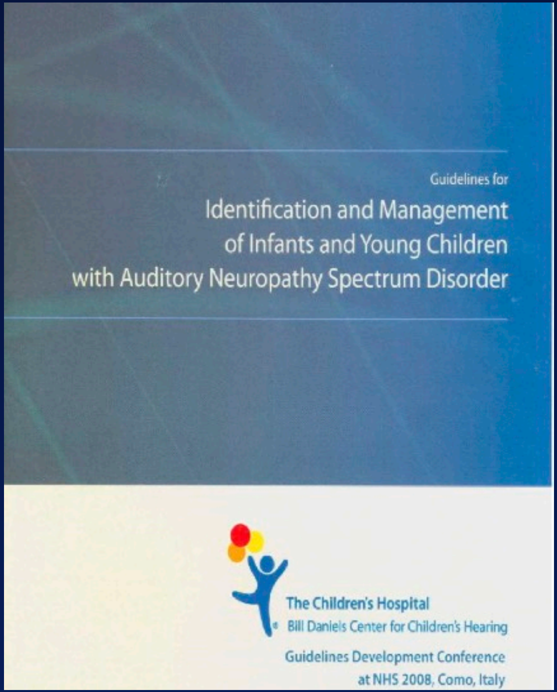
Inner hair cells

Outer hair cells

Electrococheography (ECochG):
Diagnosis of Auditory Neuropathy Spectrum Disorder

- In June 2008, at the invitation of Deborah Hayes, a panel of experts met in Como/\, Italy/\at the NHS 2008

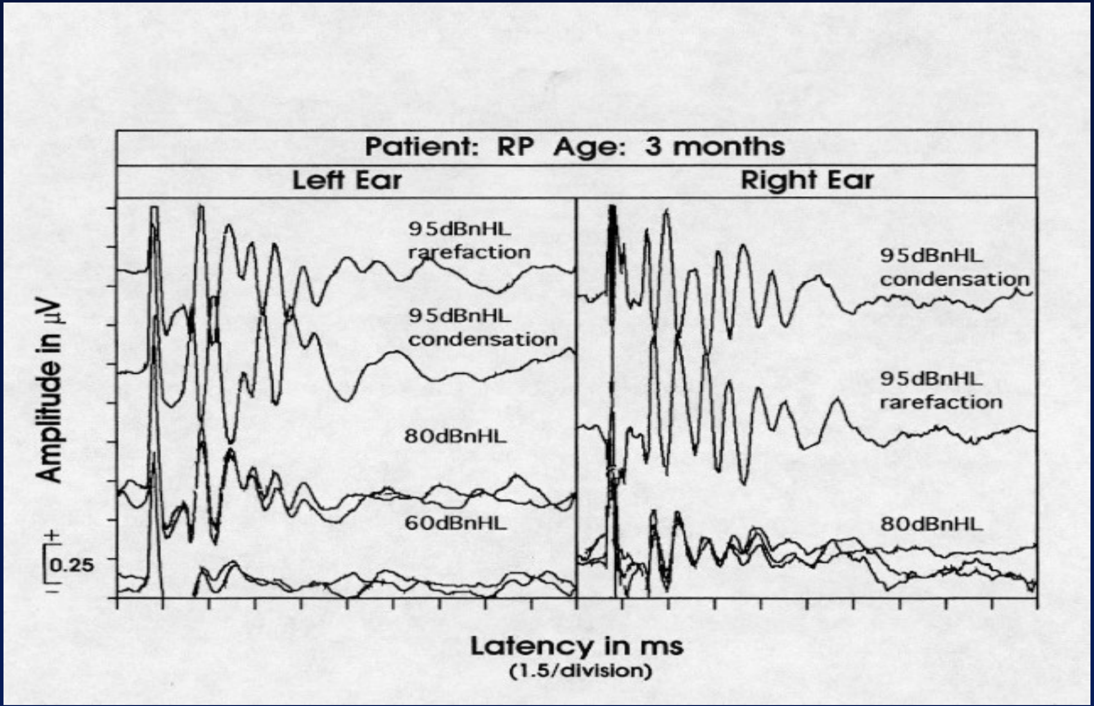
  Conference to develop Guidelines for the Identification and Management of Infants and Young Children with Auditory Neuropathy.
- The panel consisted of:
  - Yvonne Sininger, Ph.D.
  - Arnold Starr, M.D.
  - Christine Petit, M.D., Ph.D.
  - Gary Rance, Ph.D.
  - Barbara Cone, Ph.D.
  - Kai Uus, M.D., Ph.D.
  - Patricia Roush, Au.D.
  - Jon Shallop, Ph.D.
  - Charles Berlin, Ph.D.



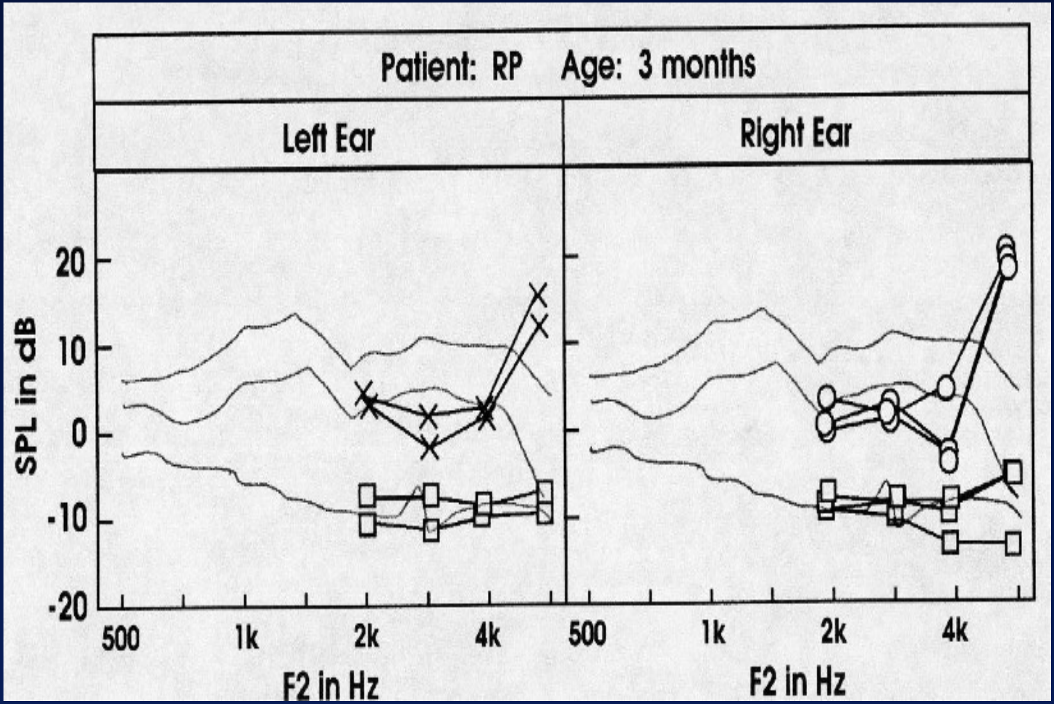
Identification and Diagnosis of Auditory Neuropathy Spectrum Disorder (ANSD): Minimal Test Battery (2008 ANSD Guidelines)

- Tests of cochlear hair cell function
  - Otoacoustic emissions (OAEs)
  - Cochlear microphonic (ECochG and ABR)
    - ✓ CM may be present when OAEs are absent (e.g., with middle ear dysfunction)
- Tests of auditory nerve function
  - ABR for high intensity click stimulation (e.g., 80 to 90 dB nHL) with separate averages for:
    - ✓ Rarefaction stimulus polarity
    - ✓ Condensation stimulus polarity
- Additional tests
  - Acoustic reflex measurement (generally acoustic reflexes are absent in ANSD)
  - Suppression of otoacoustic emissions (abnormal, e.g, no suppression in ANSD)

Identification and Diagnosis of Auditory Neuropathy Spectrum Disorder (ANSD): *A*bsent ABR … Only Cochlear Microphonic (CM)



Identification and Diagnosis of Auditory Neuropathy Spectrum Disorder (ANSD): *Robust* OAEs with Absent ABR



Electrocochleography (ECochG) in the Diagnosis and Management of Auditory Neuropathy Spectrum Disorder:
Early Diagnosis of Medical Diseases and Disorders (1)

- Perinatal Diseases
  - Hyperbilirubinemia
  - Hypoxic insults
  - Ischemic insults
  - Prematurity
- Neurological Disorders
  - Demyelinating diseases
  - Hydrocephalus
  - Immune disorders, e.g., Guillain-Barre sydrome
  - Inflammatory neuropathies
  - Severe developmental delay

Electrocochleography (ECochG) in the Diagnosis and Management of Auditory Neuropathy Spectrum Disorder:
Early Diagnosis of Medical Diseases and Disorders (2)

- Neuro-metabolic diseases
- Genetic and Hereditary Etiologies
  - Family history
  - Connexin mutations, e.g., GJB3 (D66del)
  - Otoferlin (OTOF) gene
  - Non-syndromic recessive auditory neuropathy
  - Hereditary motor sensory neuropathies (HMSN), e.g., Charcot-Marie-Tooth syndrome
  - Leber's hereditary optic neuropathy
  - Waardenburg's syndrome
  - Neurogenerative diseases, e.g., Friedreich's ataxia
- Mitochondrial disorders, e.g., mitochondrial enzymatic defect

Diagnosis and Management of Auditory Neuropathy Spectrum Disorder (2008 Guidelines): *Combination of Findings for MRI and ECochG*

- Components of assessment
  - Pediatric and developmental history
  - Otologic evaluation, plus
    - ✓Imaging of cochlea with CT
    - ✓Imaging auditory nerve with MRI
  - Medical genetics evaluation
  - Ophthalmologic evaluation
  - Neurological evaluation to assess:
    - ✓Peripheral nerve function
    - ✓Cranial nerve function
  - Communication assessment

Comprehensive Assessment of Auditory Neuropathy Spectrum Disorder (ANSD): *MRI Documentation of Auditory Nerve Structural Status*

- Brainstem and inner ear abnormalities in children with auditory neuropathy spectrum disorder and cochlear nerve deficiency. Huang et al. (UNC). American J Radiol, 31, 2010
  - CND was identified in 33.0% of children and 26.9% of ears with ANSD
  - Significantly more patients with bilateral CND had intracranial abnormalities than those with unilateral CND (60.0% versus 15.8%).
- Unilateral auditory neuropathy caused by cochlear nerve deficiency. Liu et al (China). *Int J Otolaryngol*, 2012.
  - Cochlear nerve deficiency can be seen by electrophysiological evidence and may be a significant cause of unilateral AN.
  - Inclined sagittal MRI of the internal auditory canal is recommended for the diagnosis of this disorder.

ECochG in ANSD:
Diagnosis of Site of Dysfunction
(Table from Hall JW III. eHandbook of Auditory Evoked Responses)

ANSD	Pattern of ECochG Findings
Inner hair cells	Normal CM Abnormal SP No AP
Synapse	Normal CM Normal SP No AP
Auditory nerve	Normal CM Normal SP No AP

Normal MRI of 8
Nerve

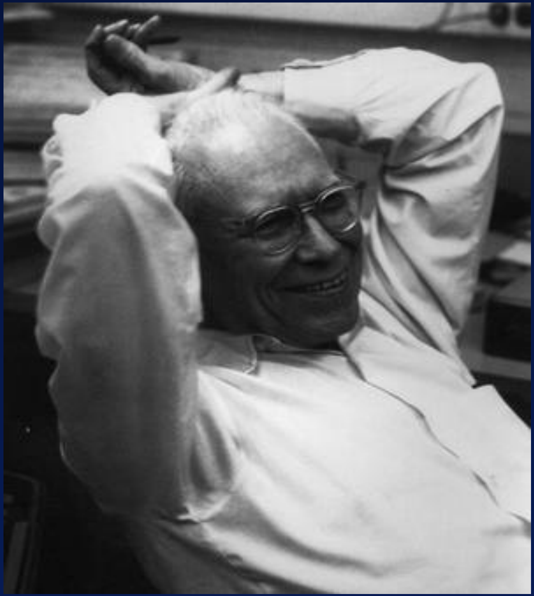
Abnormal MRI c
8^{th} Nerve

Auditory Neuropathy Spectrum Disorder (ANSD): Audiological Management

- Close monitoring every three months until behavioral audiometry is complete
  - More accurate results are obtained over time
  - Significant improvement, including “recovery”, is possible
- Monitor OAEs
- Referral to other disciplines (pediatric neurology, genetics, ophthalmology, ENT)
- Hearing aids on trial basis with evidence of either:
  - Elevated pure tone or speech thresholds
  - Behavioral observation consistent with abnormal auditory sensitivity
- Cochlear implant for pre-synaptic forms of ANSD
- Assistive listening devices
  - *Personal FM system*
  - Hearing aids with FM technology (remote microphone)
  - Cochlear implants with FM technology (remote microphone)
- Alternative communication strategies
  - Cued speech
  - Visual emphasis aural approaches
  - Signing options (e.g., www.BabySigns.com)

Conclusion of Electrocochleography Presentation

Questions?

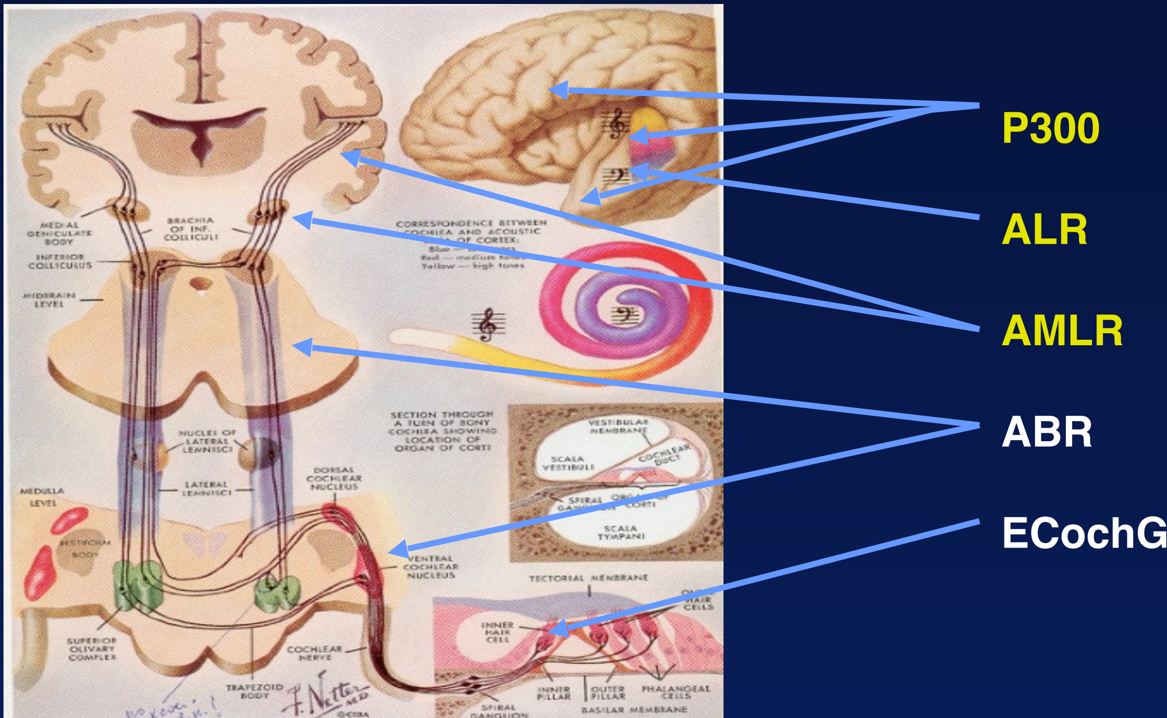


E. Glen Weaver, Ph.D.
(October 16, 1902 — September 4, 1991)

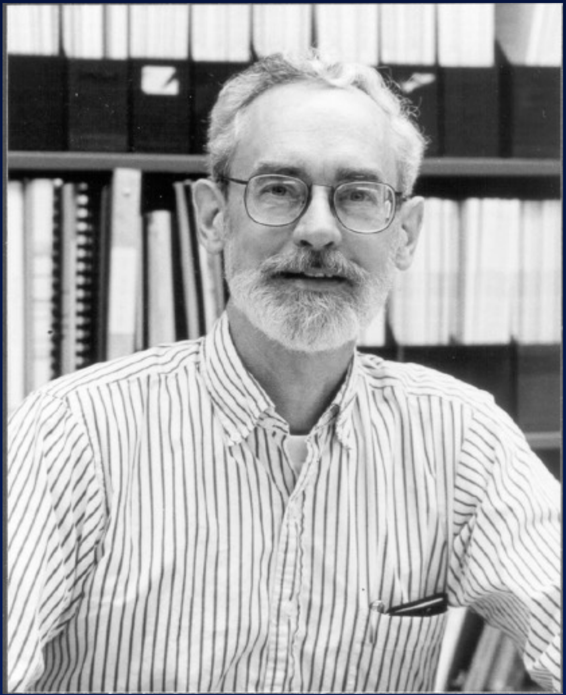
Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

- ❑ Welcome and Overview of Workshop Objectives
- ❑ The Crosscheck Principle: A 40-Year Perspective
- ❑ Auditory Brainstem Response (ABR)
  - Test Protocol and Analysis
  - Clinical Applications in Children
- ❑ Electrocochleography (ECochG)
  - Test Protocol and Analysis
  - Clinical Applications in Children
- ❑ Cortical Auditory Evoked Responses
  - Test Protocol and Analysis
  - Clinical Applications in Children

Clinical Application of Auditory Evoked Responses:
The Time Has Come



Dan Geisler, Ph.D.
Discoverer of Auditory Middle Latency Response (AMLR) in 1958



Geisler, C. D., Frishkopf, L. S., & Rosenblith, W. A. (1958). Extracranial responses to acoustic clicks in man. *Science, 128,* 1210-1211.

Cody, D. T. R., Jacobson, J. L., Walker, J. C., & Bickford, R. G. (1964). Averaged evoked myogenic and cortical

More About Auditory Middle Latency Response …

Thursday, May 25

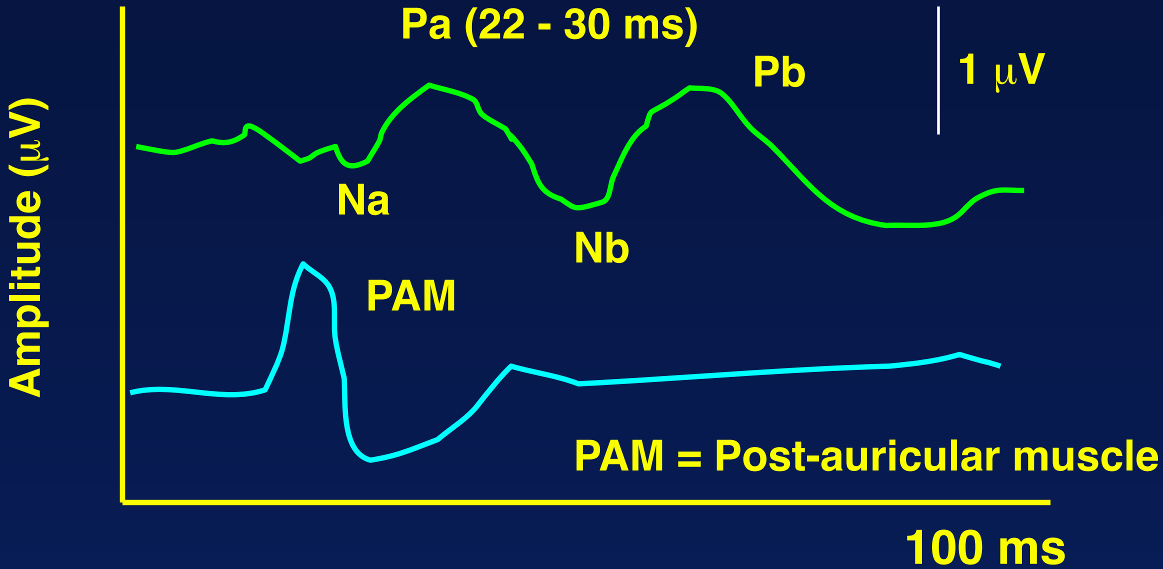
Congress Room — GRAND BALLROOM **DEF**

Keynote Lecture II – Frank E. Musiek — **8:00–9:00**

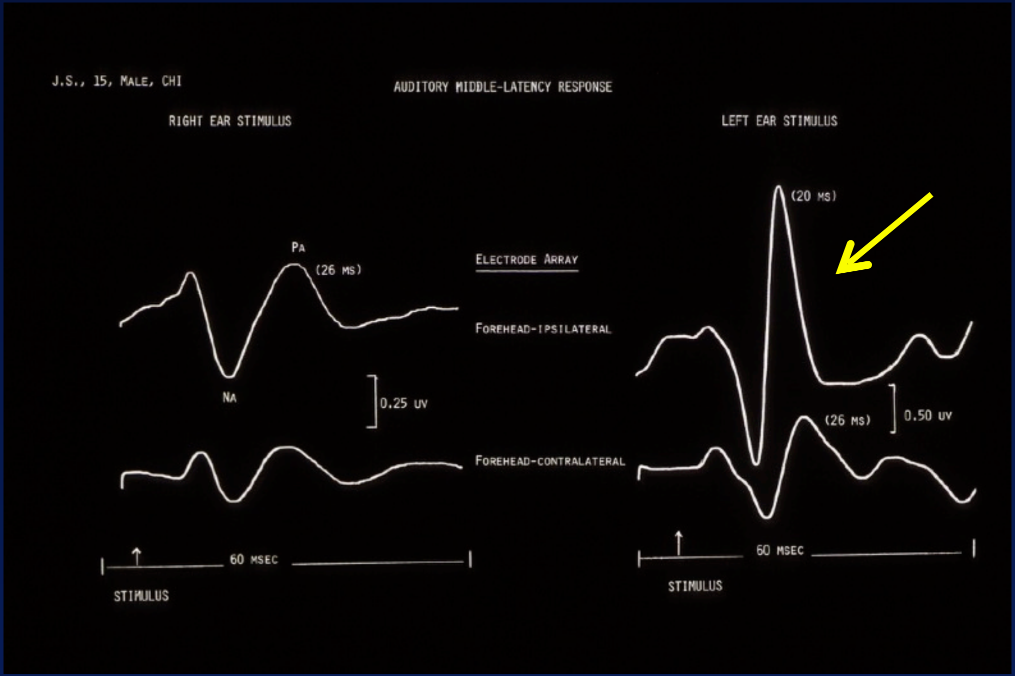
The Middle Latency Response (MLR) and Disorders of the Central Nervous System

Moderator: David McPherson

Auditory Middle Latency Response (AMLR): Analysis



Auditory Middle Latency Response (AMLR): An Example of Post-Auricular Muscle (PAM) Artifact



Auditory Middle Latency Response (AMLR): Generators in Thalamus, Projection Fibers, and Primary Auditory Cortex

Lee, Lueders, Dinner, et al. Brain 107:1984.

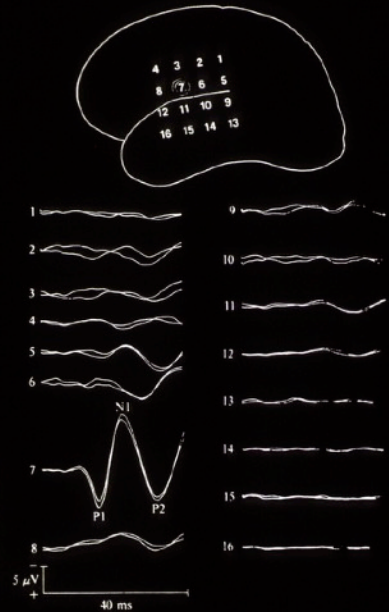
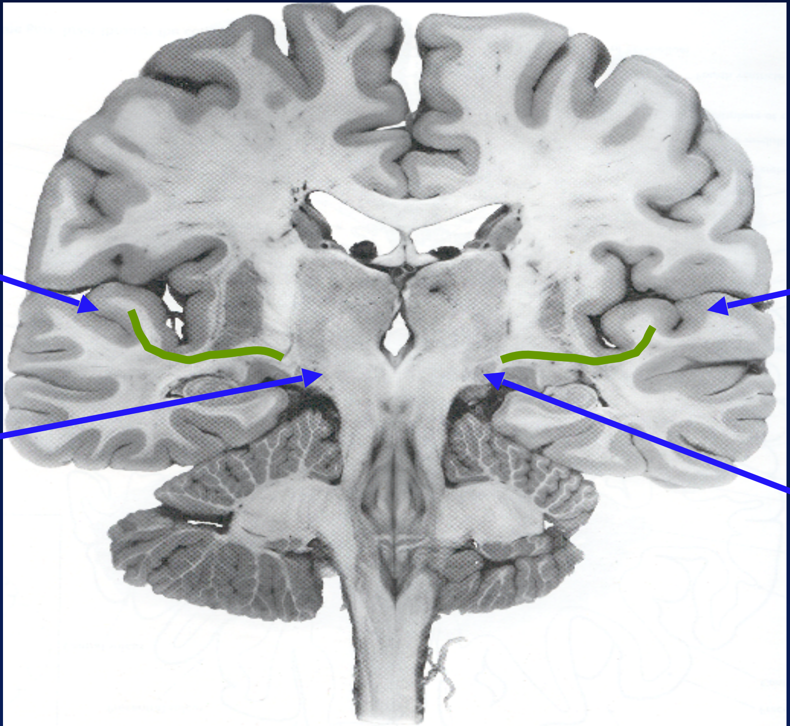


FIG. 2. Cortical AEP distribution in *Case 2*. The numbers next to each tracing correspond to the subdural electrode position on the brain. The AEPs were generated by binaural stimulation and each tracing is the average of 1000 responses. AEPs from two separate trials were superimposed at each electrode. The reference consisted of a subdural electrode distant from Heschl's gyrus.

Origins of the Auditory Middle Latency Response (AMLR)

(Photograph adapted from F.E. Musiek)



Primary Auditory Cortex

Primary Auditory Cortex

Thalamus (Medial Geniculate Body)

Thalamus (Medial Geniculate Body)

AMLR TEST PROTOCOL (1)

Stimulus Parameters

Type	Tone bursts or speech stimuli
Duration	2 cycles of rise time and long plateau
Rate	7.1/sec or slower as necessary
Polarity	Alternating or rarefaction
Intensity	70 dB nHL or less (< PAM)
Transducer	Insert
Masking	Rarely needed

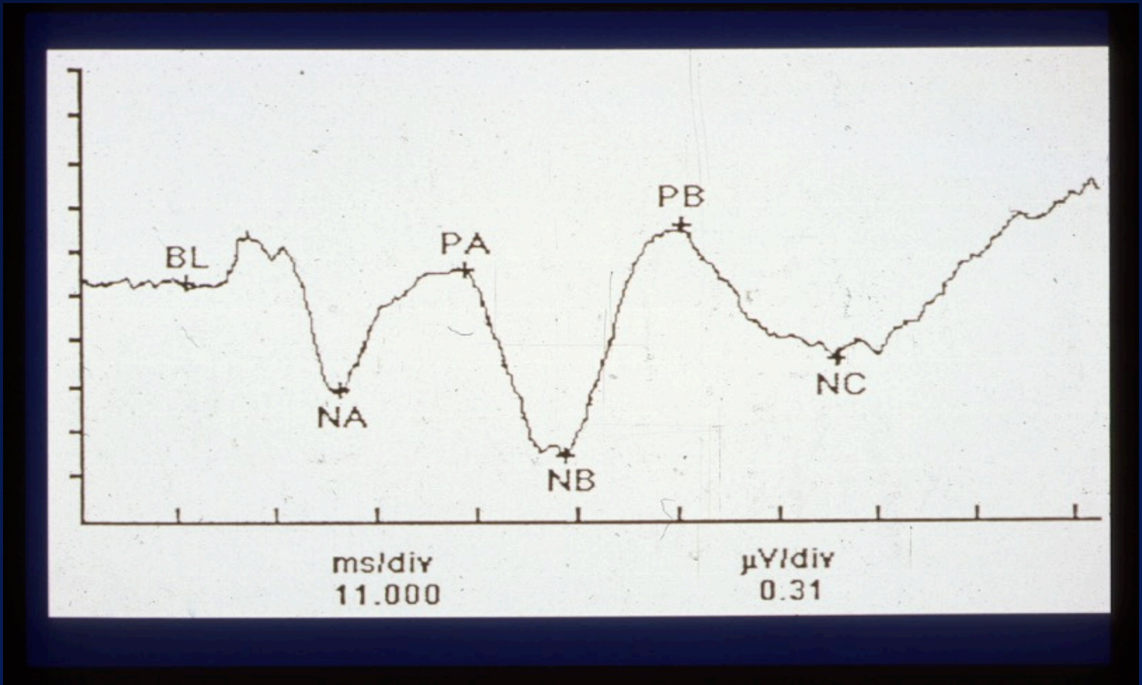
AMLR TEST PROTOCOL (2)

Acquisition Parameters

Amplification	75,000 or less
Analysis time	100-ms
Sweeps	500 or less
Filters	10 to 250 or 1500 Hz
Notch filter	Never (AMLR spectrum = 40 Hz)
Electrodes *	
channel 1	C5 to A1/A2 (linked earlobes) or Non-cephalic (nape)
channel 2	C6 to A1/A2 or non-cephalic (nape)
channel 3	Fz to A1/A2 or non-cephalic (nape)

- *With a 2 channel AER system, record AMLR with two hemisphere electrode array and then a single channel (Fz) recording*

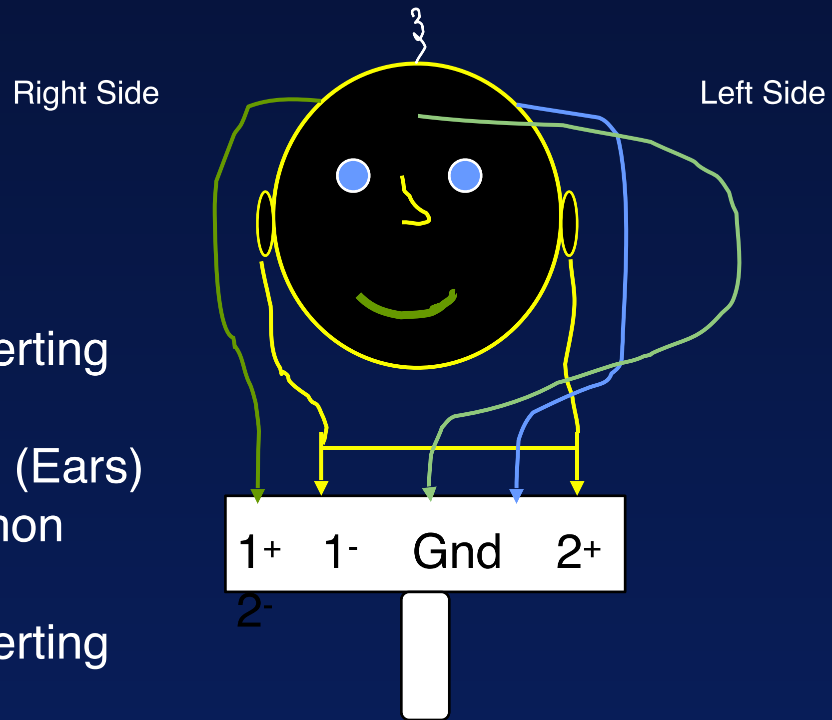
Enhancing Detection of the Elusive Pb Wave: Slow stimulus (< 1/sec), Low frequency stimulus (500 Hz), Very low high pass filter setting (1 Hz)
(*Nelson, Hall & Jacobson, 1997)*



Linked Earlobe Electrode Arrangement for Recording AMLR

Electrodes

1^{+} = Non-inverting (C6)
1^{-} = Inverting (Ears)
Gnd = Common (Fpz)
2^{+} = Non-inverting (C5)



Measurement and Non-Pathologic Factors Influencing AMLR Recordings

- **Test Parameters:**
  - **Filtering:** avoid restricted high-pass filter setting (e.g., 30 Hz) and use HP setting of $\leq$ 1 Hz to detect Pb component
  - **Stimulus intensity level:** avoid very high levels (PAM artifact)
  - **Stimulus duration:** longer (> 10 ms) is better (avoid clicks)
  - **Stimulus rate:** slower rates for children and in pathology with very slow rate (< 1/sec) to detect Pb component
- **Subject Factors:**
  - **Age:** a factor under 10 years old and interacts with rate
  - **Sleep:** AMLR more variable during sleep
  - **Post-auricular muscle (PAM) artifact:** Avoid if possible
  - **Sedation:** amplitude reduced and variable
  - **Anesthesia:** typically suppresses AMLR activity (reticular formation generators)

Sensitivity and Specificity of the AMLR in the Detection of Auditory CNS Dysfunction

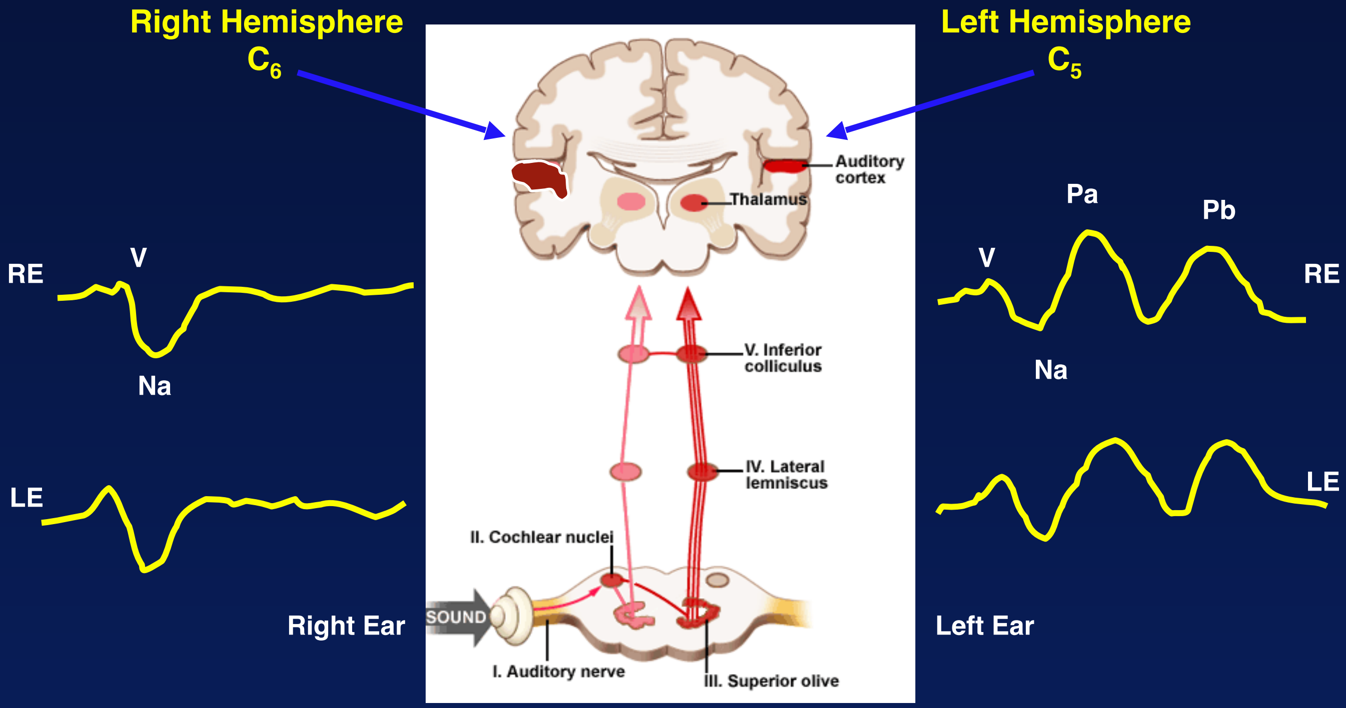
- Musiek F, Charette L, Kelly T, Lee WW, Musiek R. Hit and false-positive rates for middle latency response in patients with central nervous system involvement. JAAA 10: 1999.
  - 26 adult control subjects and 26 patients with medically confirmed CANS lesions (mostly CVAs and lobectomies)
  - Two groups matched for hearing status and age
  - AMLR measured with hemispheric electrode array (C3 and C4)
  - Latency measured for Na and Pa
  - Amplitude measured for Na-Pa
  - ROC curves generated by plotting hit rate by the false-positive rate for different criteria, e.g., absolute latency and amplitude, and differences in these parameters for ipsi versus contra AMLRs

Abnormal Patterns for Auditory Middle Latency Response (AMLR) in Patients with Confirmed Temporal Lobe Lesions

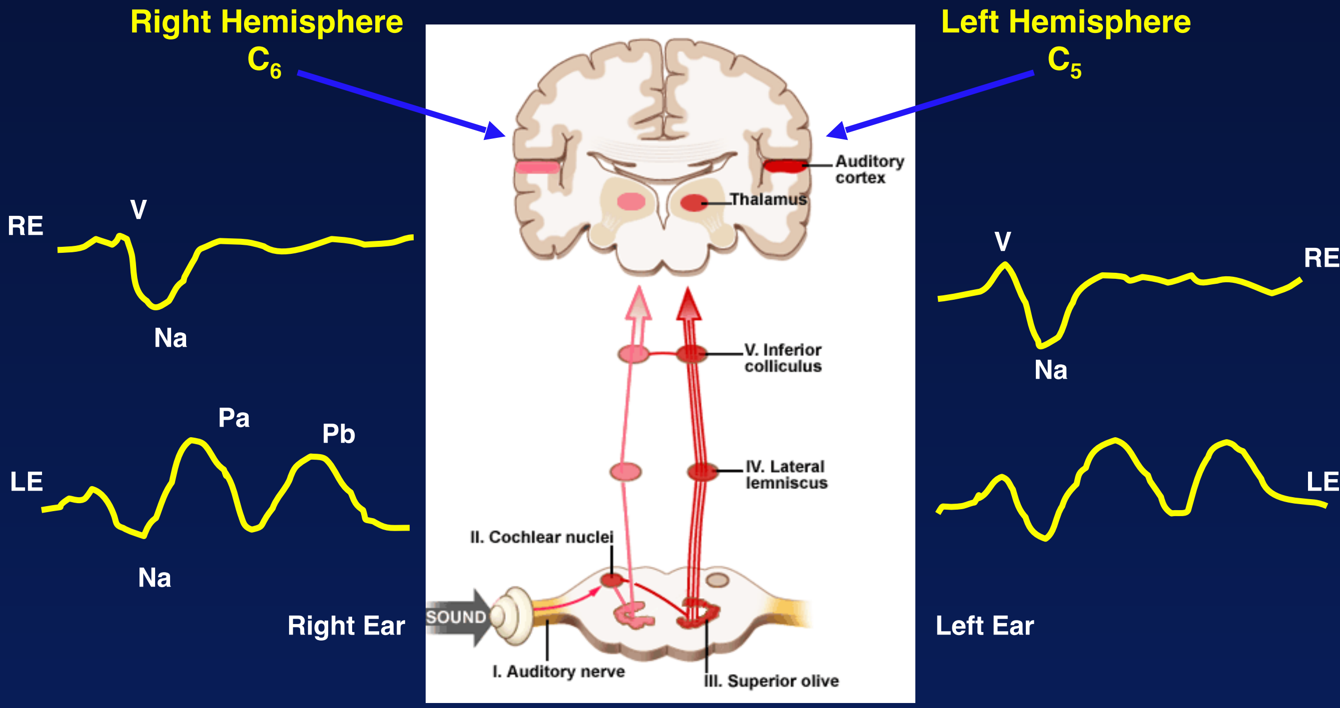
(Musiek et al, 2007)

		AMLR Component (Amplitude in μV)		
Hemisphere		Na-Pa	Na	Pa
Side of Lesion				
	Mean	0.55	0.20	0.35
	(SD)	(0.20)	(0.14)	(0.24)
Intact Side				

Abnormal Patterns of AMLR with Right Hemisphere Lesion
Electrode Effect



Abnormal Patterns of AMLR with Right Hemisphere Lesion
Ear Effect



Ear and Electrode Effects in Pediatric Auditory Middle Latency Response (AMLR) Recordings

- Weihling J, Schochat E & Musiek F. (2013) Ear and electrode effects reduce within-group variabiliy in middle latency response amplitude measures. International Journal of Audiology, 51, 405-412
  - 155 children
    - ✓ Normal peripheral function
    - ✓ Normal central auditory function
    - ✓ No history of psychological, neurological, or learning disorders
  - Na-Pa amplitude differences were measured for
    - ✓ AMLR C3 – C4 hemispheric electrode recording sites
    - ✓ Left ear – right ear stimulation
  - Conclusions
    - ✓ Within group variability was significant smaller for relative differences when compared to absolute measures
    - ✓ Electrode effects showed significantly less variability than ear effects
    - ✓ Authors reports normative data

Normal Expectations for Electrode Effects in Pediatric Auditory Middle Latency Response (AMLR) Recordings

(Weihling, Schochat & Musiek, 2013)

Table 3. Descriptive statistics for electrode effects for left ear and right ear stimulation for each age group. The electrode effect for the left ear represents the absolute value of the Na-Pa amplitude difference between C3 and C4 on left ear stimulation, while the electrode effect for the right ear represents the same difference computed for the right ear.

	Electrode Effect for Left Ear (μV)			*Electrode Effect for Right Ear (μV)*		
Age in Years	*M*	*SD*	*95% CI*	*M*	*SD*	*95% CI*
7 to 8 (N = 31)	.16	.17	.10–.22	0.12	0.09	.08–.16
9 to 10 (N = 34)	.16	.15	.10–.22	0.16	0.14	.12–.20
11 to 12 (N = 30)	.12	.13	.08–.16	0.16	0.17	.10–.22
13 to 14 (N = 30)	.18	.15	.12–.24	0.17	0.17	.11–.23
15 to 16 (N = 30)	.22	.26	.12–.32	0.15	0.17	.09–.21

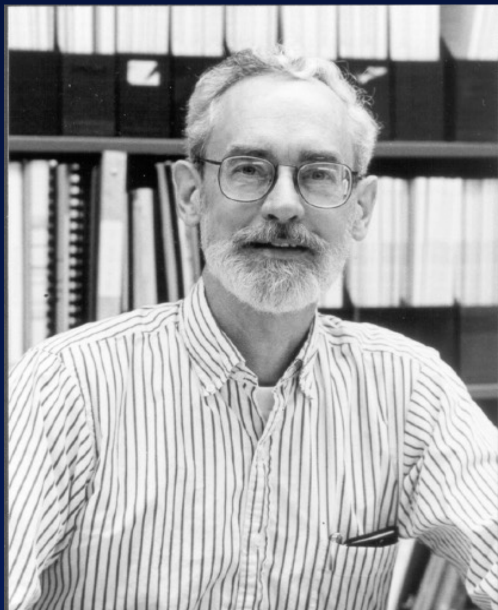
Normal Expectations for Ear Effects in Pediatric Auditory Middle Latency Response (AMLR) Recordings

(Weihling, Schochat & Musiek, 2013)

Table 2. Descriptive statistics for ear effects at C3 and C4 for each age group. The ear effect at C3 represents the absolute value of the Na-Pa amplitude difference between left and right ear stimulation, while the ear effect at C4 represents the same difference computed at the C4 electrode.

	Ear effect at C3 (μV)			*Ear effect at C4 (μV)*		
Age in years	*M*	*SD*	*95% CI*	*M*	*SD*	*95% CI*
7 to 8 (N = 31)	.33	.39	.19–.47	.38	.45	.22–.54
9 to 10 (N = 34)	.30	.47	.14–.46	.30	.43	.14–.46
11 to 12 (N = 30)	.23	.19	.15–.31	.21	.18	.15–.27
13 to 14 (N = 30)	.25	.18	.19–.31	.22	.14	.16–.28
15 to 16 (N = 30)	.25	.36	.11–.39	.27	.28	.17–.37

Conclusion of the AMLR Presentation
Questions?



Dan

Frank Musiek

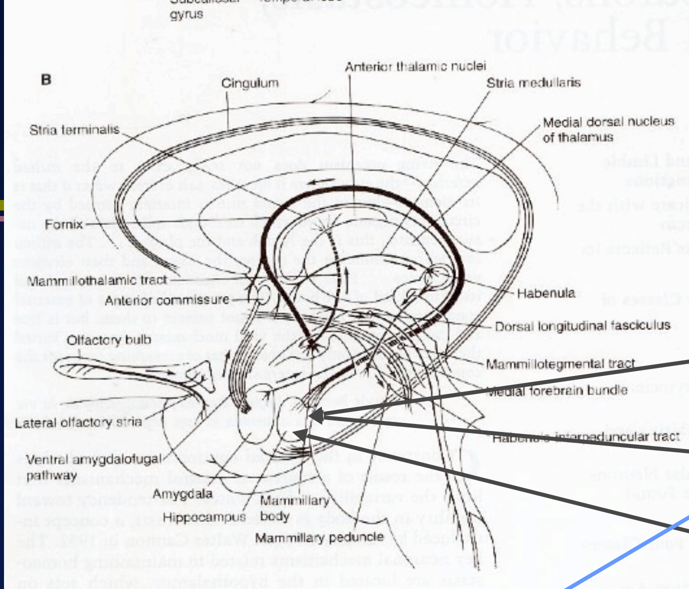
Clinical Application of Auditory Evoked Responses in Children: Evidence-Based Protocols and Procedures

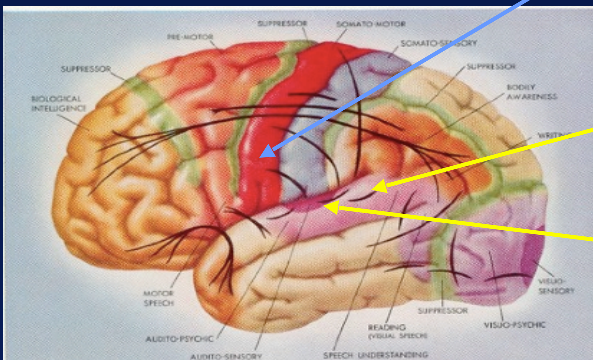
- Cortical Auditory Evoked Responses
  - Auditory Middle Latency Response (AMLR)
    - ✓ Test Protocol
    - ✓ Clinical Applications in Adults
    - ✓ Clinical Applications in Children
  - Auditory Late Response (ALR)
    - ✓ Test Protocol
    - ✓ Clinical Applications in Adults
    - ✓ Clinical Applications in Children
  - P300 Response

Auditory Late Response (ALR): Discovered by Hallowell Davis in 1939

(Also Founder of IERASG)

Auditory Late Response (ALR: Generators





P300

N2

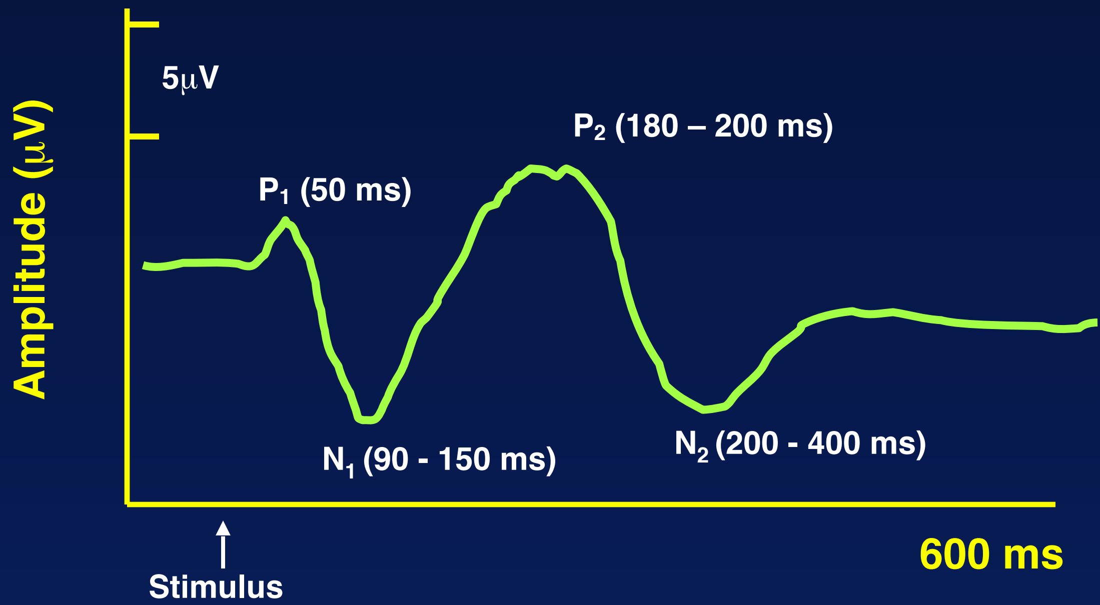
P2

N1

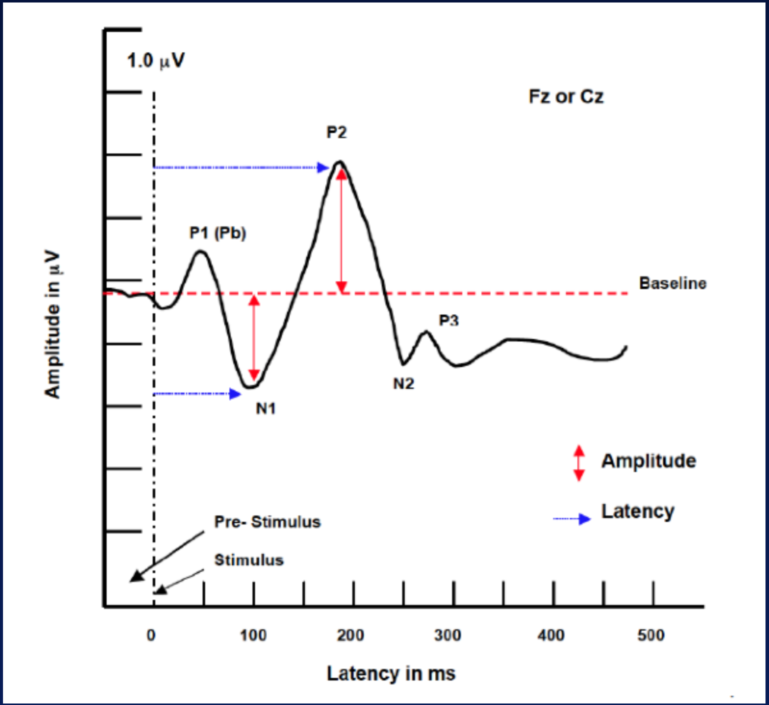
There are Many Auditory Late Responses
(Table from eHandbook of Auditory Evoked Responses)

Wave	Latency	Comme
P1	50	Also referred to as AMLR Pb wave or P1 of ALR
N1 (N100)	100	Obligatory component of the ALR
N1 b	100	Wave detected with a midline electrode
N1c	150	Detected with temporal lobe electrode
N1d	100 - ???	Negative wave persisting beyond the signal
N150	150	
N250	250	Particularly robust in children
P165	165	
P2	200	
MMN	150 – 275	Mismatch negativity response
P3a	≤ 300	Passive oddball paradigm response
P3	300	Recorded with oddball paradigm
Nc	400 – 700	Detection depends on electrode locations
Nd	60 – 700	Referred to as processing negativity (PN).
N400	400	Evoked with semantic signals.
Sustained-Negativity	50 to 1000-ms	Recorded for duration of the stimulus

Auditory Late Response (ALR): *Typical Waveform*



Auditory Late Response (ALR):
Simple Analysis
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

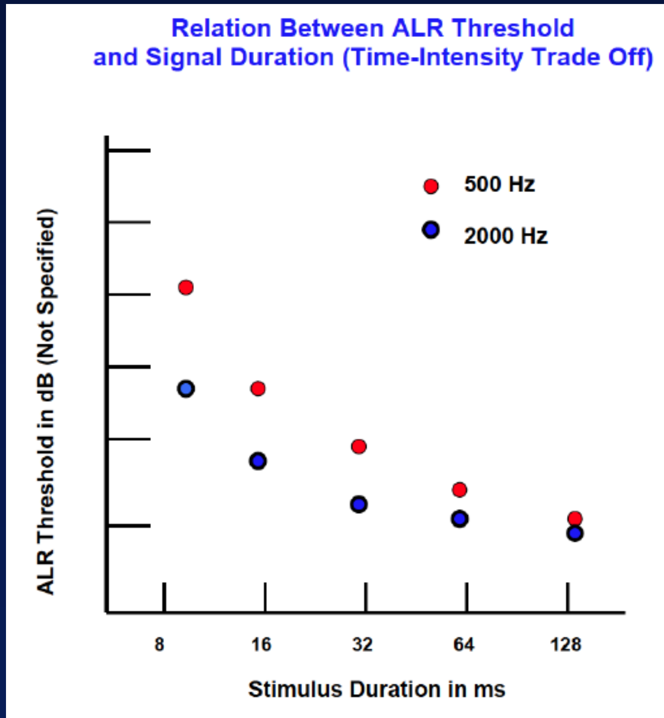


Auditory Late Responses (ALRs): Test Protocol (1)

- Stimulus parameters
  - Stimulus: tones or speech signals (e.g., phonemes /da/ or /ga/)
  - Duration: relatively long, e.g.,
    - ✓10 ms rise/fall
    - ✓30 ms plateau
  - Rate: slow (< 1/sec); amplitude increases until ISI > 5 sec)
  - Polarity: alternating (not important)
  - Intensity: moderate (< 70 dB nHL)
  - Repetitions (averages): < 200

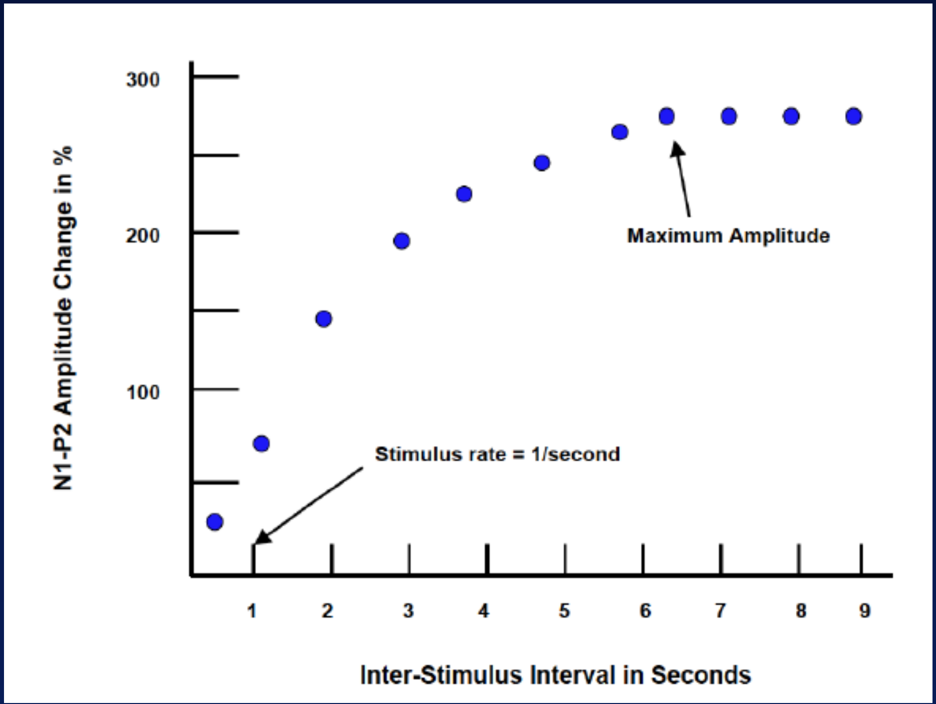
Auditory Late Responses (ALRs): Stimulus Duration

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



Auditory Late Responses (ALRs): Stimulus Rate or Inter-Stimulus Interval

(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)

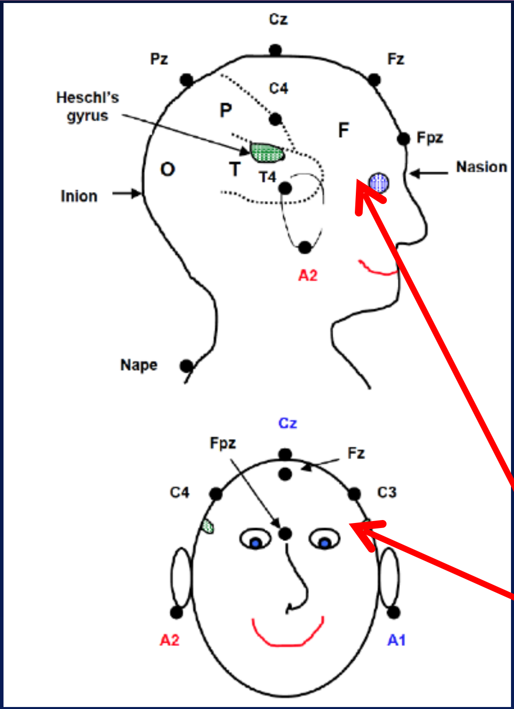


Auditory Late Responses (ALRs): Test Protocol (2)

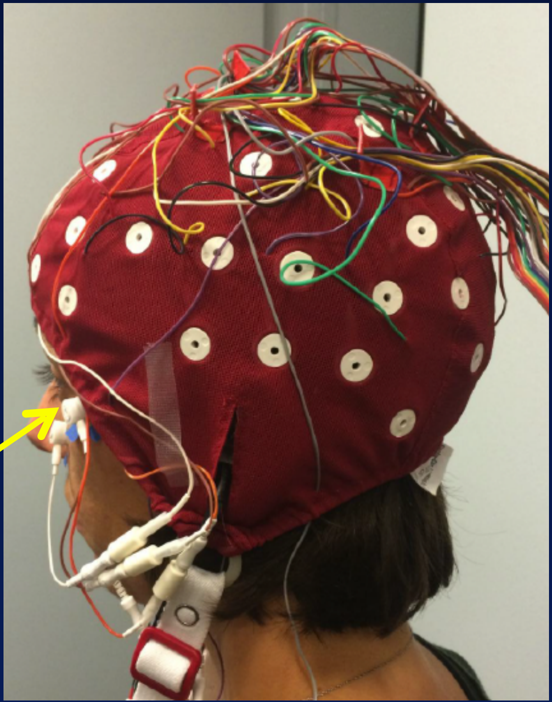
- Acquisition parameters
  - Analysis time
    - Total: 600 ms
    - Post-stimulus: 500 or 600 ms
    - Pre-stimulus: 100 ms
  - Electrodes
    - Non-inverting: Cz (and/or Fz and other scalp locations)
    - Inverting: earlobes (linked)
    - Supra-orbital/canthus: monitor eyeblink
  - Amplification: < 25,000
  - Filter settings
    - Band-pass: 0.1 to 100 Hz
    - Notch: off

Auditory Late Responses (ALRs): Electrode Locations

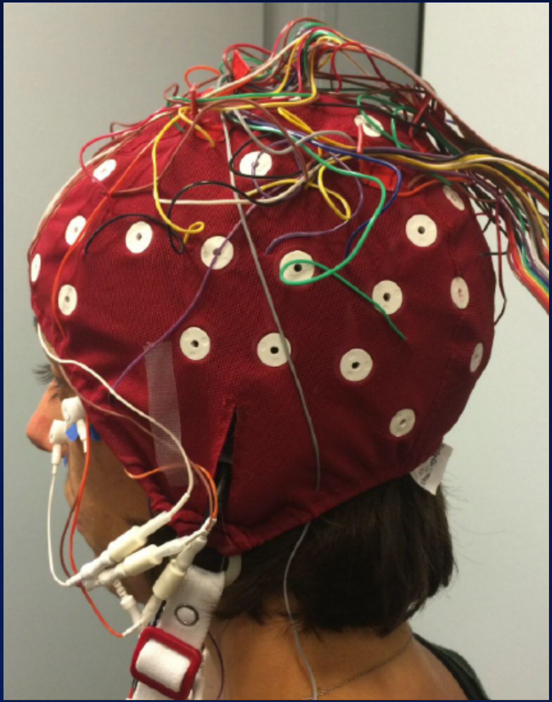
(Figure from Hall JW III. eHandbook of Auditory Evoked Responses)



Eye Blink Electrode



Auditory Late Responses (ALRs): Cap for Multiple Electrode Locations



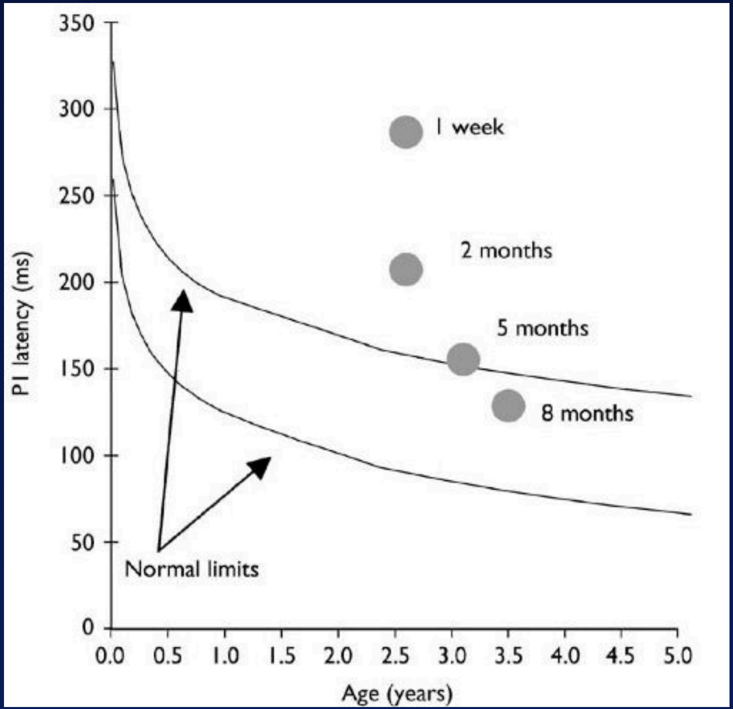
Auditory Late Responses (ALRs):
Effects of Selected Subject Factors

- Age
  - Developmental changes
    - ✓ Maturation through at least 10 to 12 years of age
    - ✓ N1 and P2 amplitude decreases, and P3 amplitude increases, with development
    - ✓ Latency decreases with development
  - Advancing age
    - ✓ Latency increase > 20 years of age for all auditory late responses
- Attention
  - Variable for different ALR components (for P2 and P3, not N1)
- Sleep
  - Stage of sleep affects ALRs
    - ✓ Variability in sleep stages 3 and 4
    - ✓ Responses in REM sleep equivalent to awake state
- *Changes in amplitude and latency can document effective intervention*

Clinical Applications of Auditory Late Response (Many IERASG 2017 Papers)

- Diagnosis of auditory processing disorders (APD)
  - Children
  - Adults with traumatic brain injury & cognitive decline
- Diagnosis of auditory neuropathy spectrum disorder
- Documenting management outcome
  - Intervention for APD
  - Hearing aid benefit
  - Cochlear implant

Clinical Applications of Auditory Late Response: Documenting Cortical Maturation
(Anu Sharma, PhD, University of Colorado)



Recording of Auditory Late Responses to Evaluate Hearing Aid and Cochlear Implant Performance is Feasible
(Anu Sharma, PhD, University of Colorado)

Hearing Aid

Cochlear Implant

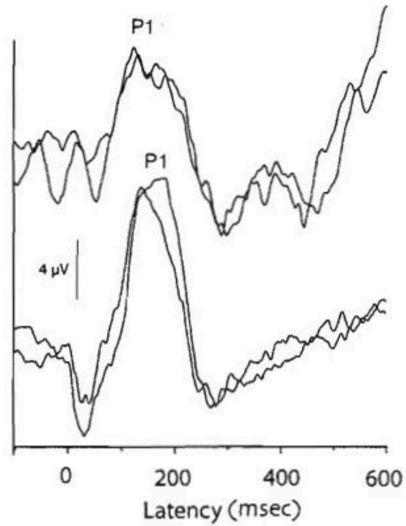
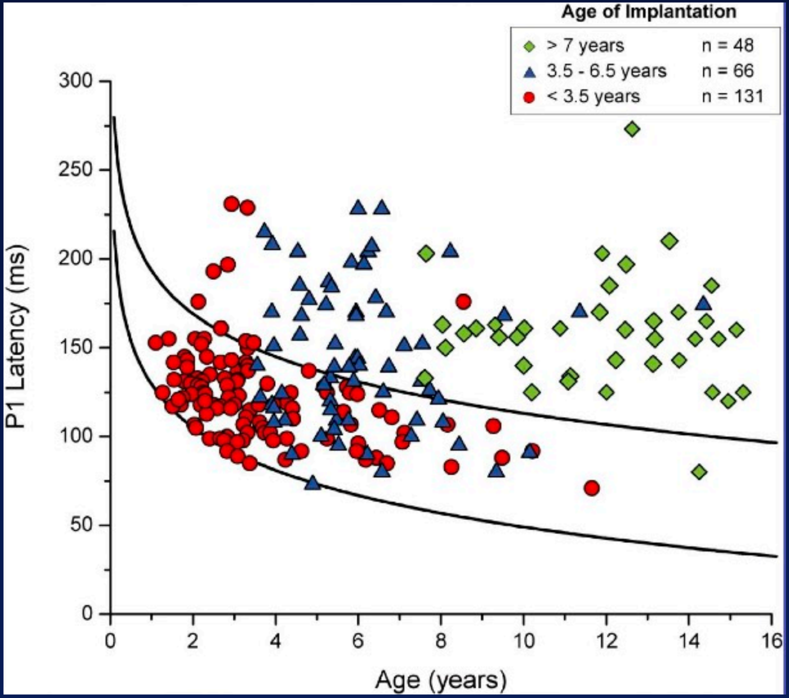


Figure 1. *Top:* Replicable CAEP waveforms from a representative subject who wore hearing aids. *Bottom:* Replicable CAEP waveforms from a representative subject who was fitted with a cochlear implant.

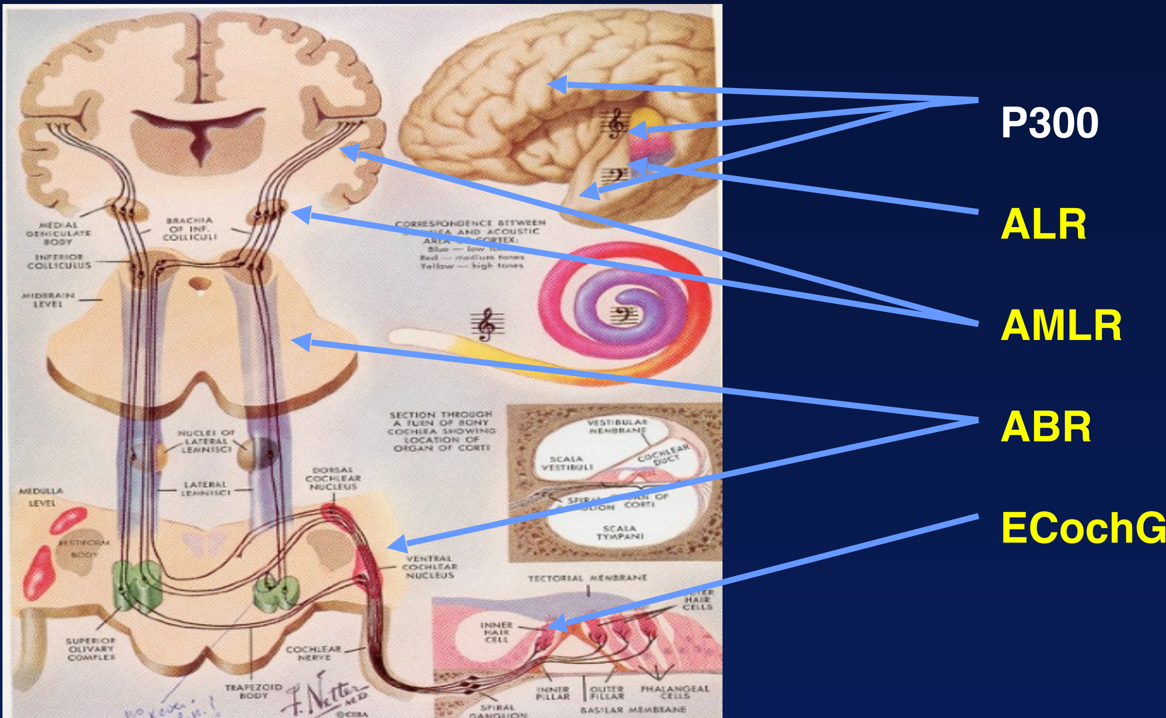
Clinical Applications of Auditory Late Response: Evaluating Cortical Differences with Age of Cochlear Implantion
(Anu Sharma, PhD, University of Colorado)



Clinical Assessment of APD with the ALR:
How Can We Make it Happen?

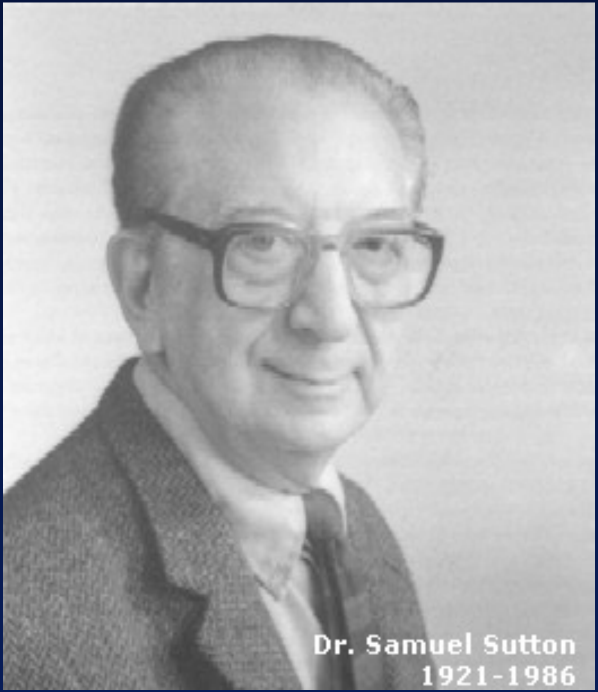
- ❑ Accepted test protocol
  - Hearing scientists use non-clinical instrumentation (NeuroScan)
  - Disagreement on basic test parameters, e.g., required number of electrodes
- ❑ Clinical instrumentation with new features (ALR options)
  - Multiple channels (e.g., 4 to 8) for hemisphere and eye blink electrodes
  - An assortment of speech stimuli available within ALR protocols
  - APD protocols for measurement of ALR with:
    - ✓ Speech-in-noise
    - ✓ Dichotic listening
    - ✓ Temporal processing (gap detection)
  - Statistical analysis of ALR parameters, e.g.,
    - ✓ Latency and amplitude
    - ✓ Amplitude under the curve
- ❑ Normative data (collected with clinical instrumentation)
  - Maturational data on ALR from infancy to adulthood (0 to 20 years)
  - Latency and amplitude data for various stimuli

Cortical Auditory Evoked Responses: P300 Response

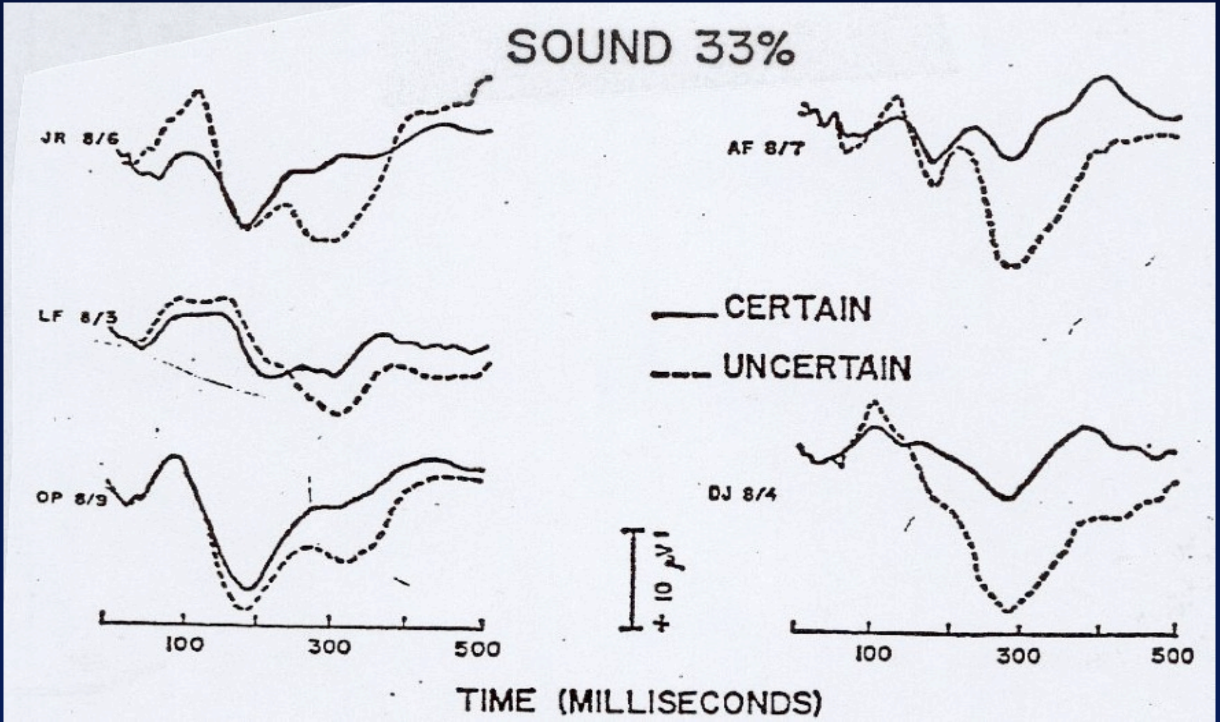


Co-Discoverers of the Auditory P300 Response

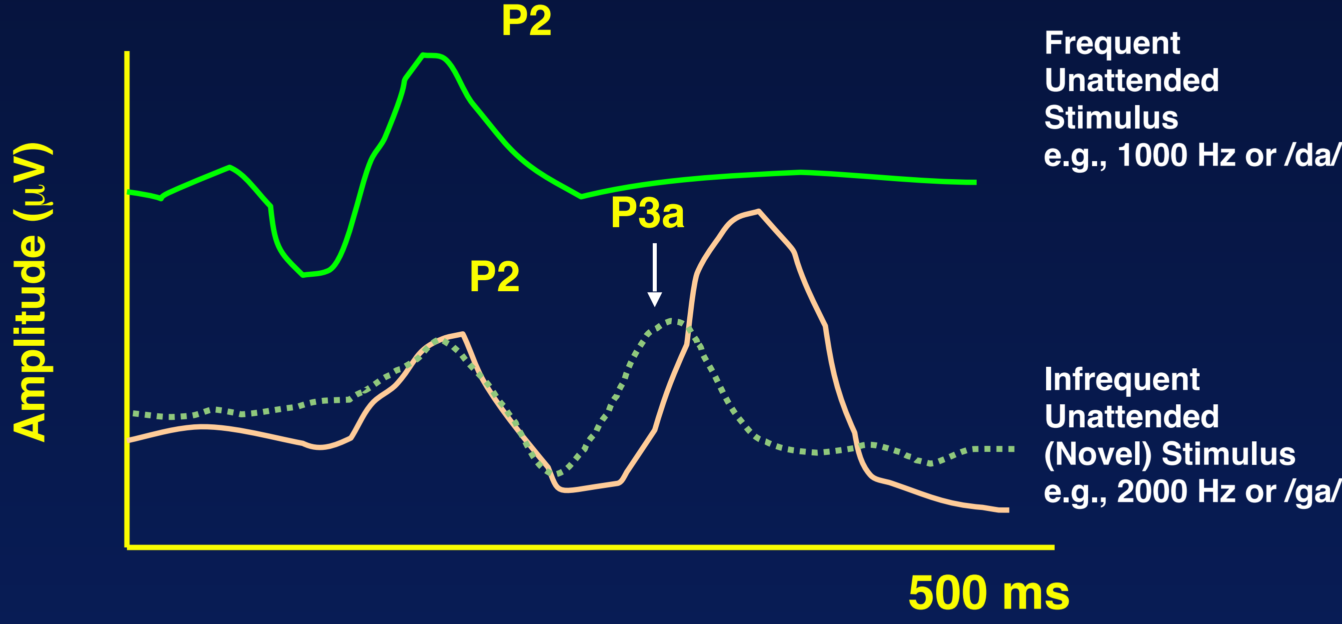
Hallowell Davis (1896-1992) *Samuel Sutton (1921-1986)*



The P300 Response
(Davis H, 1964; Sutton, Braren & Zubin, 1965)



P300 Response:
Passive Measurement Paradigm



* P3b

P300 Response: Test Protocol (1)

- Stimulus parameters
  - Stimulus: tones or speech signals (e.g., phonemes /da/ or /ga/)
  - Duration: relatively long, e.g.,
    - ✓ 10 ms rise/fall
    - ✓ 30 ms plateau
  - Rate: slow (< 1/sec); amplitude increases until ISI > 5 sec)
  - Polarity: alternating (not important)
  - Intensity: moderate (< 70 dB nHL)
  - Frequent versus Rare (oddball)
    - ✓ Some acoustic difference, e.g., frequency
    - ✓ Rare stimuli randomly presented with probability of ~20%
  - Repetitions (averages): < 200

Auditory P300 Response: Factors Influencing Latency and Amplitude

- Probability of rare stimulus
  - Shorter latency and larger amplitude with less probable stimulus
- Attention
  - Shorter latency and larger amplitude with greater attention
- Age
  - Latency decreases by about 19 ms/year up to age 20 years
  - Latency increases by 1 to 2 ms/year > age 20 years
- Gender
  - No apparent effect

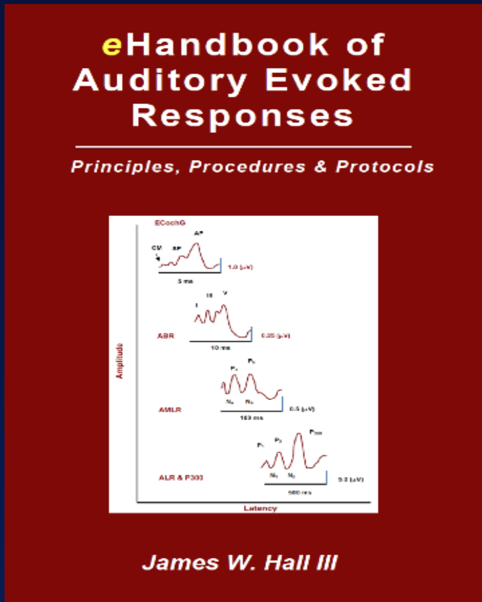
Auditory P300 Response: Factors influencing latency and amplitude

- Handedness
  - Larger P300 amplitudes for posterior electrode locations for right handed subjects and for anterior locations for left handed subjects
- Sleep
  - P300 response is highly variable depending on stages of sleep
  - P300 response is equivalent in awake and REM sleep state
- Difficulty of task
  - Latency is longer & amplitude smaller as difficulty of task increases
- Memory
  - Latency of P300 is related to memory as influenced by medications (decreased memory → increased latency)

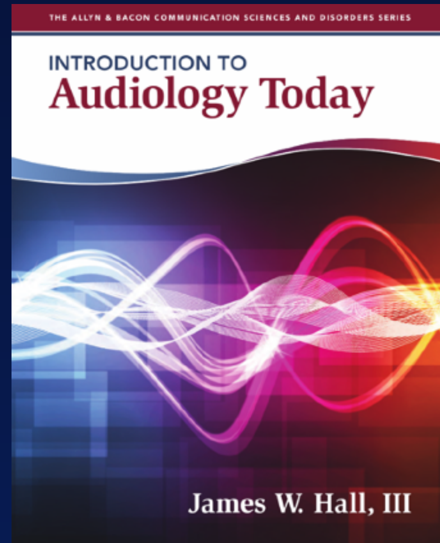
Thank You!

Questions?

www.audiologyworld.net *jwhall3phd@gmail.com*



eBook 2015 (Amazon.com)



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