Prediction of the Audiogram Using Auditory Steady-Sate Evoked Responses (ASSR)

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Requirements from the Optimal Neurophysiology Auditory Measure

- ✓ Objective in recording and interpretation
- ✓ Reliably predict the behavioral AC & BC thresholds
- ✓ Enabling masking
- ✓ Applicable in children & adults
- ✓ With frequency specificity both in the low & high frequencies
- ✓ Can be used for the severe & profound hearing losses

Requirements from the Optimal Neurophysiology Auditory Measure

- ✓ Usable in headphone & loud speakers
- ✓ Applicable for threshold and supra-threshold levels
- ✓ Short test-session
- ✓ High cost-effectiveness

Auditory Steady State Evoked Potentials

✓Brain potentials evoked and sustained by periodic amplitude or frequency **modulations** of a **carrier frequency**

Amplitude Modulation

- ✓1000 Hz pure tone Amplitude modulated at 100 Hz
- ✓ Maximal spectral energy at the carrier frequency with sidebands at +/- the AM frequency

1000 Hz +/- 100 Hz = 900 – 1100 Hz

(CF) (MF)

Frequency Modulation

- ✓ 1000 Hz pure tone Frequency Modulated at 10%
- ✓ Maximum spectral energy at the carrier frequency +/- the FM %

- ✓ 1000 Hz +/- 10% (100 Hz) = 900 – 1100 Hz

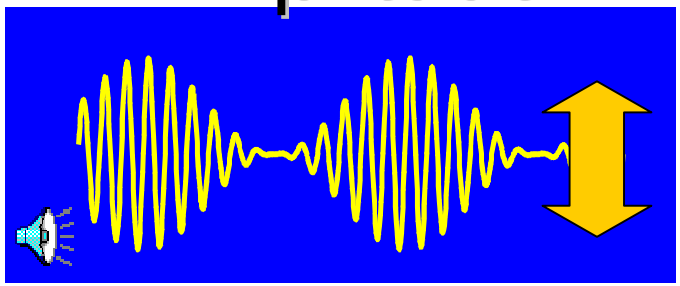
ASSR most robust with combined AM/FM Stimulus and for AM^2/FM

Stimulus Characteristics

- ✓ Carrier Frequency
  - – Pure tones of 250 – 8000 Hz

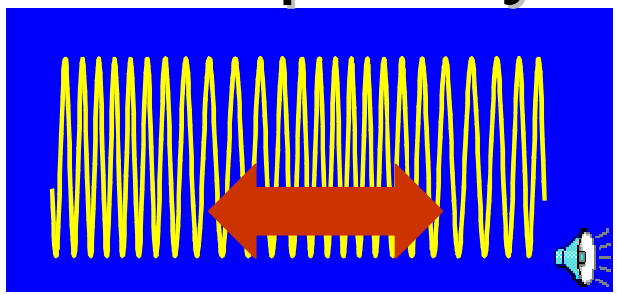
- ✓ Modulation Frequency
    - • AM modulation 100%
    - • FM Modulation 10% (GSI) or 25% (Bio-Logic)

Amplitude



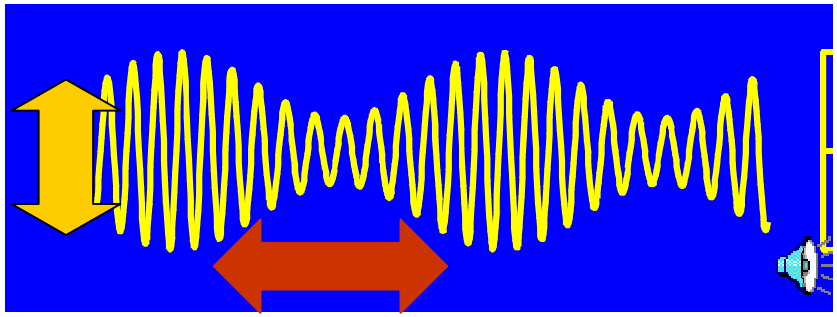
100% AM

Frequency



50% FM

MM

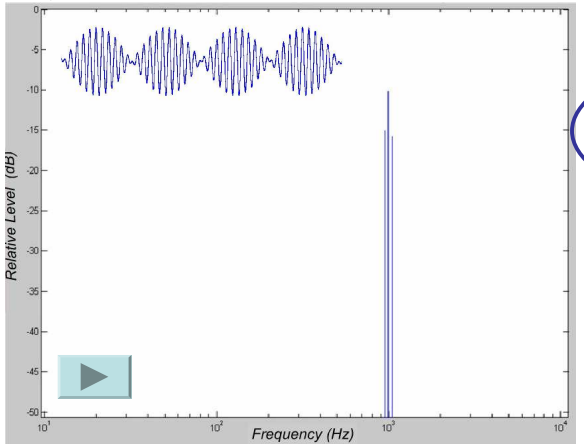


50% AM 20% FM

Slide courtesy of Dr. Terry Picton

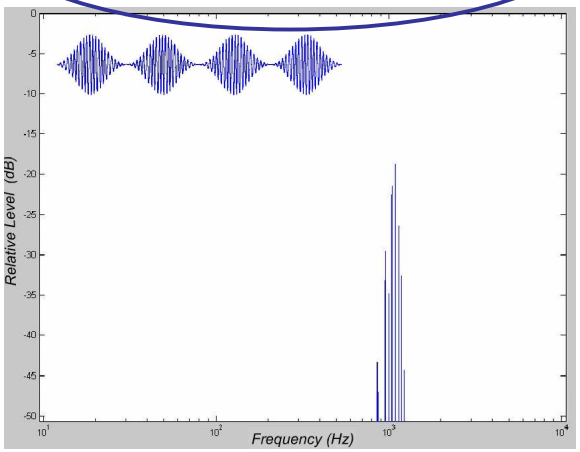
ASSR & ABR Stimuli

Amplitude Modulated 1kHz

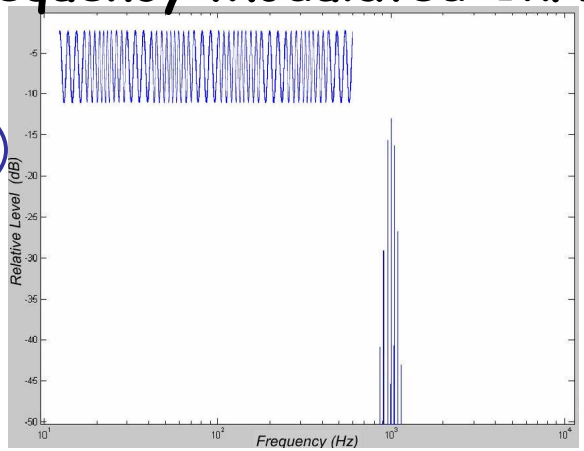


ASSR

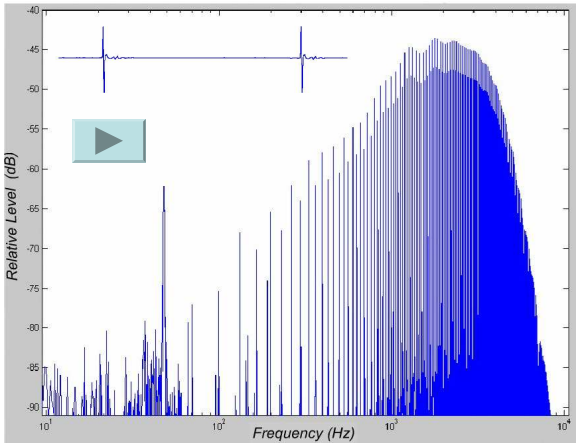
Amplitude & Frequency Modulated 1kHz



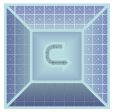
Frequency Modulated 1kHz



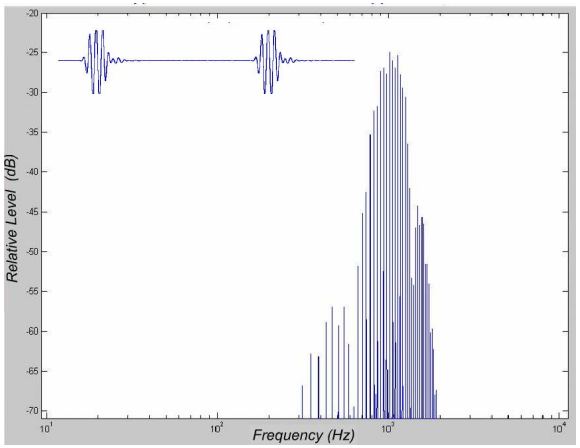
Click



ABR



Tone Burst 1kHz

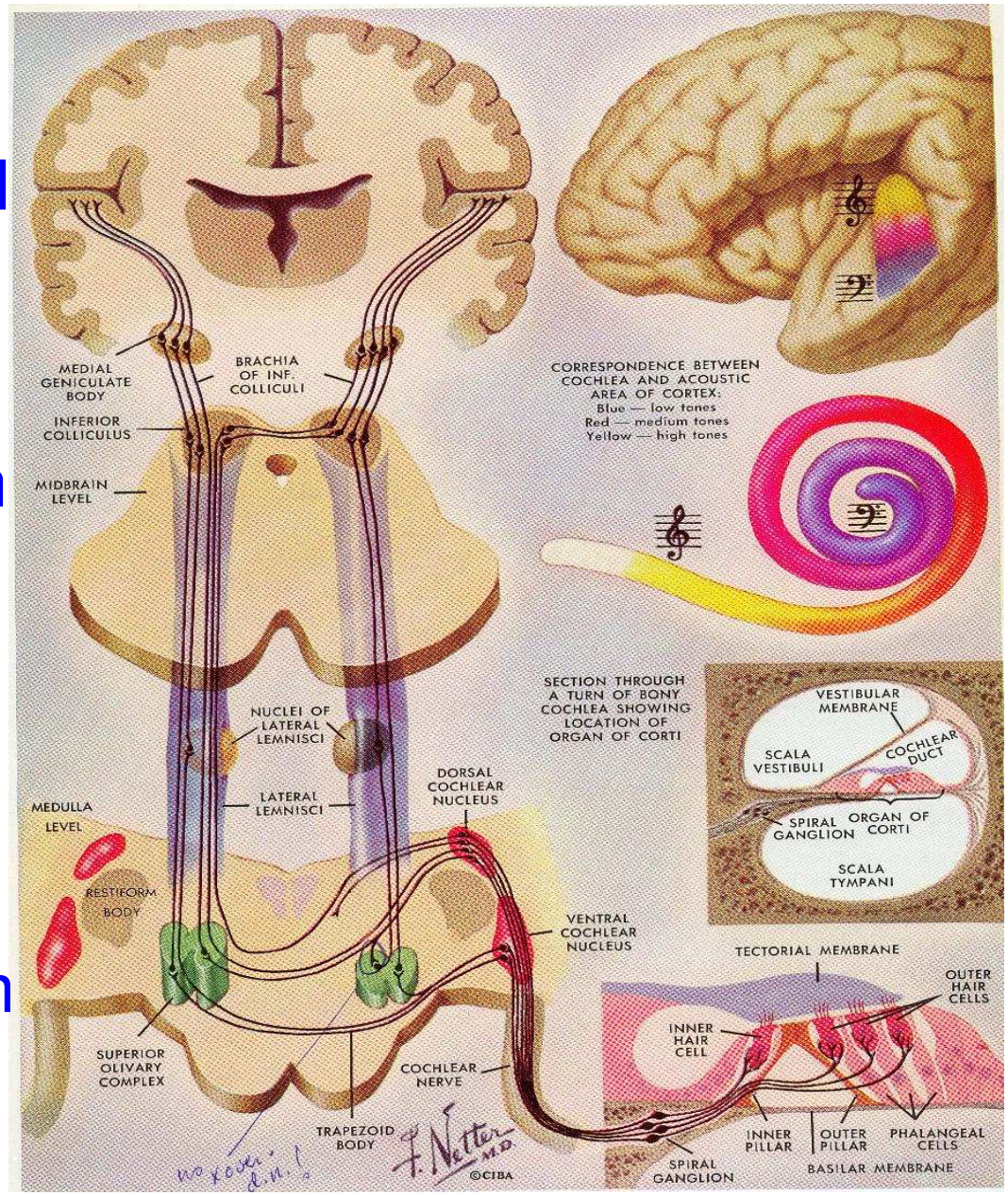


Sources of ASSR

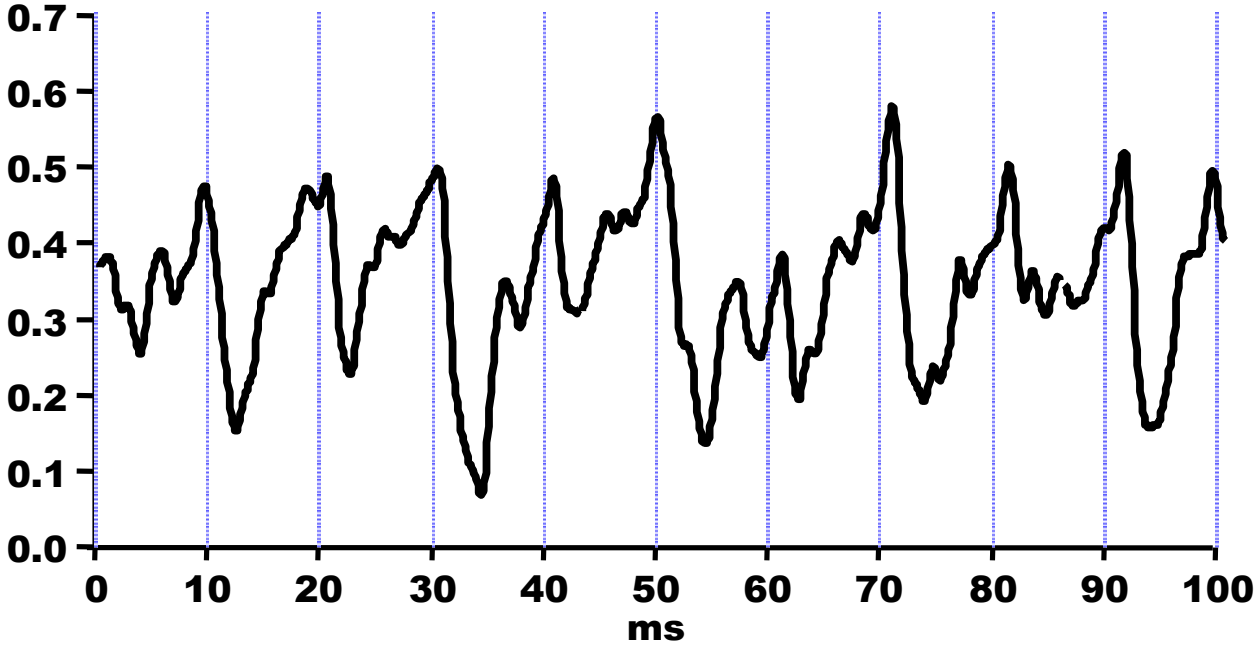
< 20 Hz –Cortical

< 20-60 Hz –
Upper Mid Brain

> 60 Hz –
Lower Brain Stem

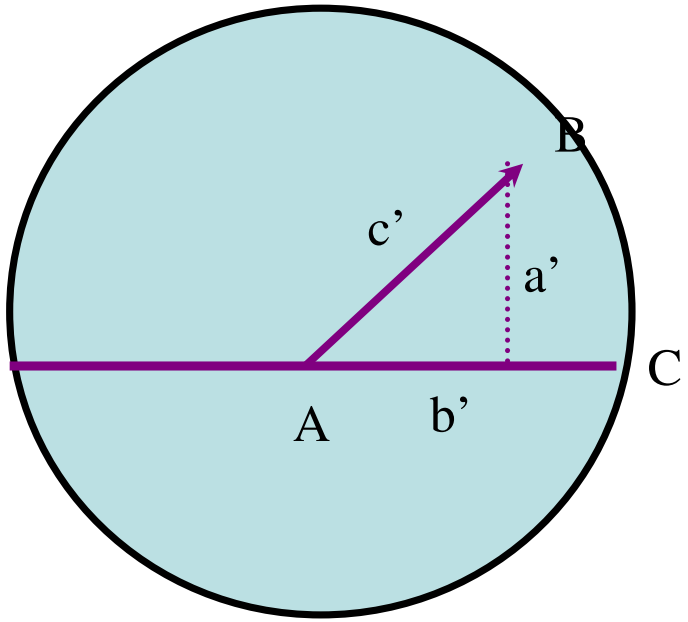


EEG with ASSR Response Analyzed by Latency



Consider an alternative way of displaying phase (latency) information.

- ✓ **Show each response latency as a phase.**
- ✓ **Any phase lag between the stimulus and response can be shown on a circular plot.**



Sin=a'/c'

Cos=b'/c'

Vector Plot

- ✓ The peak amplitude of each sample of EEG is depicted as a vector on a polar plot
- ✓ Length of vector = amplitude of EEG in μV
- ✓ Angle = phase of peak in relation to stimulus (in degrees)

Phase Coherence Squared

- ✓ Related to signal to noise ratio
  (response embedded in overall EEG)

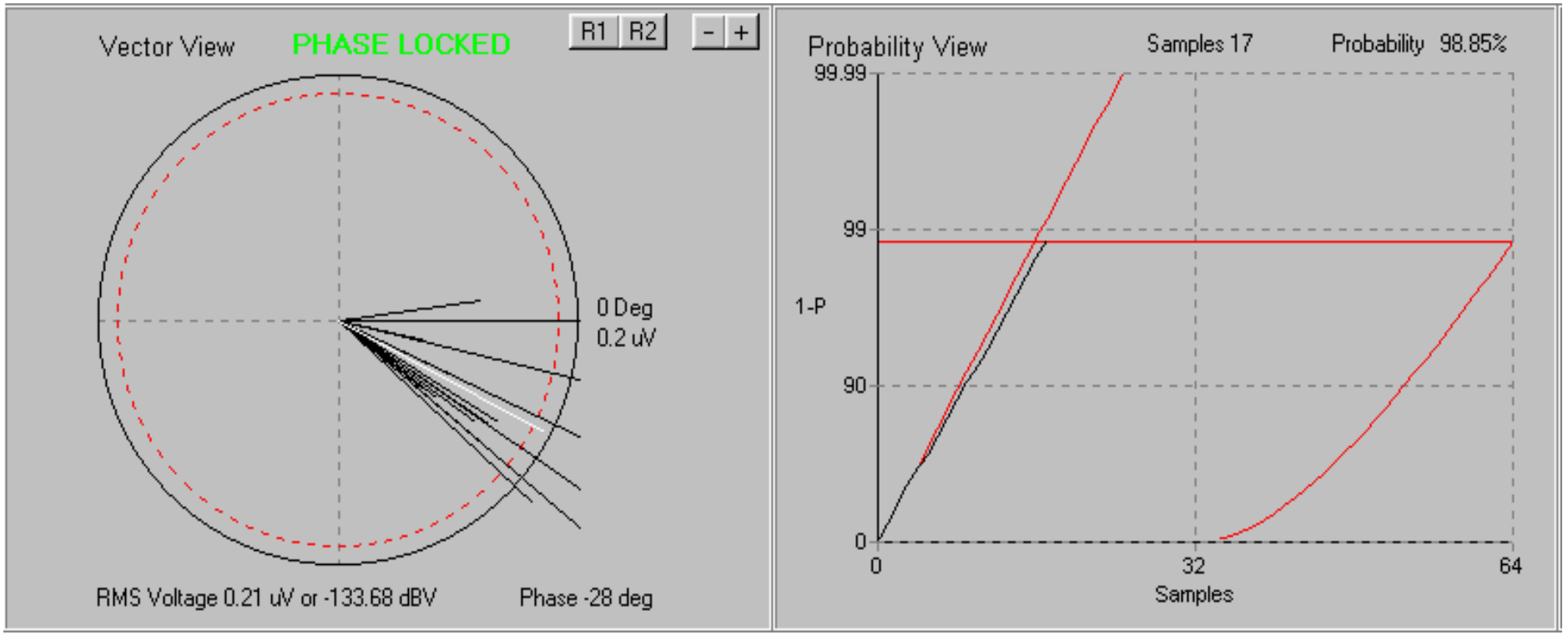
- ✓ As the stimulus is being presented samples of EEG are analyzed to determine both the amplitude and the phase of the peak activity in each EEG sample

- ✓ The phase and amplitude calculations for each EEG sample are displayed as vectors in a polar plot

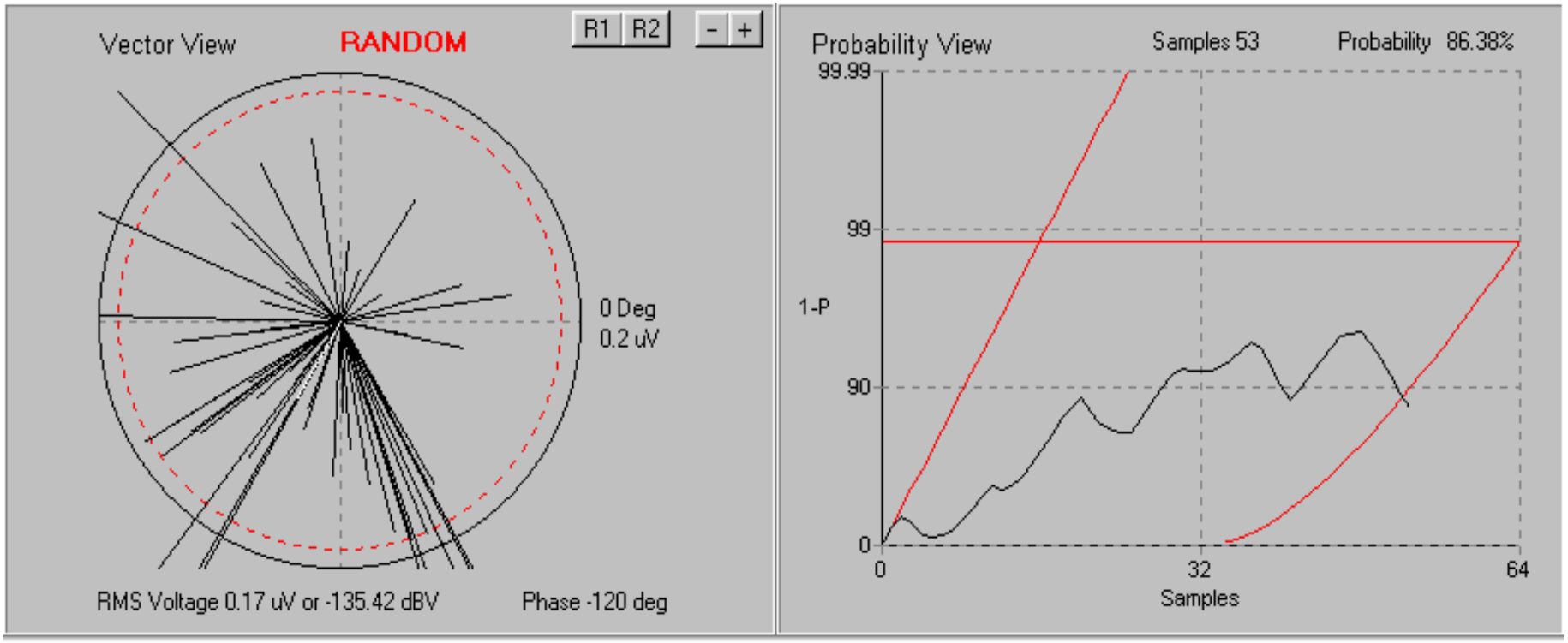
Detection Algorithm: Phase Coherence

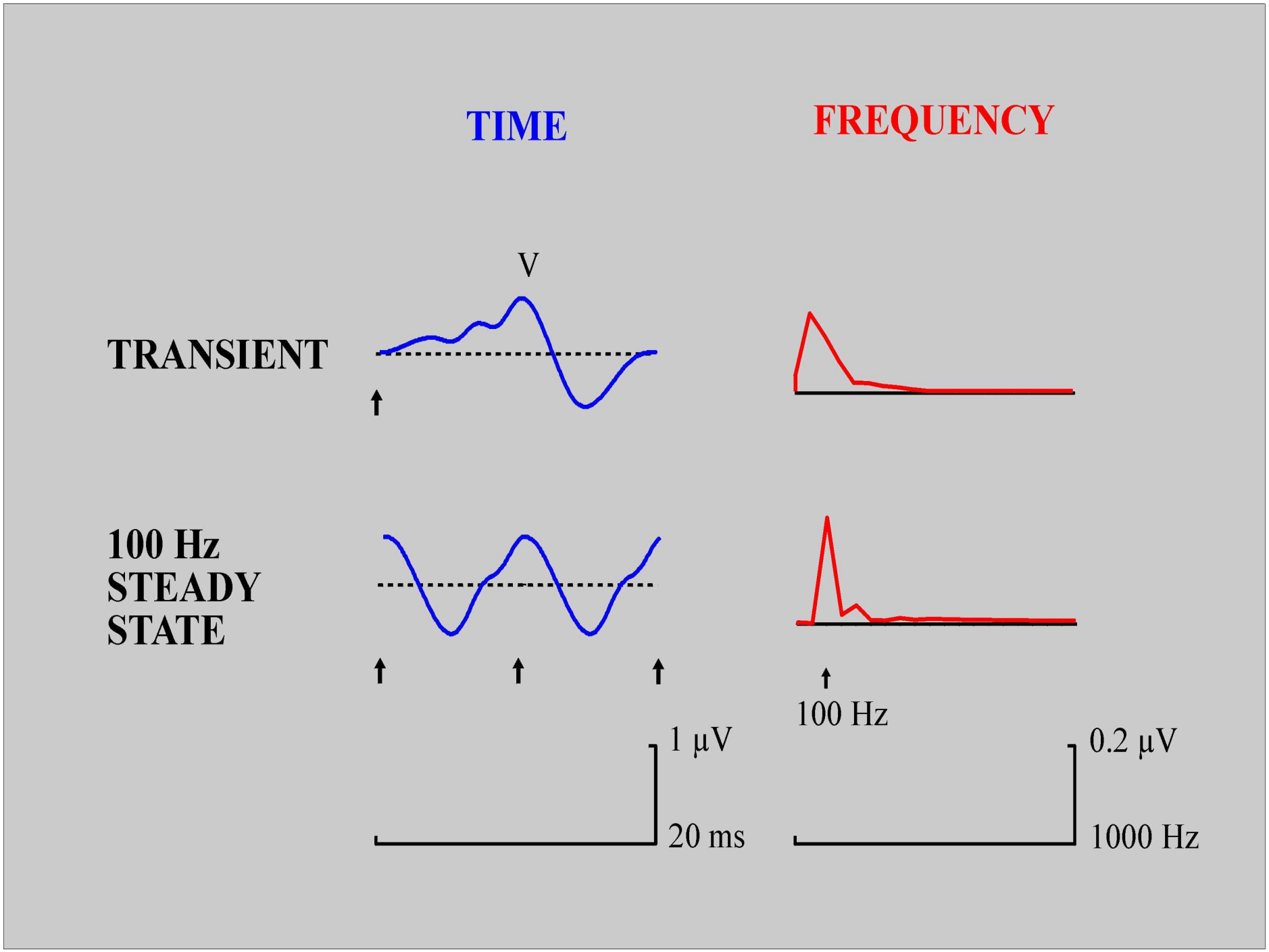
- ✓ Phase of brain wave response in relation to modulation frequency.
- ✓ “Phase-locked” vs. “Random” phases.
- ✓ PC varies from 0 (random) to 1.0 (perfect phase-locking).
- ✓ Test whether brain waves meet a statistical criterion for “phase-locked” (known error rates).

Phase Locked “Response”



No Response Condition



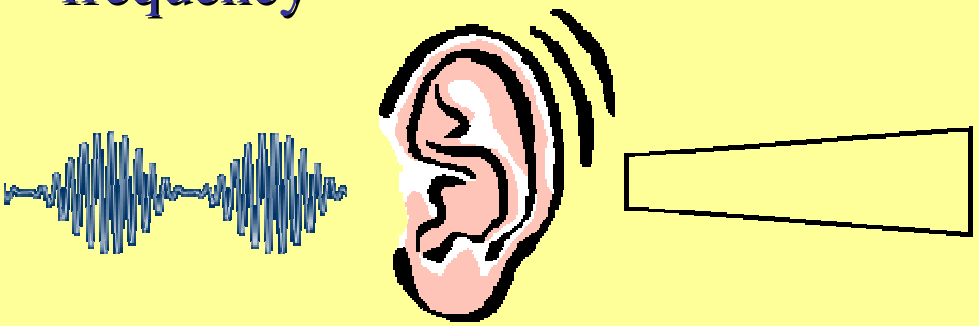

TIME
FREQUENCY
V
TRANSIENT
100 Hz
STEADY
STATE
100 Hz
1 µV
20 ms
0.2 µV
1000 Hz

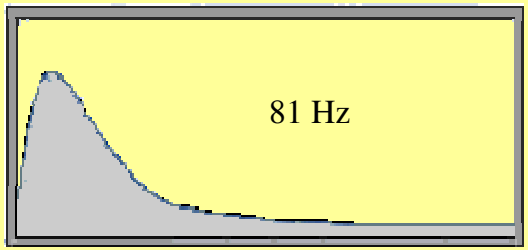
Modulated Stimuli Produce Steady-State Responses at the Modulation Frequency

Carrier at 1 kHz
100% AM
81Hz modulation frequency

Activation at 1 kHz region of basilar membrane

Steady-State response at the modulation frequency





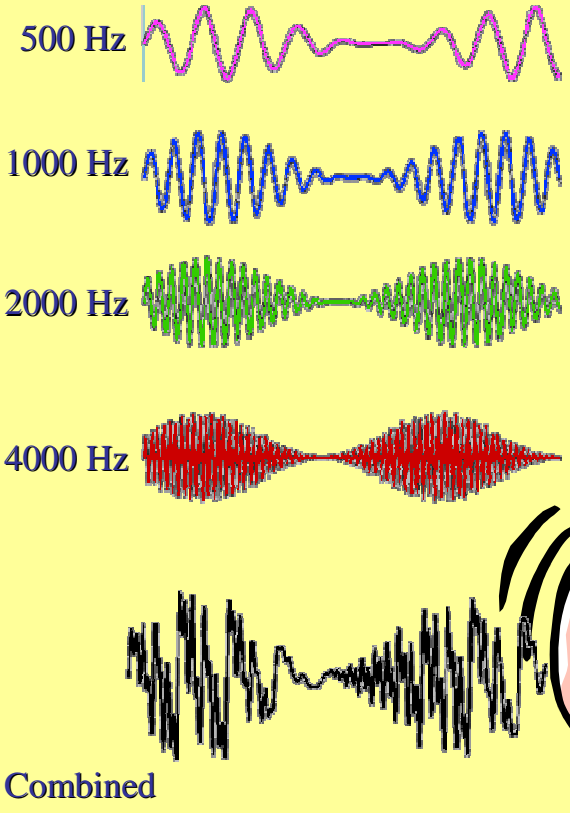
Frequency Spectra – EEG & ASSR

Sound

Cochlea

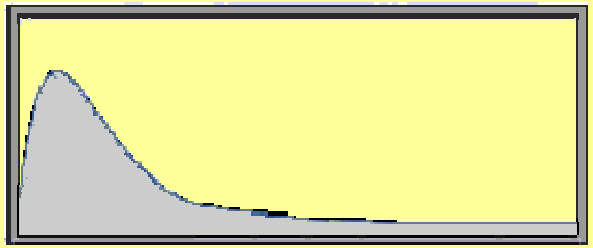
Brain

Four Stimuli Presented Simultaneously to One Ear



Activation at the carrier frequency regions of the basilar membrane

Steady-State response at the modulation frequencies



Frequency Spectra – EEG & ASSR

Sound

Cochlea

Brain

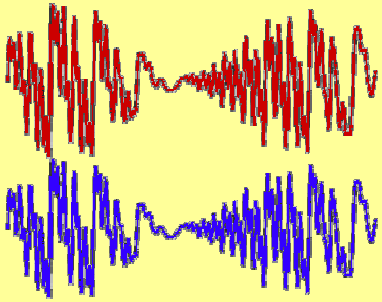
Four stimuli to the Right ear

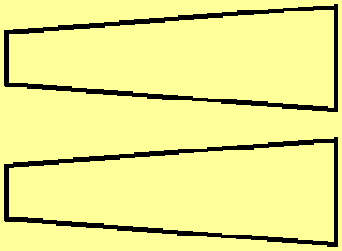
Four stimuli to the Left ear

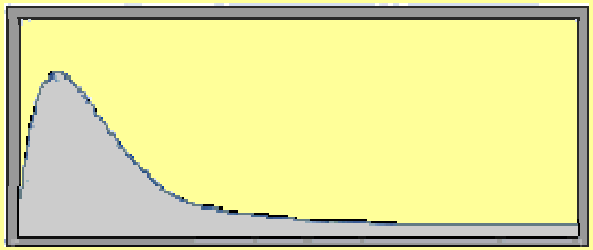
Carrier Hz	Mod Hz Right	Mod Hz Left
500	77	81
1000	85	89
2000	93	97
4000	101	105

Activation at the carrier frequency regions of the basilar membrane

Steady-State response at the modulation frequencies







Frequency Spectra – EEG & ASSR

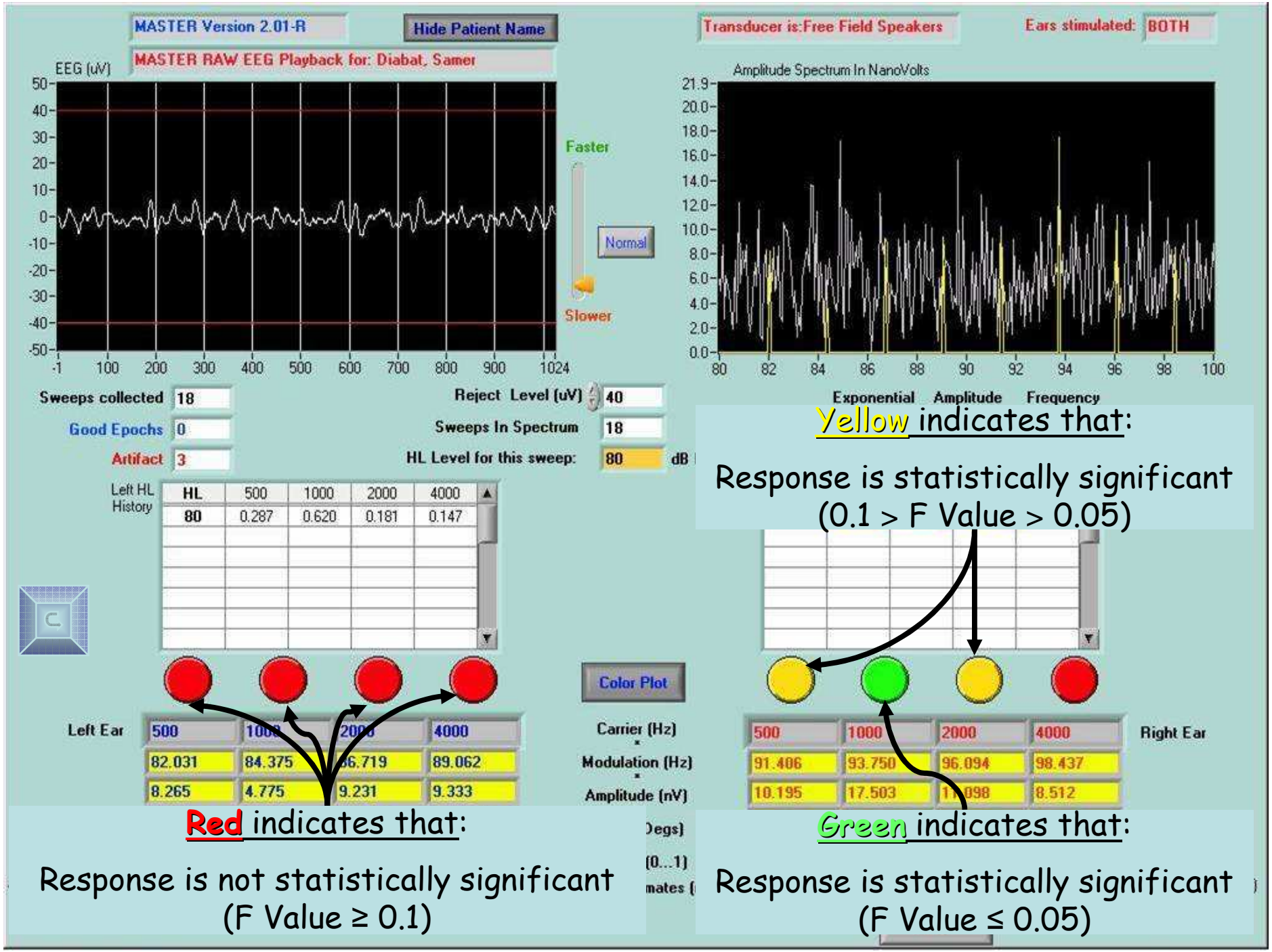
Sound

Cochlea

Brain

Detecting the ASSR signal using F test

- ✓Takes into account the variance of the noise along with the variance of the response
- ✓ F-ratio of Significance must have a p<.05 or better
- ✓ Response color plot
  - ✓ Red = >.101
  - ✓ Yellow = .051 - .101
  - ✓ Green = <.050



Yellow indicates that:

Response is statistically significant
(0.1 > F Value > 0.05)

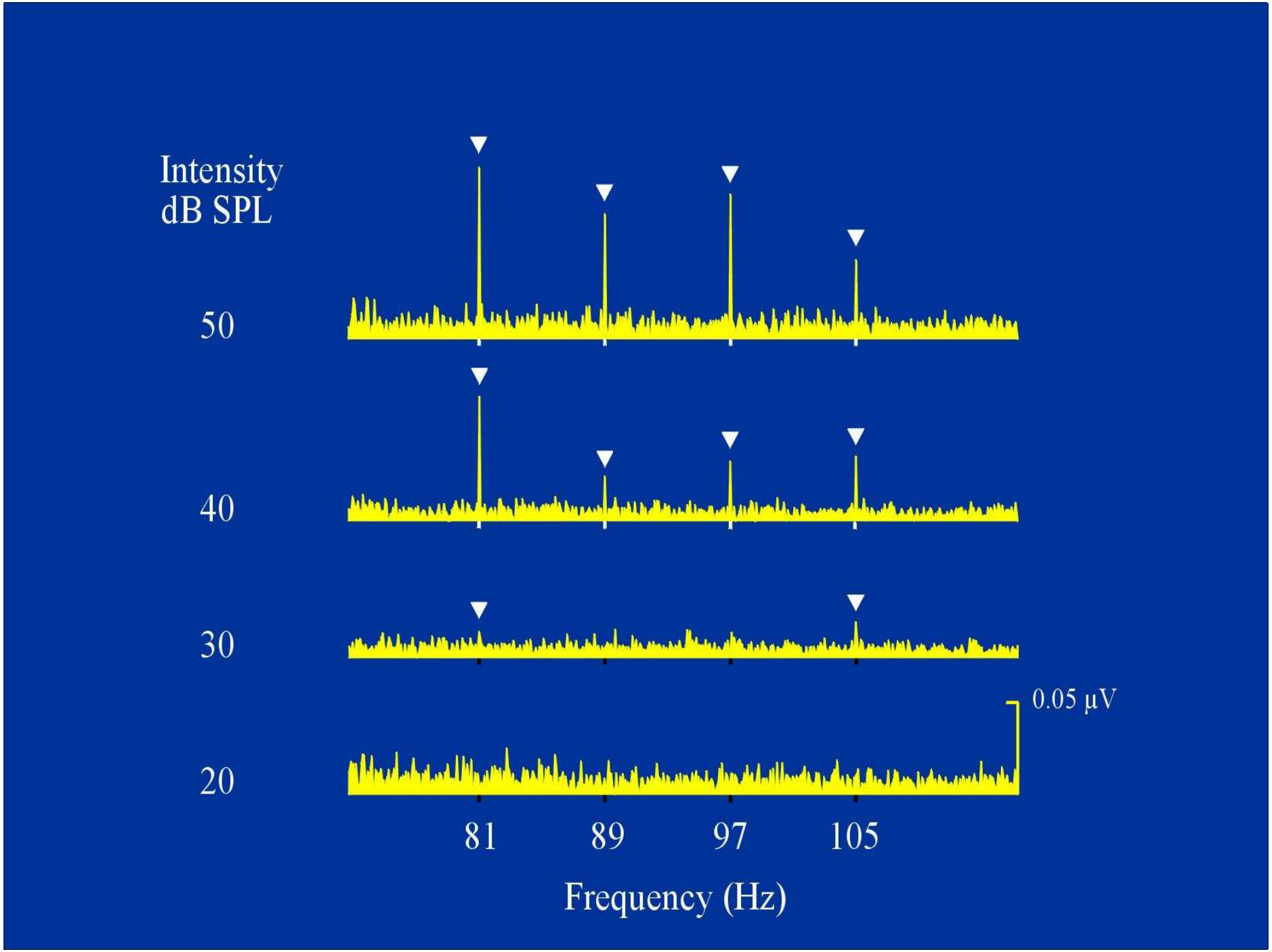
Red indicates that:

Response is not statistically significant
(F Value ≥ 0.1)

Green indicates that:

Response is statistically significant
(F Value ≤ 0.05)

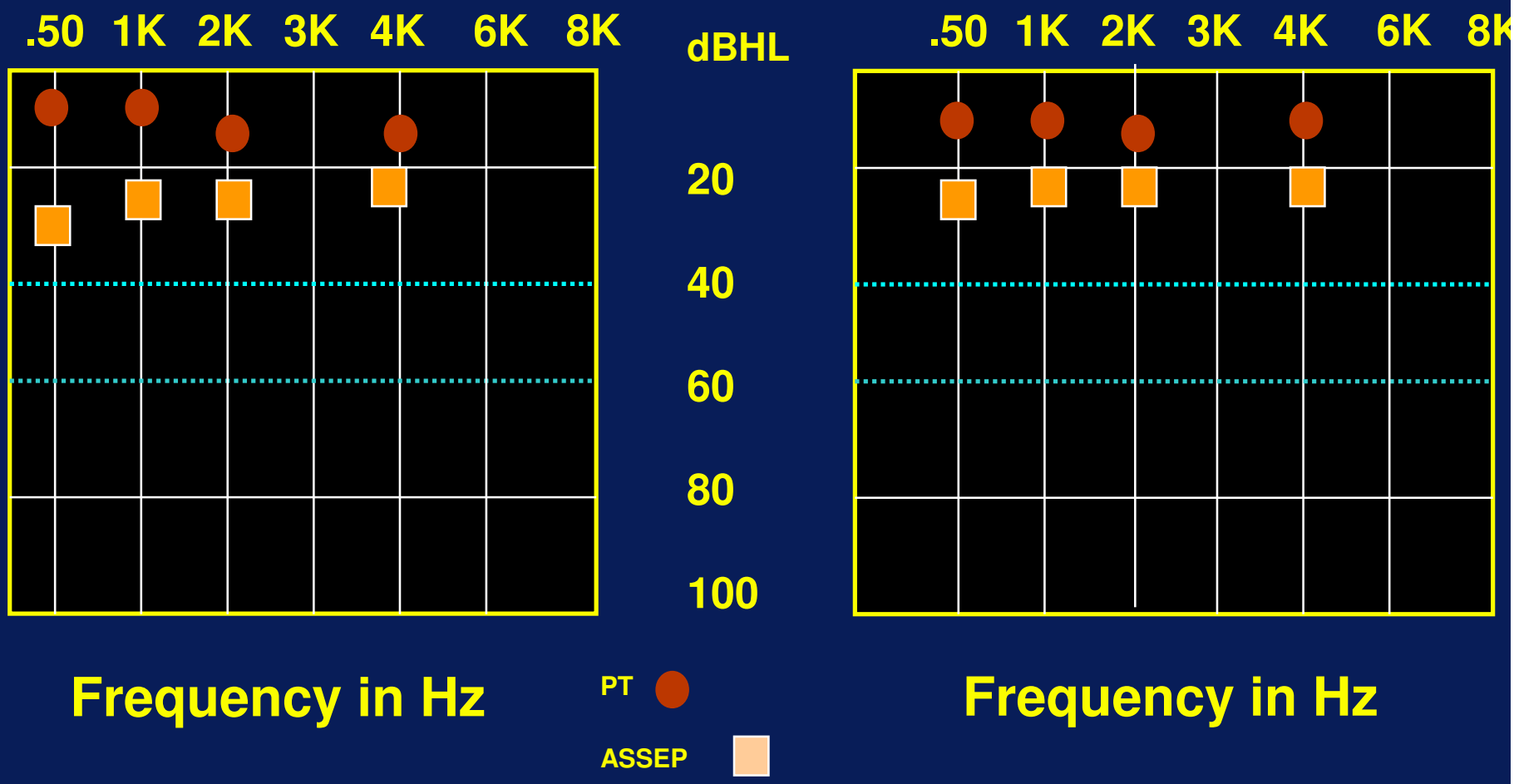
Prediction of the Audiogram by ASSR


Intensity
dB SPL
50
40
30
20
0.05 µV
81
89
97
105
Frequency (Hz)

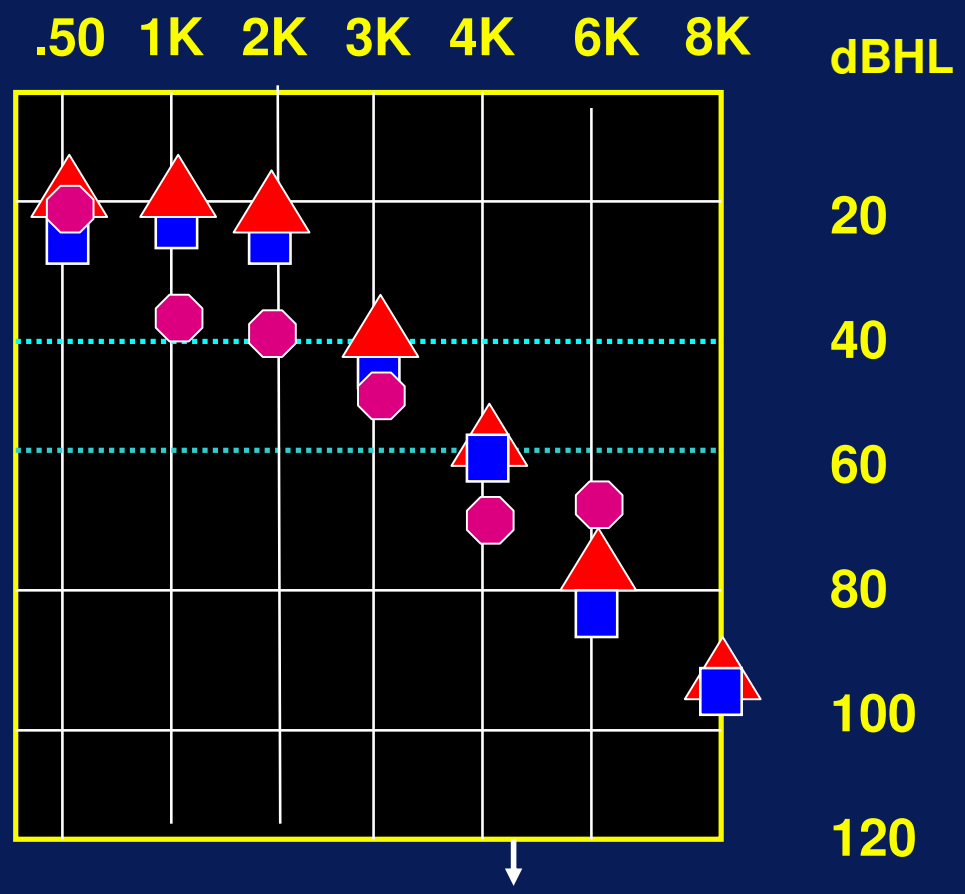
Acquisition ASSR with the MASTER

- ✓ Electrode montage: Cz, C7, A2
- ✓ 1200 Hz sampling rate
- ✓ Filters : 3-300 Hz
- ✓FFT with 0.061 Hz resolution
- ✓Automatic artifacts rejection (>90nV)
- ✓Multiple stimulation up to 80 dBHL and single stimuli beyond that level (up to 132 dB)

Normal Audiogram



AS, 56Y- Bilateral NIHL

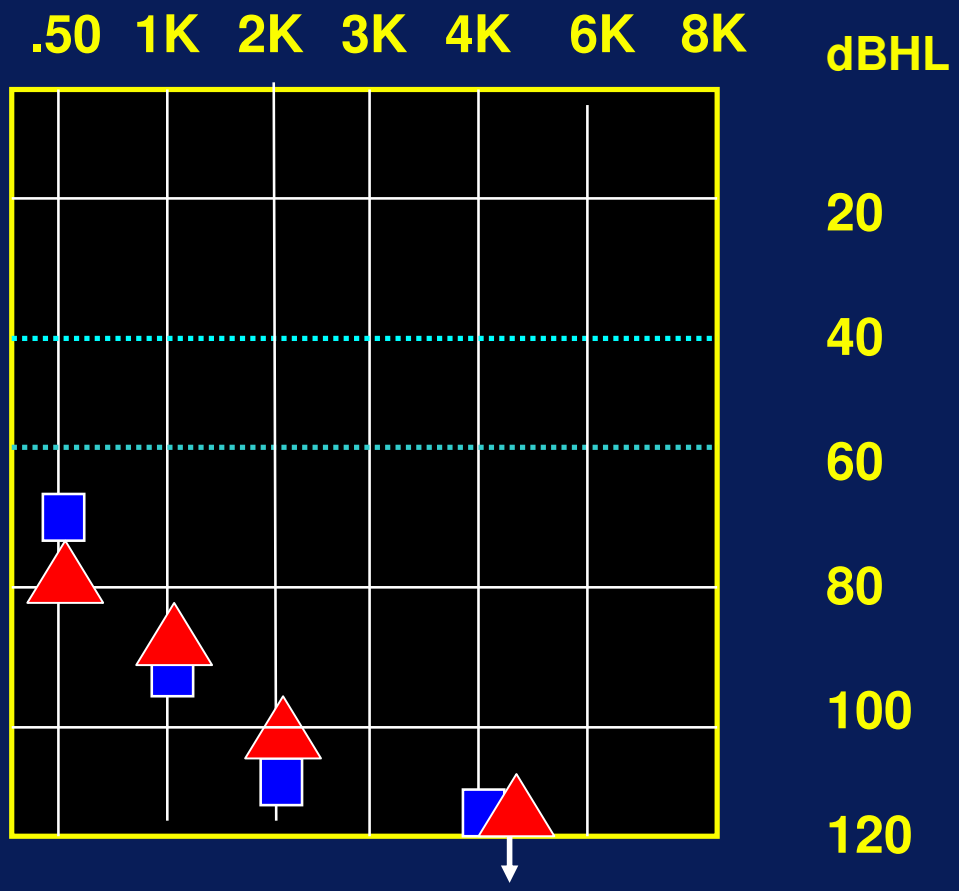


Good correlation between Audiogram to ASSEP

ASSEP to RT Ear

4/11/2003

DM, 1m-Congenital Bilateral Deafness

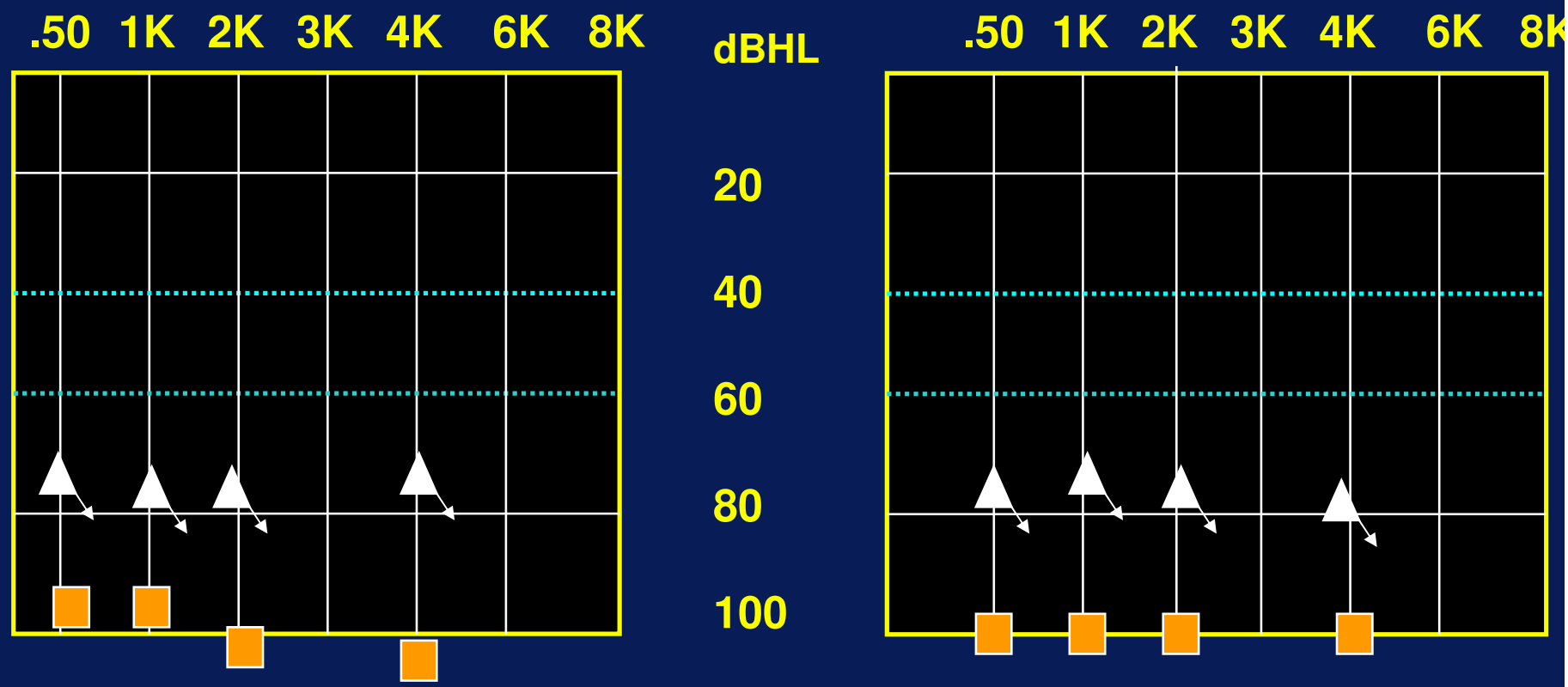


**No ABR to 90 dBHL Alternate Clicks

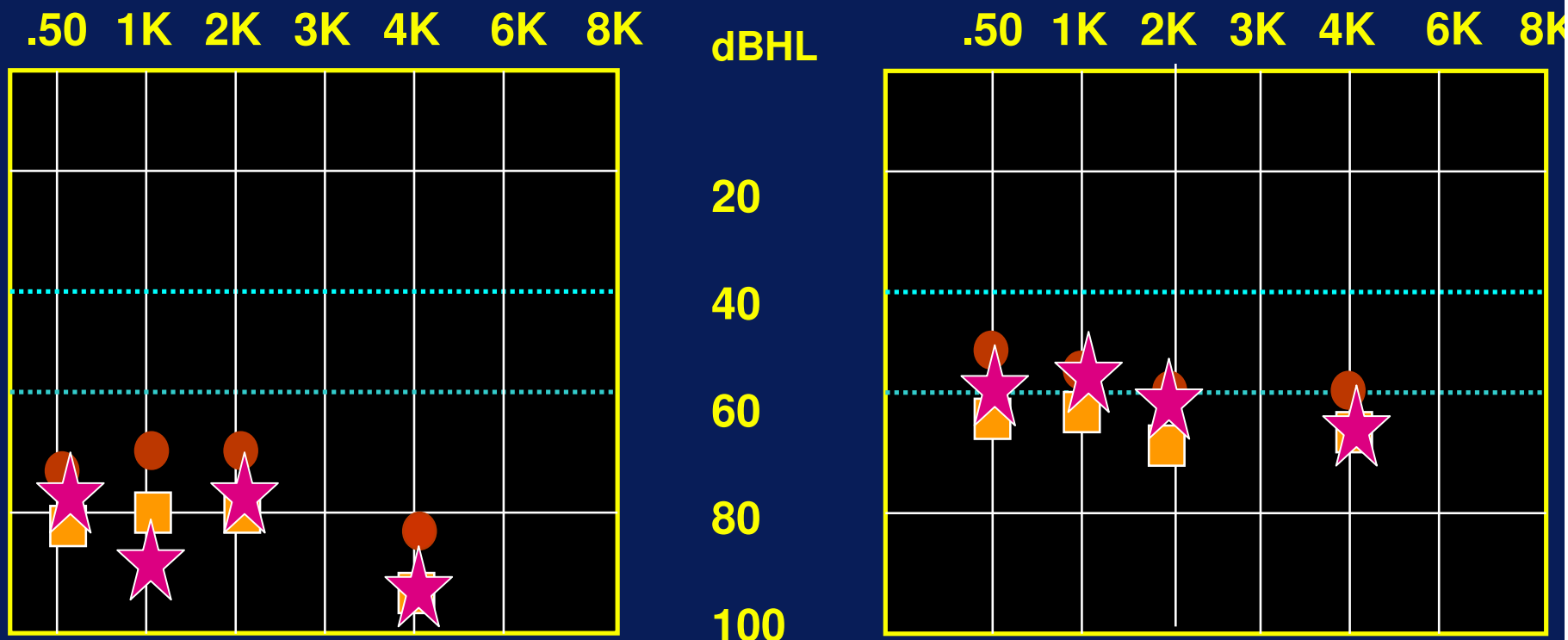
**No Behavioral Responses

25/12/2004

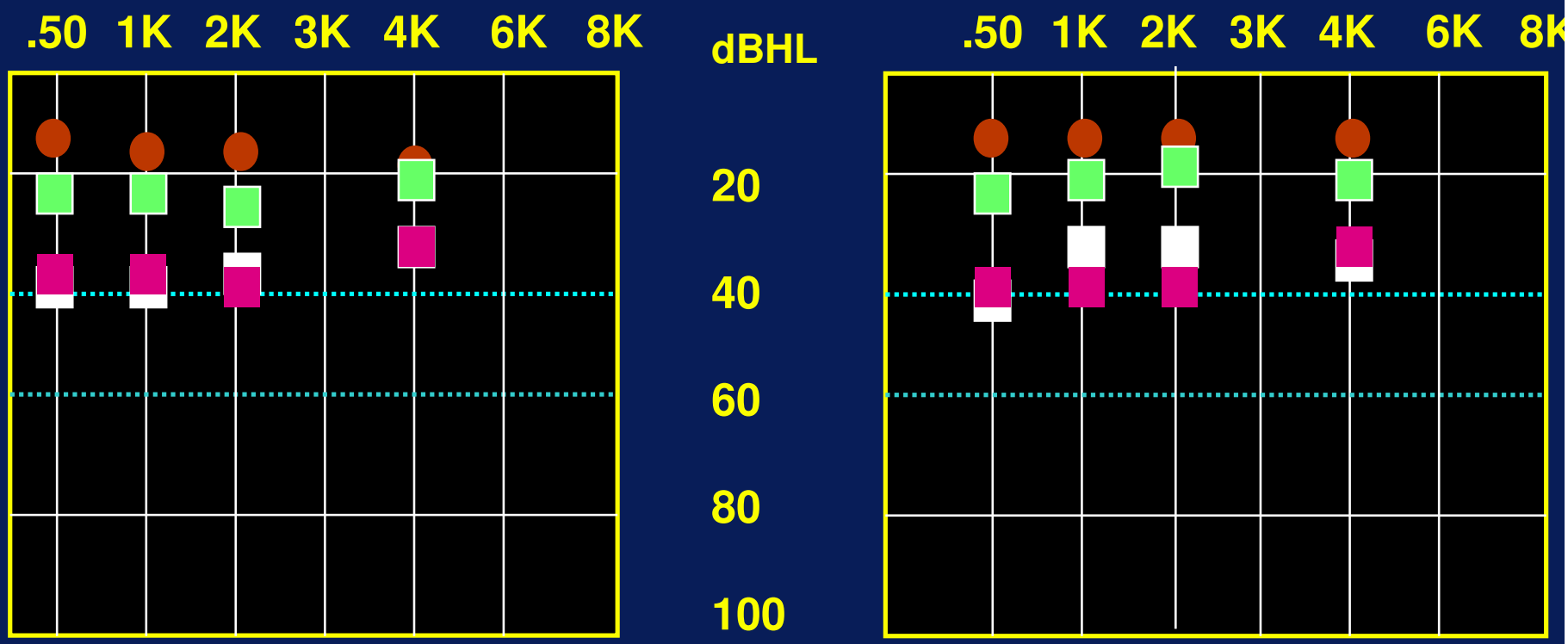
TB ABR and ASSR in 4m Infant



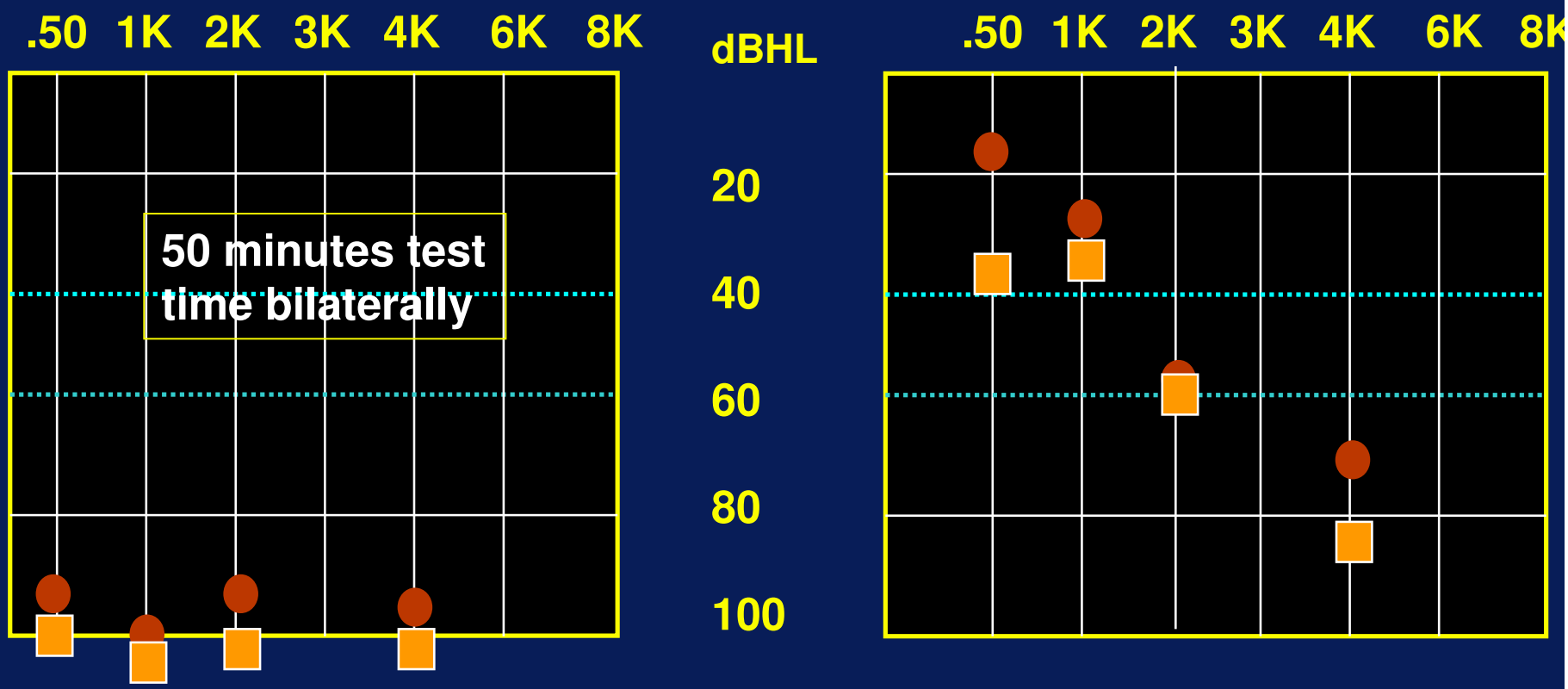
Repeating Behavioral Audiogram and ASSR (1 week apart)



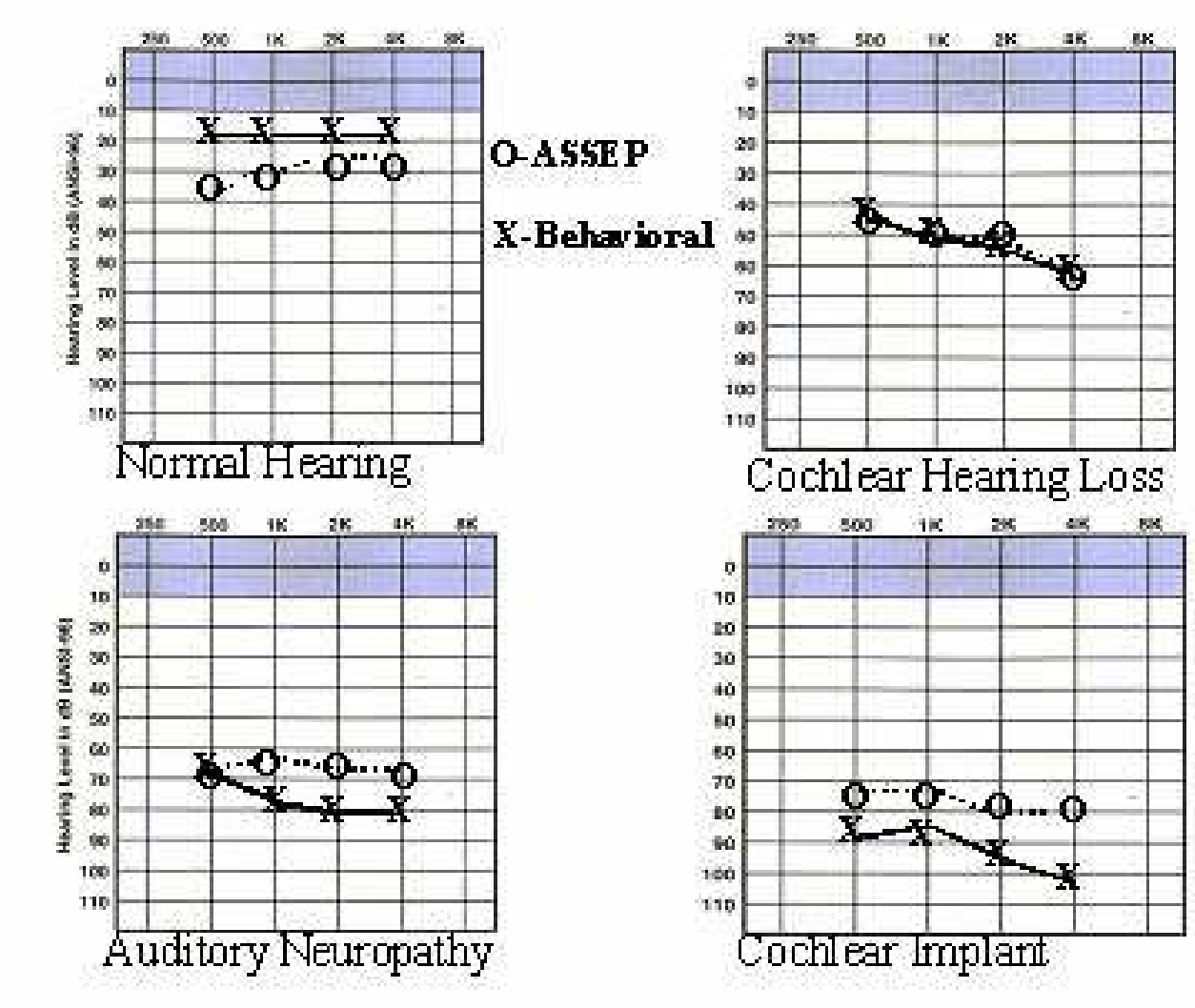
Pure Tones vs. ASSR Awake; ASSR Asleep; ASSR Sedated (with Ambient/Hydrocodone)



Pure Tones vs. MASTER: (Adult)

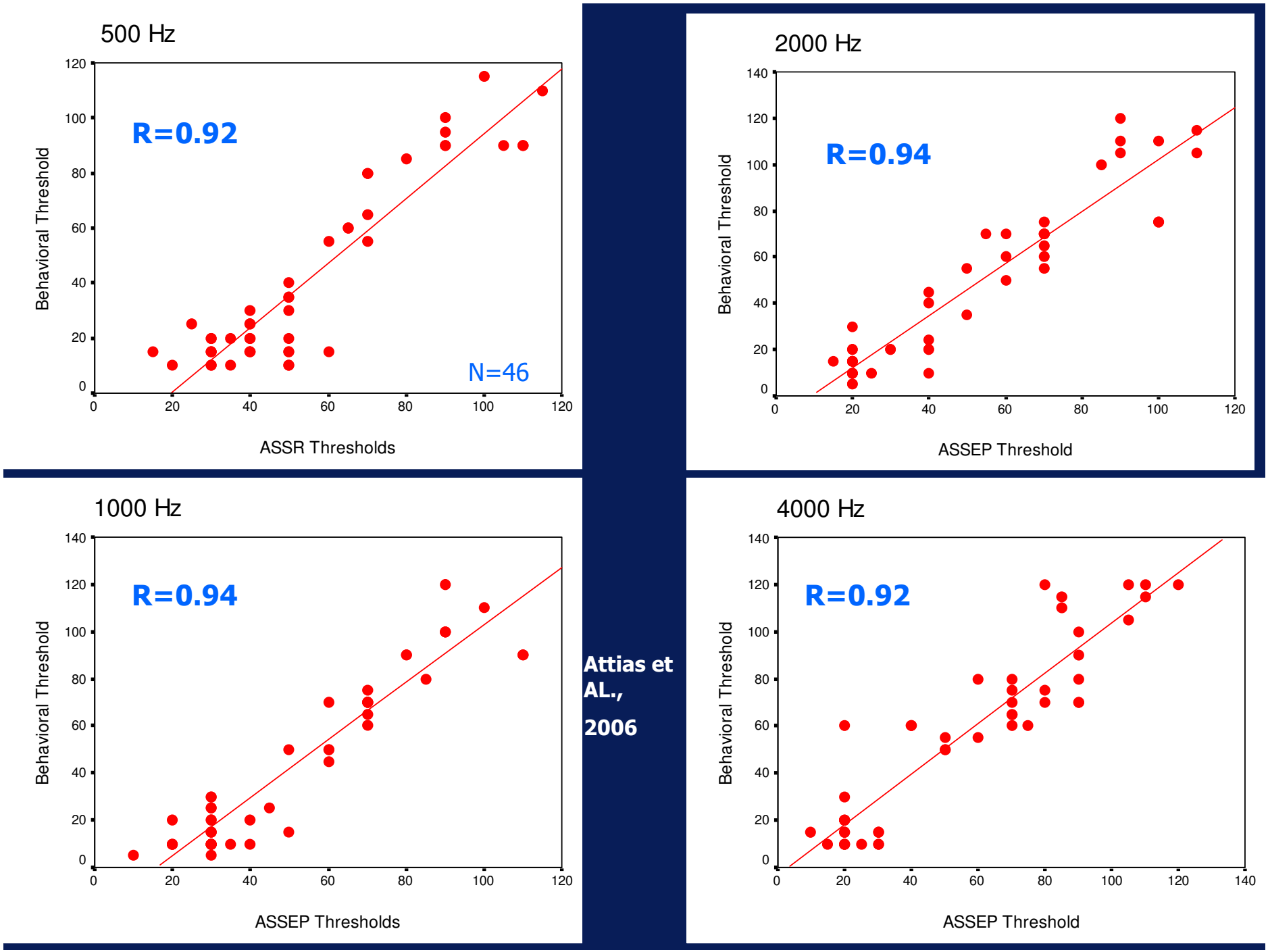


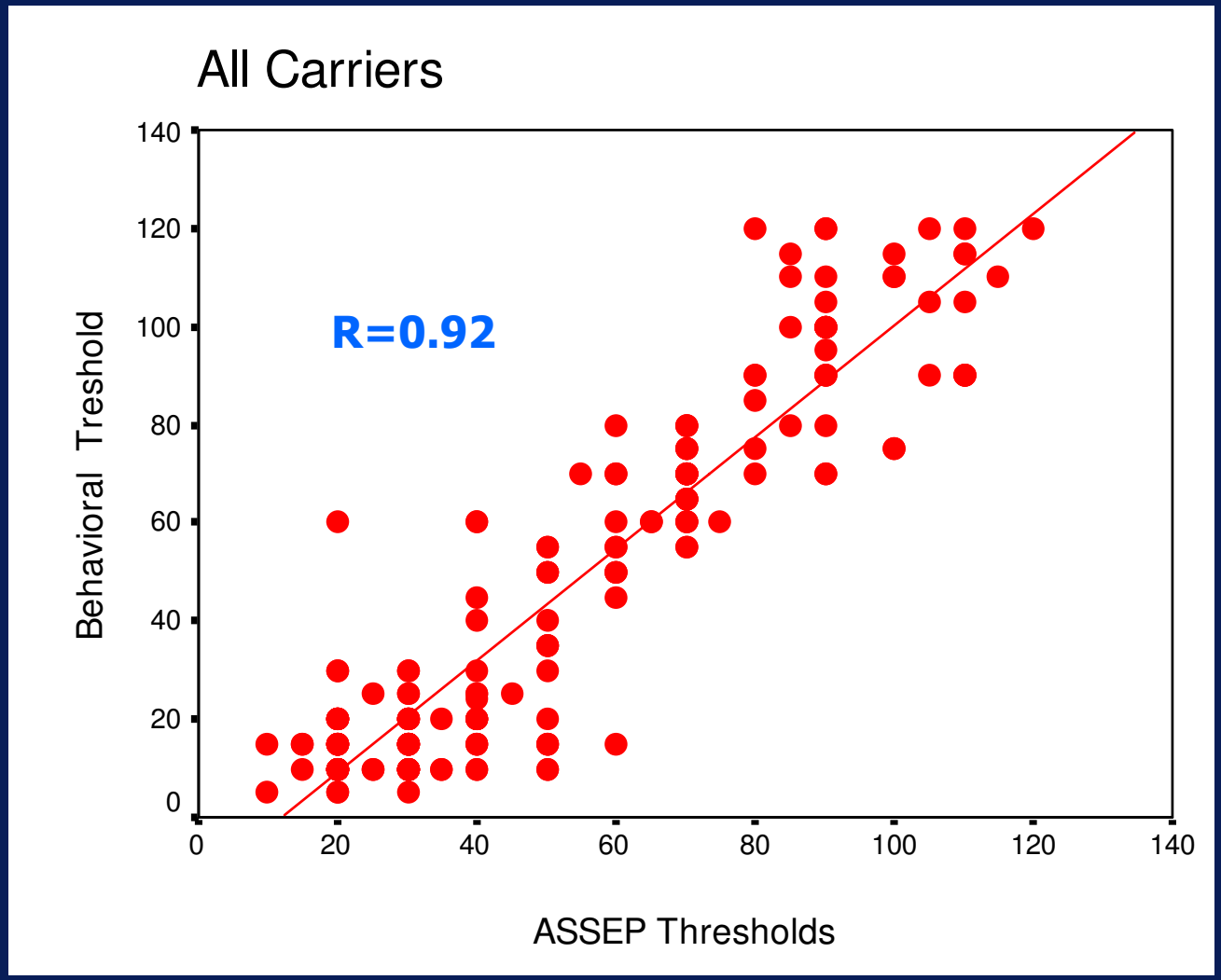
ASSR & Audiograms



2 ears & 8 frequencies
25–40 min

Attias et al., 2006

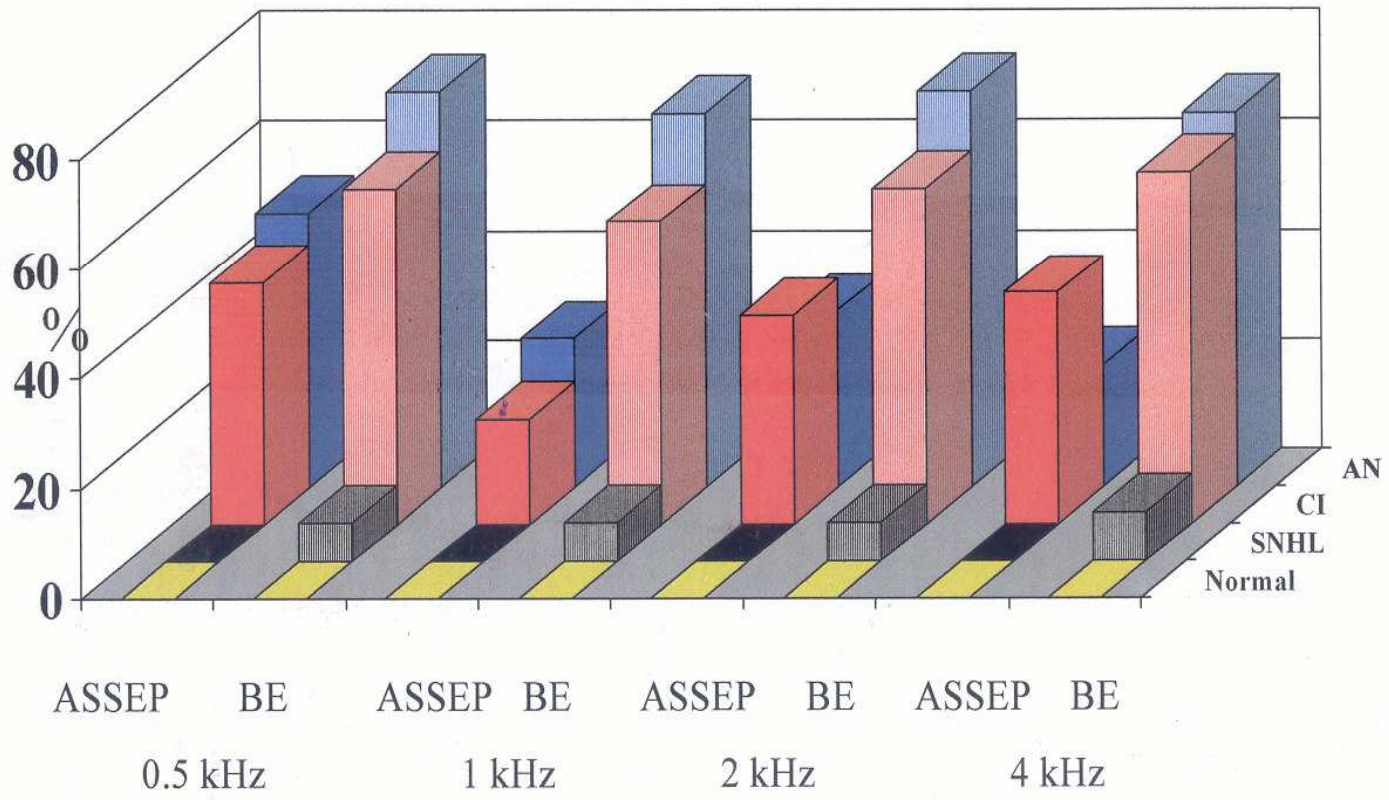

500 Hz
R=0.92
N=46
Behavioral Threshold
ASSR Thresholds
2000 Hz
R=0.94
Behavioral Threshold
ASSEP Threshold
1000 Hz
R=0.94
Behavioral Threshold
ASSEP Thresholds
Attias et AL.,
2006
4000 Hz
R=0.92
Behavioral Threshold
ASSEP Threshold


All Carriers
R=0.92
Behavioral Treshold
ASSEP Thresholds
0
20
40
60
80
100
120
140

Differences between ASSR and Behavioral Thresholds

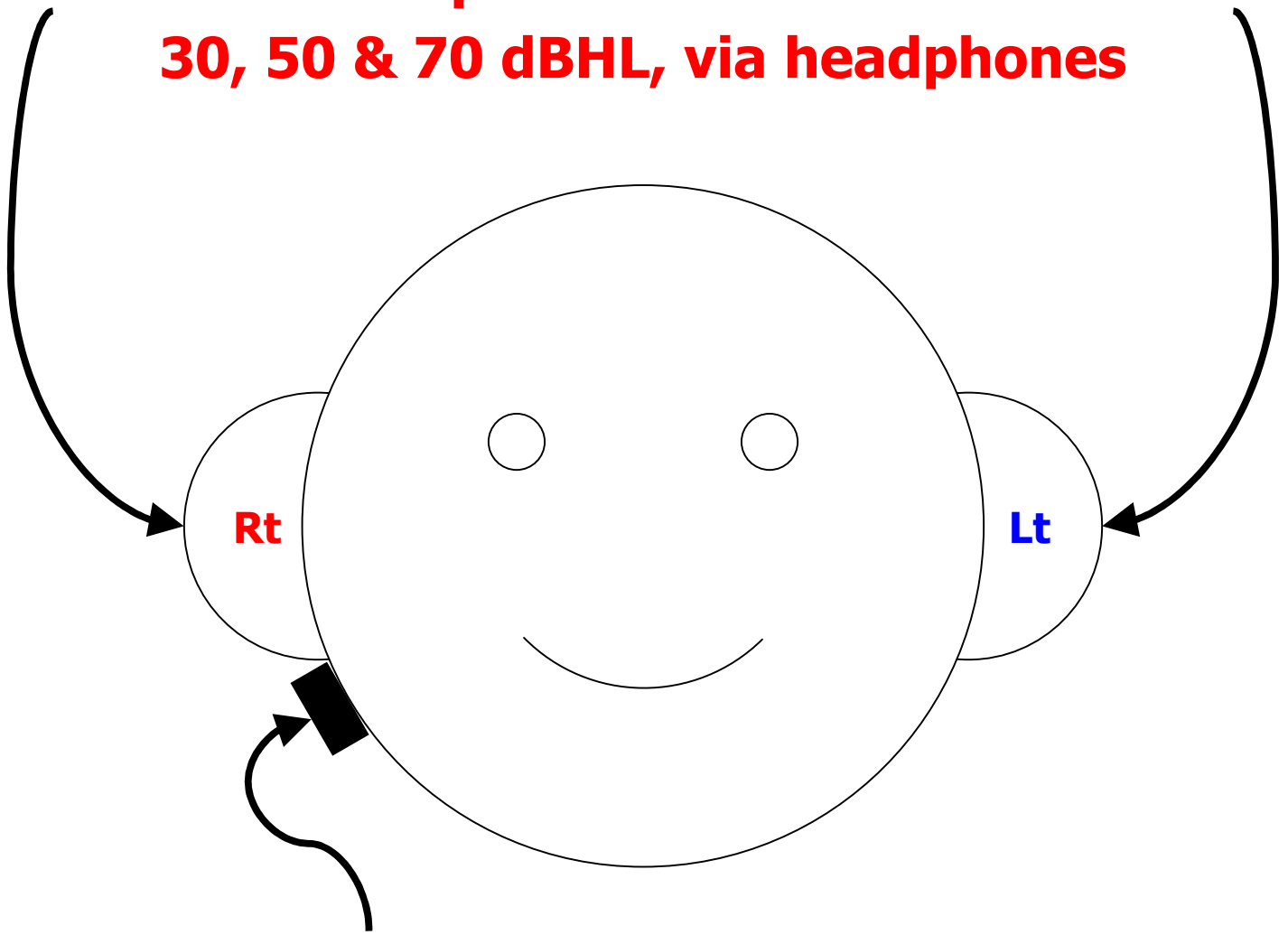
	0.5 KHz	1 KHz	2 KHz	4 kHz
Normal Hearing	-12.7±13.3	-10 ±8.2	3.4 ±6.5	-2.6 ±6.5
SN	-2 ±11.8	0.18 ±7	0.1 ±9.6	1.8 ±8
CI	12.3 ±9.2	12.5 ±7.7	7.5 ±10.5	15.3 ±18.1
AN	-5 ±18.7	7.1 ±17	8.3 ±14.7	8.5 ±17.5

Absence of ASSEP & Behavioral Responses



Masking

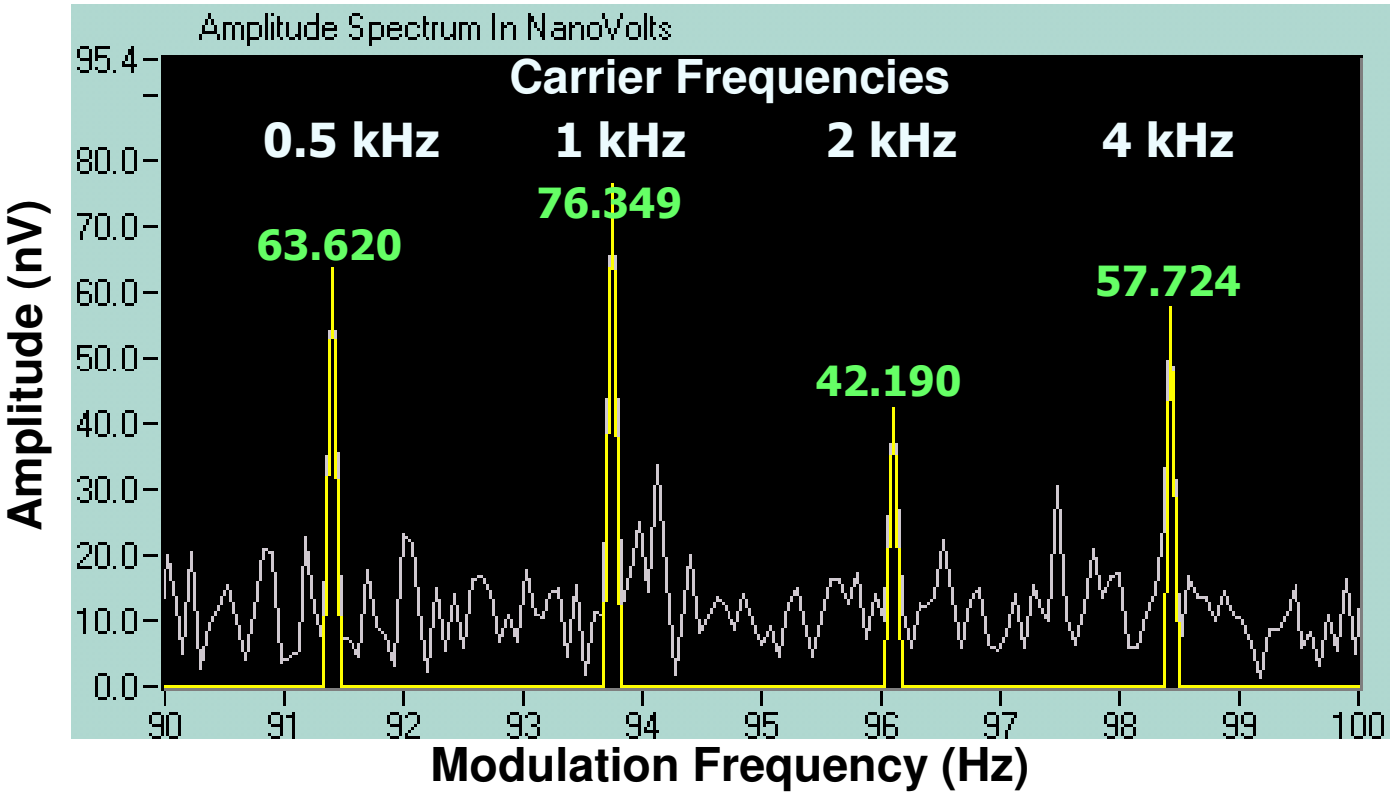
White Noise presented at 3 intensities- 30, 50 & 70 dBHL, via headphones



Stimulus presented at fixed intensity of 50 dBHL via bone vibrator

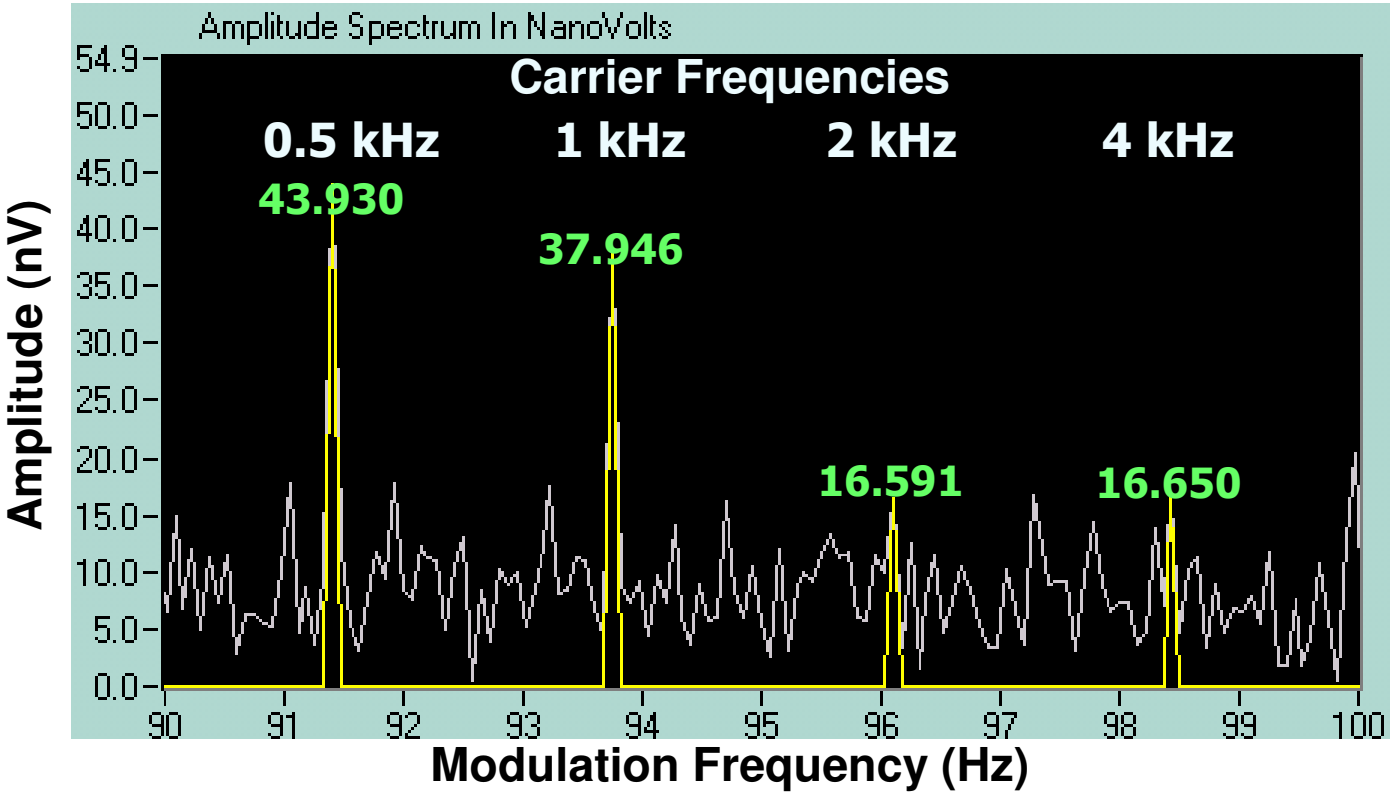
Stimulus Level (BC) = 50 dBHL

Masking Level (AC) = 30 dBHL



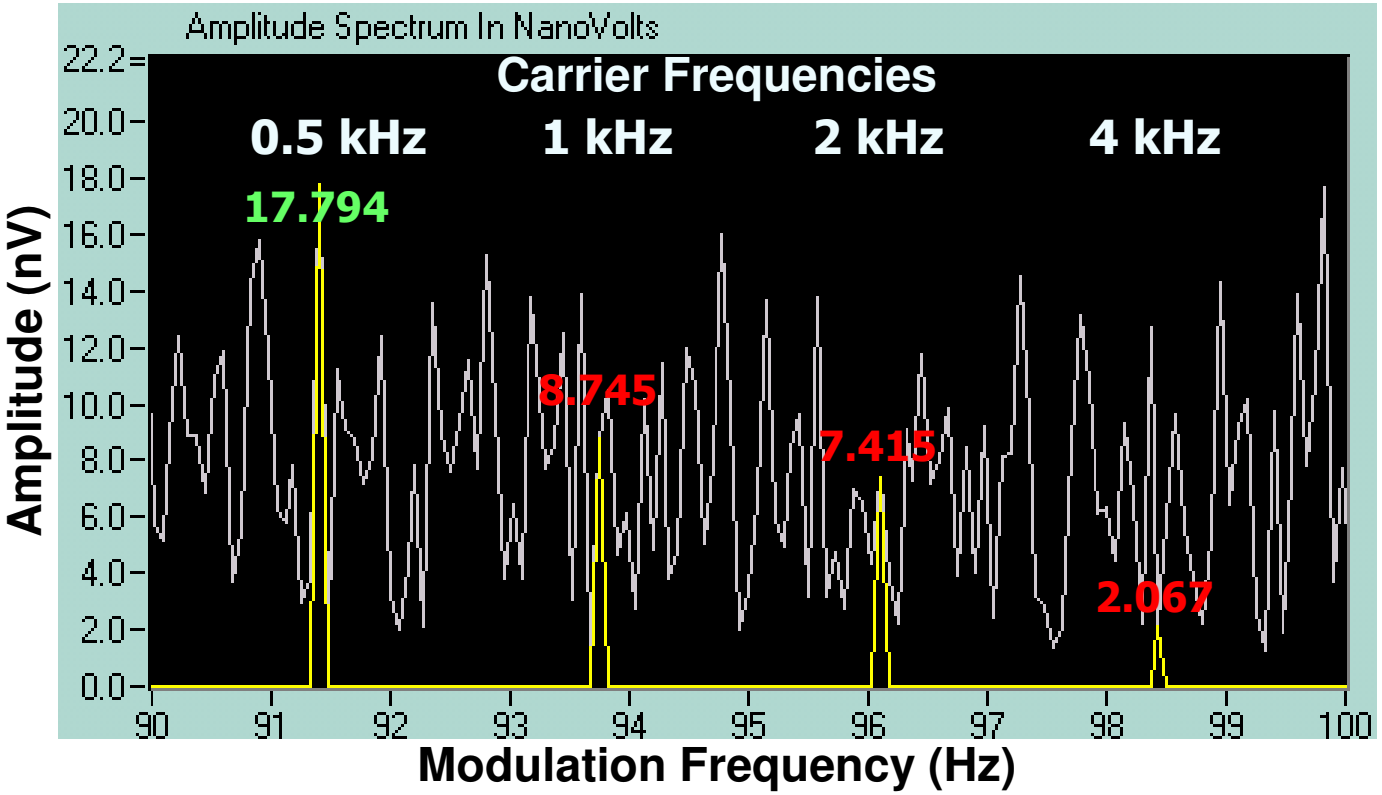
Stimulus Level (BC) = 50 dBHL

Masking Level (AC) = 50 dBHL

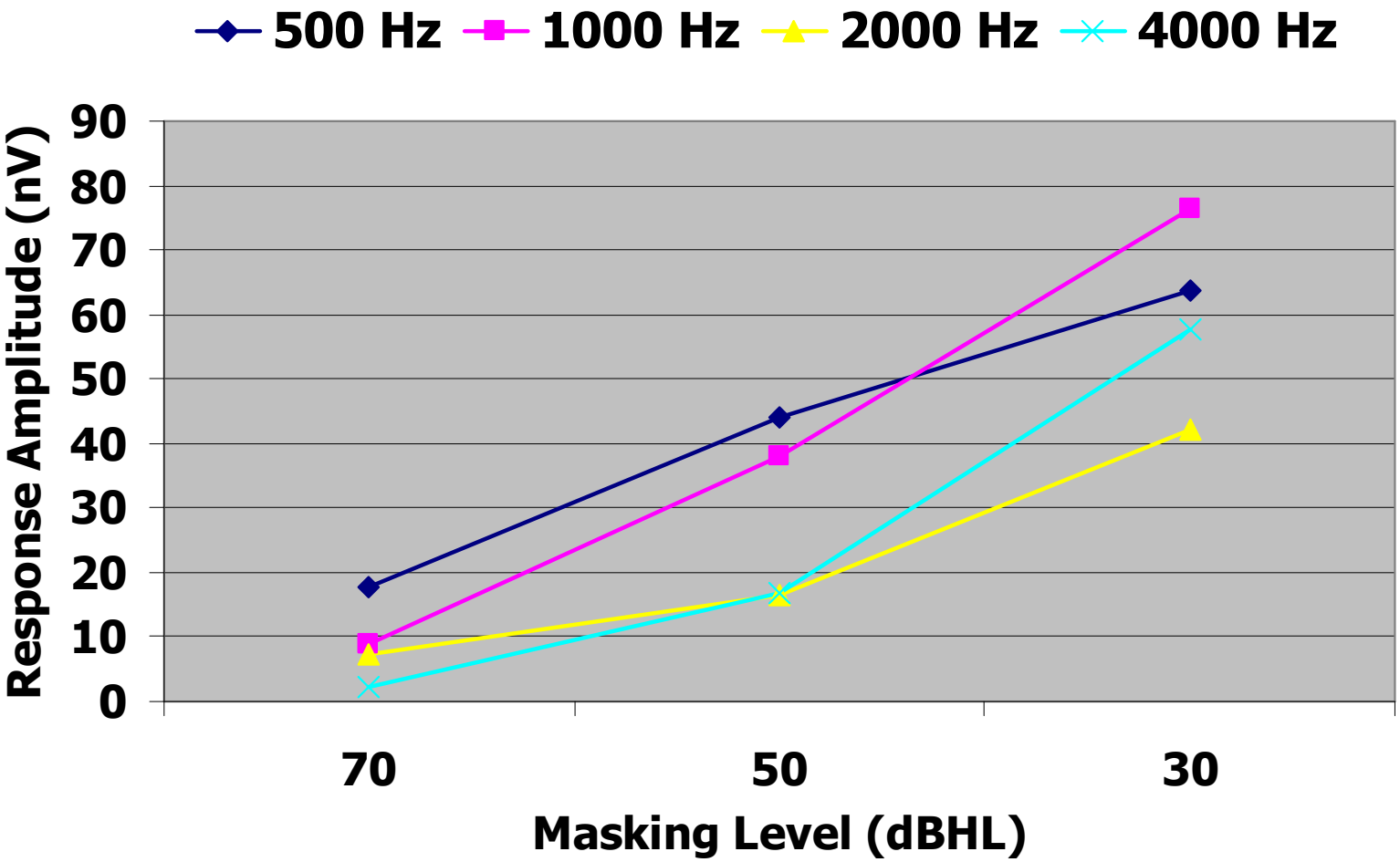


Stimulus Level (BC) = 50 dBHL

Masking Level (AC) = 70 dBHL

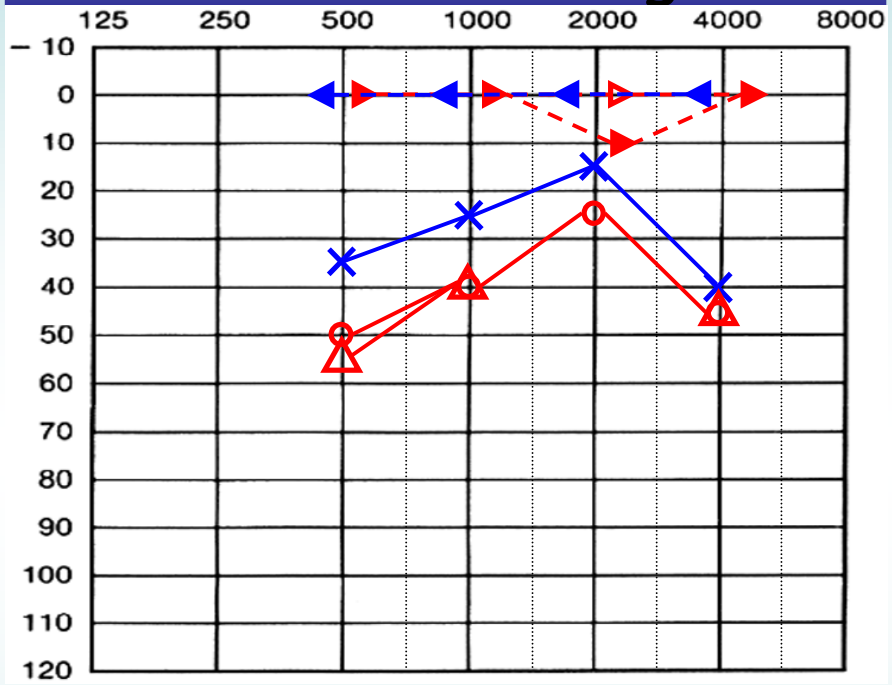


Response amplitude Vs. masking level

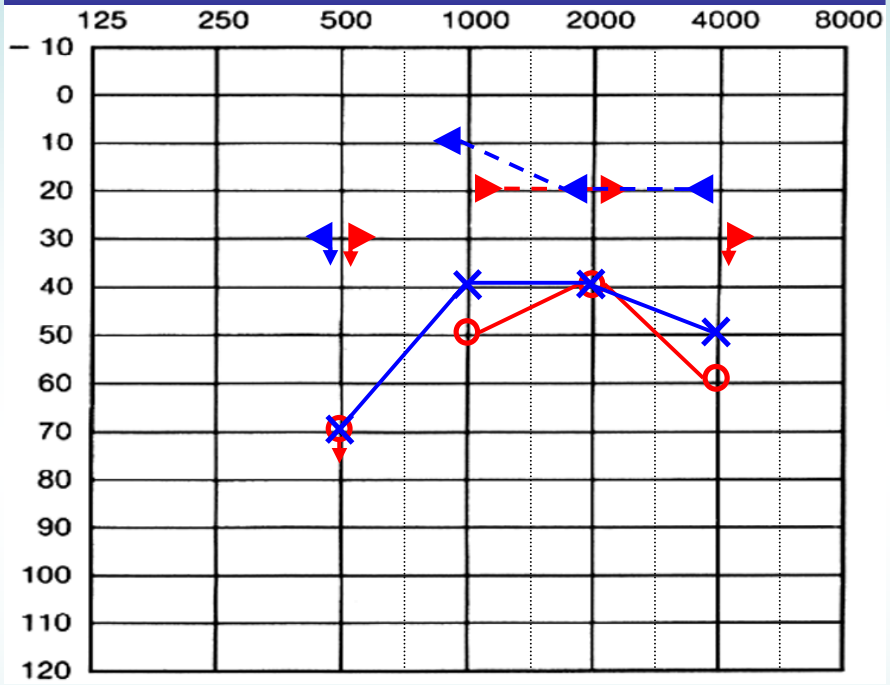


Bilateral mild to moderate conductive Hearing loss

Behavioral Audiogram



ASSR



ASSR - Behavioral discrepancies

Medium \ Ear	Frequency (kHz)	0.5	1	2	4
Air	Rt	>15	10	15	15
	Lt	35	15	25	10
Bone	Rt	>30	20	10	>30
	Lt	>30	10	20	20

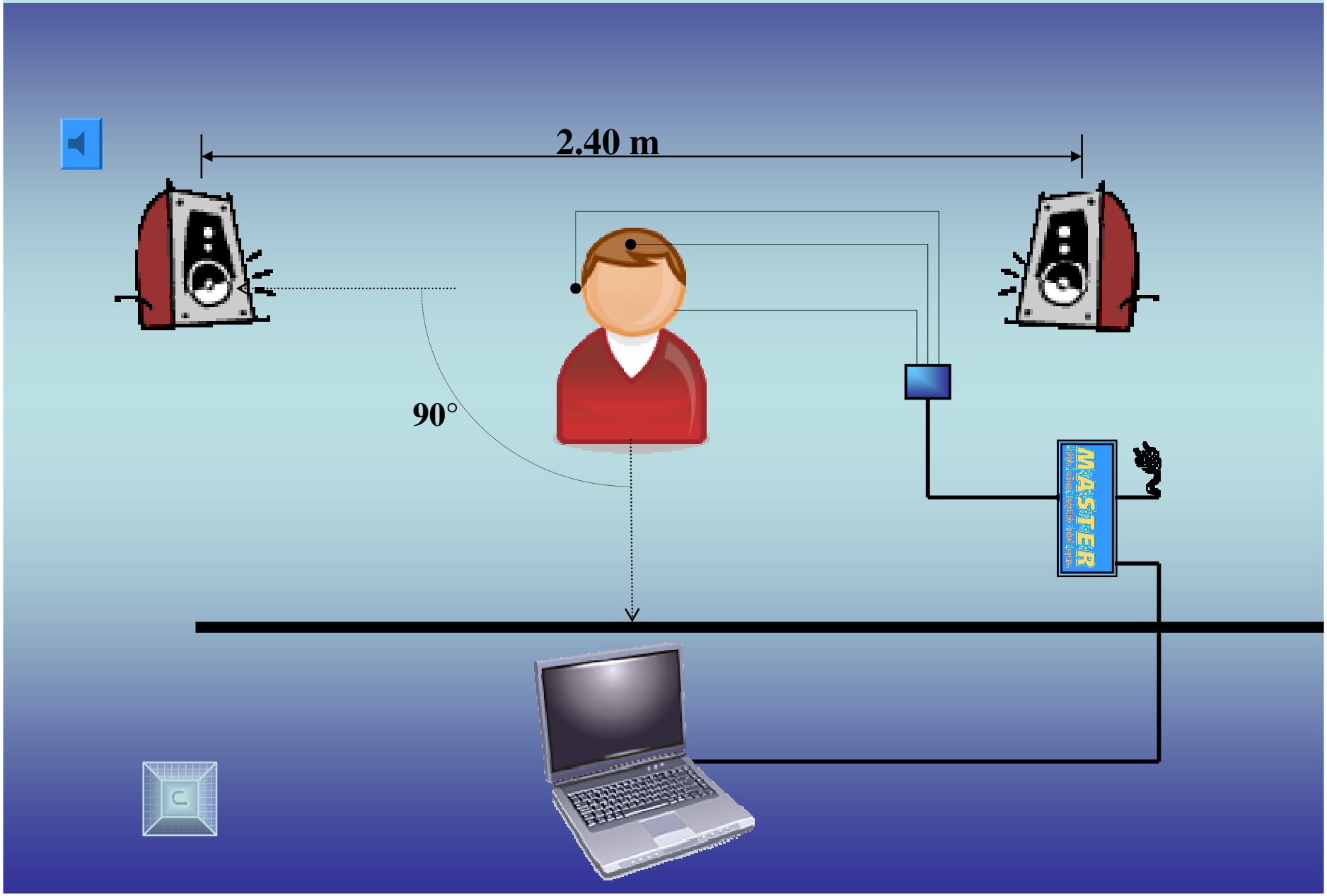
Fitting Hearing Aides

- **Subjects:** 10 subjects (adults and children) with symmetrical hearing loss. Fitted monaurally Severity range (Mild-Severe).
- **Behavioral Thresholds**: Thresholds estimation of four audiometric frequencies (0.5-4 kHz) via Sound Field speakers (**aided & unaided**).

  (Untested Ear was either masked with WN or occluded by foam plug).
- **ASSR Thresholds**: Estimating thresholds using the MASTER System (Multiple Auditory Steady-State Responses).

  four frequencies simultaneously at each stimulus intensity.
- **Total test duration**: ~1.5 hrs.

Physical arrangement



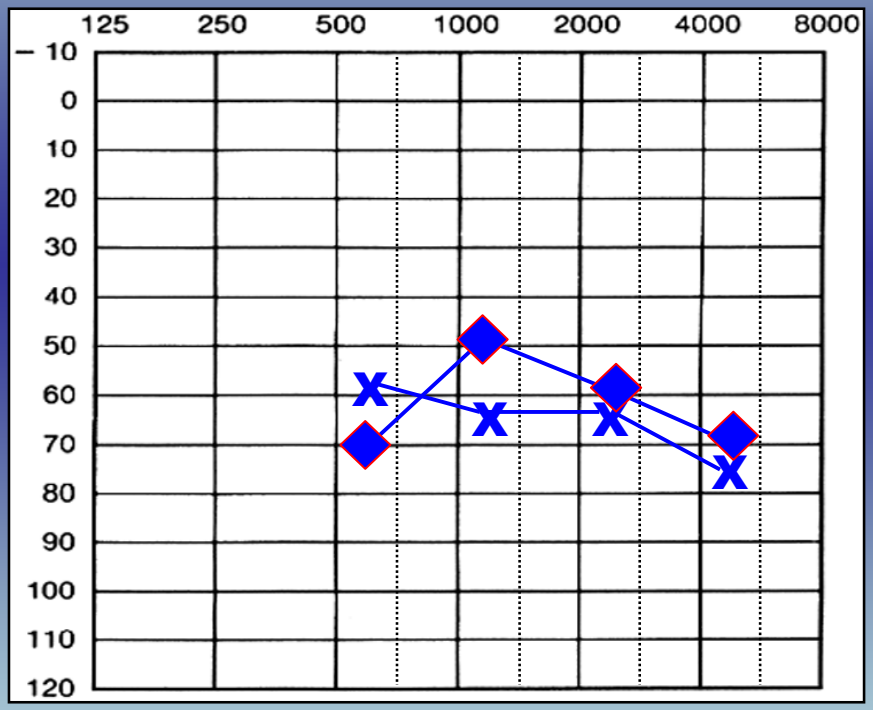
Physical arrangement

Young children

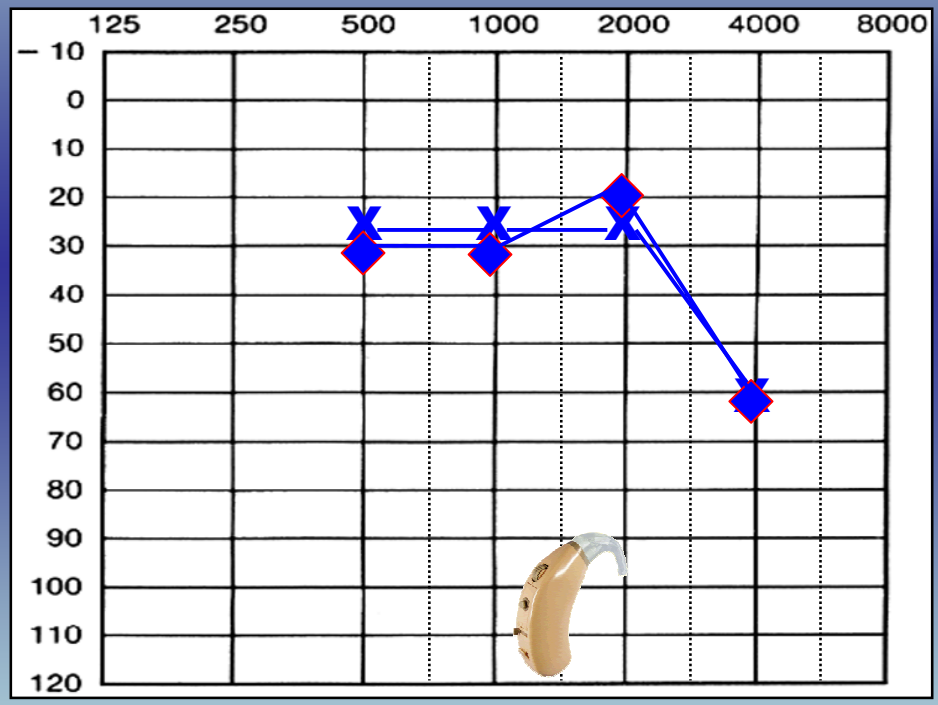
Sample Case:

female, □□ yrs, left ear aided.

Free Field - Unaided



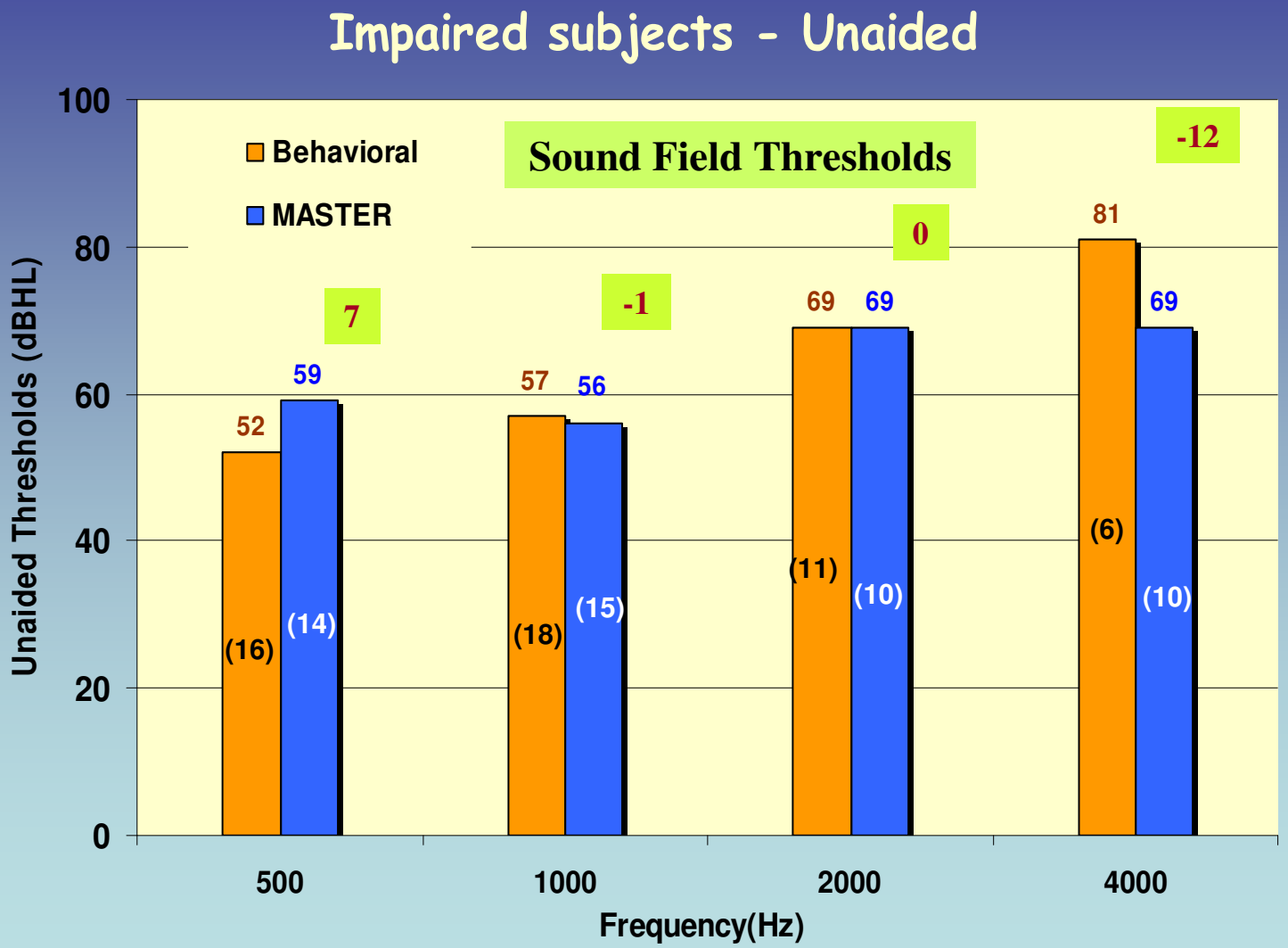
Free Field - Aided



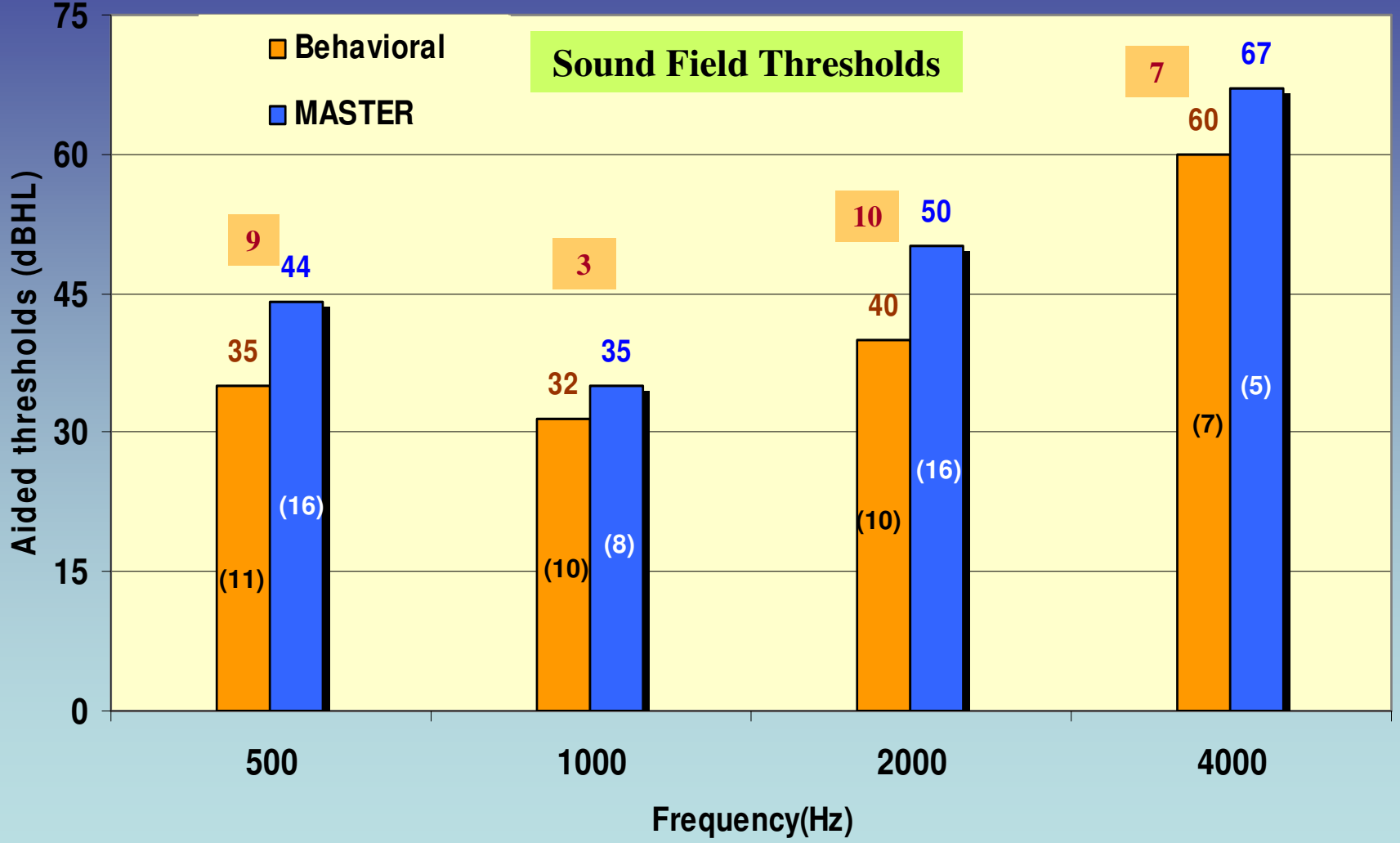
X –Behavioral threshold

◆ - ASSR threshold

RESULTS:


Impaired subjects - Unaided
Behavioral
MASTER
Sound Field Thresholds
Unaided Thresholds (dBHL)
100
80
60
40
20
0
7
-1
0
-12
52
59
57
56
69
69
81
69
(16)
(14)
(18)
(15)
(11)
(10)
(6)
(10)
500
1000
2000
4000
Frequency(Hz)

Aided Subjects



Correlation coefficients of aided/unaided thresholds with Behavioral thresholds

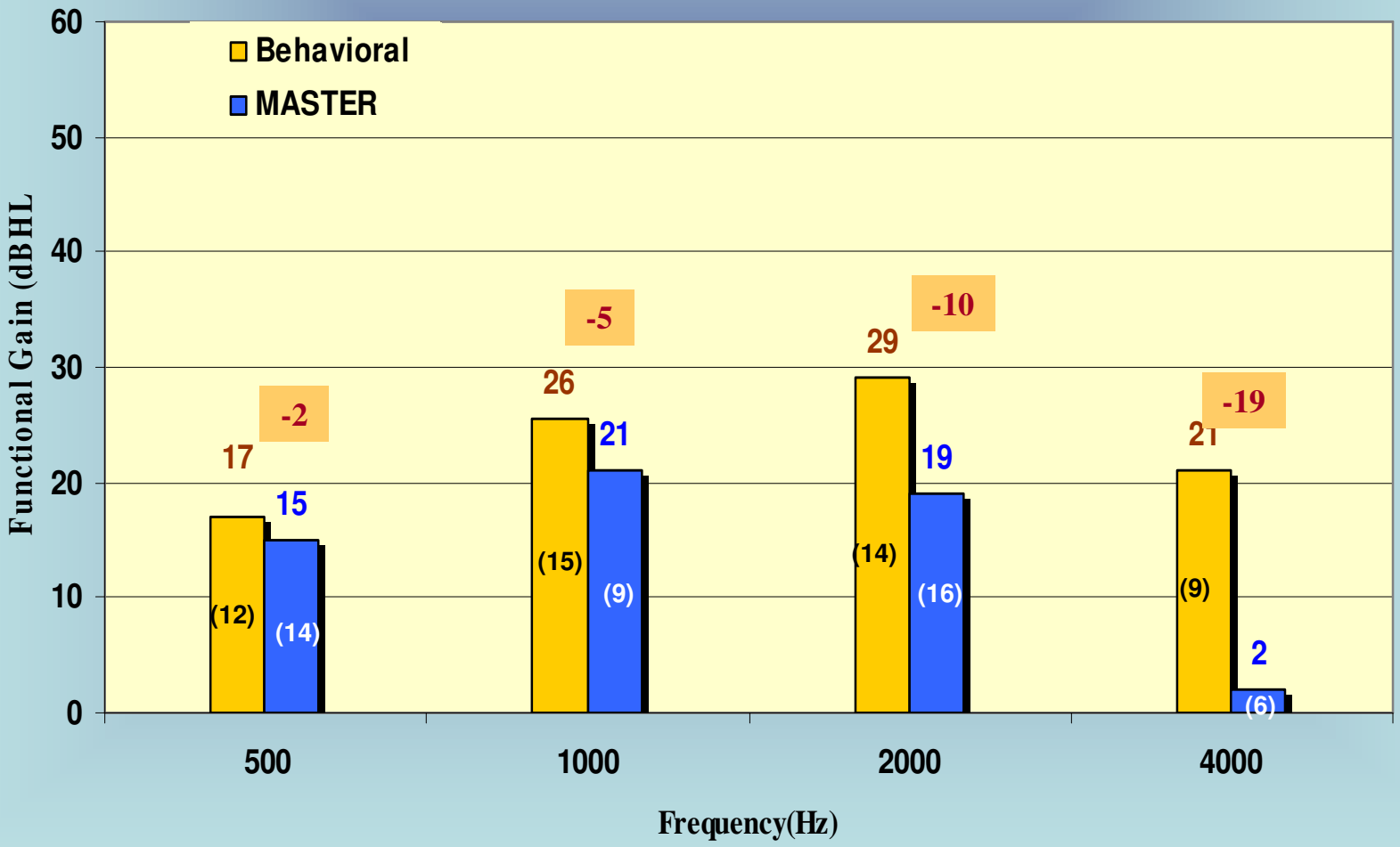
Correlation between ASSR & Behavioral thresholds				
	500 Hz	1000 Hz	2000 Hz	4000 Hz
unaided	0.939**	0.682*	0.646*	0.546
aided	0.83□**	0.821**	0.3□4	0.344

**. Correlation at the 0.01 level (2-tailed).

*. Correlation at the 0.05 level (2-tailed)..

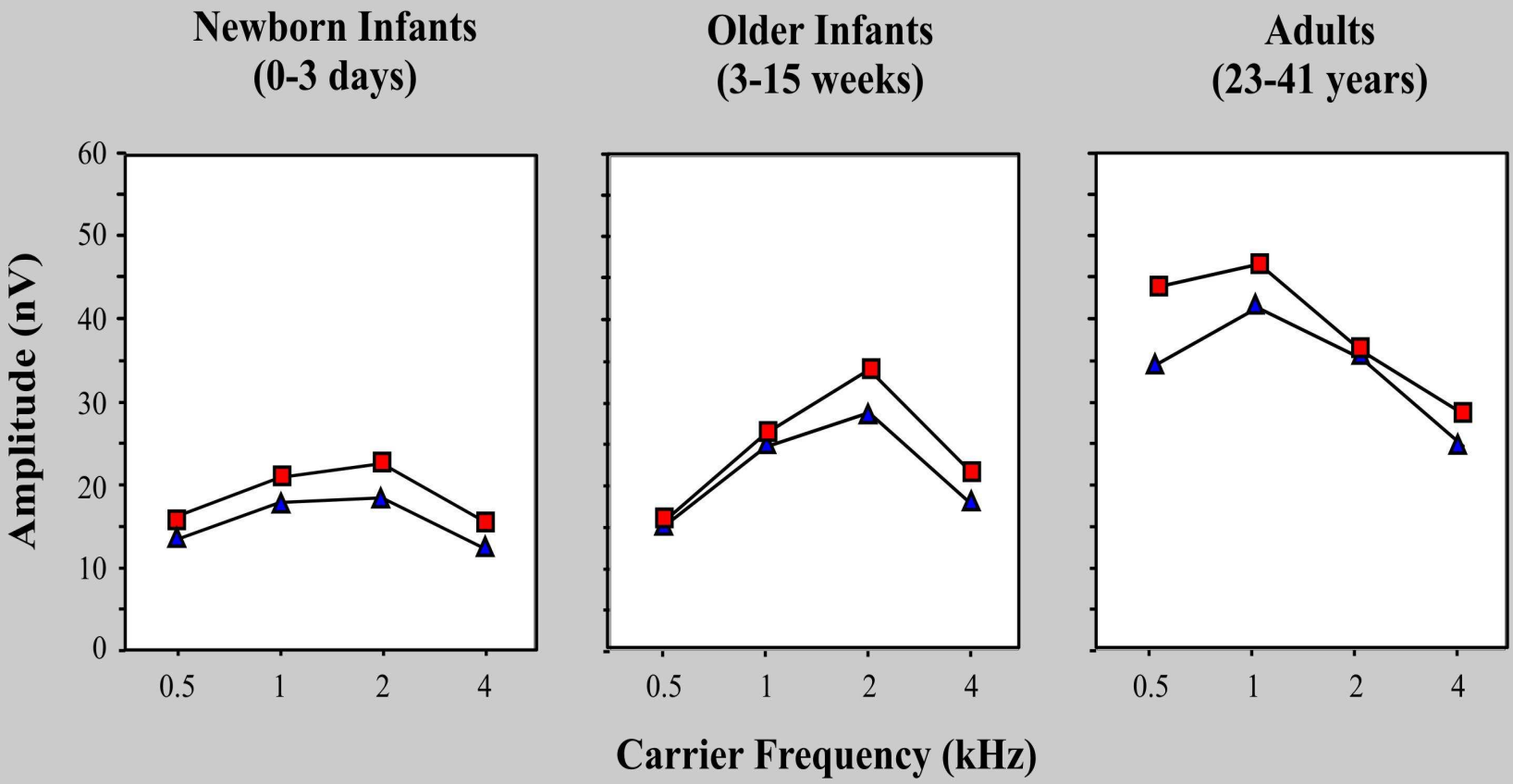
Functional Gain = Unaided threshold - aided threshold

Functional Gain - Behavioral vs. MASTER



Supra-threshold ASSR

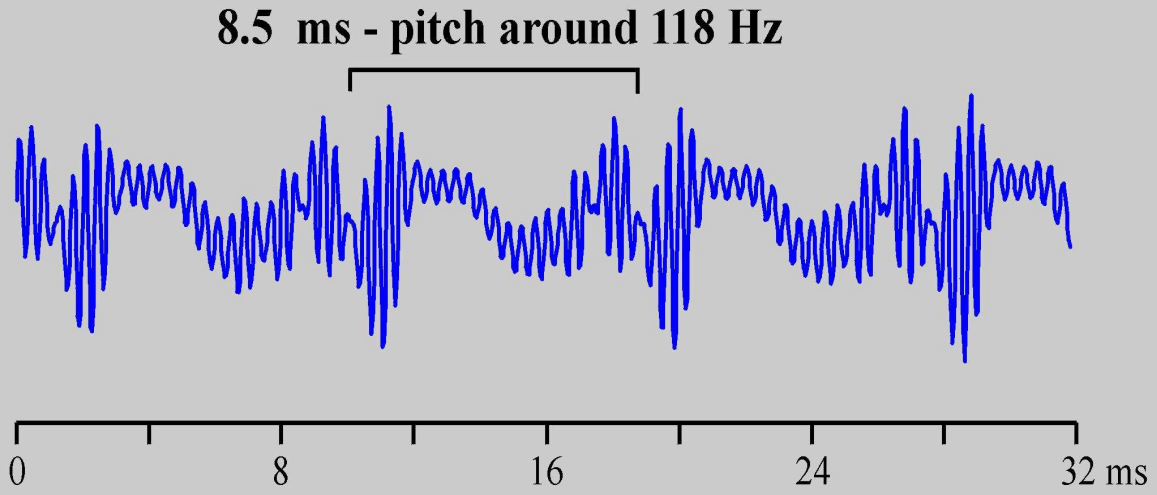
Maturation of the ASSR



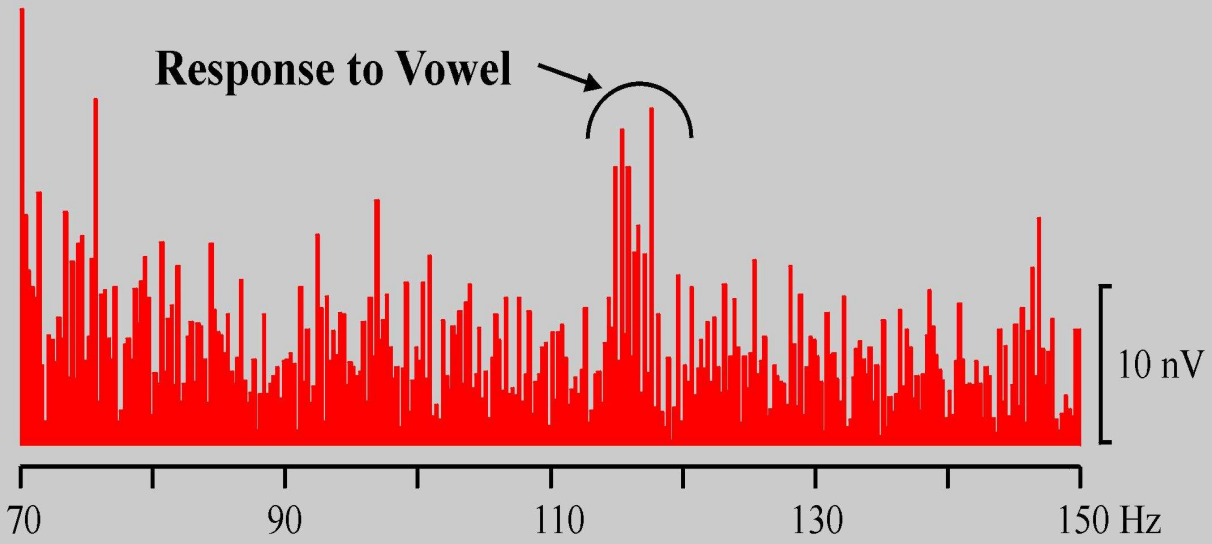
Infant data from John et al., 2004 (50 dB SPL)
Adult data from John et al., 2002 (55 dB pSPL)

Time Waveform of Vowel

/IU/



Spectrum of Brain Response to Vowel



ASSR for Auditory Diagnosis

- ✓ Objective in recording and interpretation
- ✓ Accurate in predicting the behavioral AC & BC thresholds
- ✓ Unilateral Hearing losses
- ✓ Efficient in objective hearing aid fitting
- ✓ Optimal for severe & profound hearing losses

ASSR for Auditory Diagnosis

- ✓ Potential relevance to in central auditory processing
- ✓ Two ears, 4 frequencies lasted about 1 hour

- ✓ High cost-effectiveness

Cautions

- ✓ Artifacts especially in high stimulus levels & BC & Multiple Stimuli due to :
- ✓ Aliasing effect (stimulus aliased back to the same frequency as the MF)
- ✓ Upward Spread of Masking
- ✓ Myogenic responses

- ✓ Actions:
- ✓ Sampling rate different from the carrier frequency
- ✓ Filters
- ✓ Single stimulus presentations

Cautions

- ✓ In statistical test there is a chance for an error therefore actions must taken to reduce this possibility
- ✓ Calibration
- ✓ Further studies on clinical populations are urgently needed

Thank You

The vertical slit below the leg joint of this katydid is actually its ear opening, behind which lies the ear drum. By moving its legs apart, the katydid can control its directional hearing. This makes it easier for the female to locate the male katydid mating calls attract her.