# INNOVATION IN OBJECTIVE AUDITORY TESTING: ELECTRICALLY EVOKED AUDITORY POTENTIALS


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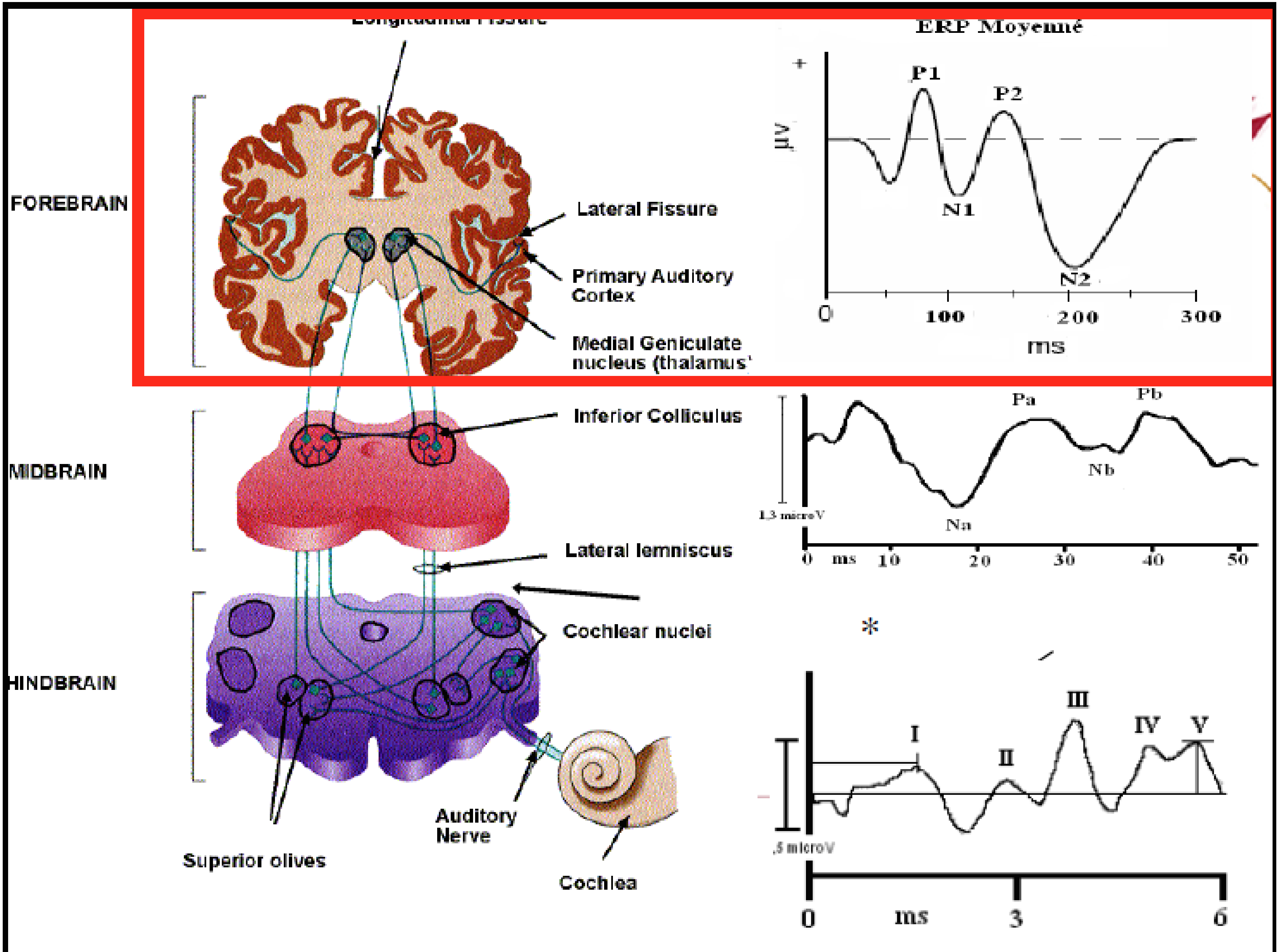
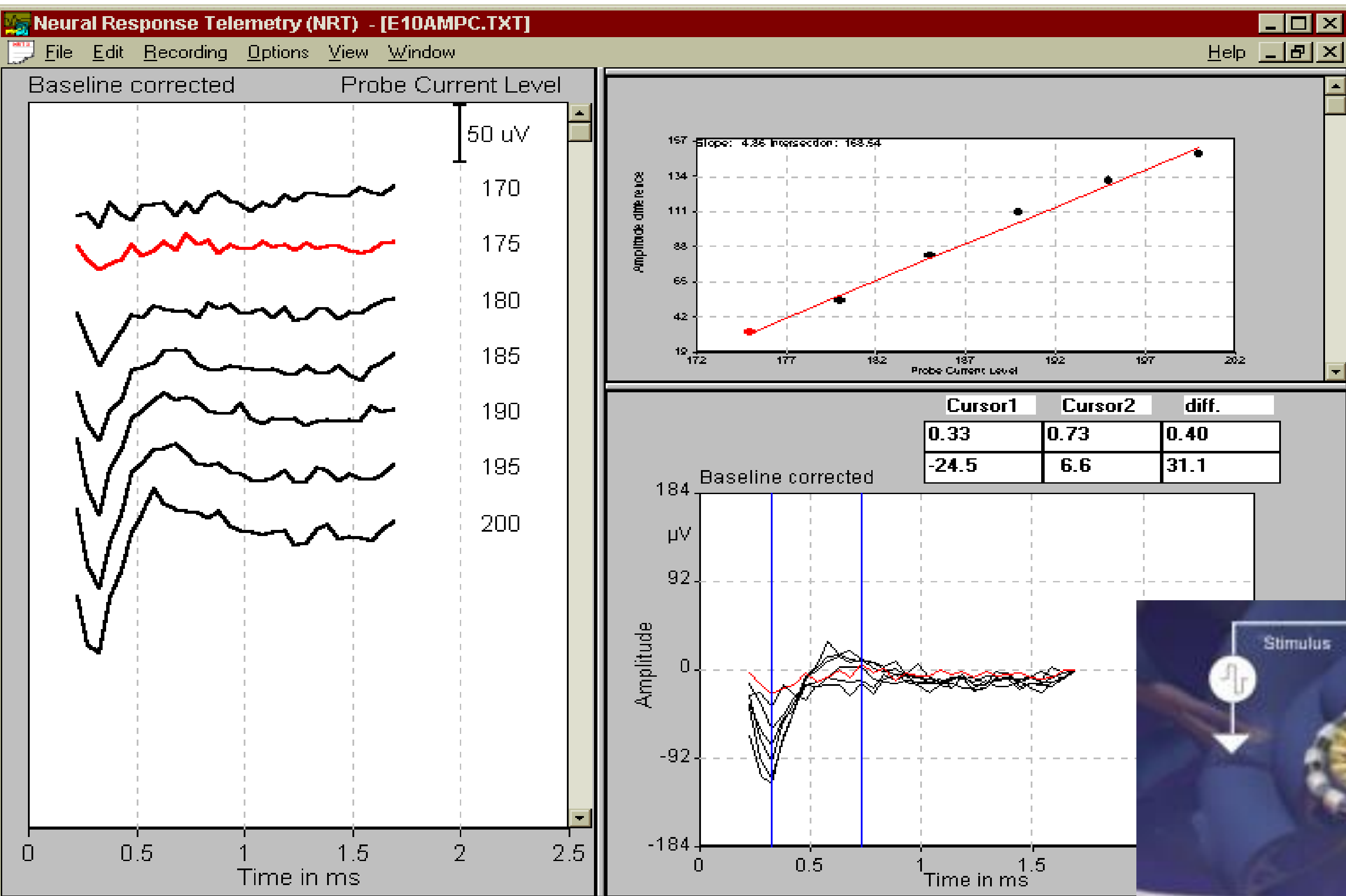


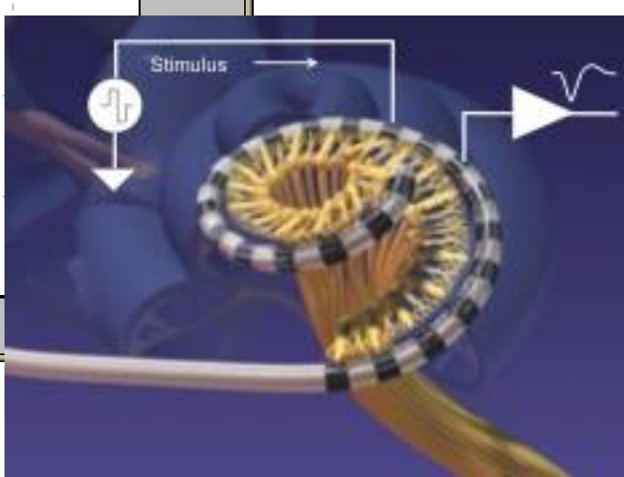
Longitudinal Fissure
ERP Moyenné
FOREBRAIN
Lateral Fissure
Primary Auditory Cortex
Medial Geniculate nucleus (thalamus)
P1
P2
N1
N2
μV
0
100
200
300
ms
MIDBRAIN
Inferior Colliculus
Pa
Pb
Nb
Na
1.3 microV
0 ms 10 20 30 40 50
Lateral lemniscus
HINDBRAIN
Cochlear nuclei
I
II
III
IV
V
.5 microV
0 ms 3 6
Superior olives
Auditory Nerve
Cochlea

# OBJECTIVE MEASURES

- Electrically evoked stapedial reflex,
- Electrically evoked auditory nerve compound action potential – Neural Response Telemetry (NRT),
- Electrically evoked brain stem responses (eABR),
- Electrically evoked potentials of auditory cortex (eAEP)

# NEURAL RESPONSE TELEMETRY (NRT)

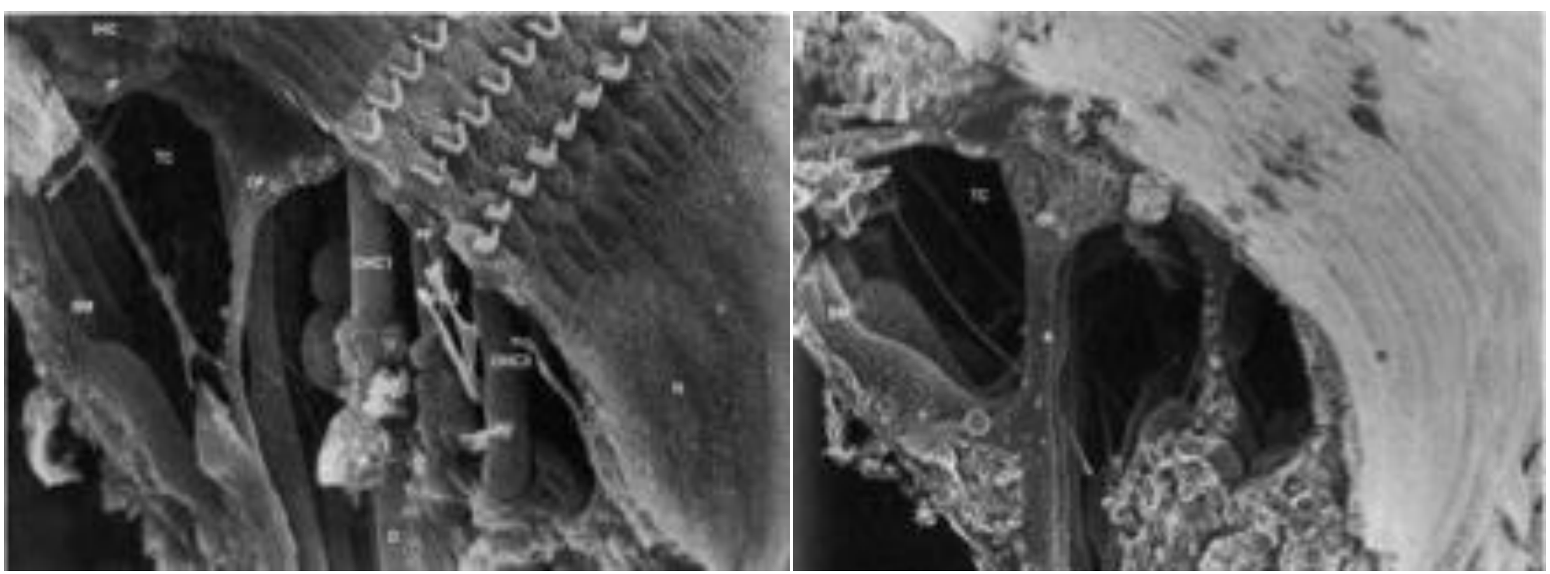


# Neural Response Telemetry

Each electrode stimulates different populations of neurons.

From histological data revealed in animals with experimentally induced deafness and data obtained from human temporal bones it is possible to conclude that degeneration  of spiral ganglion neurons and their peripheral axons differs along the cochlear partition.



# Neural Response Telemetry

Each electrode stimulates different populations of neurons.

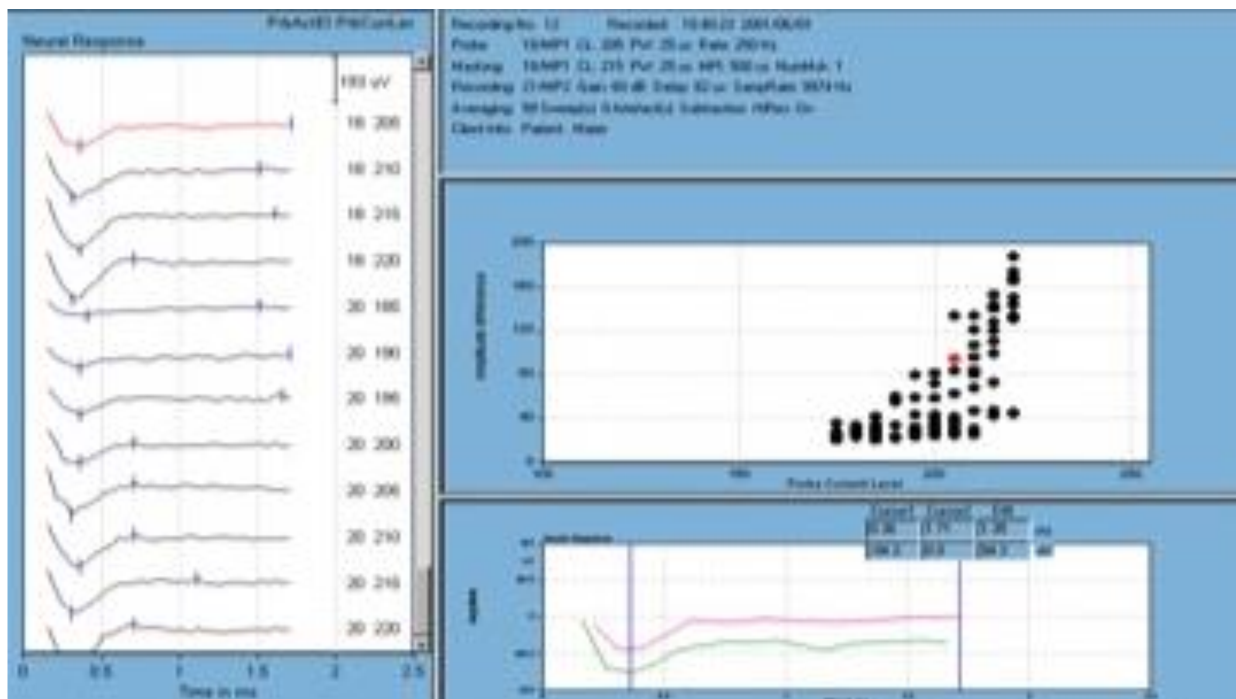
From histological data revealed in animals with experimentally induced deafness and data obtained from human temporal bones it is possible to conclude that degeneration  of spiral ganglion neurons and their peripheral axons differs along the cochlear partition.

Assuming that eCAP parameters reflect parameters of stimulating neuronal populations it is possible to conclude that responses will vary not only between patients but according the place of stimulation as well.

# Neural Response Telemetry

Based on our results it was concluded that NRT could be used for psychophysical levels as well as speech processor individual stimulation map estimation.

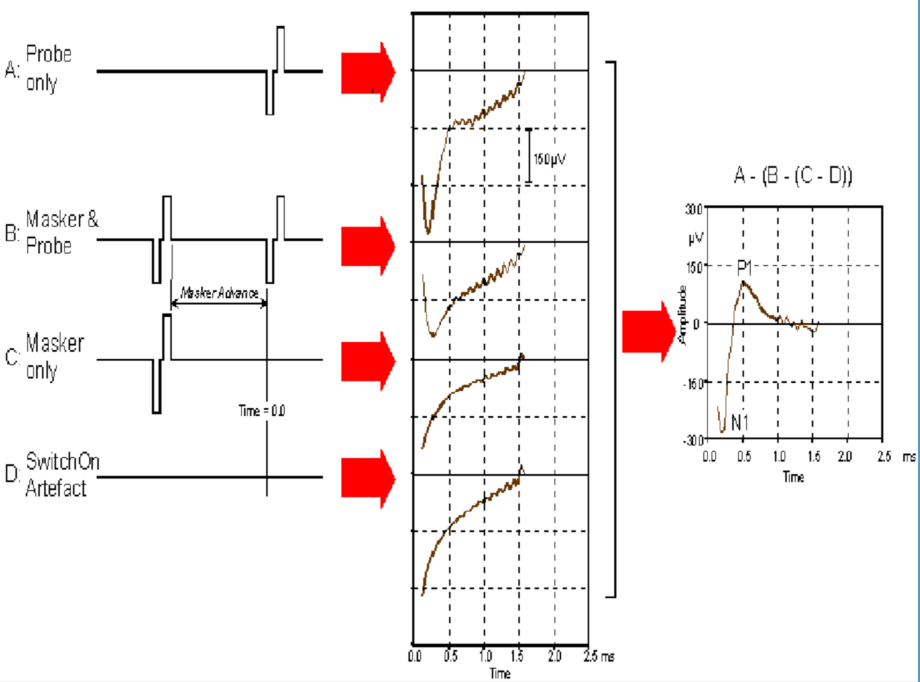
This is particularly important when constructing individual speech processor mapping based on the NRT data in small children and patients with multiple malformations

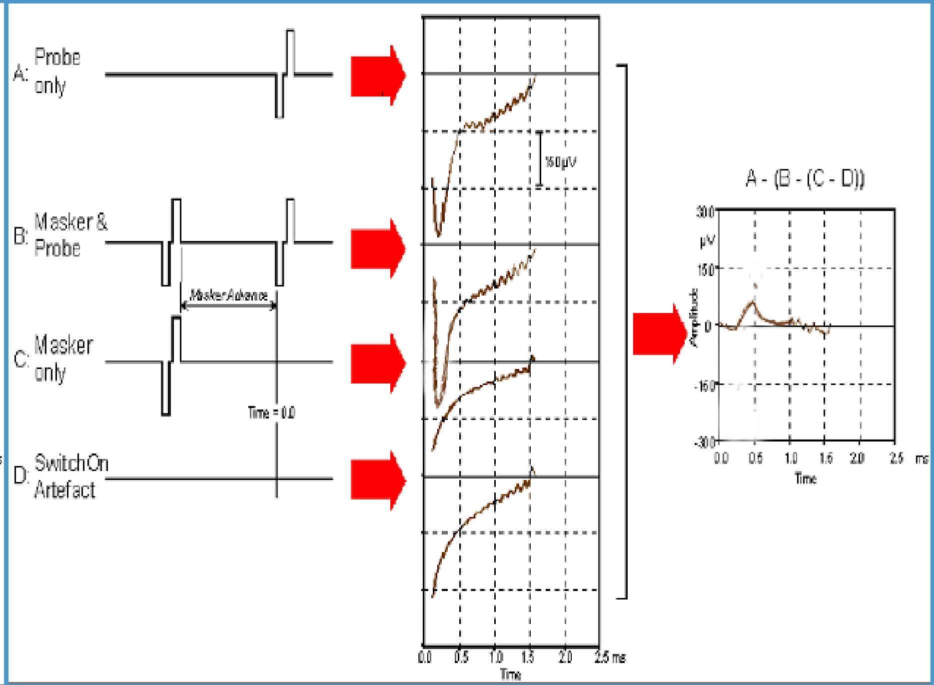


# NRT – excitation summation

Levels close to MCL

sub-threshold levels St = M

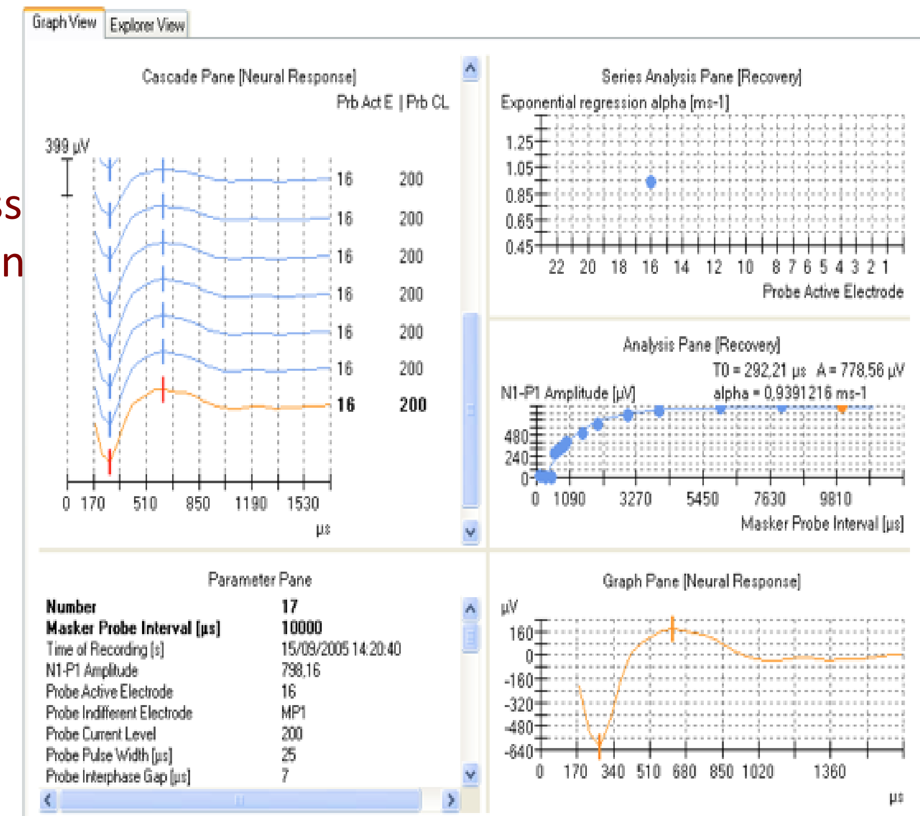


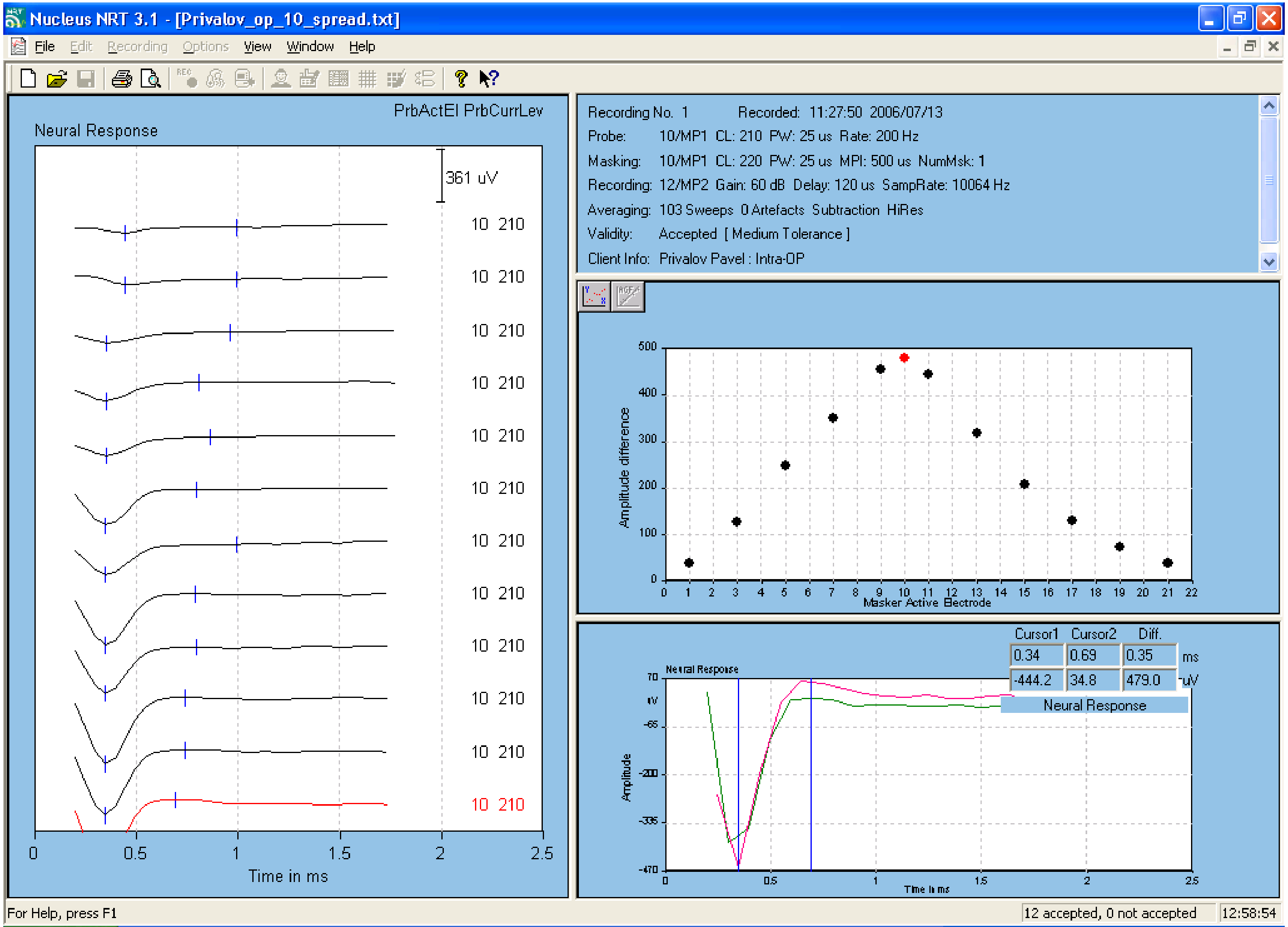
# NRT – recovery function

- Auditory nerve fibres refractory period
- Could be used for the diagnosis of some forms of neuropathies (increased AN refractory period time)

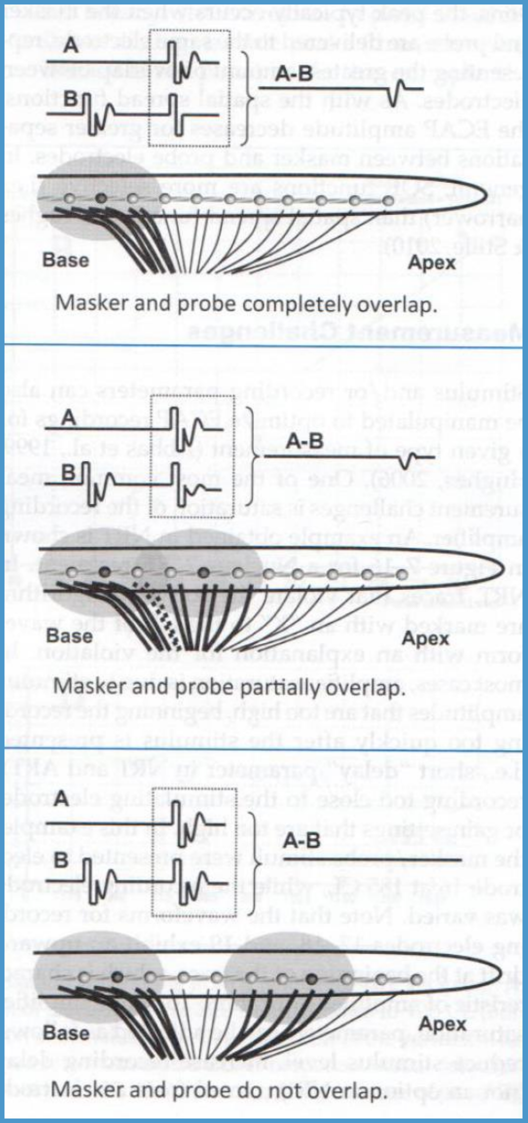
The correlation between the AN refractoriness parameters and patients individual stimulation frequency preferences (for experienced CI users) was obtained



# NRT – spread of excitation



# NRT – spread of excitation



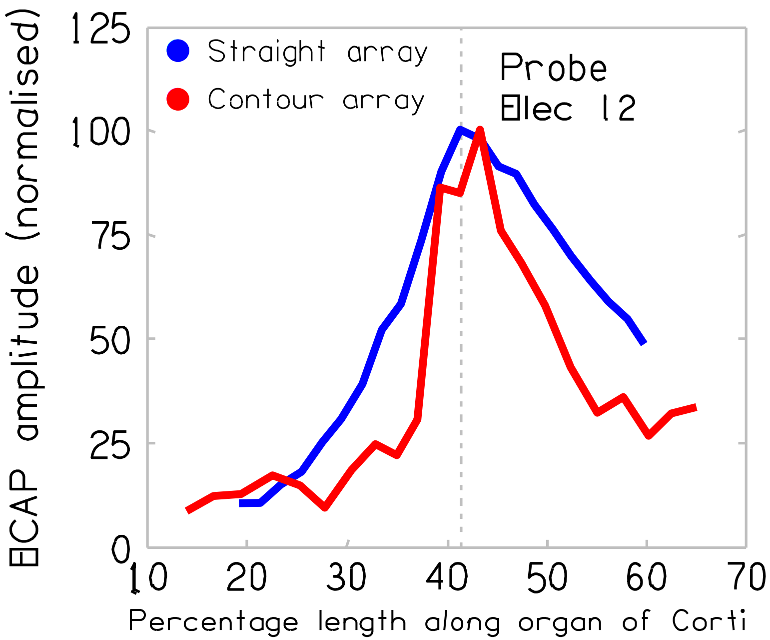

Masker and probe completely overlap

Masker and probe partially overlap

Masker and probe do notoverlap

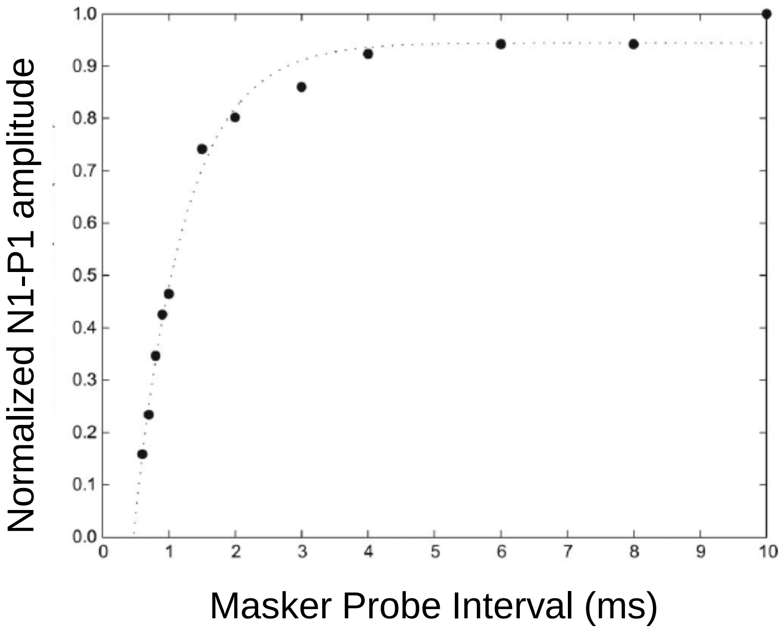
# NRT – spread of excitation

**Spread of Excitation**



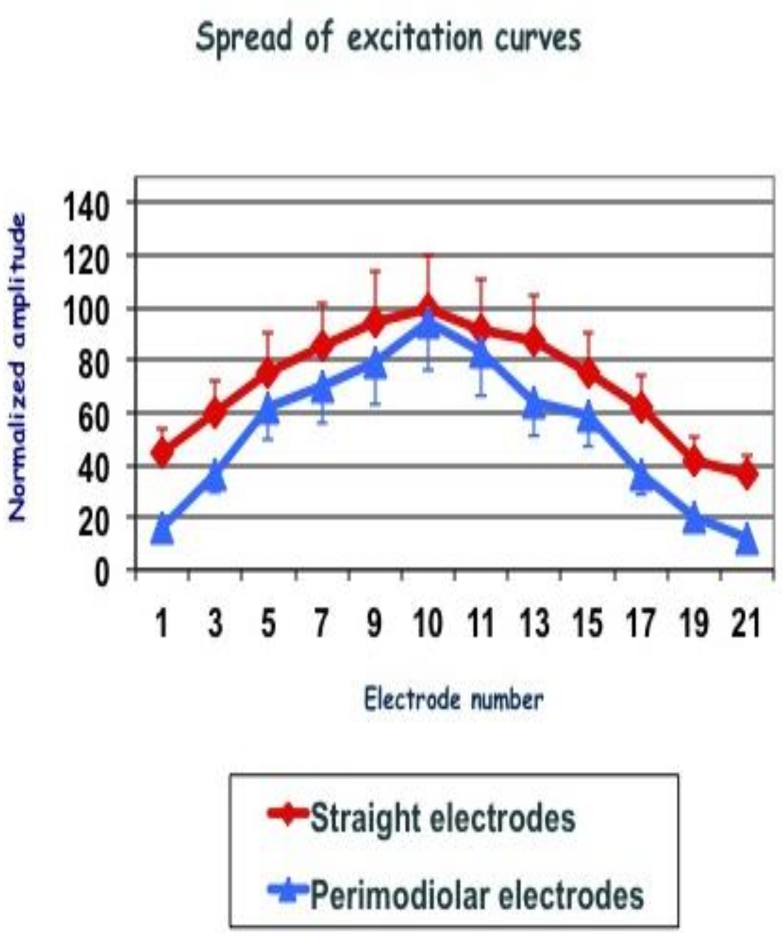

Cohen, L.T. et al. 2003. Spatial spread of neural excitation in cochlear implant recipients. HearRes

**Recovery Function**




Botros, A., Psarros, C. 2010, Neural Response Telemetry Reconsidered: II. The Influence of Neural Population on the ECAP Recovery Function and Refractoriness. Ear&Hearing

# NRT – spread of excitation

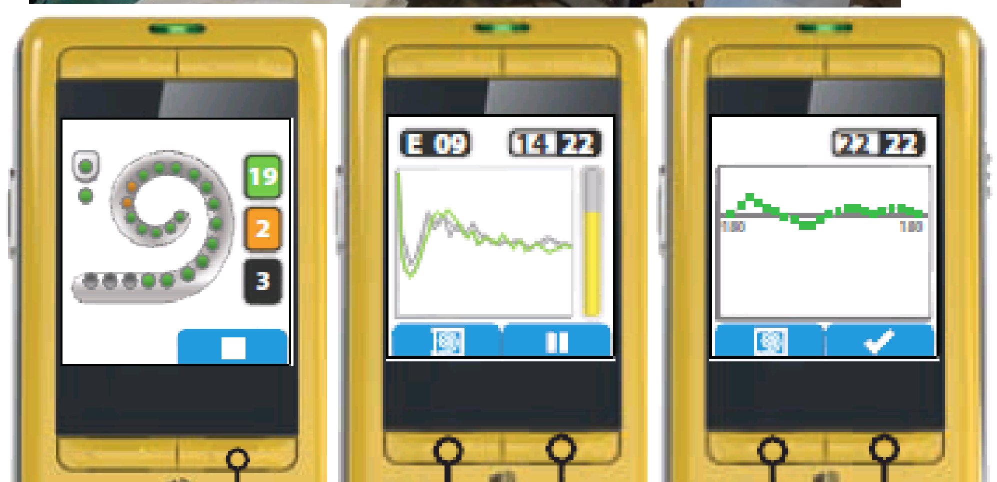



Spread of excitation is significantly narrower in case of perimodiolar electrode which could suggest better differentiation (discrimination) with this location.

The significant decrease of stimulation threshold level was also obtained

# Cochlear® CR120/220

- Handheld & wireless
- Conducts
  - AutoNRT
  - Impedance
- CR 120/220 requires
  - Sound Processor
- Gives instant results for
  - Electrode integrity
  - ECAP thresholds (t-NRT)



# eABR

# EABR

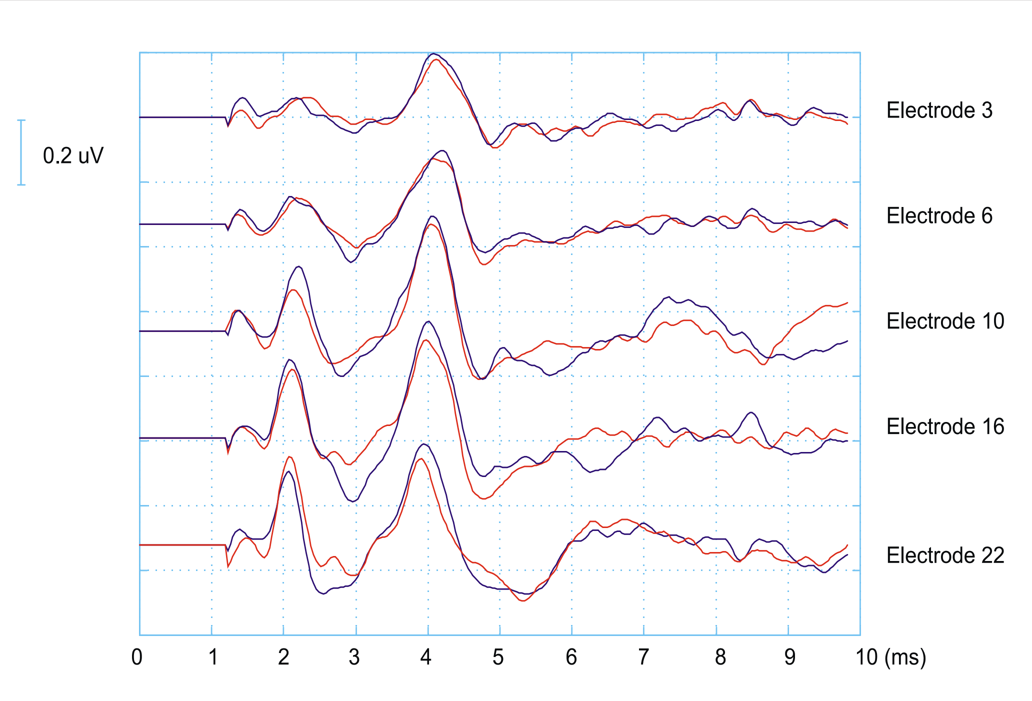
## PROBLEMS

1. eABR distortion by the electrical stimulus artifact contamination

2. Difference in the stimulus presentation rate during EABR registration (low-pulse-rate) and conventional psychophysical threshold estimation (high-pulse-rate) in cochlear implant patients.

# eABR

New original method of eABR registration with the use of simultaneous masking paradigm was developed

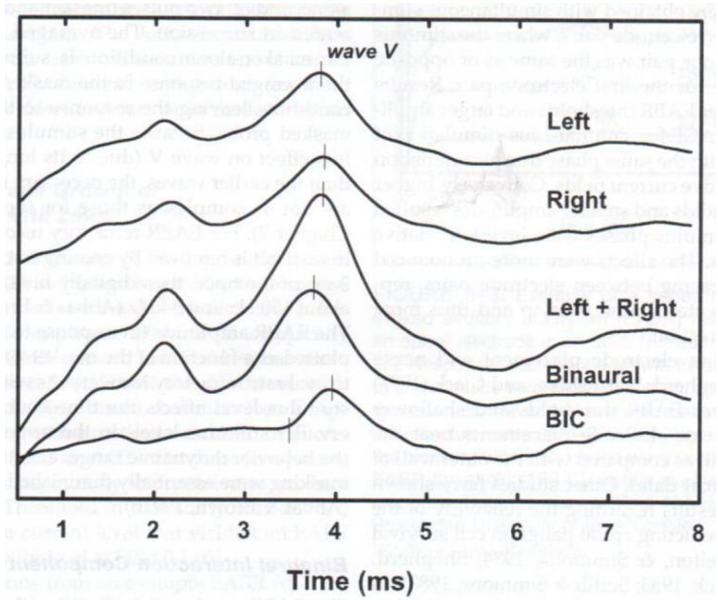



*Tavartkiladze GA, Potalova LA, Kruglov AV, Belov OA. Effect of stimulation parameters on electrically evoked auditory brainstem responses. Acta Otolaryngol.- 2000.-V.120. - N2, P.214-217*

# eABR

- Threshold and growth of response (wave V) with level
- Refractory recovery
- Binaural interaction component
- Use of eABR latency to assess longitudinal changes in neural responsiveness to electrical stimulation (significant decrease in wave III and wave V latencies within the first year of device use for a group of pre-lingually deafened children )

# eABR - Binaural Interaction Component (BIC)




Gordon et al (2007, 2008) used the BIC response to assess auditory brainstem Development in children who were bilaterally implanted either simultaneously with a short time interval between ears (<1 year), or with a longer time interval between ears. Results showed prolonged eABR and BIC latencies for the later-implanted ear for both groups of children implanted in sequential surgeries. Within the first 9 months of bilateral implant use latencies for the short-delay group were similar to those for the simultaneous group

# eABR

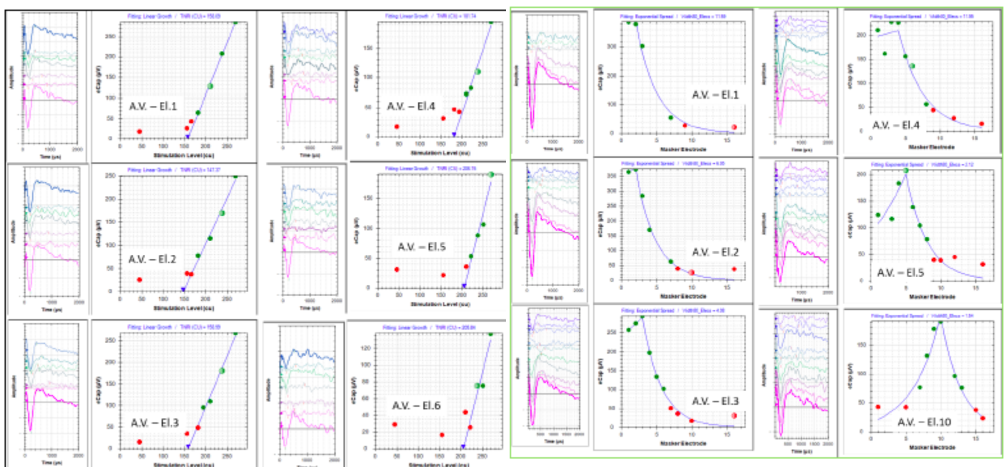
## Speech processor adjustment

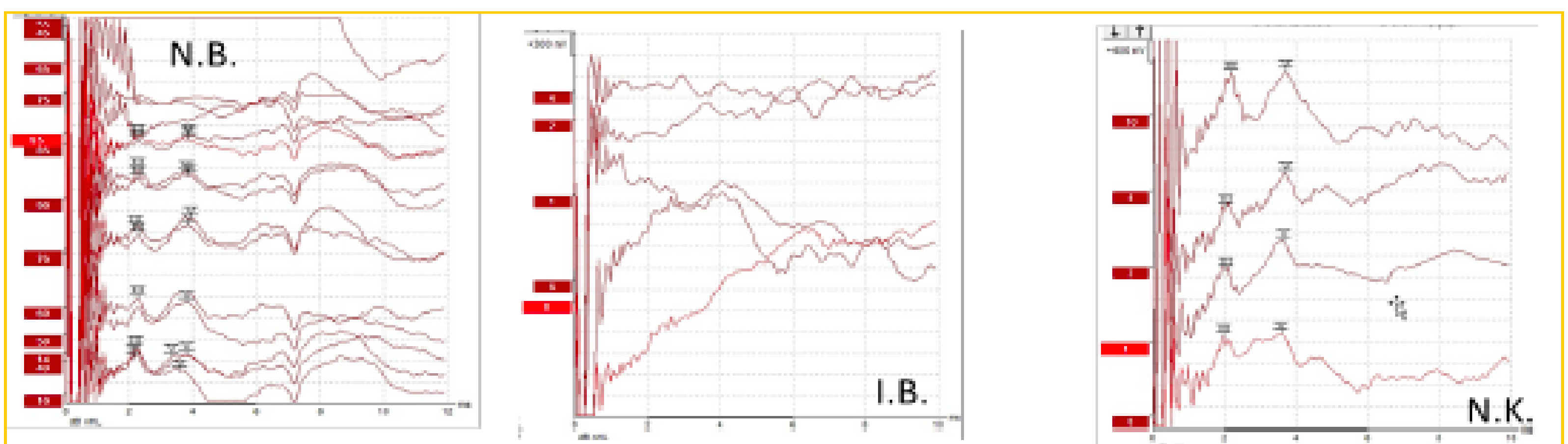
1. estimation of behavioural threshold, comfortable and threshold levels of stimulation (based on eABR data) for stimulus presentation rate used for the eABR recording;
2. extrapolation of the data obtained to the conventional stimulus presentation rate

# NRI +eABR

*Advanced Bionics European Research Center, Hannover*

- Combined registration of the peripheral (eCAP) and central parts (eABR) of the auditory system

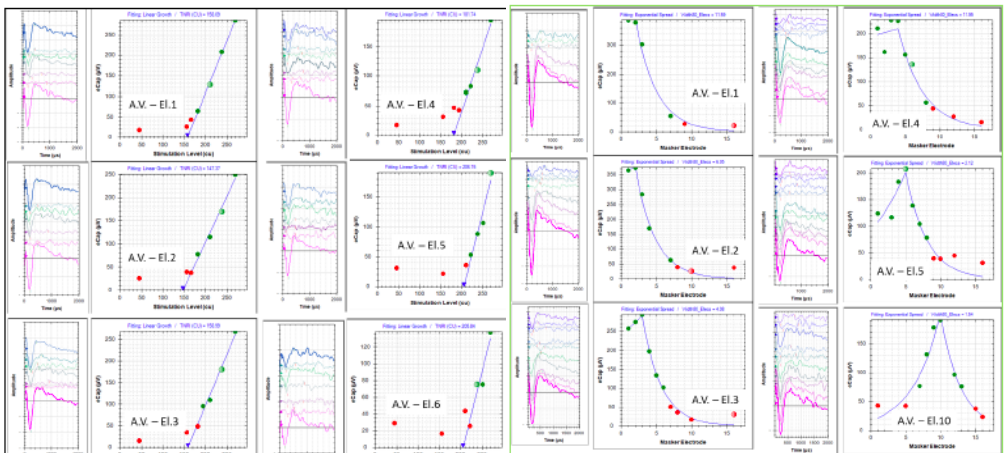


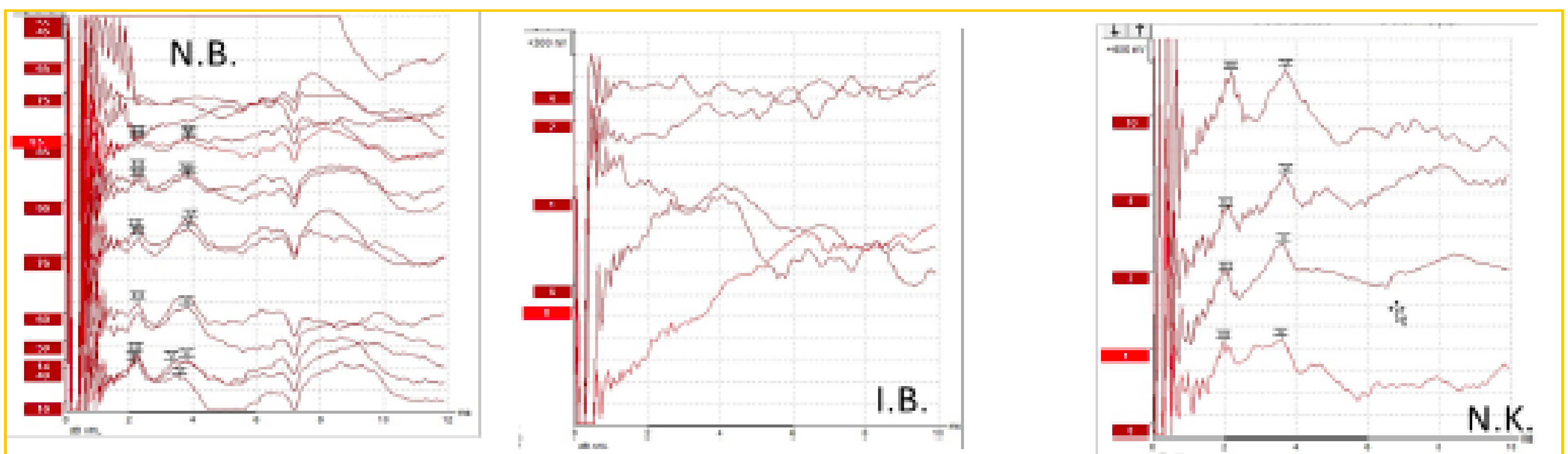



# NRI +eABR

*Advanced Bionics European Research Center, Hannover*

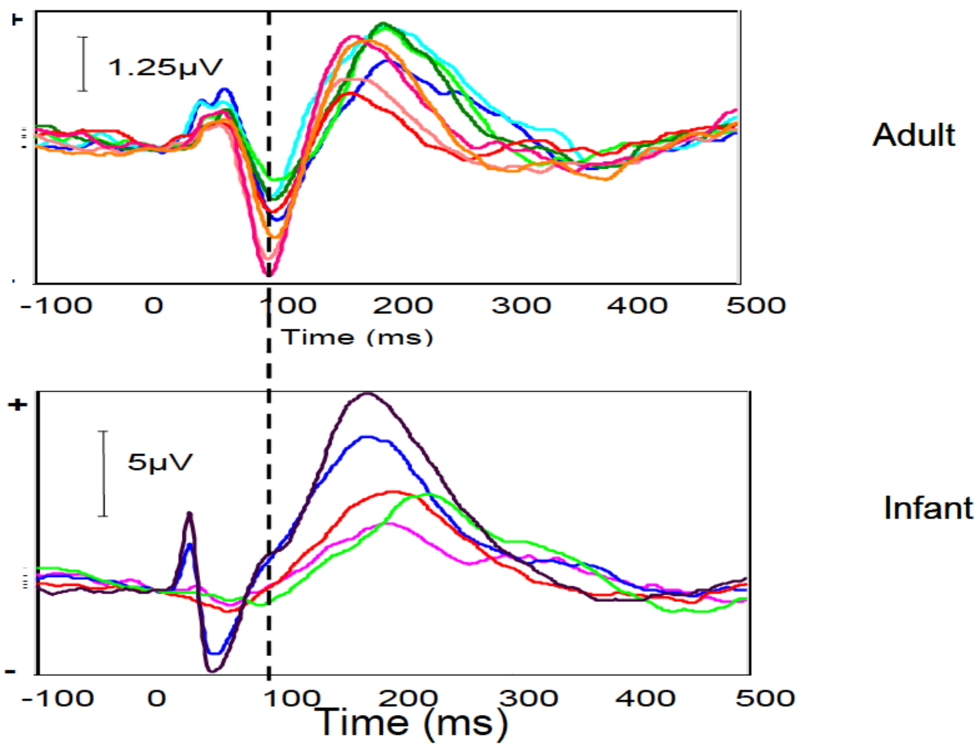
- Results of express NRI and presence/absence of eABR were compared with results of rehabilitation: behavioral thresholds and phoneme perception



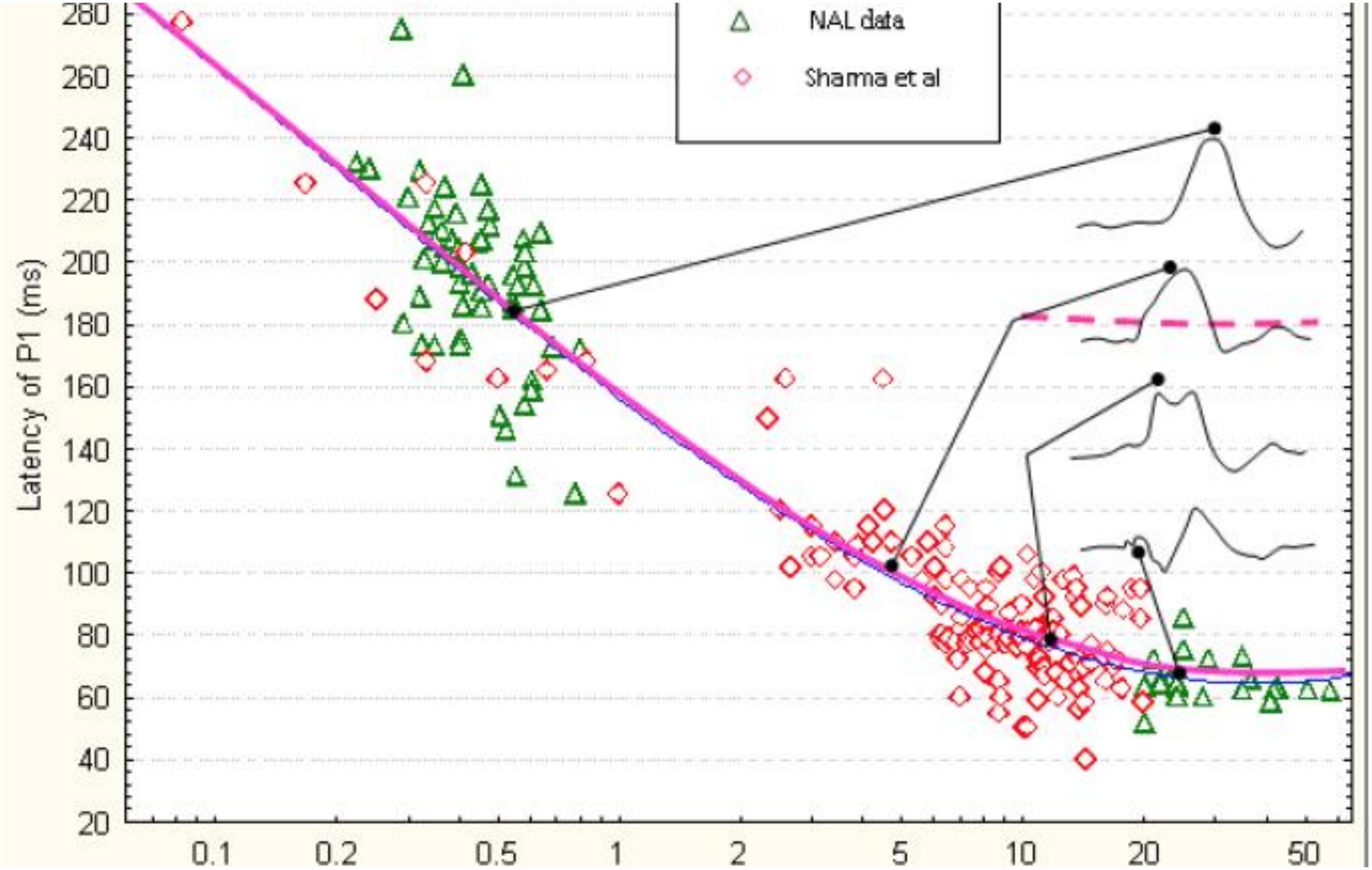



# BACKGROUND

Cortical auditory evoked potentials (CAEPs) are brain responses that are evoked by sound and processed in or near the auditory cortex. The responses must be recorded when the subject is awake



# MATURATION OF CAEPS WITH AGE



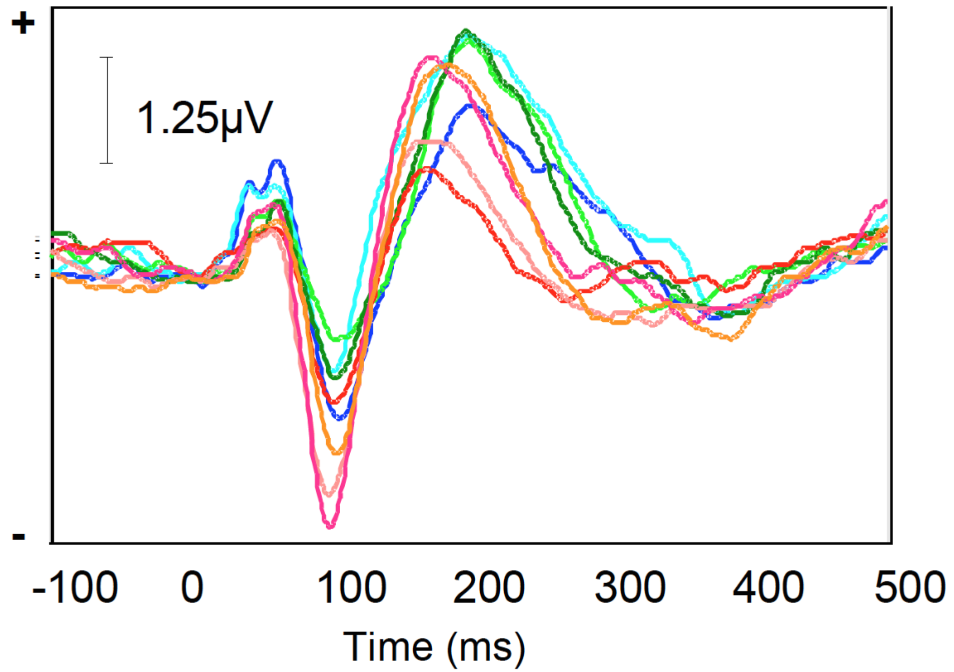

Age (years)

# AN IMPORTANT DISTINCTION

We are not trying to verify hearing aid fitting or CI adjustment by measuring aided thresholds using evoked potentials

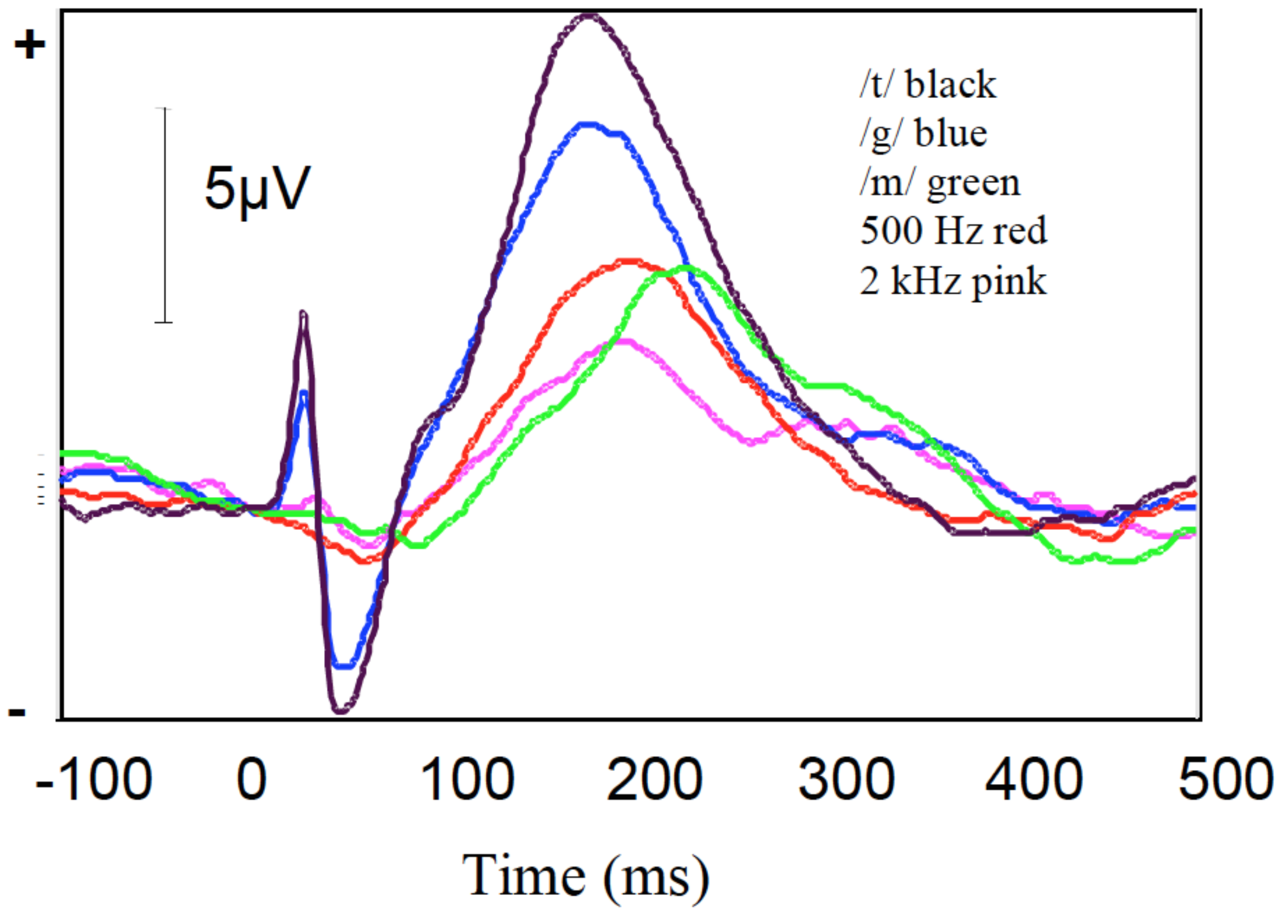
We are trying to validate the hearing aid fitting or CI effectiveness by showing that speech stimuli across the speech spectrum evoke a neural response at the level of the auditory cortex and therefore are likely to be perceived by the infant

# CAEPs TO DIFFERENT STIMULI




Grand average adult (N=14) CAEP for the eight tonal and speech stimuli, recorded at Cz.
500 Hz = orange, 1 kHz = dark pink,
2 kHz = light pink, 4 kHz =red,
/k/ = aqua /t/ = dark blue,
/d/ = dark green, /g/ = light green.

# CAEPs TO DIFFERENT STIMULI



# SUMMARY

Cortical responses are present in most aided infants and children with moderate-to-profound hearing loss

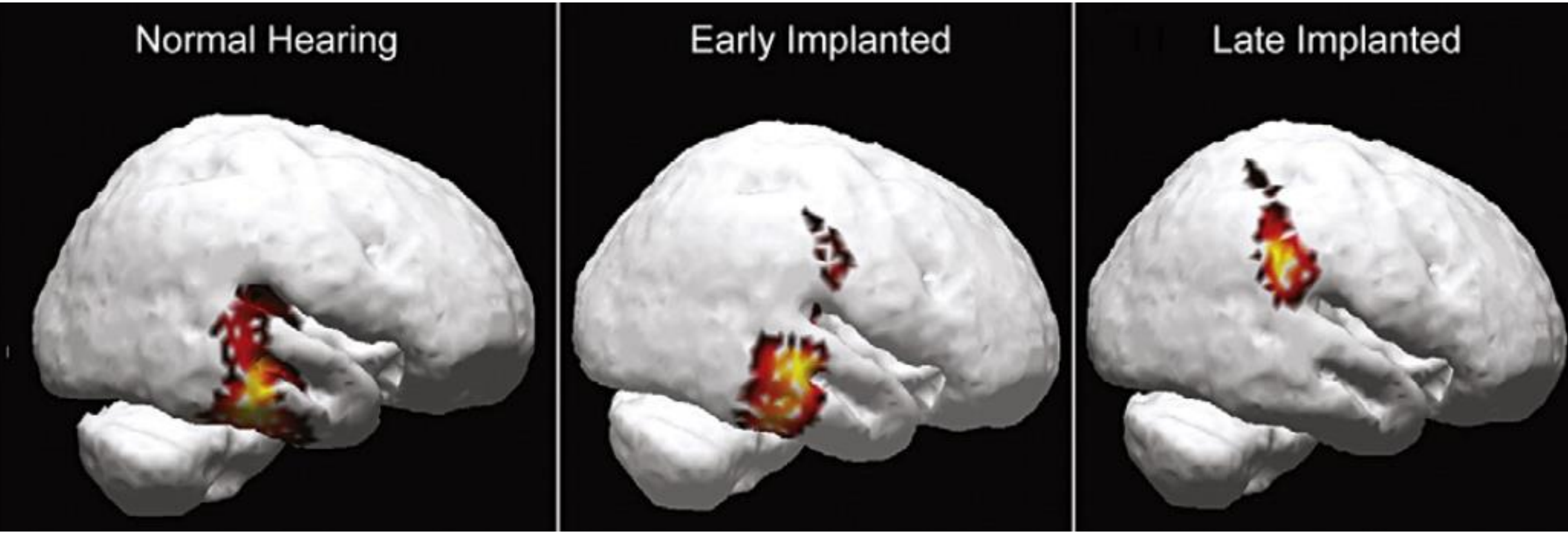
Different stimuli often lead to different response shapes within individual hearing impaired children

Aided responses are consistent with and sensitive to changes in CI fitting parameters in many implanted children

# PLASTICITY OF THE AUDITORY CORTEX

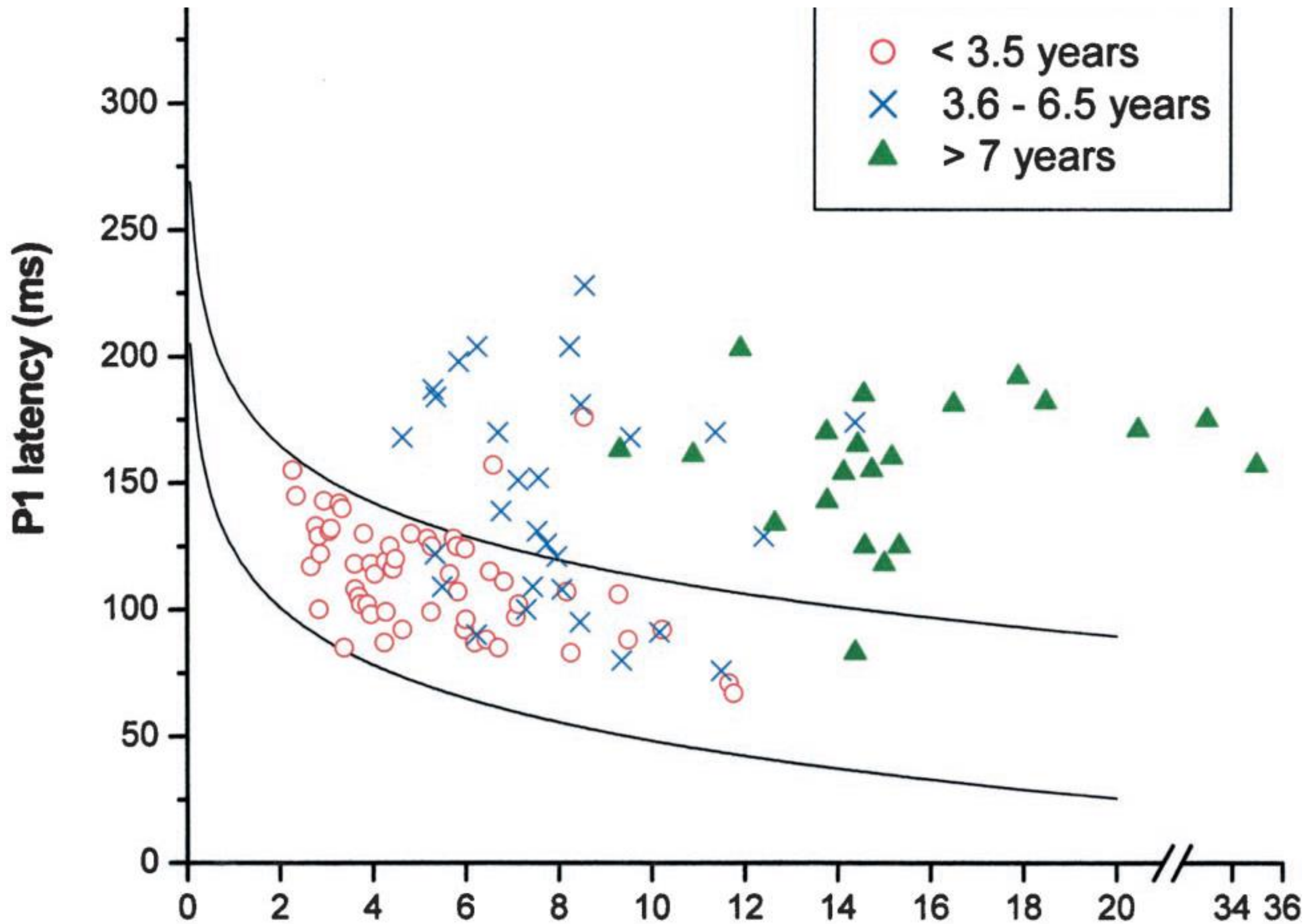
Child’s brain plasticity decreases and becomes less adaptive to new acoustical input in the age of 3-4 years

**CROSS-MODAL REORGANIZATION AFTER CI (optical and somatosensory) which is followed by additional activation of temporal lobe**

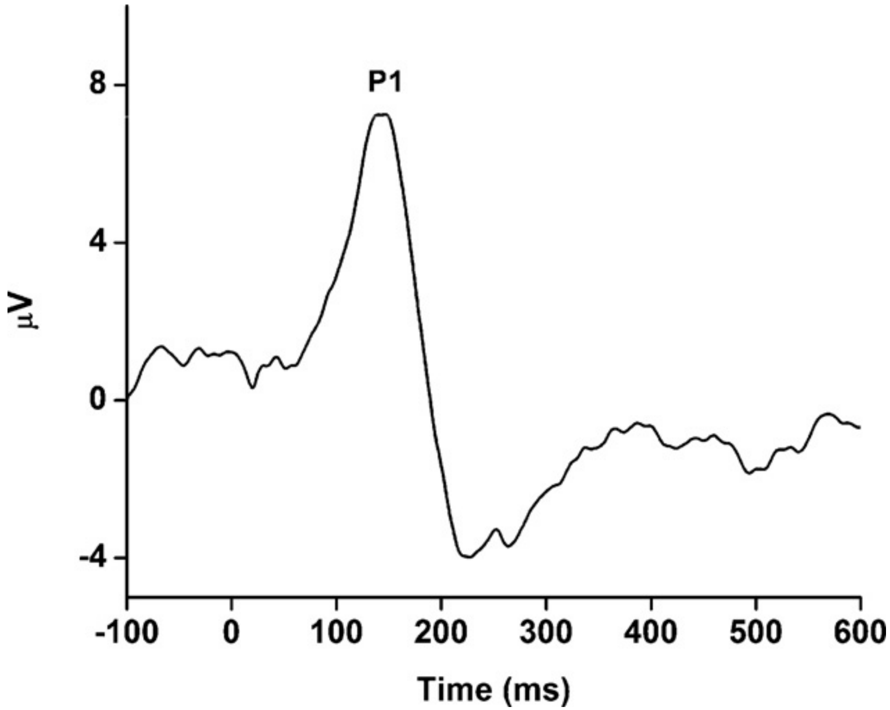



*Dorman et al 2009*

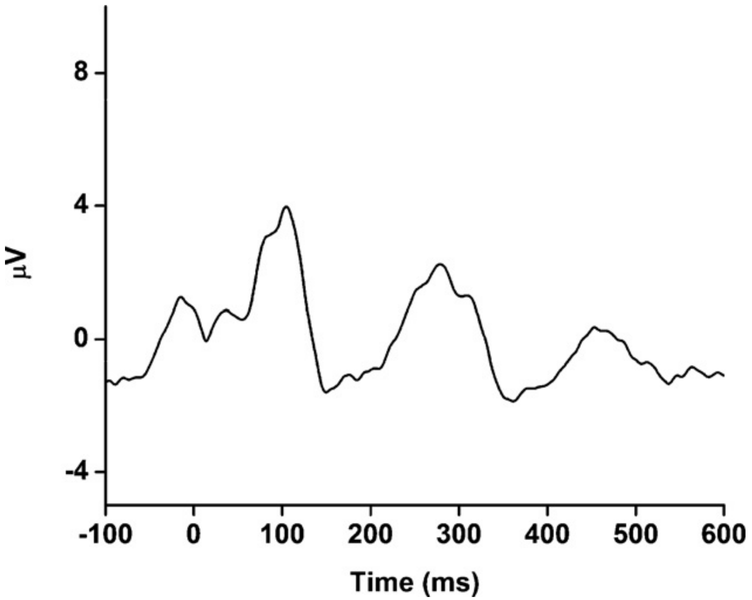
# $P_1$ latency as function of the chronological age of children with CI



# CAEP DYNAMICS IN CHILDREN WITH CI

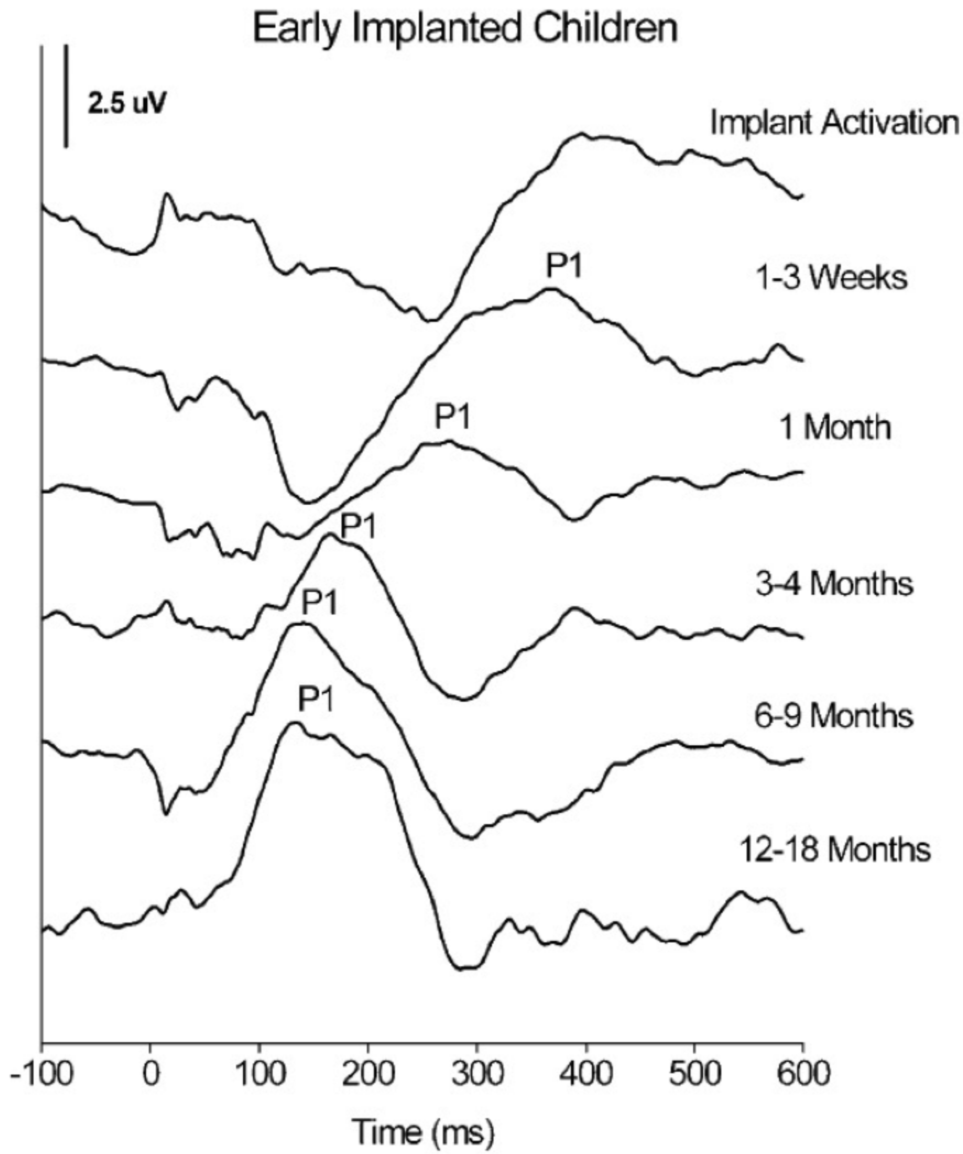



Early implantation




Late implantation

# CAEP DYNAMICS IN CHILDREN WITH CI



# INTERNATIONAL CLINICAL TRIALS

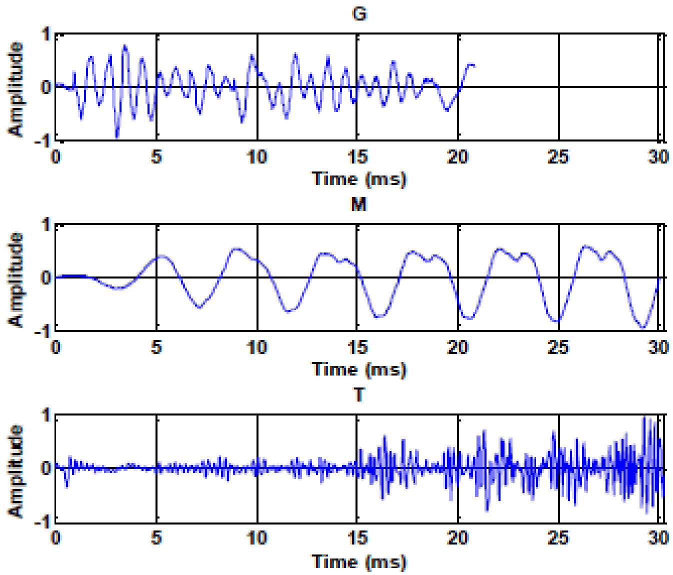
## HearLab® System

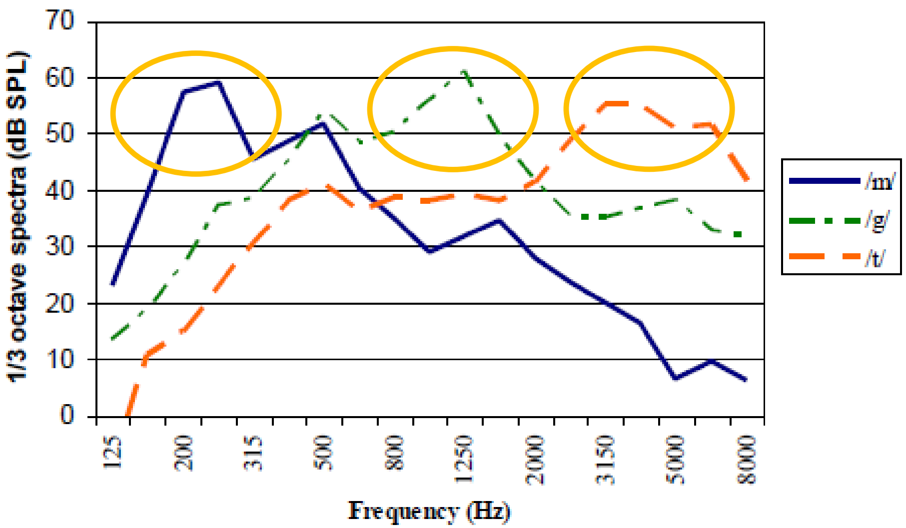
National Acoustic Laboratories

***(Australia)***

# NAL-ACA Stimuli

## Three speech sounds: /m/ /g/ /t/




/M/ 250 Hz
/G/ 1250 Hz
/T/ 3250 Hz

## Aided Cortical Assessment

- Free field presentation
- Speech sounds
- Can be tested aided or unaided
- Focused on infants

# Demographics

- 87 Cochlear Implant user
  - 65 Cochlear Nucleus
  - 22 Advanced Bionics
- 11 Adult
- 76 Children
  - Age: 3 – 137 (mean: 6.7)
  - CI Experience: 2 – 9 years (mean: 5.8 y)

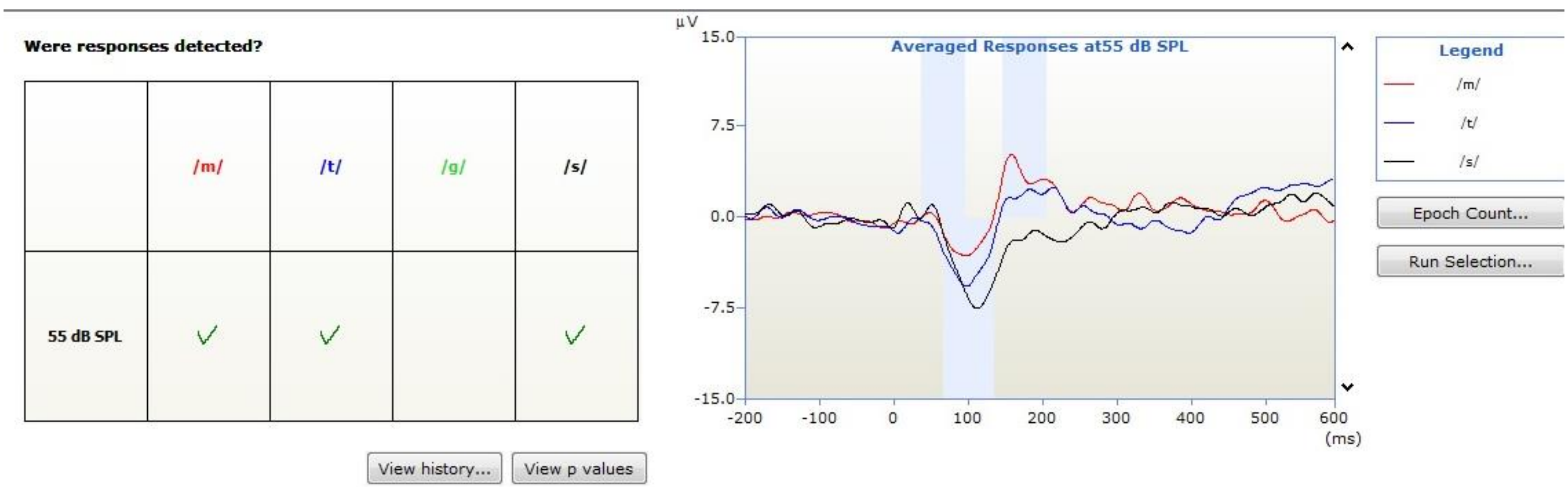
# Case Report I

| 250 Hz | 25 dB |
|---|---|
| 500 Hz | 25 dB |
| 1000 Hz | 25 dB |
| 2000 Hz | 25 dB |
| 4000 Hz | 25 dB |

- Adult, Female, age 33
- Cochlear Nucleus since 3 y
- 80% word score @ 65 dB

(polysyllables in quite)

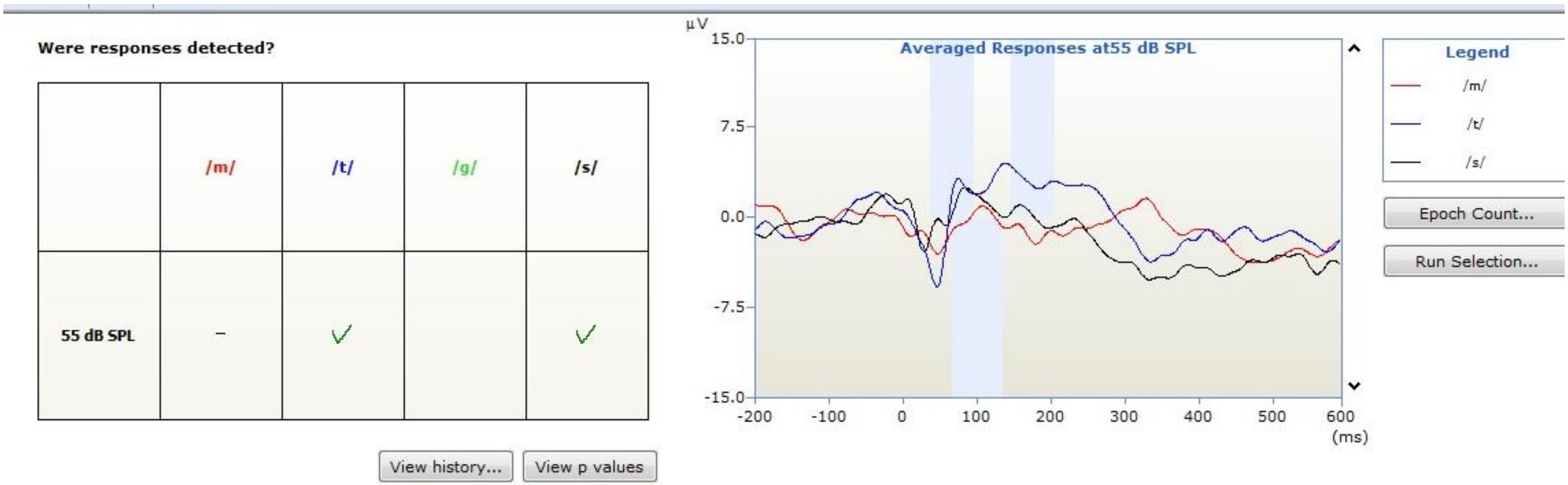
- Good correlation between results



# Case Report II

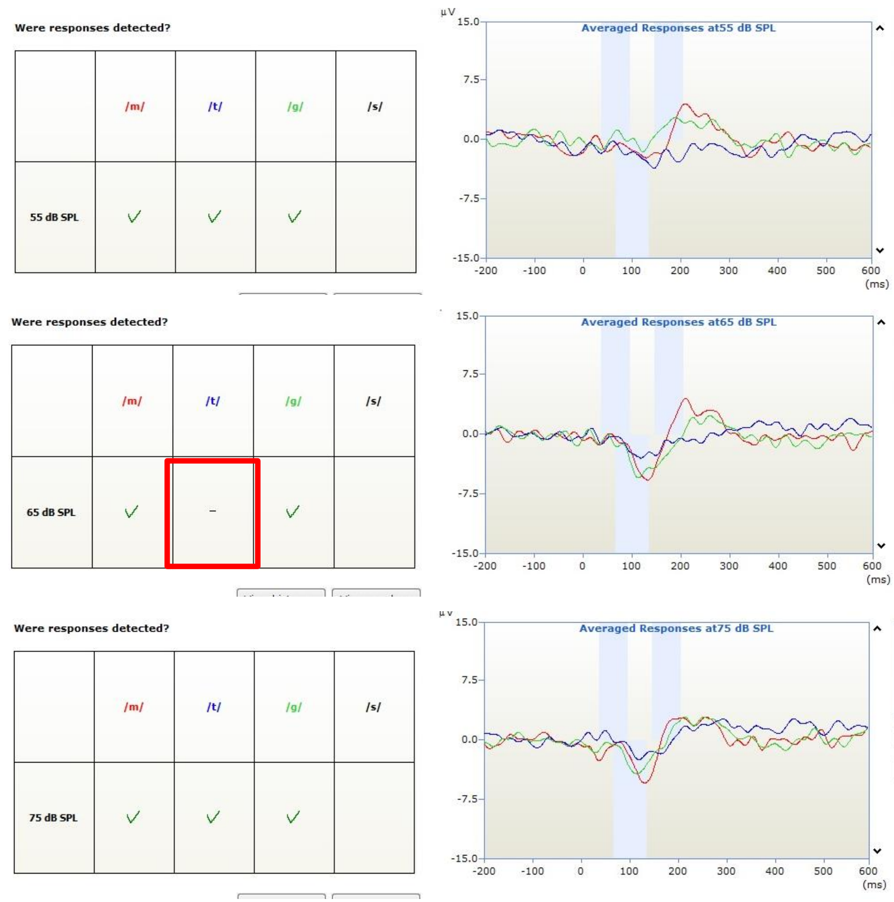
| 250 Hz | 25 dB |
|---|---|
| 500 Hz | 45 dB |
| 1000 Hz | 30 dB |
| 2000 Hz | 25 dB |
| 4000 Hz | 30 dB |
| 8000 Hz | 25 dB |

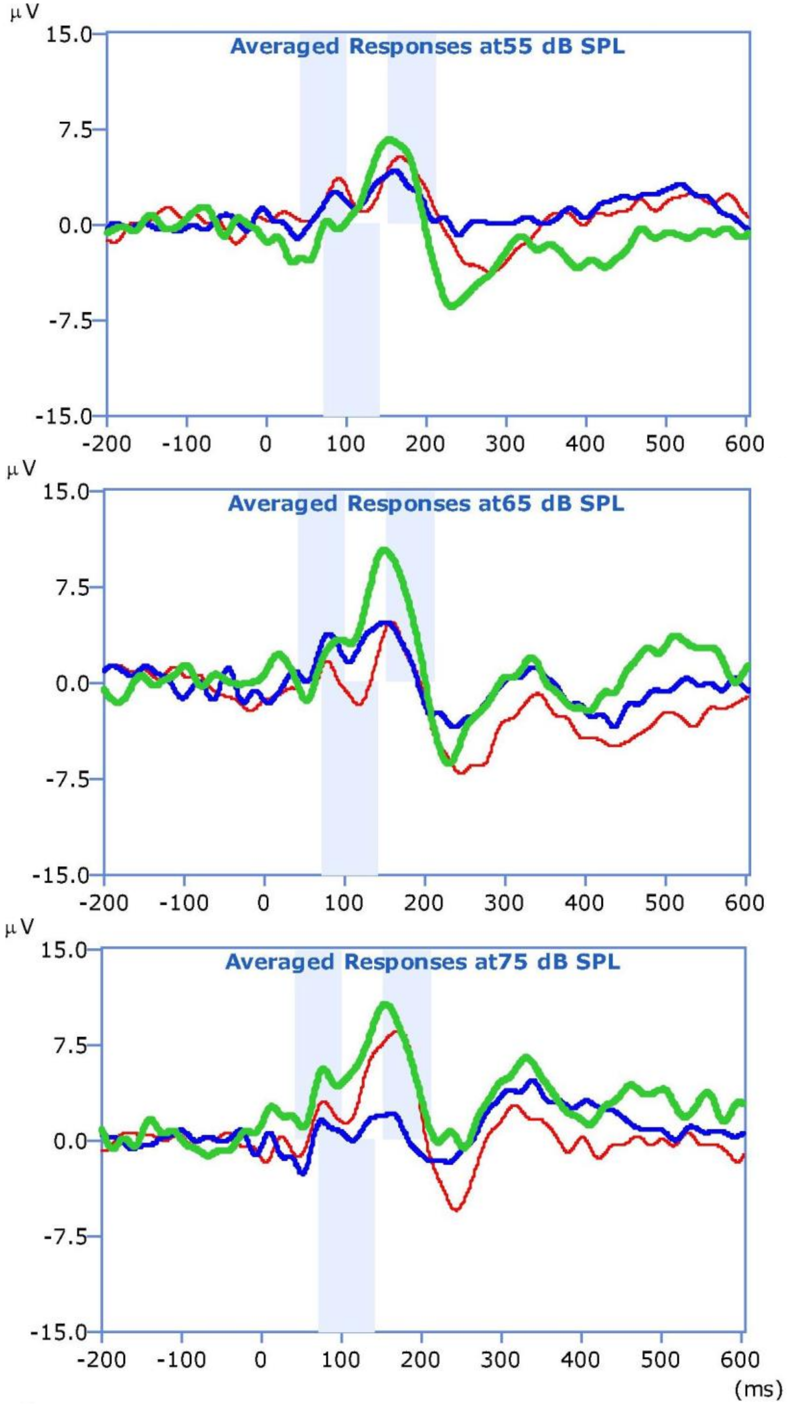
- Child, male, age: 13
- Cochlear Nucleus since 2 y
- Good correlation of results (no response at LF)



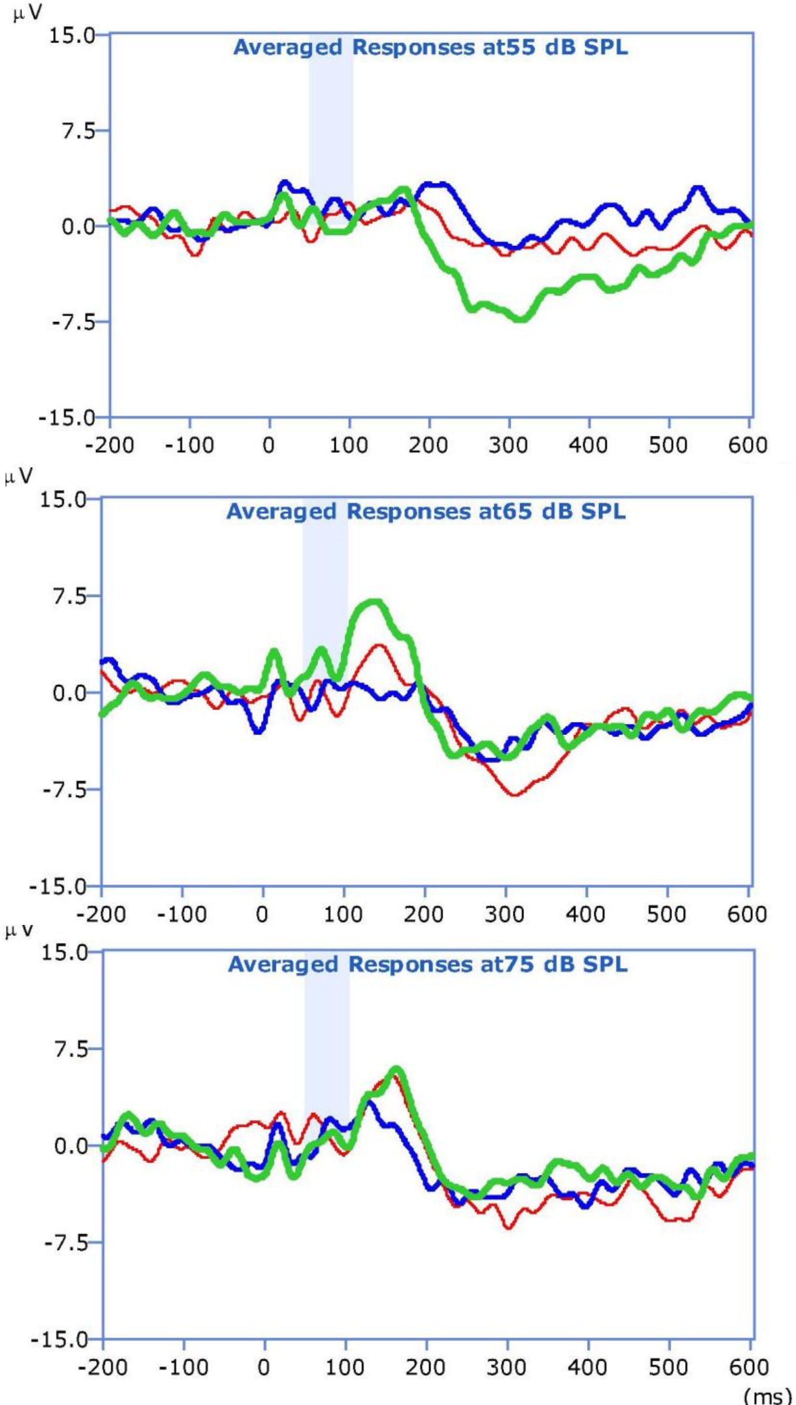
# Case Report III

- Adult, Female, age 33
- Cochlear Nucleus since 6 months
- 80% word score @ 65 dB (polysyllables in quite)
- Some uncertainties @ 65 dB ACA
- Optimization of parameter or retest

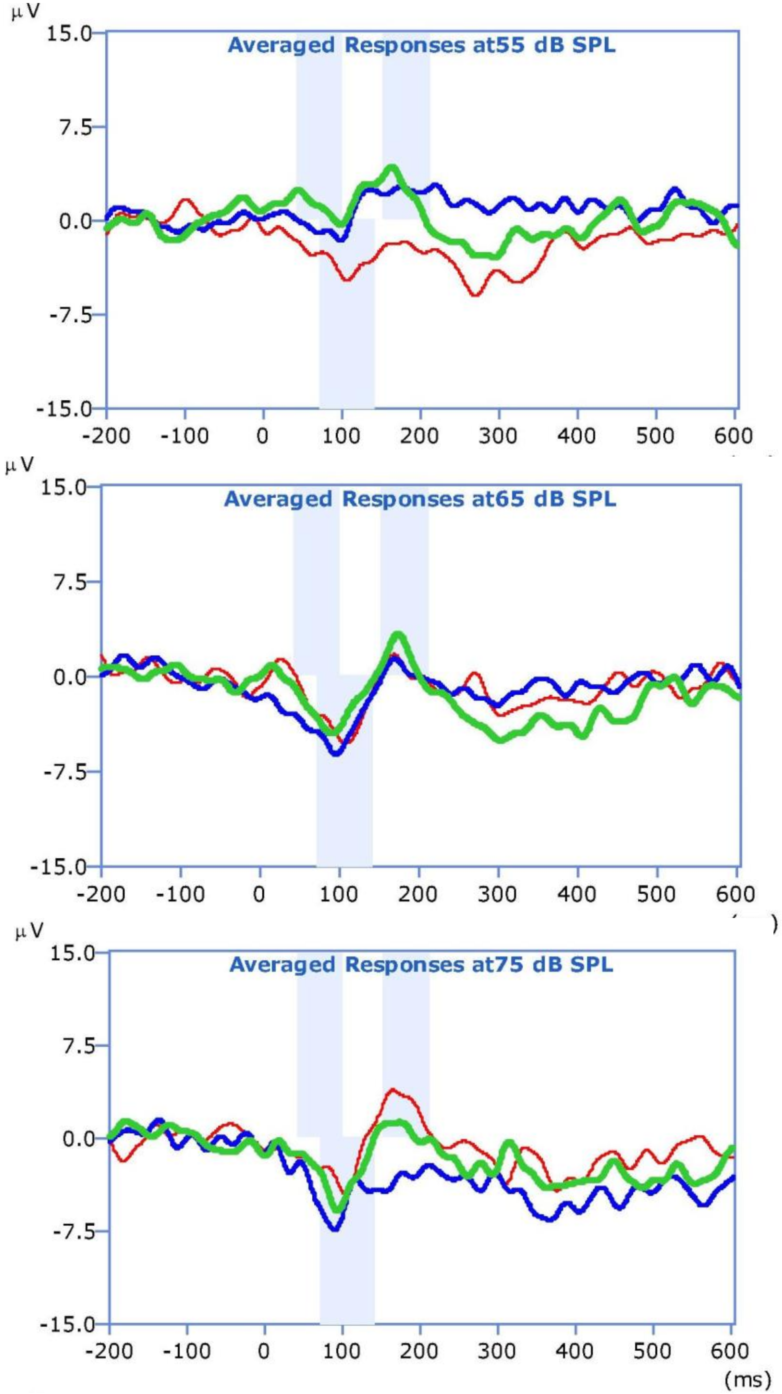





Age – 21
CI – 2010
Progressive hearing loss since 4yrs




Age – 11
CI – 2006
Progressive hearing loss since 1 year




Age – 18

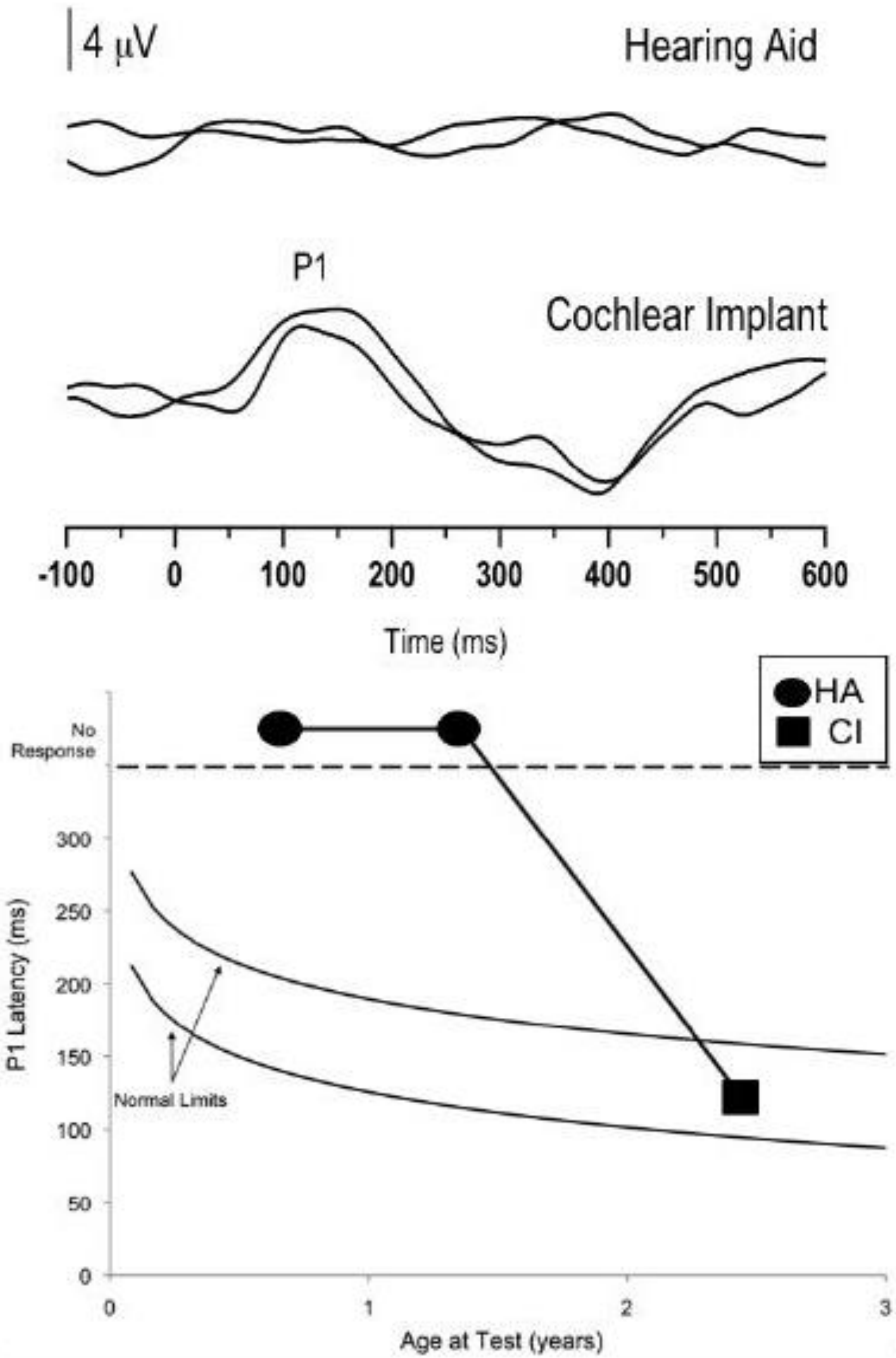
CI – 2010

Progressive hearing loss since 3 yrs

# eCAEP

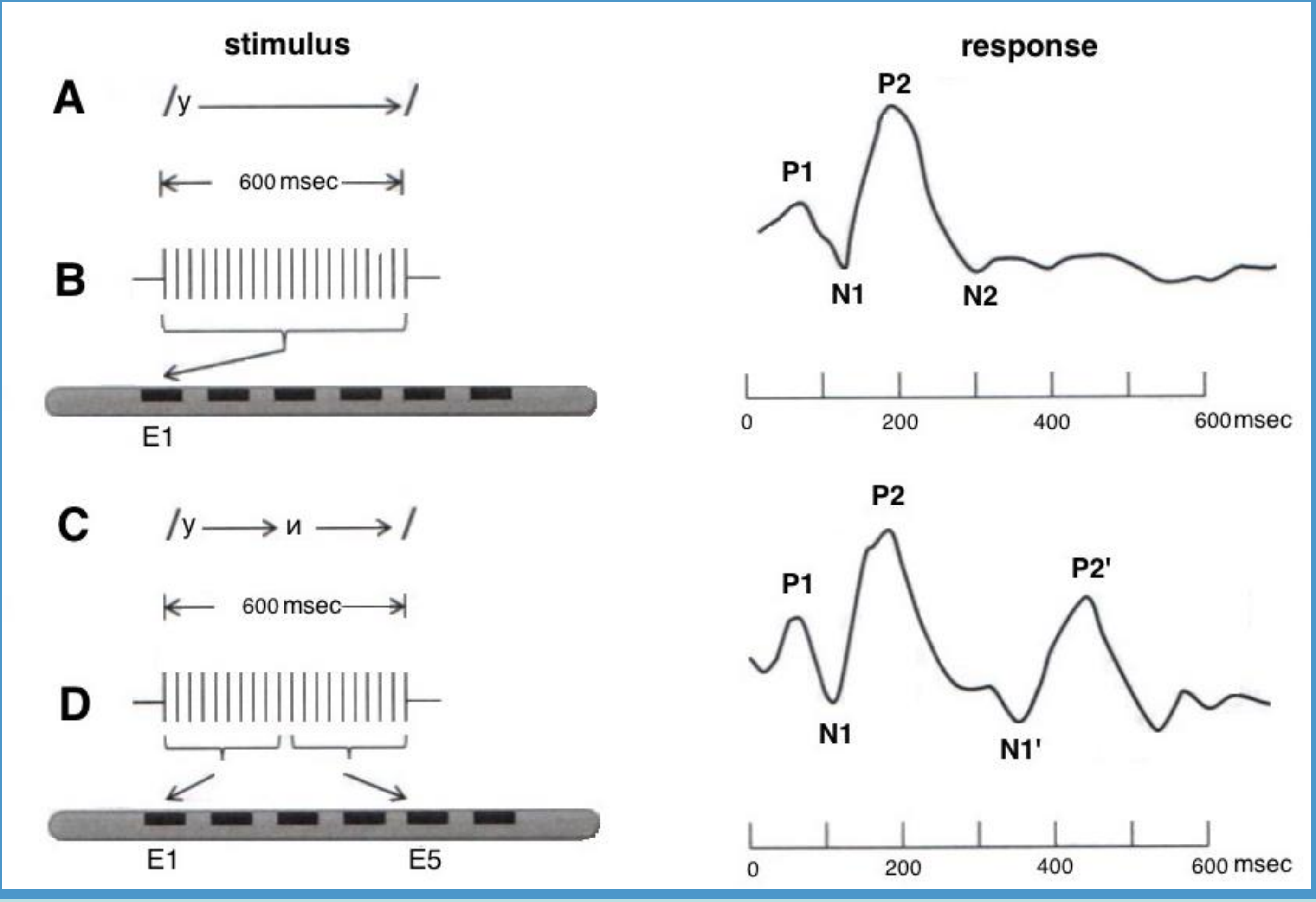
- Longer deafness period and late CI are accompanied by eCAEP immaturity and leaks longer latencies
- eCAEP could be used for the quality of HA amplification before CI or for the estimation of auditory cortex development  after CI
- Changes in the eCAEP morphology could be followed by worse speech discrimination

# eCAEP



4 μV
Hearing Aid
P1
Cochlear Implant
-100
0
100
200
300
400
500
600
Time (ms)
HA
CI
No Response
300
250
200
150
100
50
0
P1 Latency (ms)
Normal Limits
0
1
2
3
Age at Test (years)

# eACC

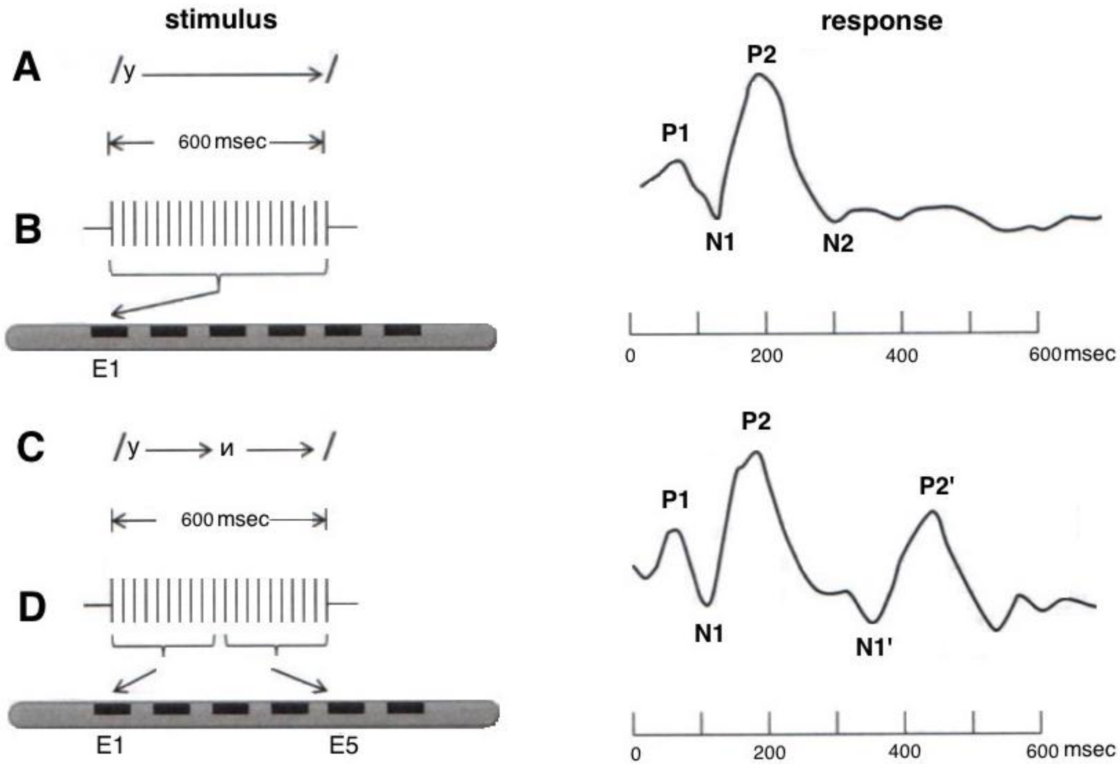



ACC is essentially a second N1-P2 complex that occurs in response to a change in a longer-duration continuous stimulus

# eACC

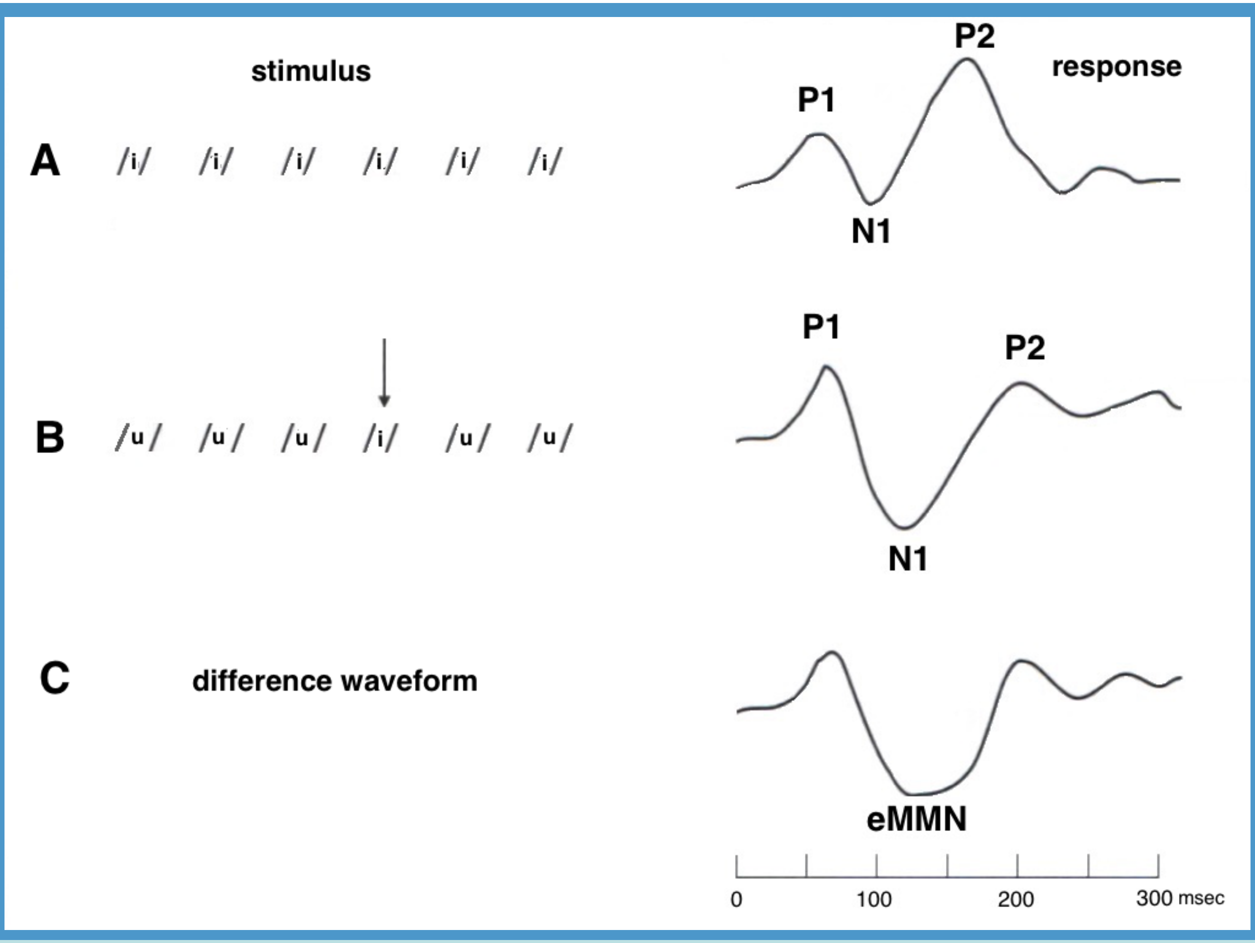
- eACC is based on cortical detection of spectral, temporal or amplitude changes in the stimulus
- It may have clinical utility as an objective indication that a difference in the stimulus was detected by the central auditory system
- eACC represents the detection of a stimulus change at the level of the auditory complex, which is a prerequisite to discrimination

# eACC




Results showed that the magnitude of the eACC increased with the spatial separation between the two stimulated electrodes, consistent with larger pitch differences that may have been perceived between these electrodes

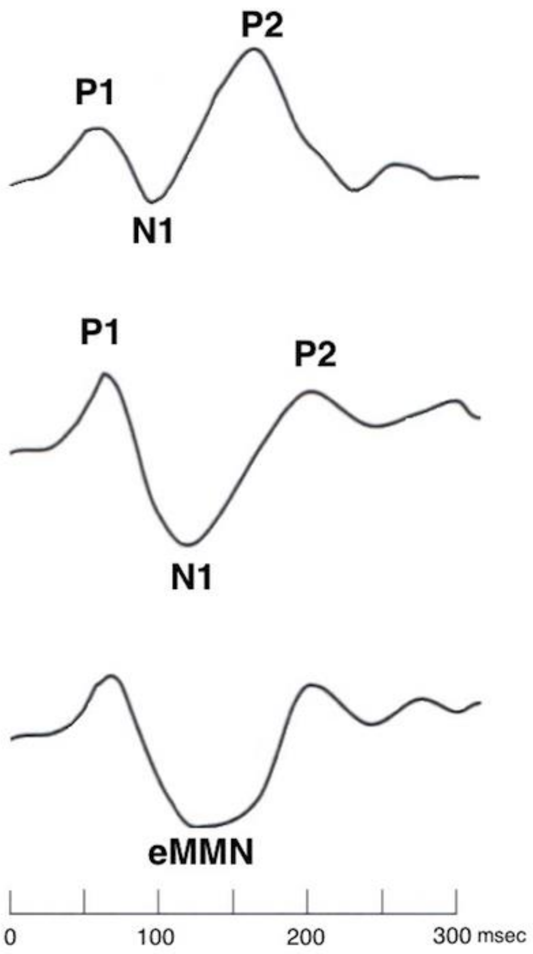
# eMMN



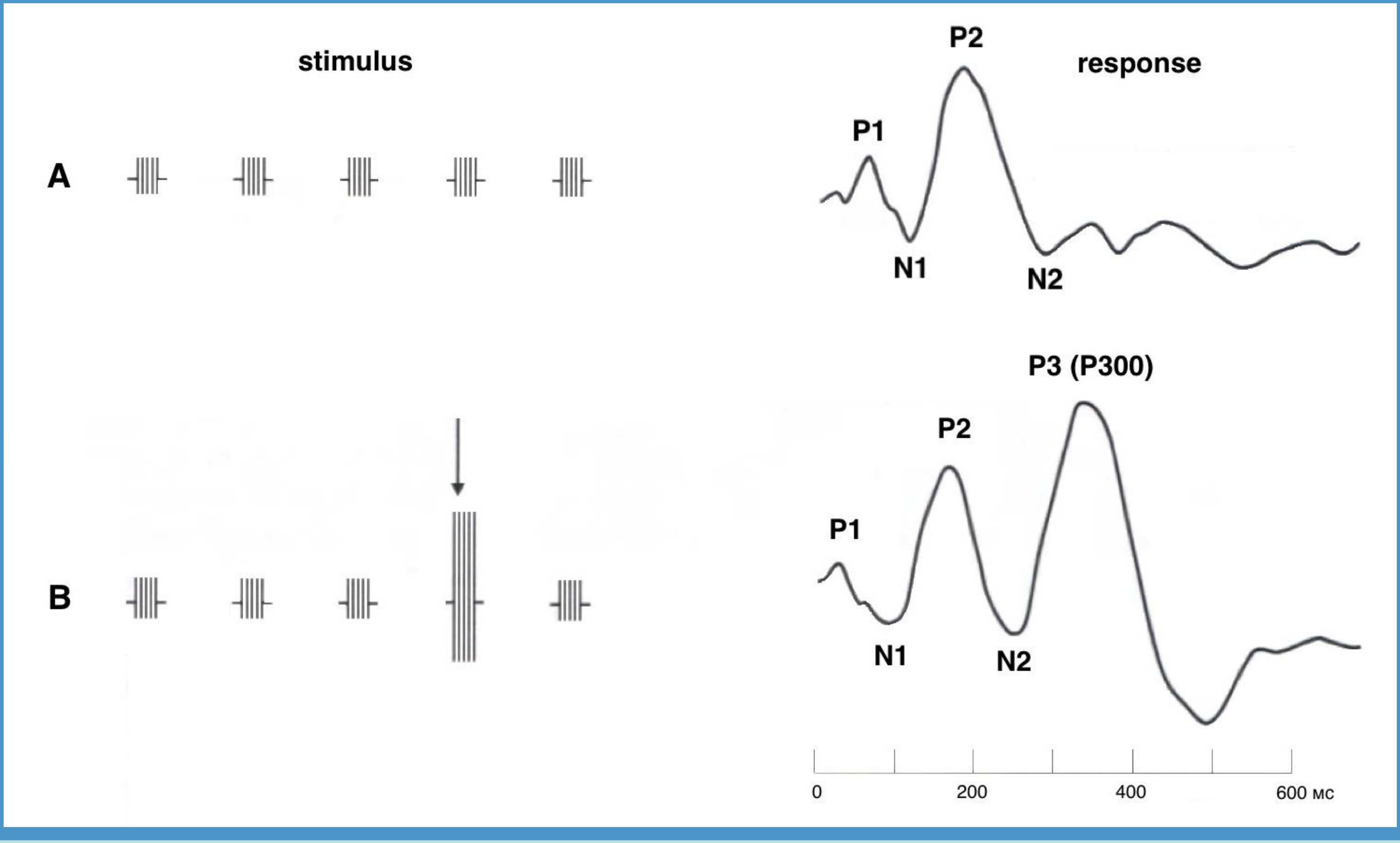

eMMN is a difference waveform derived from a change in the P1-N1-P2 complex that occurs in response to a frequent (standard) versus infrequent (deviant) stimulus presented using "oddball" paradigm

# eMMN

- The response measured for the deviant stimulus typically presents as an enhanced N1 and/or reduced P2
- eMMN reflects the central auditory system's ability to resolve differences in stimuli and therefore provides an objective measure of physiological mechanisms underlying auditory discrimination
- May have some utility in predicting  speech perception ability
- In contrast to the eACC which is measured in response to sustained stimuli the eMMN is measured in response to repeated shorter duration stimuli and is quantified as a difference wave
- Significant negative correlation was shown between speech perception and eMMN latency and amplitude in a group of children with cochlear implants (better performance was found in individuals with shorter latencies and larger amplitudes)



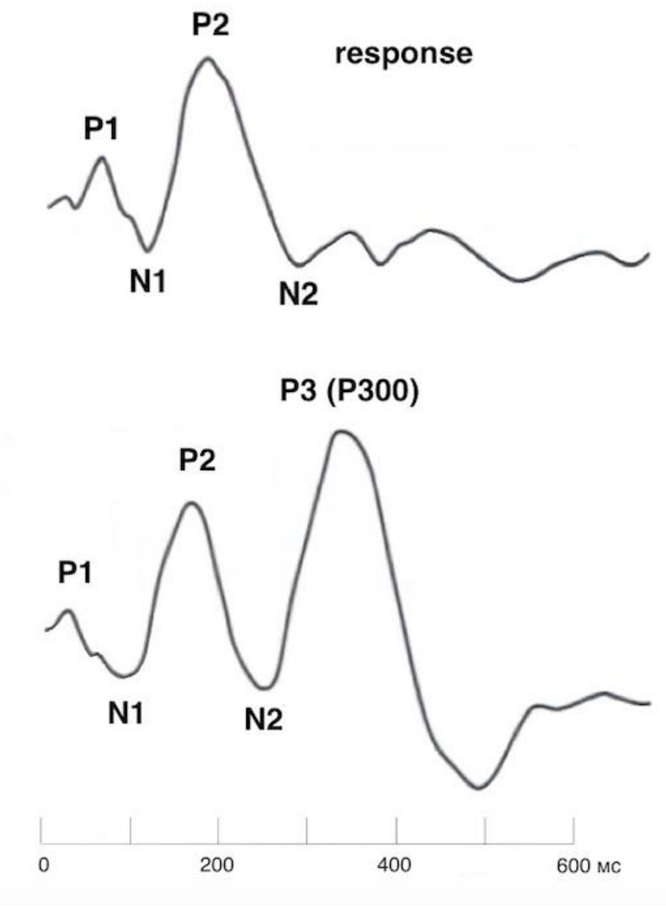
# eP300




eP300 consists of the P2-N2-P3 complex. Stimuli are presented using an oddball paradigm (as for the eMMN).

# eP300

- The primary difference between the eP300 and eCAEP, eACC and eMMN is that the P300 is an endogenous response that requires  the listener to attend to the stimulus and actively participate in the task.
- It involves auditory detection/differentiation mechanisms as well as cognitive processes.
- Because the P300 reflects auditory attention and discrimination processes it can provide some indication of how speech is differentiated at the cortical level.
- Significant correlation was shown between speech perception and eP300 latency and amplitude in a group of children with CI



# CONCLUSION

- Cortical responses are useful for providing information about central auditory pathways, stimulus detection, perceptual discrimination and/or physiological maturation at higher levels of the auditory system
- One advantage that auditory cortical potentials have over more peripheral measures is that a wider range of stimuli can be used to elicit responses
- The benefit is that it is possible to objectively evaluate the brain’s ability to detect or discriminate different stimulus characteristics such as loudness differences, temporal changes or speech tokens
- Longer duration of deafness and larger age at implant result in immature morphology and delayed eCAEP latencies
- Introduction of different classes of electrically evoked responses of auditory cortex will provide an objective control of rehabilitation effectiveness in children after cochlear implantation