Use of New Stimulus and Detection Technologies for Pediatric Electrophysiology

Sponsored By

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New Technologies

- CE-CHIRPS
- ABR F_{mp} Noise and Signal Detection
- Bayesian Weighting
- Next Generation ASSR

Why Have Clicks Been Used for Eps?

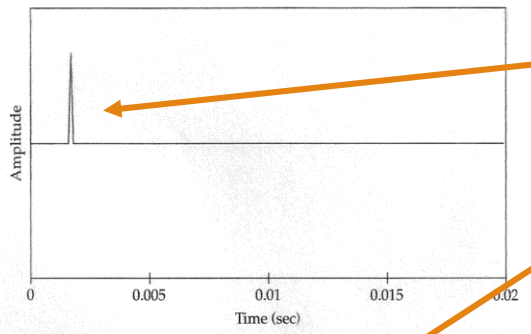
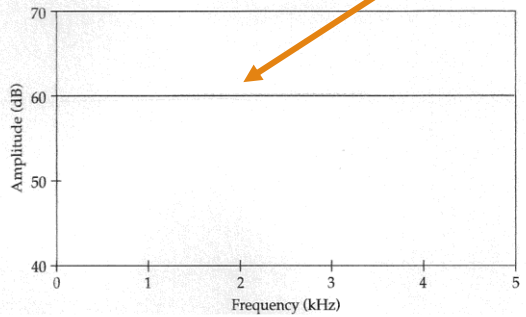
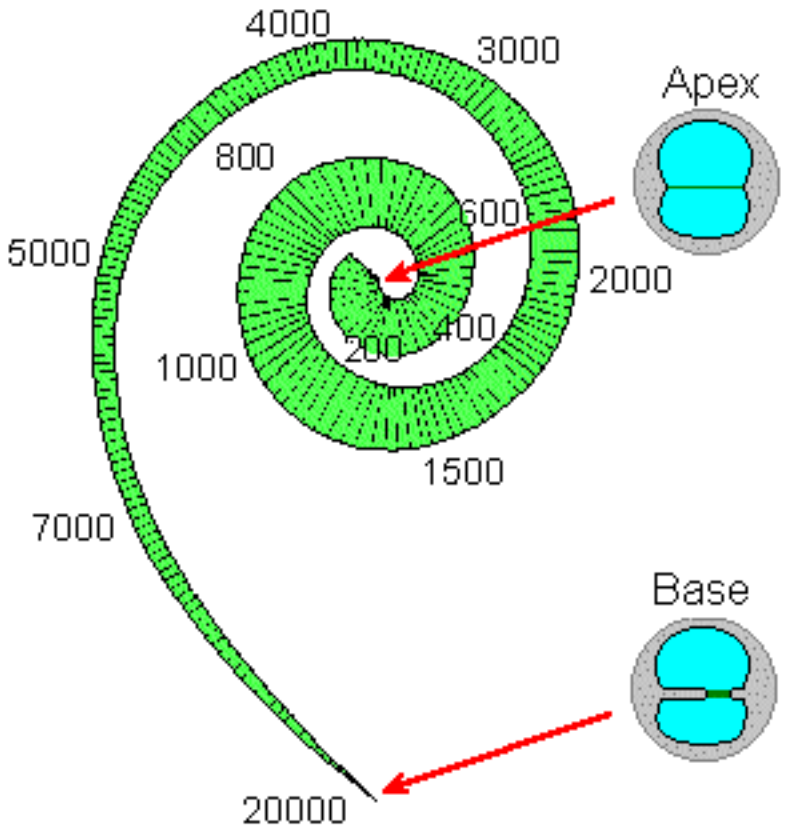
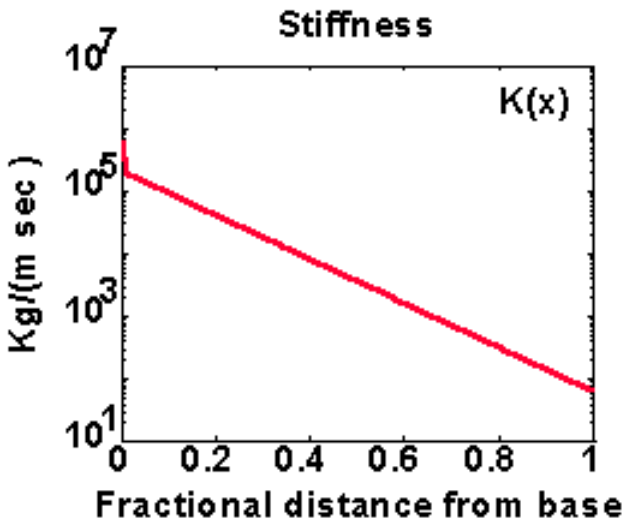


Figure 1.10 Acoustic waveform of a transient sound (an impulse).

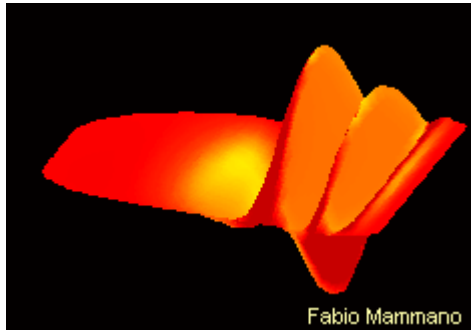


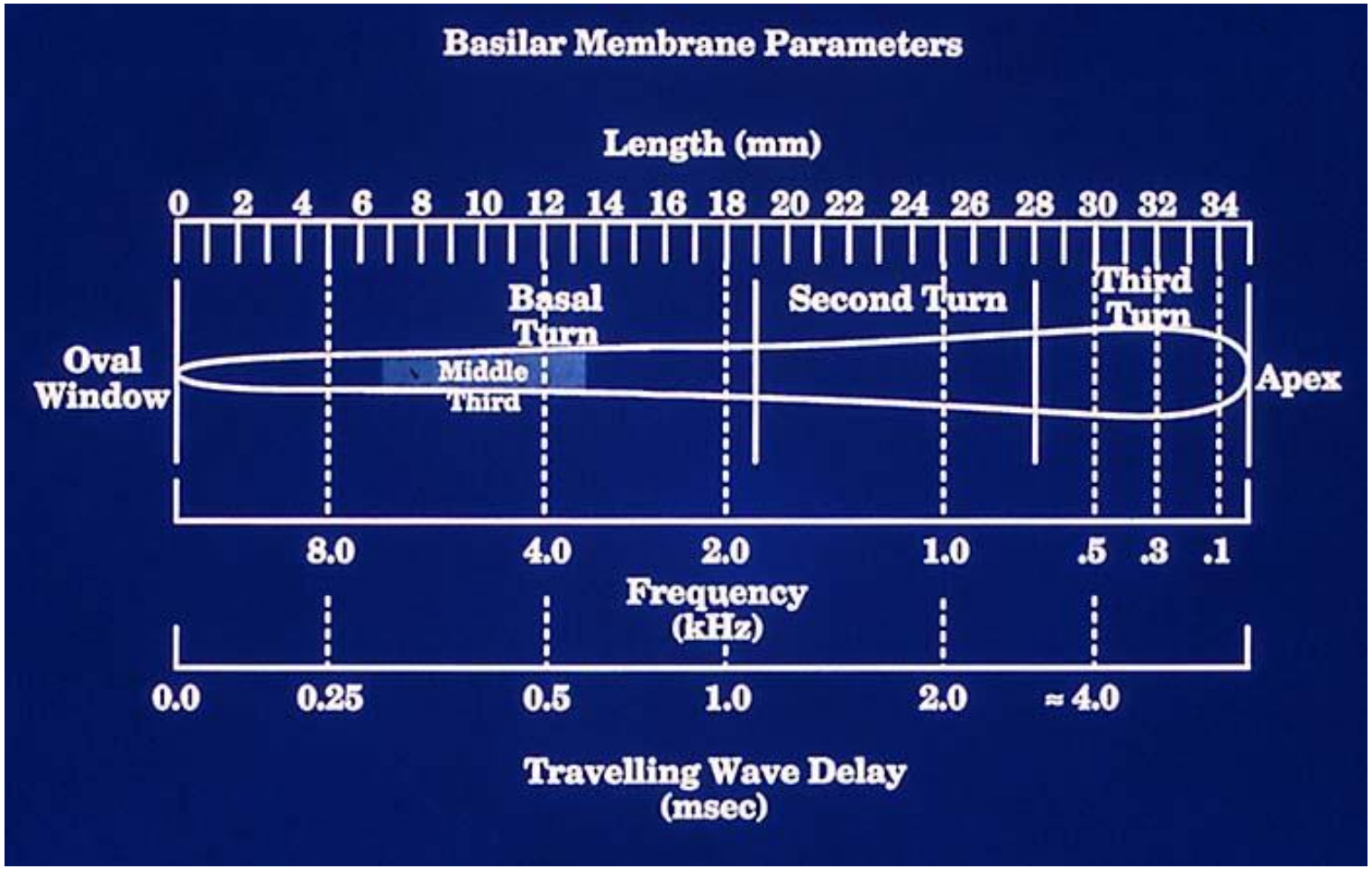
- Click has a very short duration.
- This produces a **broad, flat spectrum**.
- Because of the broad spectrum, the entire basilar membrane and **all the corresponding neurons are activated revealing a large response.**


4000
3000
Apex
800
600
5000
2000
400
200
1000
1500
7000
Base
20000

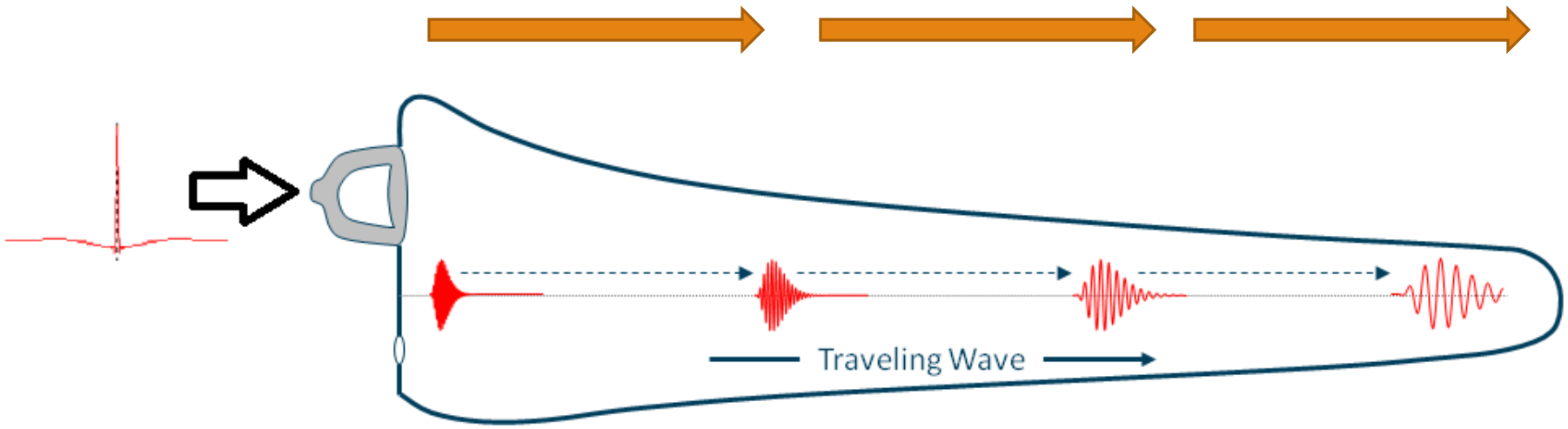

Stiffness
K(x)
Kg/(m sec)
10^7
10^5
10^3
10^1
0
0.2
0.4
0.6
0.8
1
Fractional distance from base

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



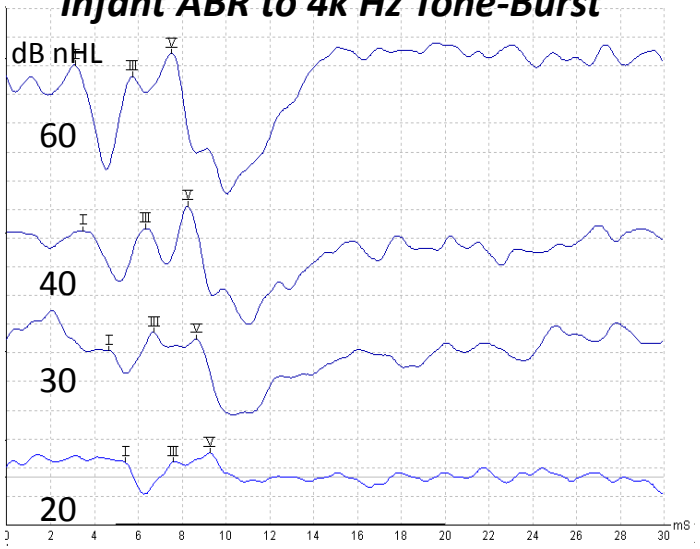


A CLICK WILL *PROGRESSIVELY* ACTIVATE THE ENTIRE LENGTH OF THE BASILAR MEMBRANE SEQUENTIALLY

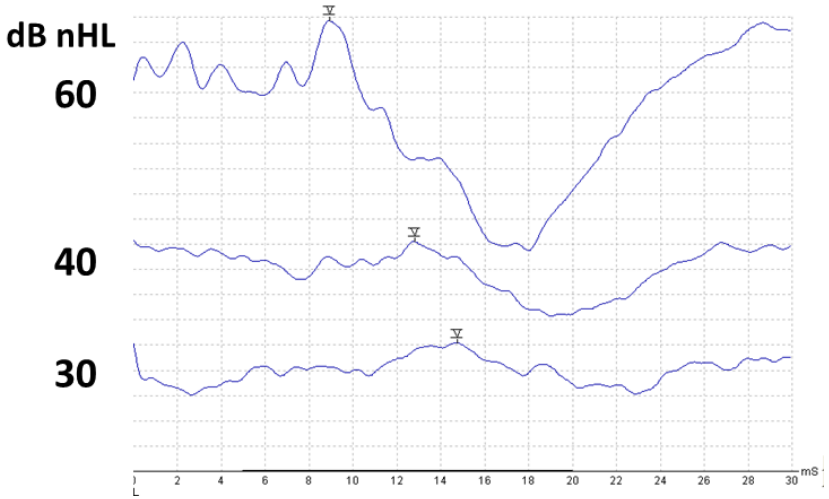


Transient, broad band stimuli

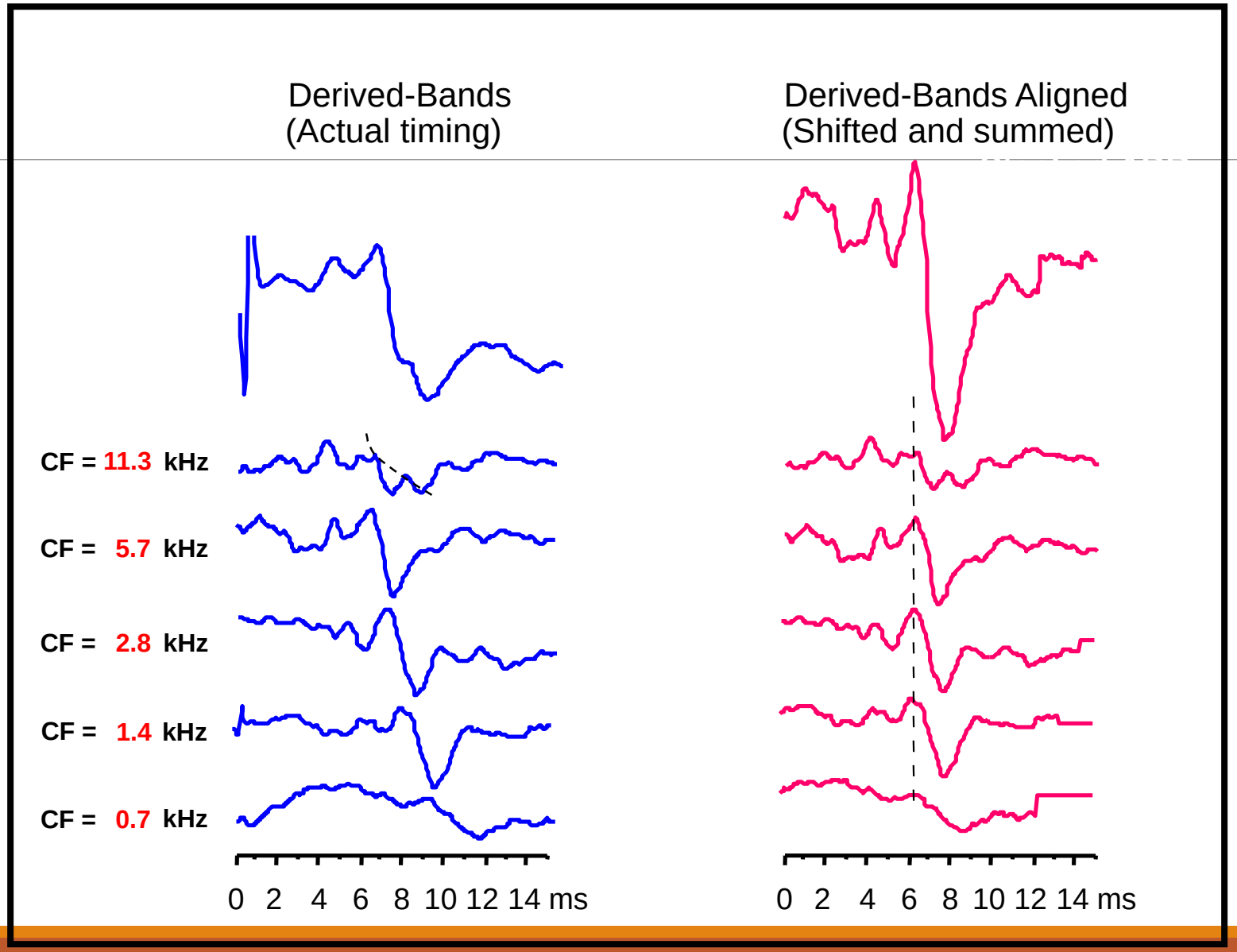
Infant ABR to 4k Hz Tone-Burst



Infant ABR to 500 Hz Tone-Burst



Stacked ABR



M. Don – House Ear Institute, 2002

Input compensation for traveling time

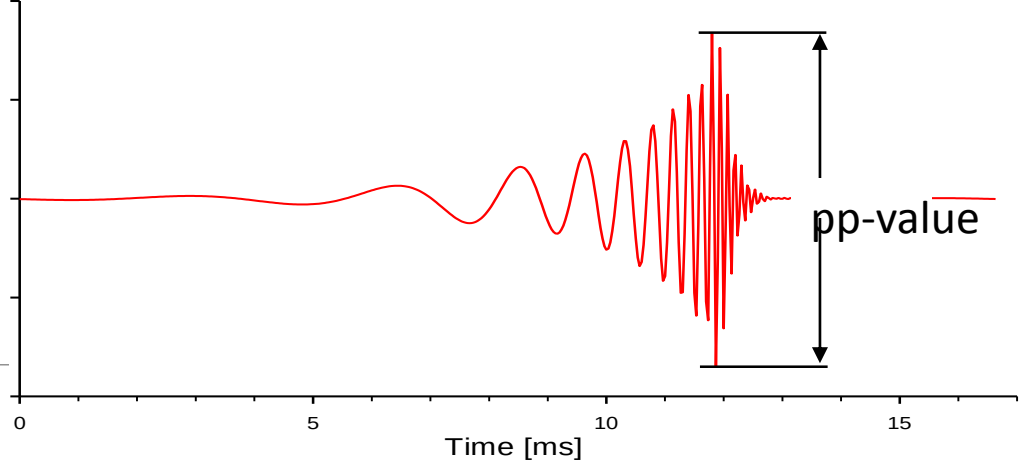
Another way to compensate for the traveling time is to time-shift the different frequency components of the ***click stimulus***

This is done by allowing the low-frequencies to appear before the high-frequencies. (Like starting the slow runners in a race first, staggering the runners by speed so they all cross the finish line together.)

Such a click with re-shuffled frequency components is called a ***Chirp***

A *chirp ABR* is significantly larger than a click ABR for the same reason that the stacked ABR is bigger.

The Amazing CE-Chirp®

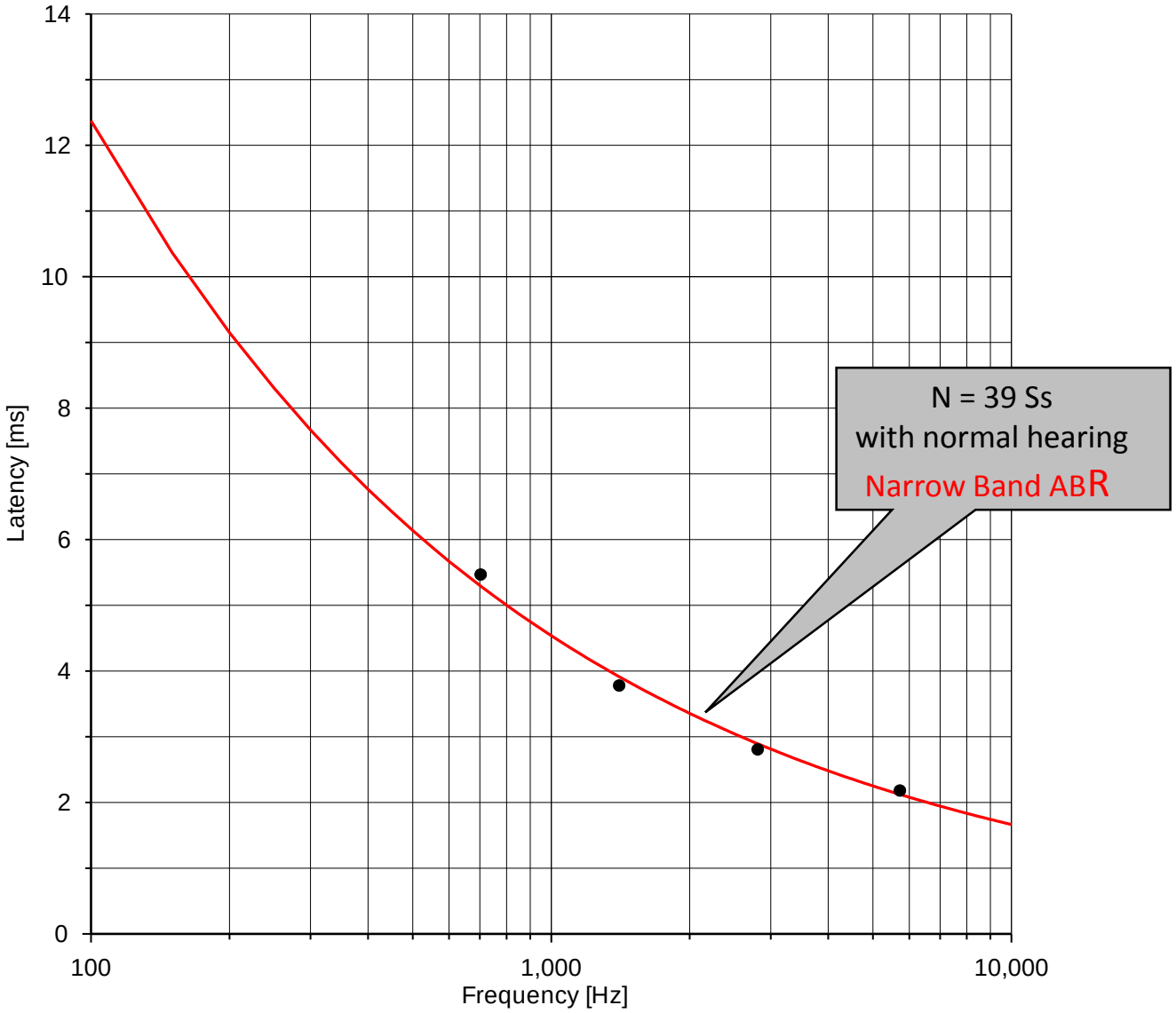


- Stimulus that reorganizes timing of spectral components to synchronize cochlear response base on research of Claus Elberling (CE) and colleagues.
- CE-Chirps are of the same energy and frequency composition as traditional stimuli- clicks and tone bursts.
- Produces neural response (ABR, ASSR,…) with up to 2X amplitude of traditional stimuli.
- Greater amplitude enhances response detection.
- Reduces time to automated detection.
- Lowers threshold of response detection and reduces correction factors.

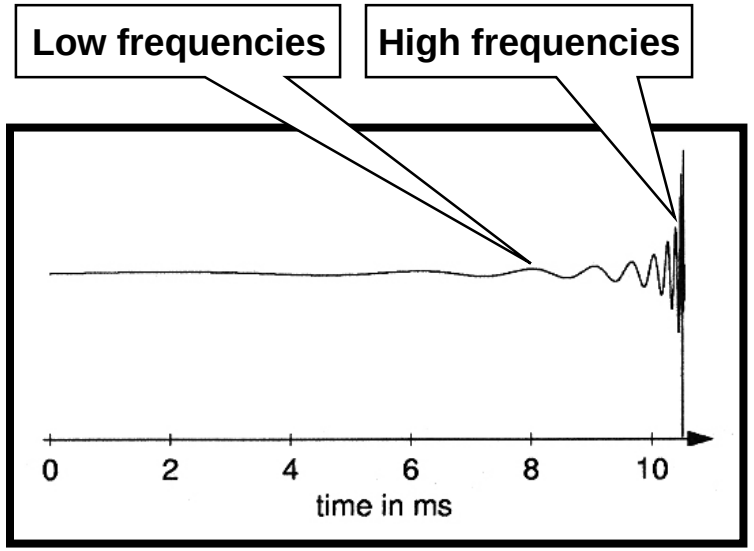
Frequency Component Delays are Based on Latency Information from Human Subjects.

Narrow-band ABR latencies (- 4.1 ms)

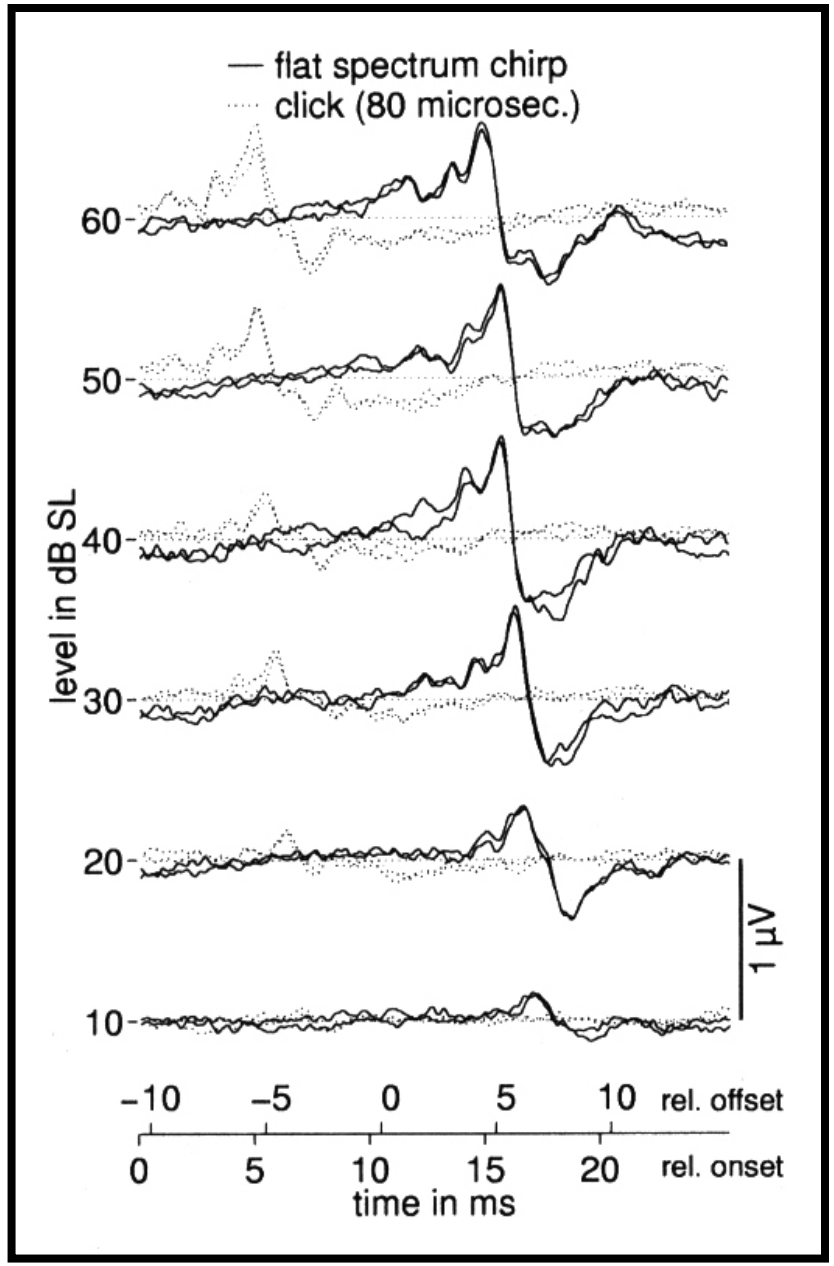
based on data from M. Don



Chirp ABR



Chirp stimulus



Dau et al. 2000

Free Lunch

Using a chirp is no more work that using a click or a tone burst. Except for expected response latency, there is no other change in procedures.

What is a *CE*-Chirp

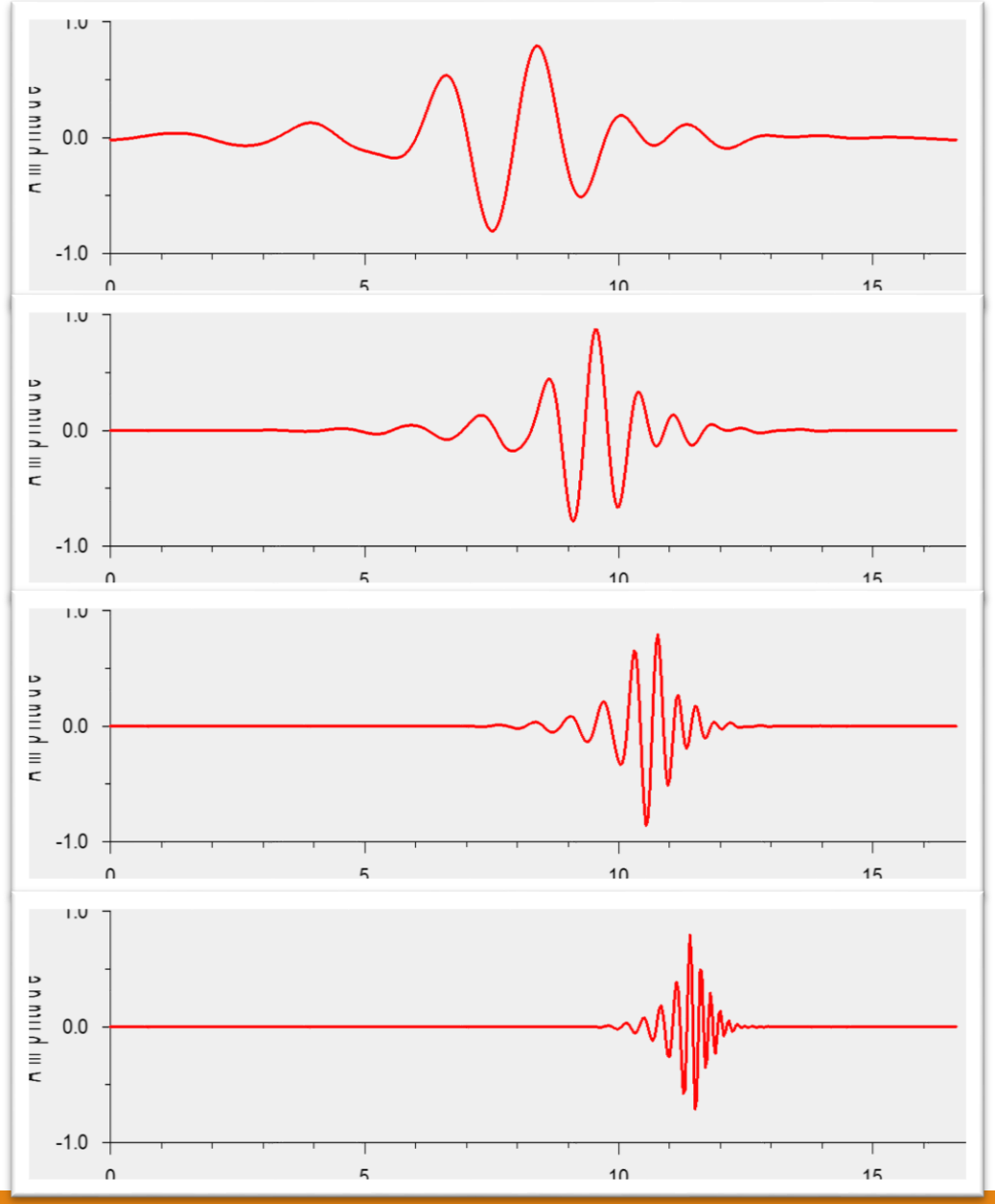
All chirps are not the same

Each is based on an estimate of cochlear travel time from different data sources.

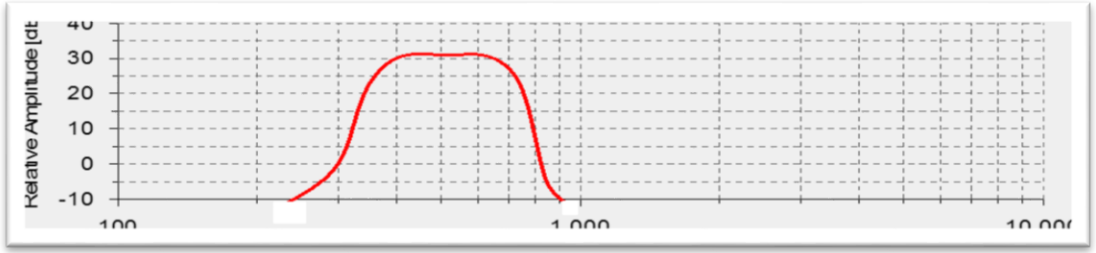
The CE-Chirp was created using data from Manny Don and Claus Elberling using tone-burst ABR and derived band ABRs collected over many years of research.

Elberling, C. & Don, M. A direct approach for the design of chirp stimuli used for the recording of auditory brainstem responses. J Acoust Soc Am. Nov 2010; 128(5): 2955–2964.

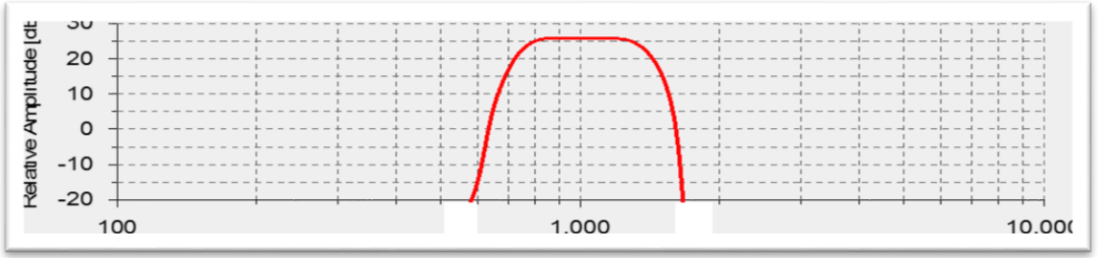
Narrow band CE-Chirps for Clinical Audiology



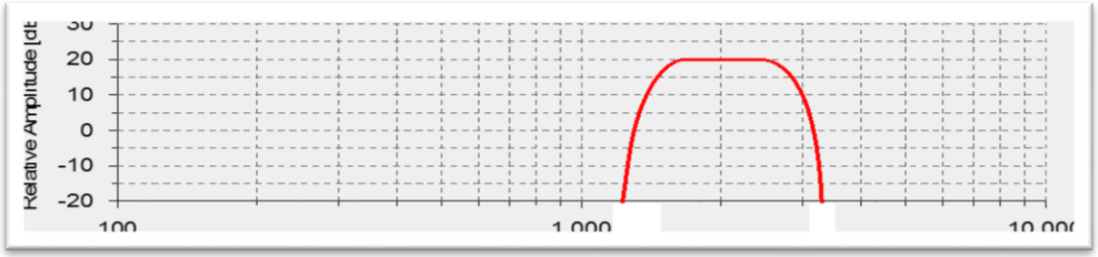
500 Hz



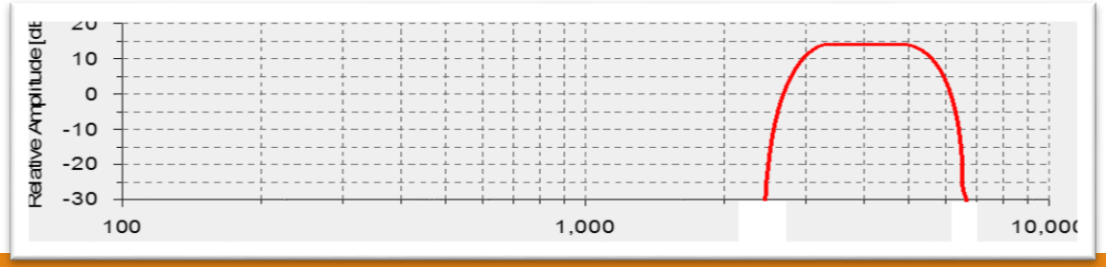
1000 Hz



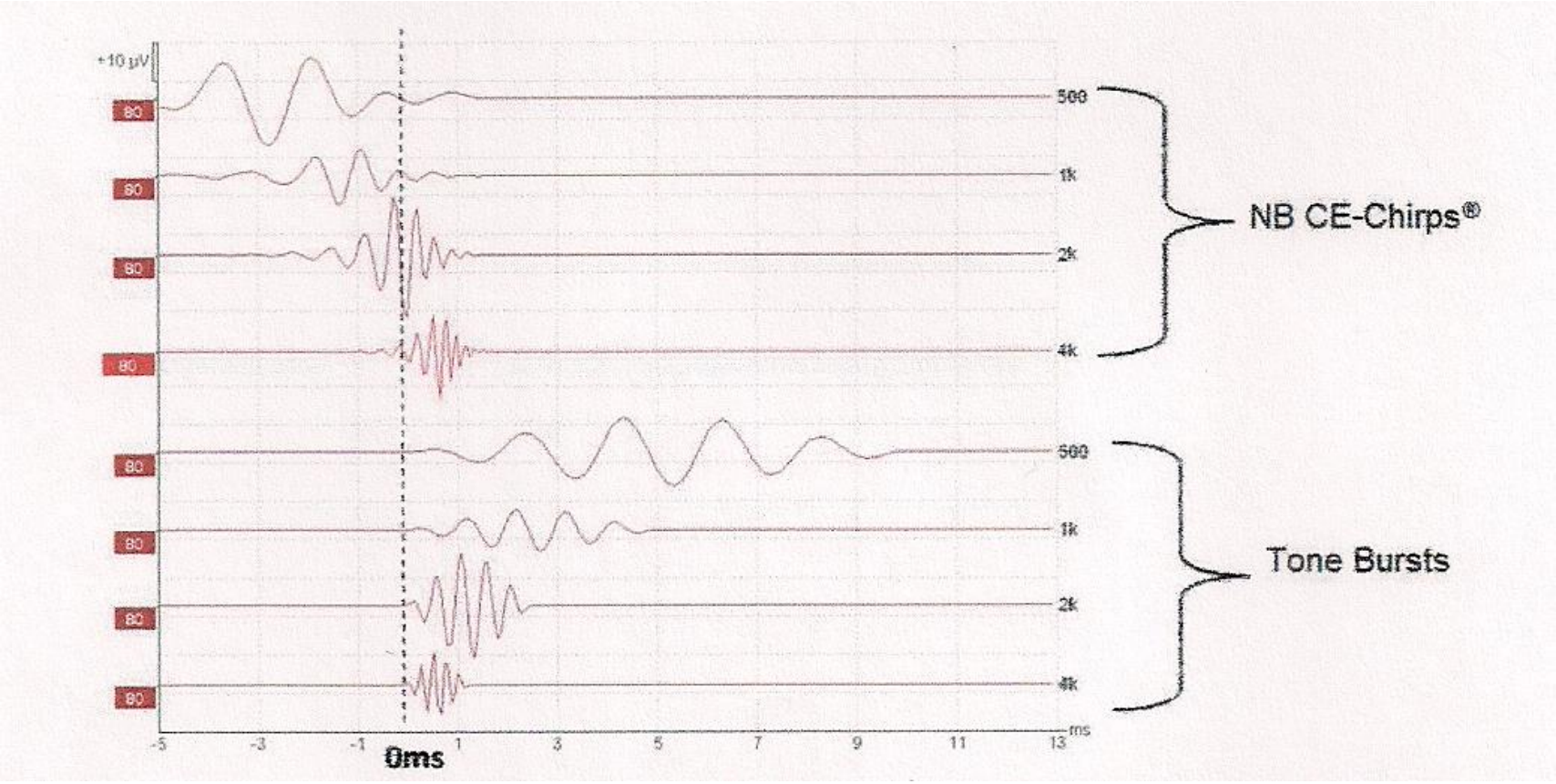
2000 Hz



4000 Hz



NB CE-Chirps are staggered in time relative to the recording time, just as they are in the wide band CE-Chirp.

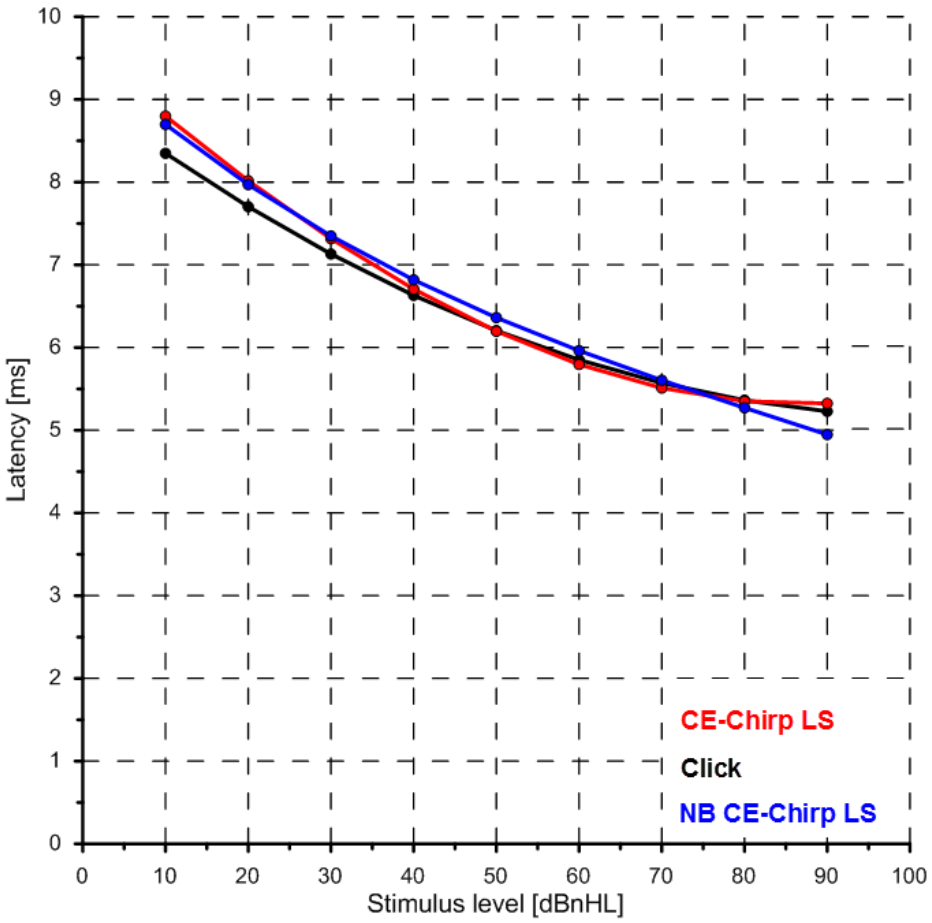


Therefore:

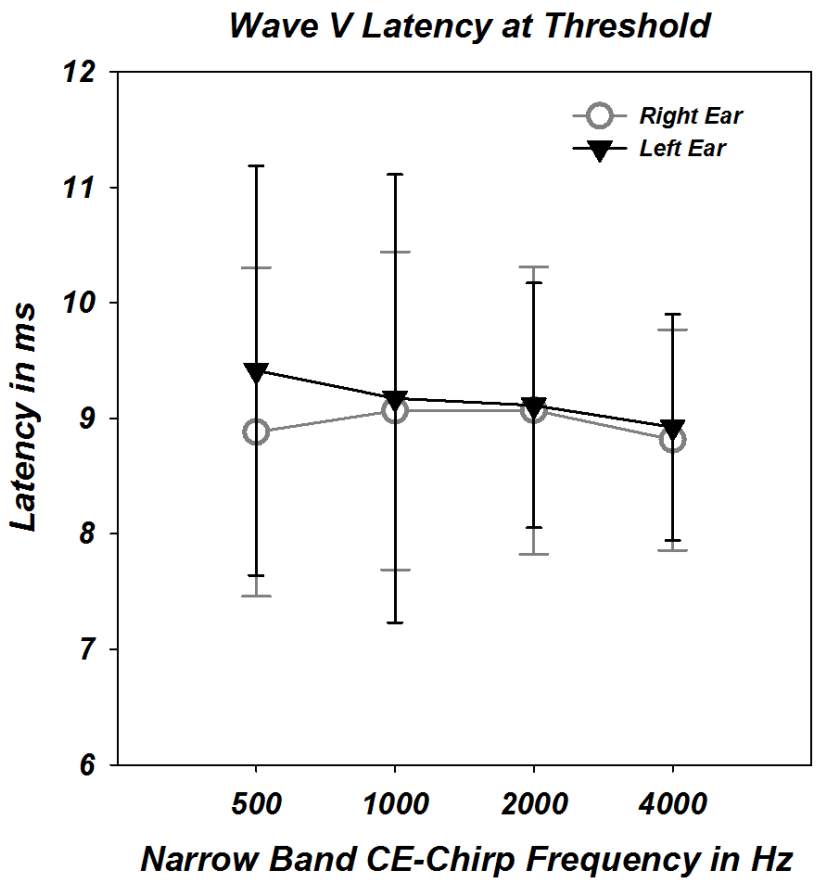
- Response window can be consistent across stimuli for the NB CE-Chirps which is convenient for setting the response detection window.
- The NB CE-Chirp response is less likely than the tone burst to have interference from stimulus artifact.

Wave V Latency Norms

With the release of EP4.4 the wave V latency norms for Click, CE-Chirp® LS and NB CE-Chirp® LS have been aligned to make it easier to locate the wave V response. The figures below show how response latencies for all three types of stimuli are aligned for the different stimuli levels. Note that age, rates and filter settings can influence response latencies.



LS= Level Specific



Recent Study of Infants and Toddlers Using NB CE-Chirps:

Wave V latency for all frequencies at threshold are ~ 9 ms.

No more need for extended windows to view low frequency responses!

British NBHS Compare NB CE-chirps and Tone Pips for Threshold Testing Following Screening Fails

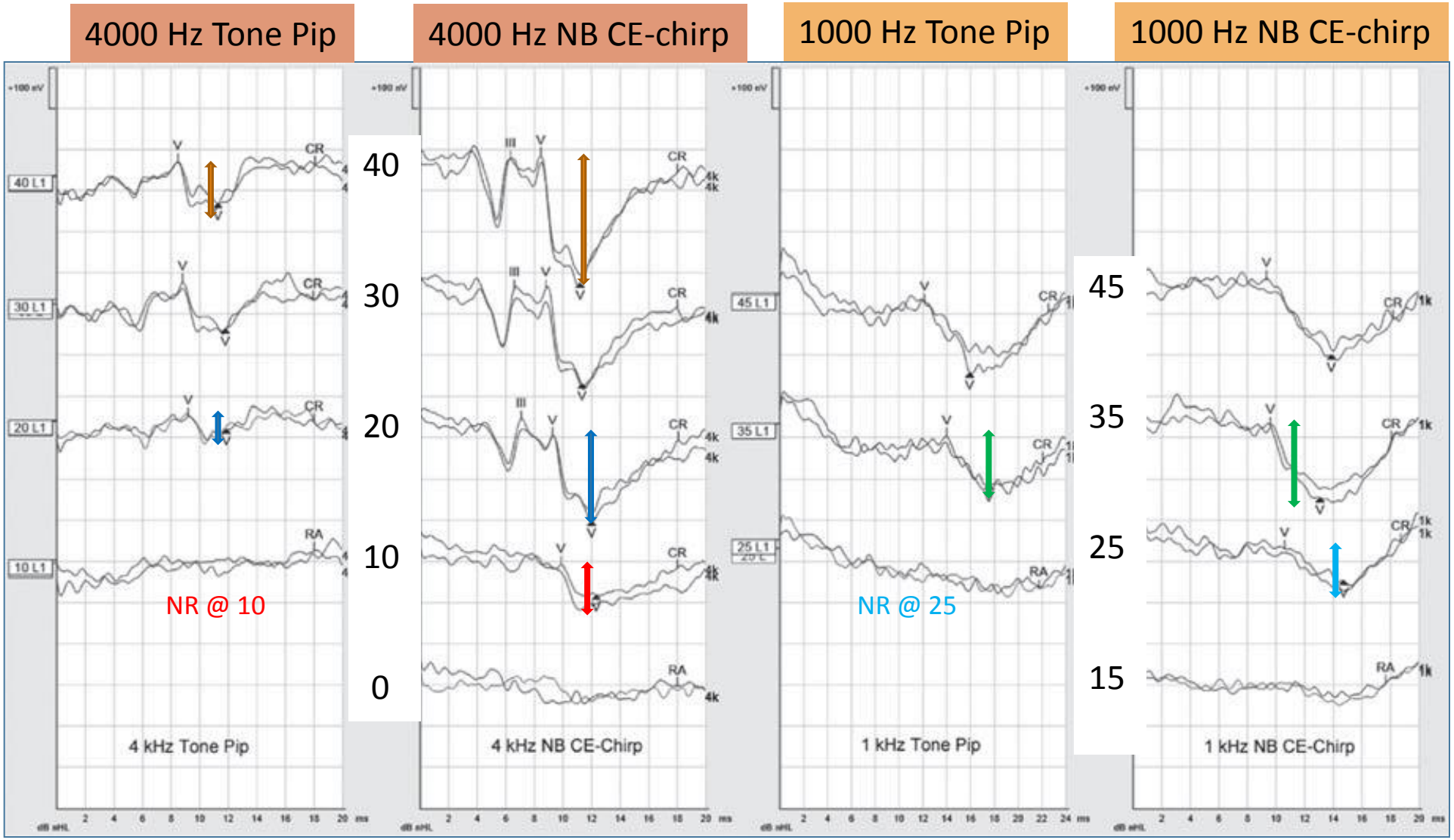
Comparison of ABR response amplitude, test time, and estimation of hearing threshold using frequency specifi ce-chirp and tone pip stimuli in newborns
International Journal of Audiology 2013; 52: 419–423 ***Inga Ferm, Guy Lightfoot & John Stevens***

Inga Ferm* and Guy Lightfoot **Amplitudes, test time and estimation of hearing threshold using frequency specific chirp and tone pip stimuli in newborns**. HEAL 2014, Lake Como, Italy

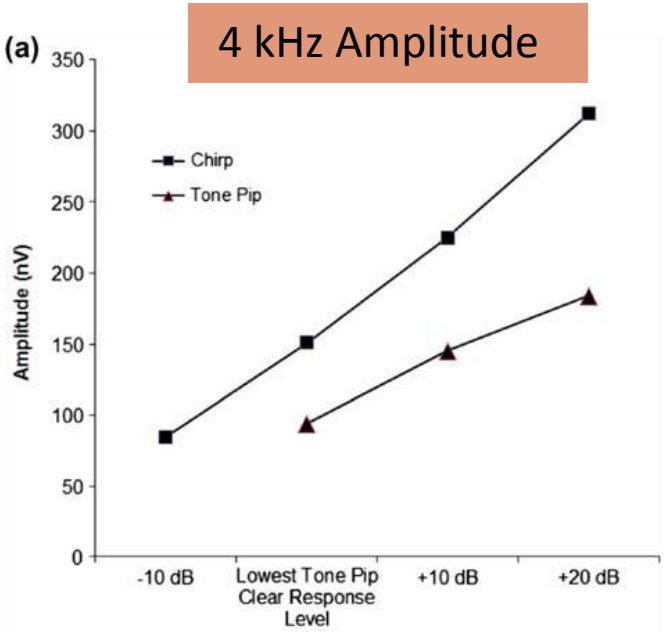
- English newborn hearing screening programme guidance for ABR testing in babies (2010) and the English newborn hearing screening programme guidelines for early audiological assessment (2011).

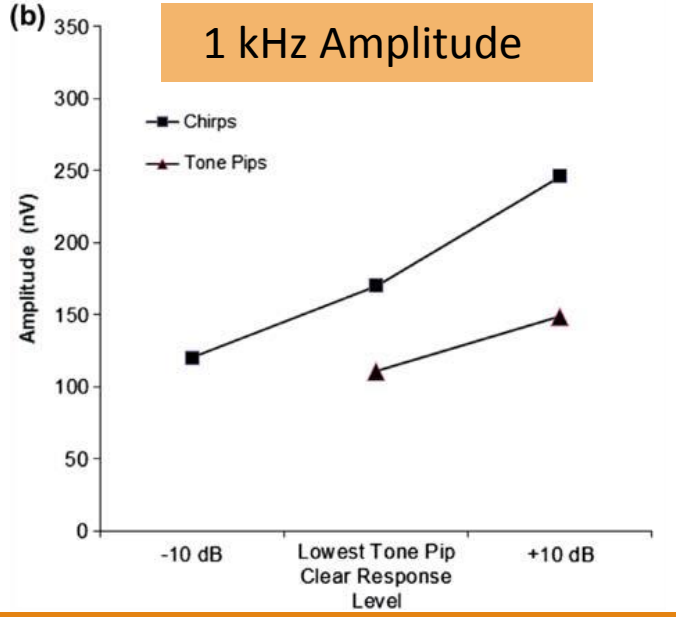
- The tone pip and chirp wave V to SN 10 ABR amplitudes and Fmp values were compared in this study.

- Infants with corrected ages under three months. Initially the NHSP discharge criterion for satisfactory hearing was satisfied (4-kHz tone tip ABR at 30 dBeHL).



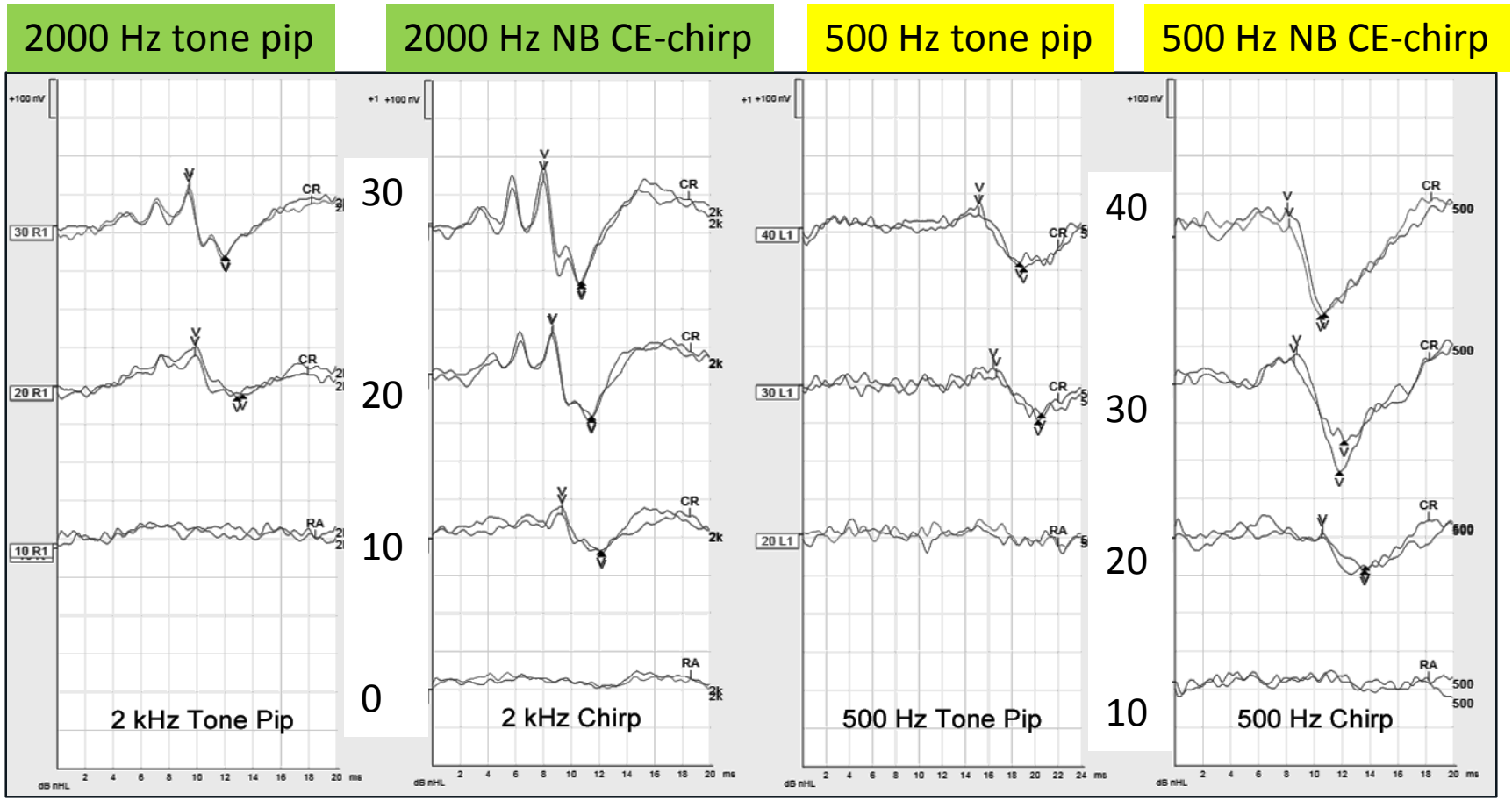
Ferm, Lightfoot & Stevens International Journal of Audiology 2013;



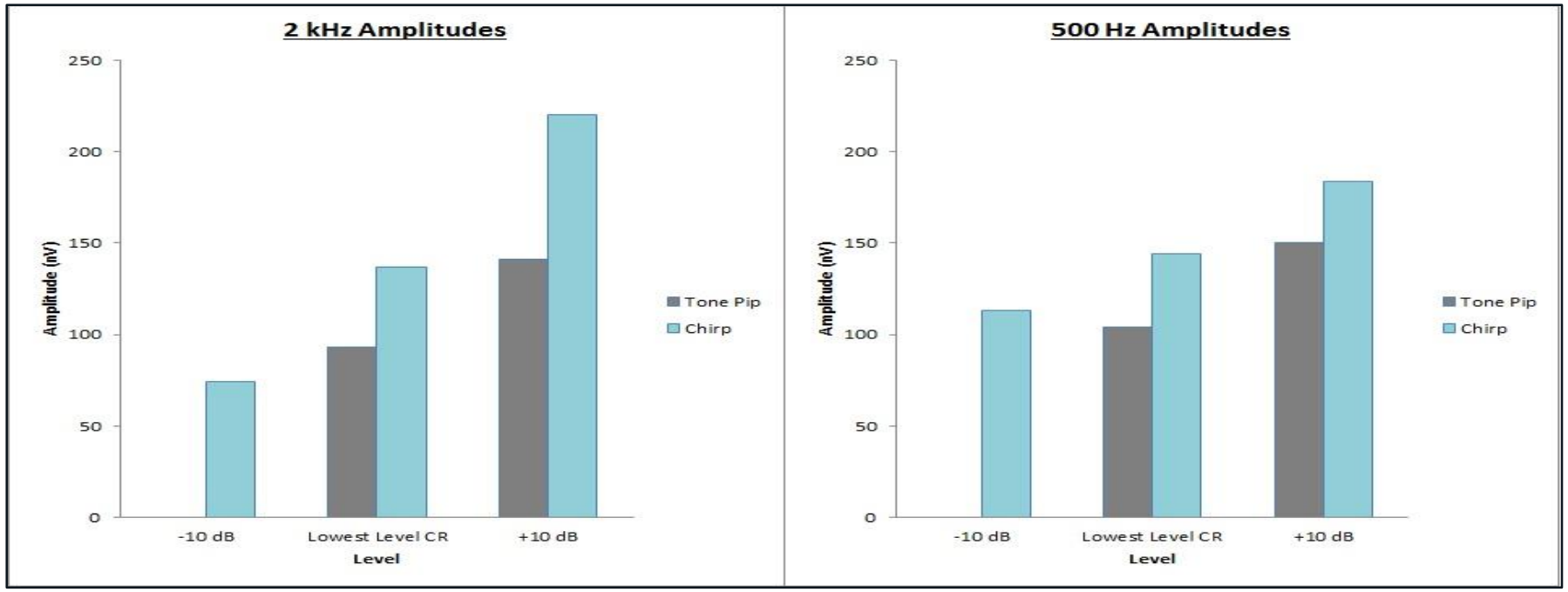


Responses to NB CE-Chirps were larger and generally showed lower thresholds than tone pips.

Lake Como Poster filled in .5 and 2k Hz Results



Inga Ferm* and Guy Lightfoot **Amplitudes, test time and estimation of hearing threshold using frequency specific chirp and tone pip stimuli in newborns**. HEAL 2014, Lake Como, Italy



The results ***support the use of NB CE-Chirps when testing newborns. In England, the NHSP protocols[5,6] now allow the use of chirp stimuli as an alternative to tone pips for post-screening ABR diagnostic assessments.*** We propose that the ABR nHL threshold to eHL correction for NB CE-Chirps should be approximately 5 dB less than the corrections for tone pips at 2 kHz and 500 Hz, in line with NHSP guidance at 4 & 1 kHz.

Frequency	Sample Size	Amplitude (nV)				Fmp			
		Tone Pip	NB CE Chirp	Chirp : Tone Pip Ratio		Tone Pip	NB CE Chirp	Chirp : Tone Pip Ratio	
		mean	mean	mean	% ratio >1	median	median	median	% ratio >1
2 kHz	21	124	189	1.52	93	1.8	3.7	2.06	98
500 Hz	21	135	177	1.31	71	1.1	3.3	3.00	98

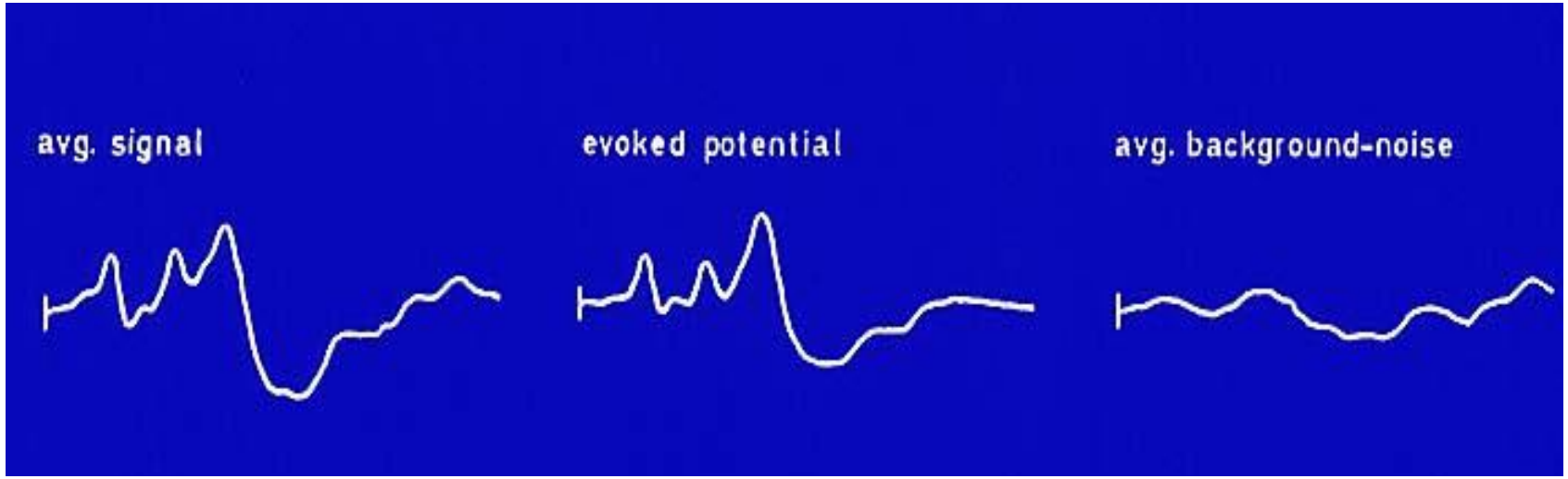
The NB CE chirps evoked a larger response than the tone pips in 93% of 2 kHz comparisons and 71% of 500 Hz comparisons.

The mean NB CE-chirp response amplitude was approximately 50% larger than that of a pip at 2 kHz and approximately 30% larger at 500 Hz.

Fmp values were typically double for NB CE-chirps.

New (?)Technologies

- ABR Noise and Signal Detection

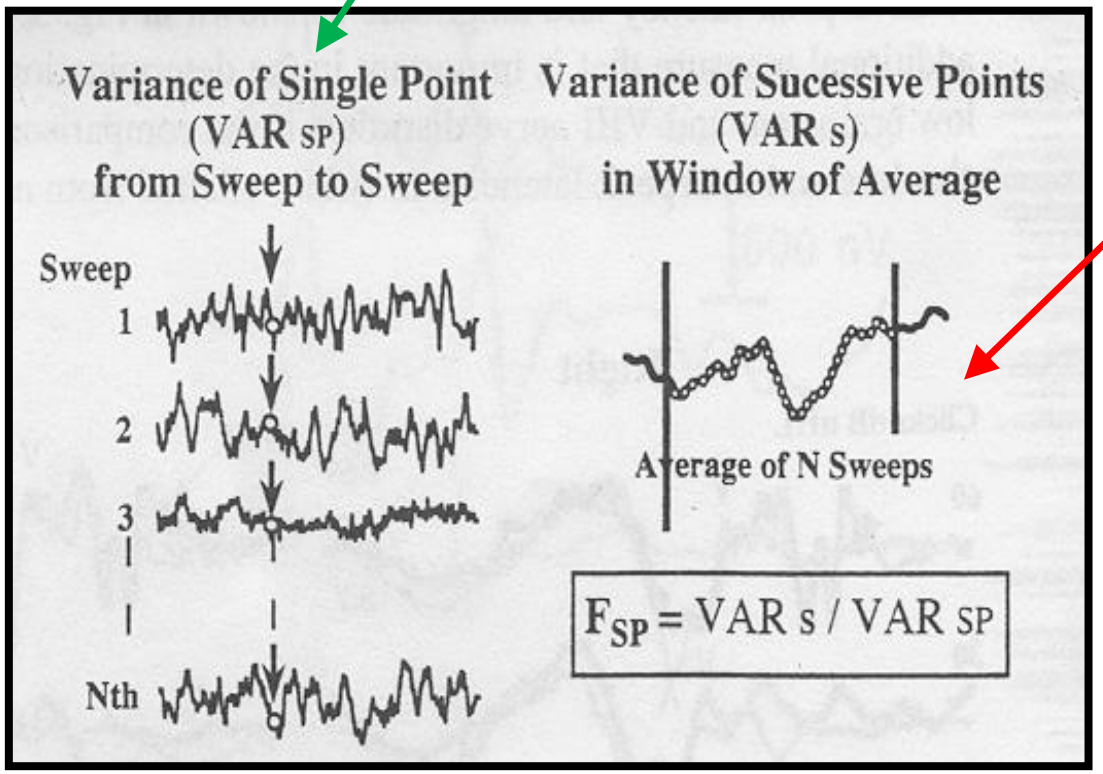


Average ABR = Neural Potential + Noise.

It is not possible to accurately determine how much of each is present, merely by looking.

Noise can obscure a response so it is important to know how much noise is present.

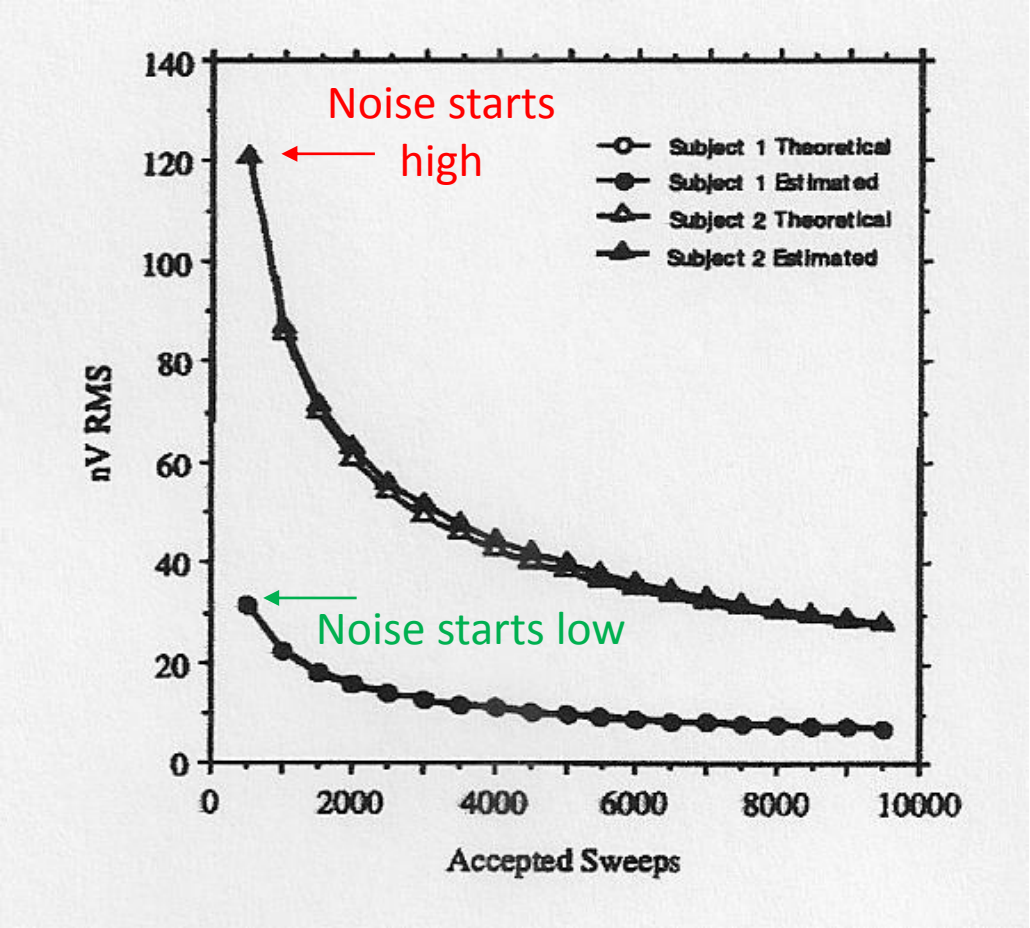
Noise can be measured as the change in amplitude of fixed points from sweep to sweep. The bigger the amplitude variation, the more noise is entering the recording. Fsp uses one point per sweep, Fmp (multiple point) uses 5 per sweep.



Measuring the amplitude variance across the *average* response gives an estimate of the strength of the neural potential + background noise.

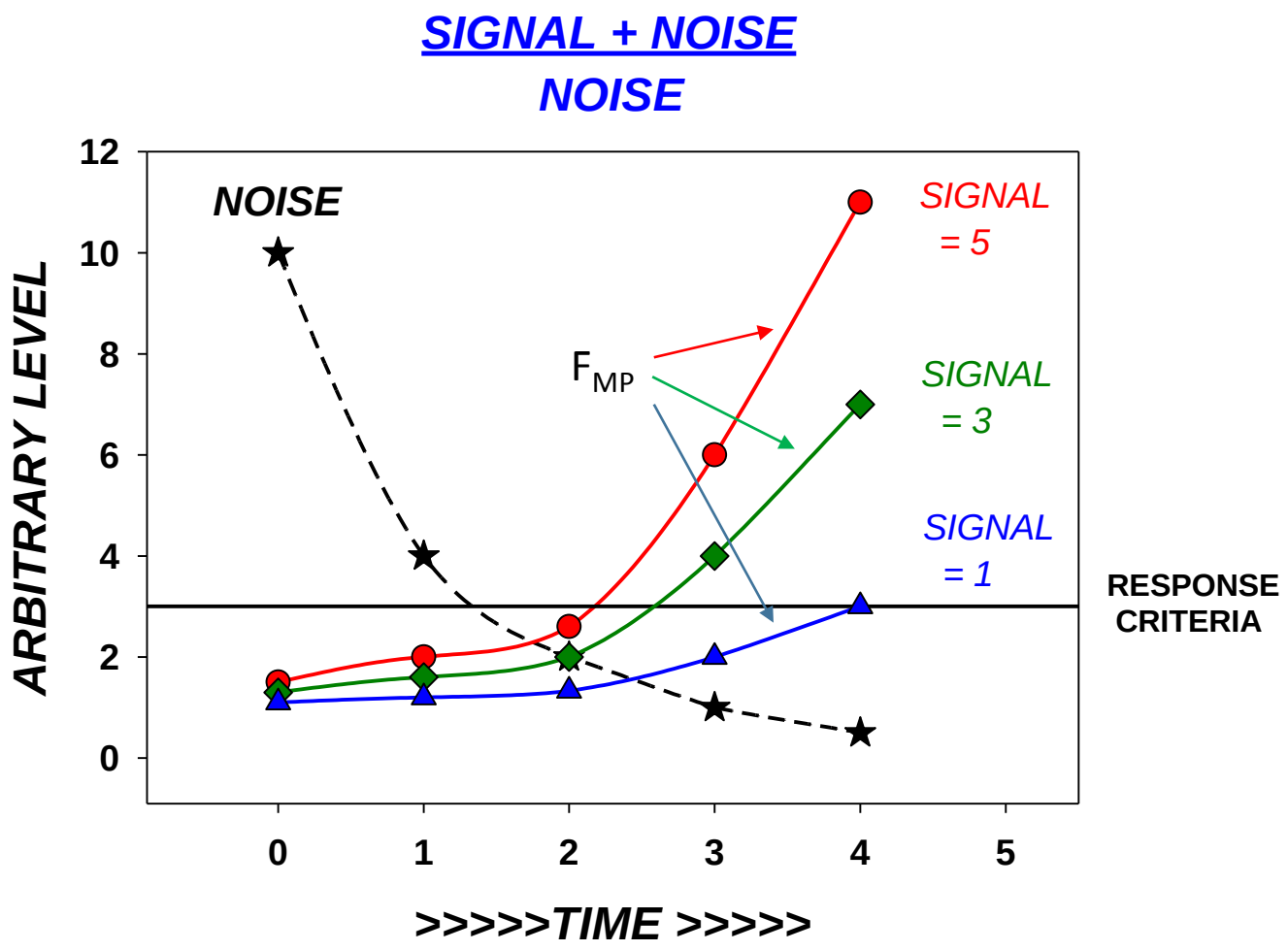
Fsp or Fmp = Signal +Noise/Noise

Averaging Reduces Stationary Noise by the Square Root of Sweeps

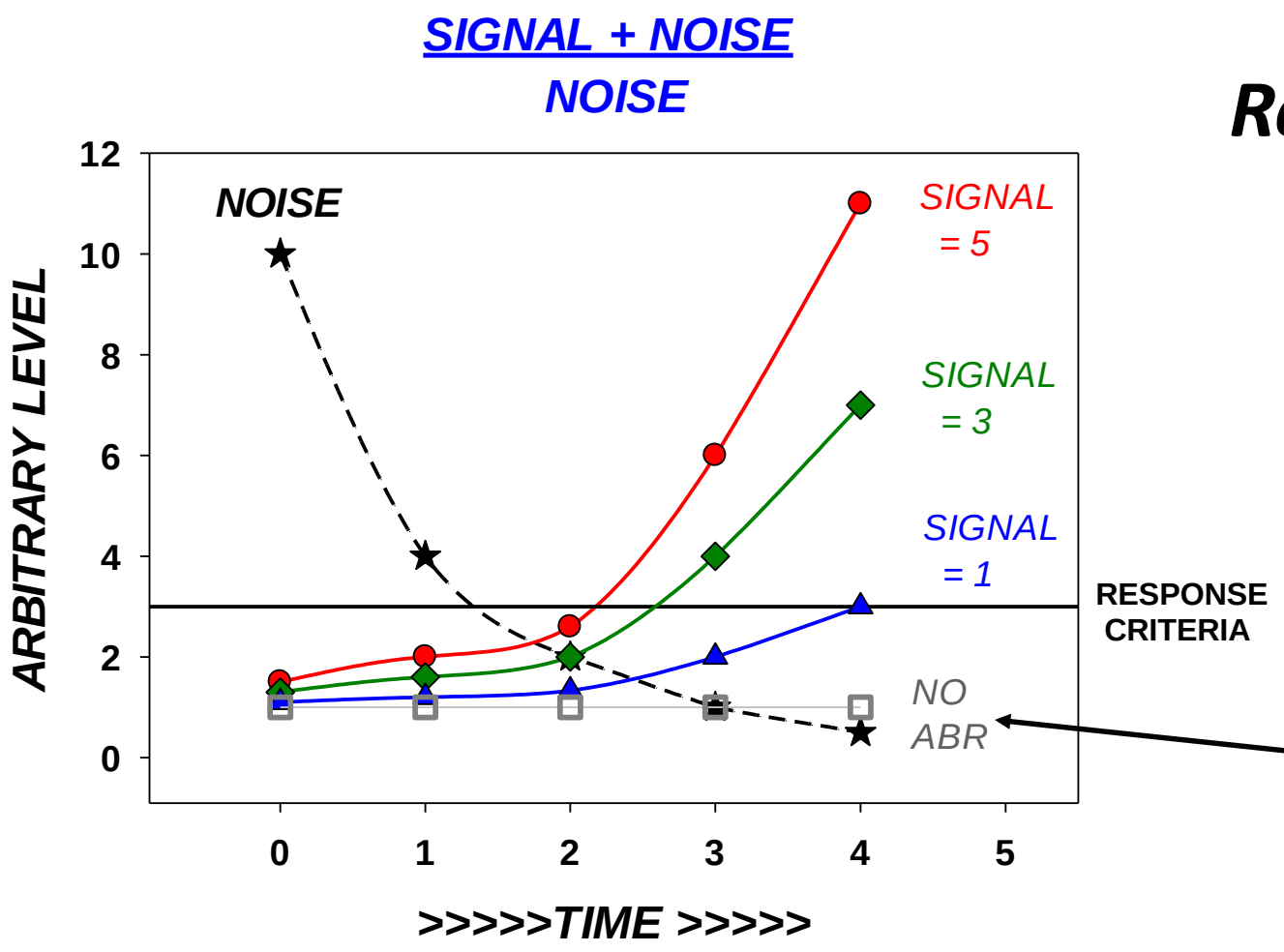


Don & Elberling
JASA 96:5, 1994

Response Detection as Amplitude Changes (Noise is unchanged)



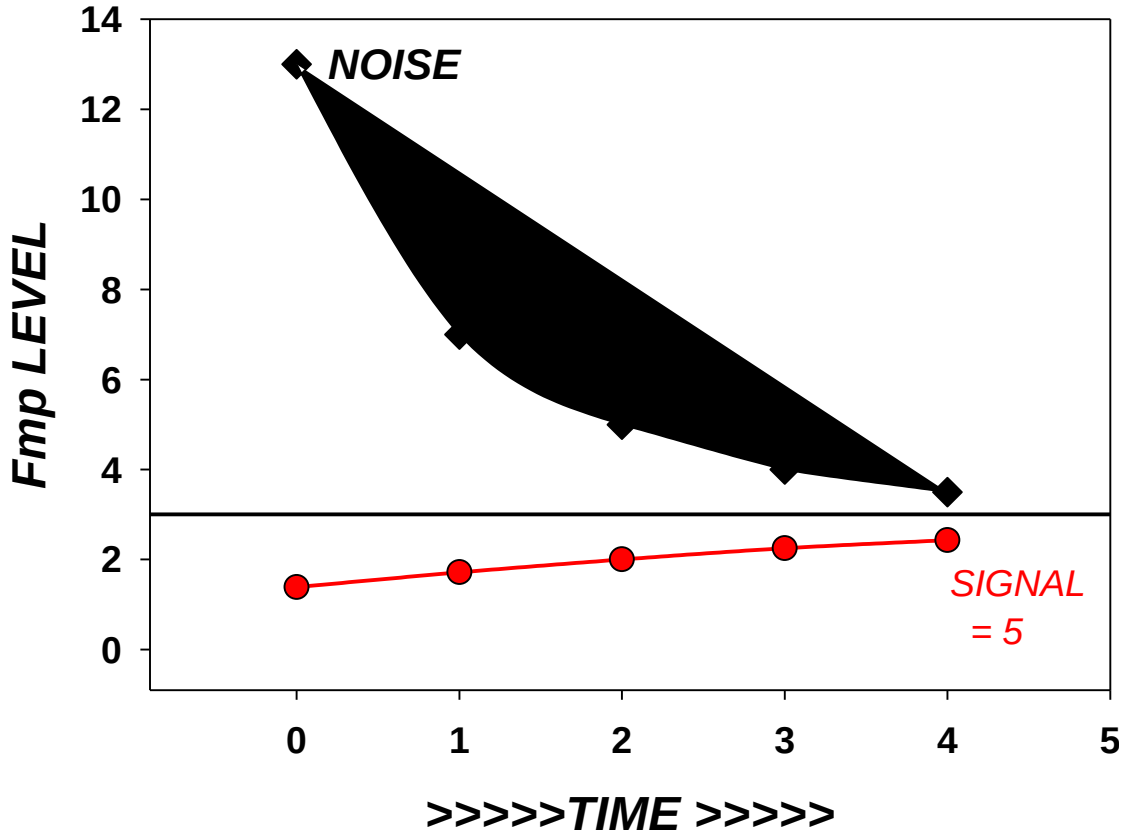
As signal (response amplitude) increases- Fmp grows faster and response is achieved earlier!

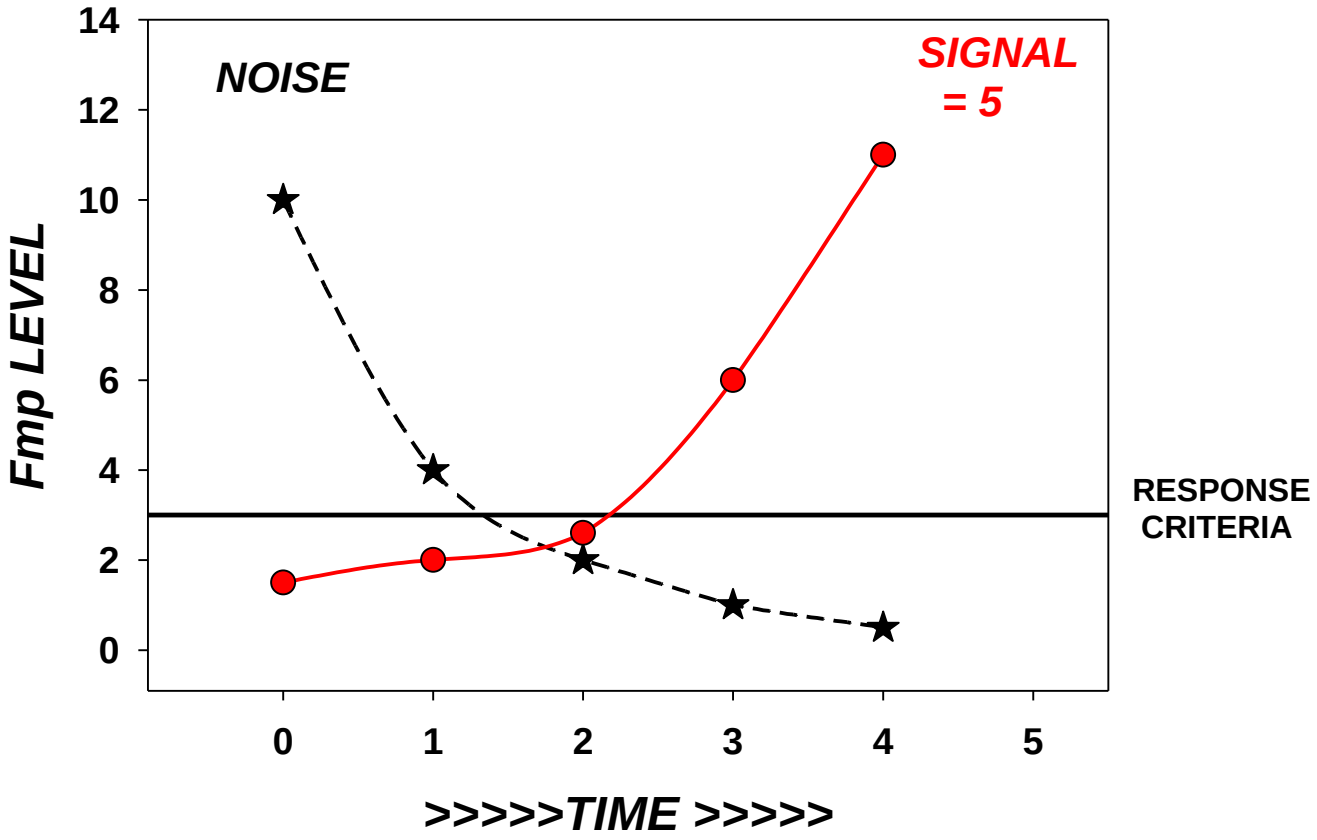


Response slope is related to signal strength

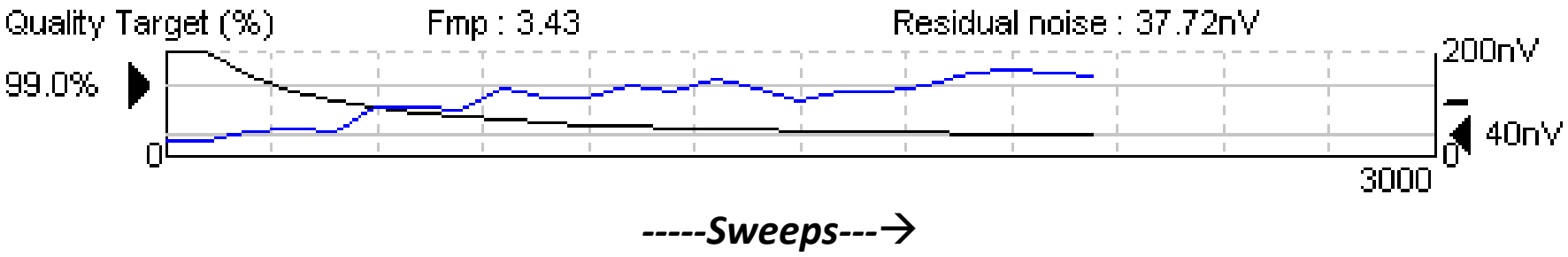
When stimulus is below threshold (no signal) Response does not grow!

Same Signal (ABR) With Different Background Noise
High Noise Prevents Detection





Fmp and Noise Plot



Noise and Fmp values are updated every 50 sweeps

Average can be set to stop when 1) Fmp is large enough to judged a good response <u>OR</u> 2) when the noise is low enough to be sure of a no response or 3) some maximum # of sweeps.

3482 CINCY. Current date : 09-19-2017 Reader Station - Edit Mode

File Edit View Help

YS 2kHz CE-Chirp | 09-08-2016 | 39.7 Hz | 2 kHz

Record | Edit... | Latency

Latency times

	ms	µV	
I			tr
II			tr
III			tr
IV			tr
V	9.73		tr
CR			tr
RA			tr
INC			tr

I-III
III-V
I-V

Cursor

	Fixed	Cursor	Diff.
ms			
µV			

Display filter setting

Low pass: 1000 Hz
High pass: None

Response confidence: 95.0%
Fmp : 2.44
Recorded : 1200
Residual noise : 37.11nV
200nV
25nV
0
6000
0

R
L
60ms

Show conditions
Show Fmp graph

+100 nV

40 R
35 R
30 R
50 R

NB Chirp LS 2k 37.1 Alt.

V

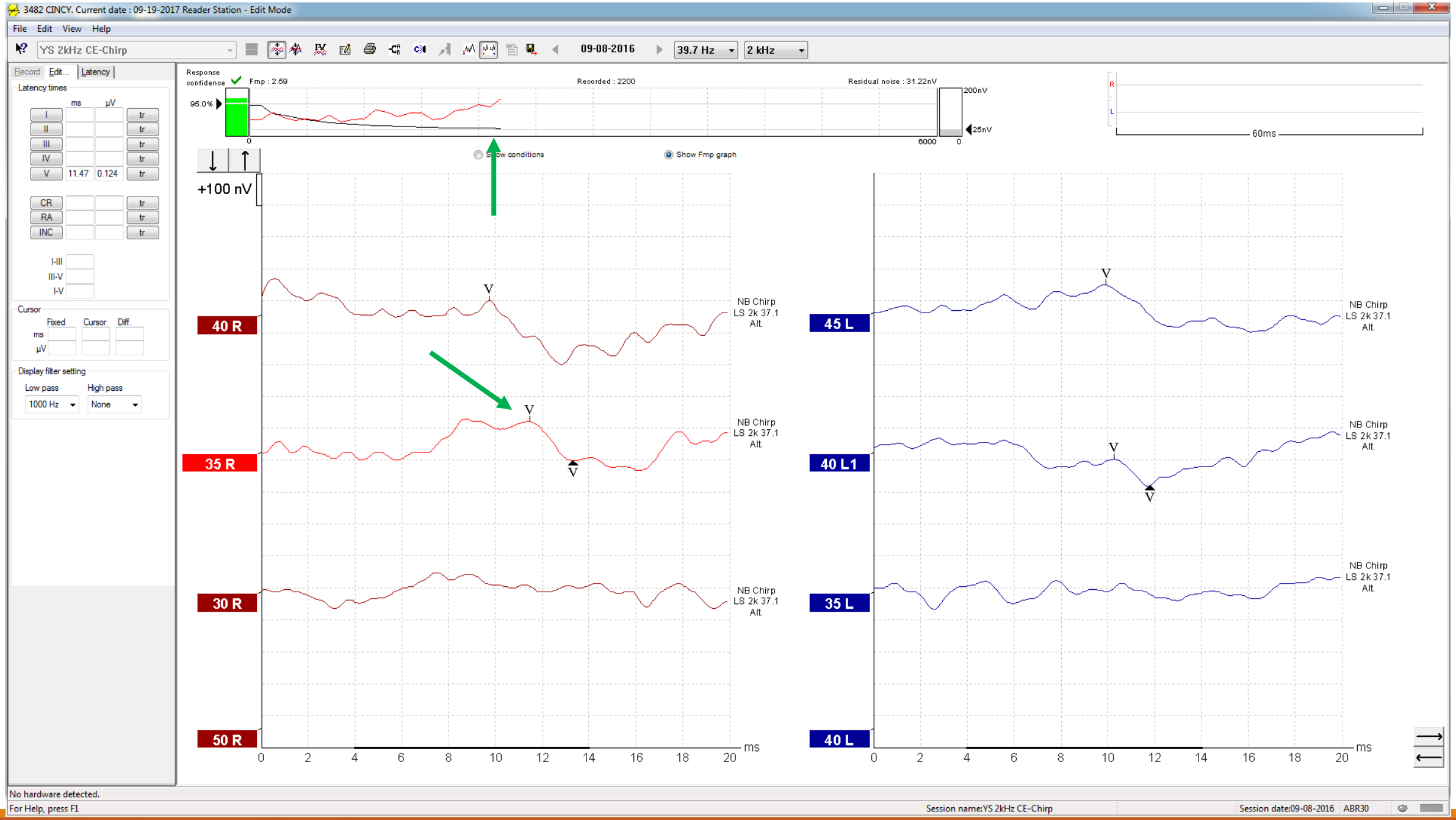
0 2 4 6 8 10 12 14 16 18 20 ms

45 L
40 L1
35 L
40 L

No hardware detected.

For Help, press F1

Session name:YS 2kHz CE-Chirp | Session date:09-08-2016 | ABR30


3482 CINCY. Current date : 09-19-2017 Reader Station - Edit Mode
File Edit View Help
YS 2kHz CE-Chirp
09-08-2016
39.7 Hz
2 kHz
Record Edit... Latency
Latency times
ms µV
I
II
III
IV
V 11.47 0.124
CR
RA
INC
tr
I-III
III-V
I-V
Cursor
Fixed Cursor Diff.
ms
µV
Display filter setting
Low pass High pass
1000 Hz None
Response confidence
Fmp : 2.59
Recorded : 2200
Residual noise : 31.22nV
95.0%
200nV
25nV
6000
Show conditions
Show Fmp graph
R
L
60ms
+100 nV
40 R
35 R
30 R
50 R
45 L
40 L1
35 L
40 L
NB Chirp
LS 2k 37.1
Alt.
V
0 2 4 6 8 10 12 14 16 18 20
ms
No hardware detected.
For Help, press F1
Session name:YS 2kHz CE-Chirp
Session date:09-08-2016
ABR30

3482 CINCY. Current date : 09-19-2017 Reader Station - Edit Mode

File Edit View Help

YS 2kHz CE-Chirp | 09-08-2016 | 39.7 Hz | 2 kHz

Record | Edit... | Latency

Latency times

	ms	µV	
I			tr
II			tr
III			tr
IV			tr
V			tr
CR			tr
RA			tr
INC			tr

I-III
III-V
I-V

Cursor

	Fixed	Cursor	Diff.
ms			
µV			

Display filter setting

Low pass: 1000 Hz
High pass: None

Response confidence
95.0%
Fmp : 1.18
Recorded : 3300
Residual noise : 24.67nV
200nV
25nV
0
6000
0

R
L
60ms

Show conditions
Show Fmp graph

+75 nV

40 R
35 R
30 R

V
V
V

NB Chirp
LS 2k 37.1
Alt.

dB nHL

0 2 4 6 8 10 12 14 16 18 20 ms

45 L
40 L1
40 L
35 L

V
V
V

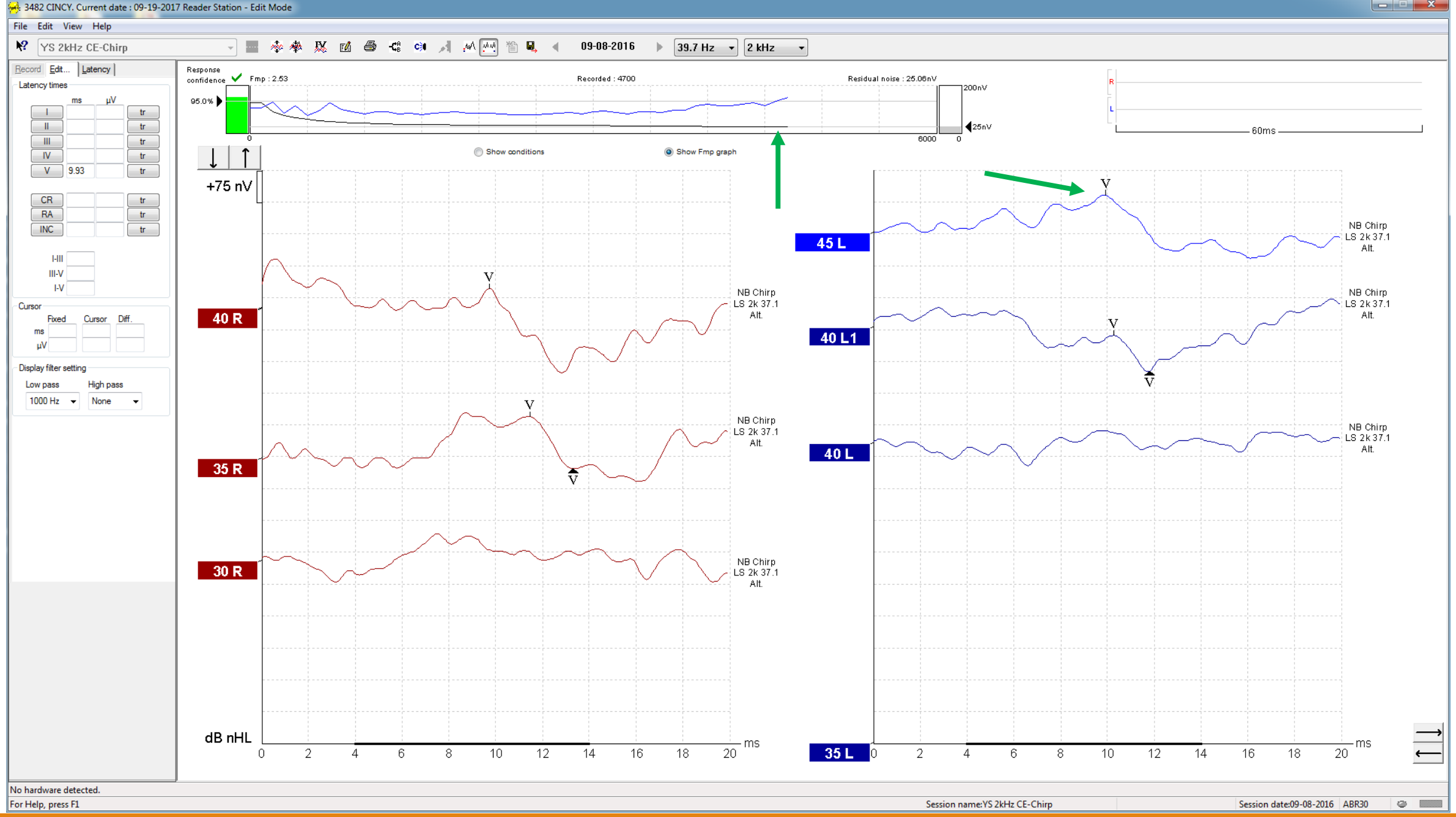
NB Chirp
LS 2k 37.1
Alt.

0 2 4 6 8 10 12 14 16 18 20 ms

No hardware detected.

For Help, press F1

Session name:YS 2kHz CE-Chirp | Session date:09-08-2016 | ABR30


3482 CINCY. Current date : 09-19-2017 Reader Station - Edit Mode
File Edit View Help
YS 2kHz CE-Chirp
09-08-2016
39.7 Hz
2 kHz
Record Edit... Latency
Latency times
ms µV
I
II
III
IV
V 9.93
CR
RA
INC
tr
I-III
III-V
I-V
Cursor
Fixed Cursor Diff.
ms
µV
Display filter setting
Low pass High pass
1000 Hz None
Response confidence
Fmp : 2.53
Recorded : 4700
Residual noise : 25.06nV
95.0%
200nV
25nV
6000
60ms
Show conditions
Show Fmp graph
+75 nV
40 R
35 R
30 R
45 L
40 L1
40 L
35 L
NB Chirp LS 2k 37.1 Alt.
V
dB nHL
ms
0 2 4 6 8 10 12 14 16 18 20
No hardware detected.
For Help, press F1
Session name:YS 2kHz CE-Chirp
Session date:09-08-2016
ABR30

3482 CINCY. Current date : 09-19-2017 Reader Station - Edit Mode

File Edit View Help

YS 2kHz CE-Chirp | 09-08-2016 | 39.7 Hz | 2 kHz

Record | Edit... | Latency

Latency times

	ms	µV	
I			tr
II			tr
III			tr
IV			tr
V	10.27	0.083	tr
CR			tr
RA			tr
INC			tr

I-III
III-V
I-V

Cursor

	Fixed	Cursor	Diff.
ms			
µV			

Display filter setting

Low pass: 1000 Hz | High pass: None

Response confidence | Fmp : 2.48 | Recorded : 3900 | Residual noise : 27.49nV

95.0% | 0 | 6000 | 200nV | 25nV

R | L | 60ms

Show conditions | Show Fmp graph

+75 nV

40 R | 35 R | 30 R

NB Chirp LS 2k 37.1 Alt.

V

dB nHL

0 2 4 6 8 10 12 14 16 18 20 ms

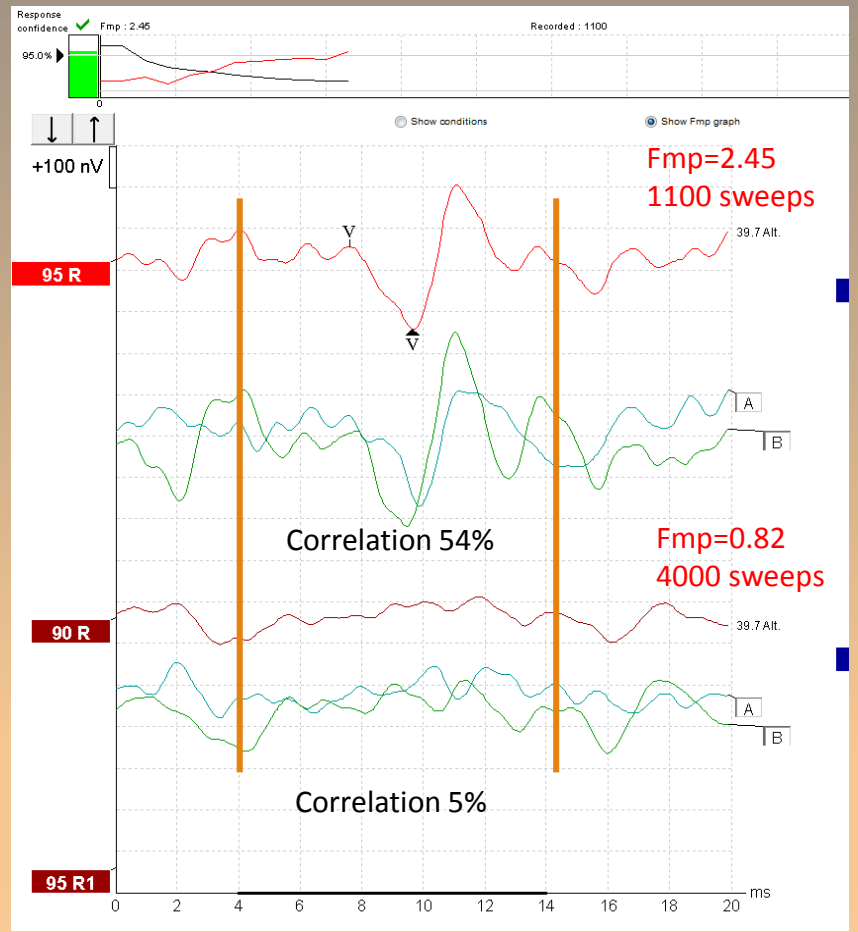
45 L | 40 L1 | 40 L | 35 L

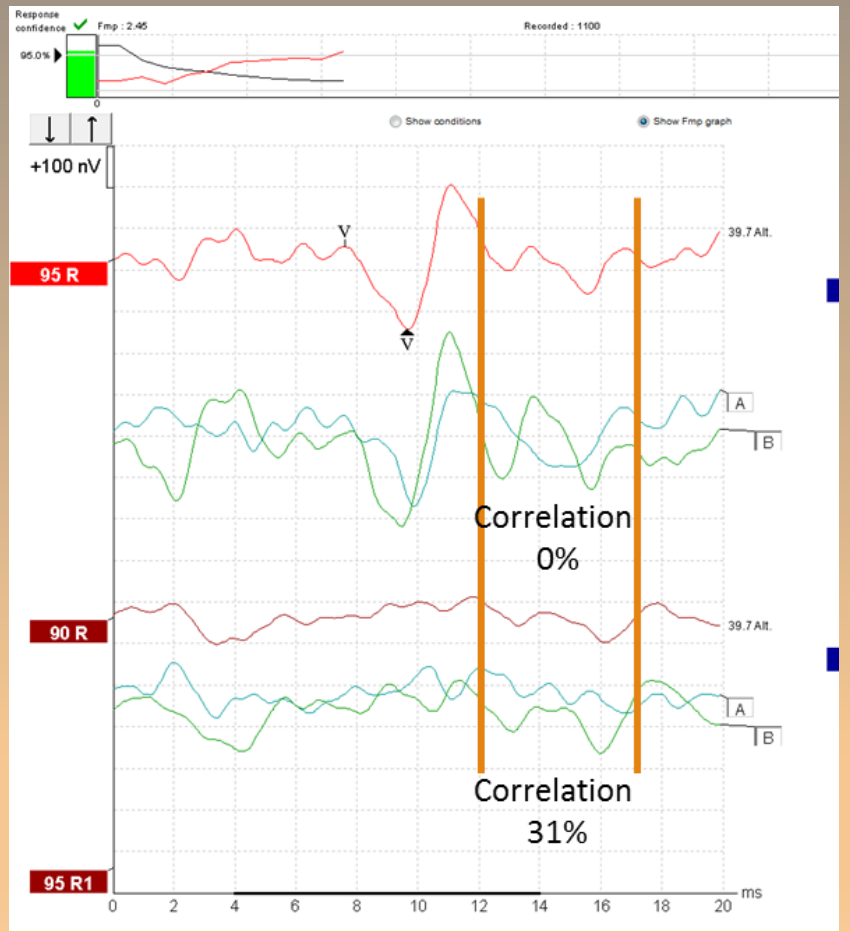
No hardware detected.

For Help, press F1 | Session name:YS 2kHz CE-Chirp | Session date:09-08-2016 | ABR30


3482 CINCY. Current date : 09-19-2017 Reader Station - Edit Mode
File Edit View Help
YS 2kHz CE-Chirp
09-08-2016
39.7 Hz
2 kHz
Record Edit... Latency
Latency times
ms µV
I II III IV V CR RA INC
tr
I-III
III-V
I-V
Cursor
Fixed Cursor Diff.
ms
µV
Display filter setting
Low pass High pass
1000 Hz None
Response confidence
Fmp : 0.78
Recorded : 4000
Residual noise : 24.87nV
95.0%
200nV
25nV
6000
0
60ms
Show conditions
Show Fmp graph
+75 nV
40 R
35 R
30 R
45 L
40 L1
40 L
35 L
NB Chirp LS 2k 37.1 Alt.
V
dB nHL
ms
0 2 4 6 8 10 12 14 16 18 20
No hardware detected.
For Help, press F1
Session name:YS 2kHz CE-Chirp
Session date:09-08-2016
ABR30

Cross Correlation for Detection
An Alternative "Objective" Detection Scheme





How does Fmp compare to Cross Correlation detection and noise measurements??

Fmp

1) Fixed time window length
2) Statistically based response criteria
3) Noise is considered in the detection criteria
4) Constant updated readout
5) Clear published guidelines

Cross-Correlation

1) Arbitrary Time window length
2) No clear response criteria –How much is good?
3) Noise can be estimated but how much is too much?
4) Many systems require stopping and calculating
5) No set guidelines

New Technologies

- Bayesian Weighting

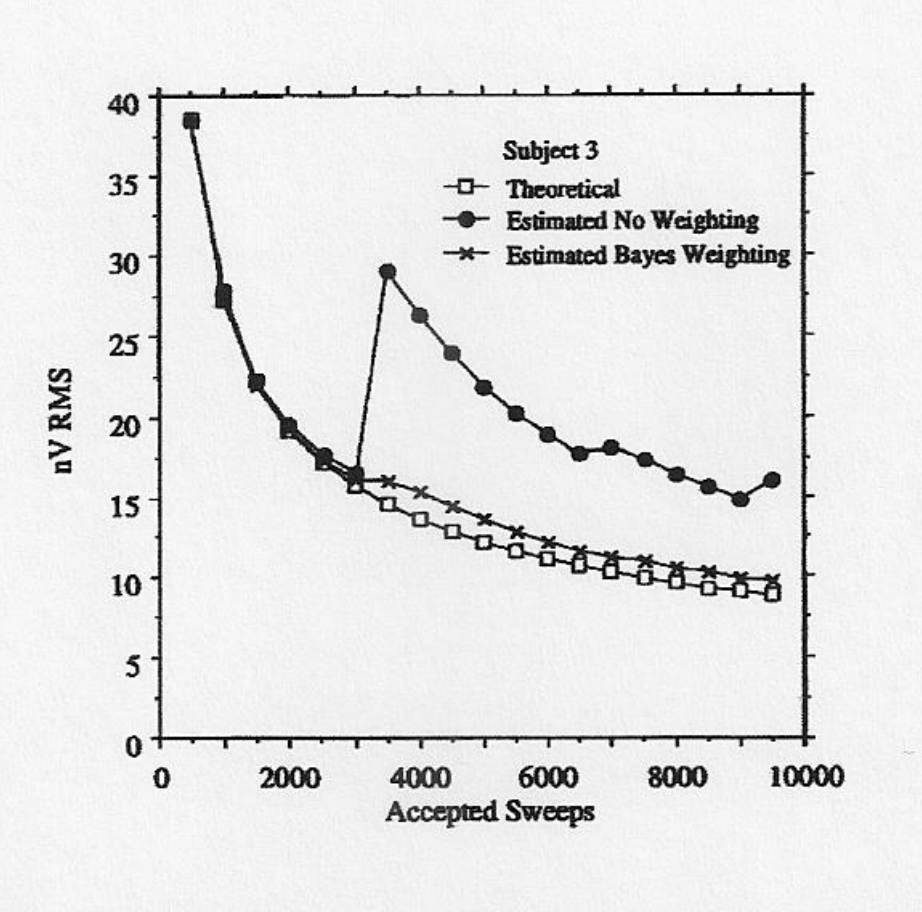
Bayesian Weighting
What is it and why would I use it?

First proposed by Elberling & Wahlgren in 1985 as a method of noise reduction during averaging.

Rather than rejecting all sweeps with high amplitude (traditional noise rejection) Bayesian weighting assigns a “weight” to each block (50) of sweeps based on estimated noise in the block.

When a block is quiet, it is given greater “weight” in the average than when a block is noisy. Almost nothing is discarded.

Bayesian Weighting with Sudden Noise Burst



Don & Elberling
JASA 96:5, 1994

New Technologies

- Next Generation ASSR Detection

Skepticism Regarding ASSR

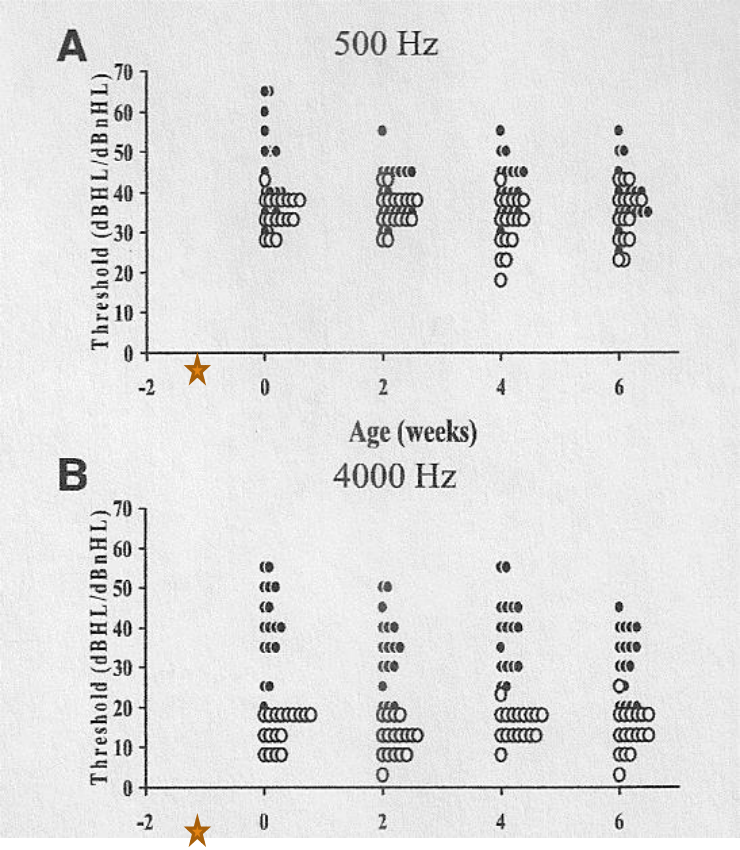
"*ASSR testing (as carried out in this study) cannot reliably differentiate between normal ears and those with mildly elevated hearing levels. The accuracy of the technique does, however, improve dramatically in ears with sensorineural hearing loss*" (Rance et al., 2005, p. 298).

Early ASSR technology could detect supra-threshold responses but missed low-levels near threshold in normally-hearing subjects.

Comparison of Thresholds from Normally-Hearing Infants by ASSR and ABR Using GSI Audera

Rance et al. 2006 Ear & Hearing.

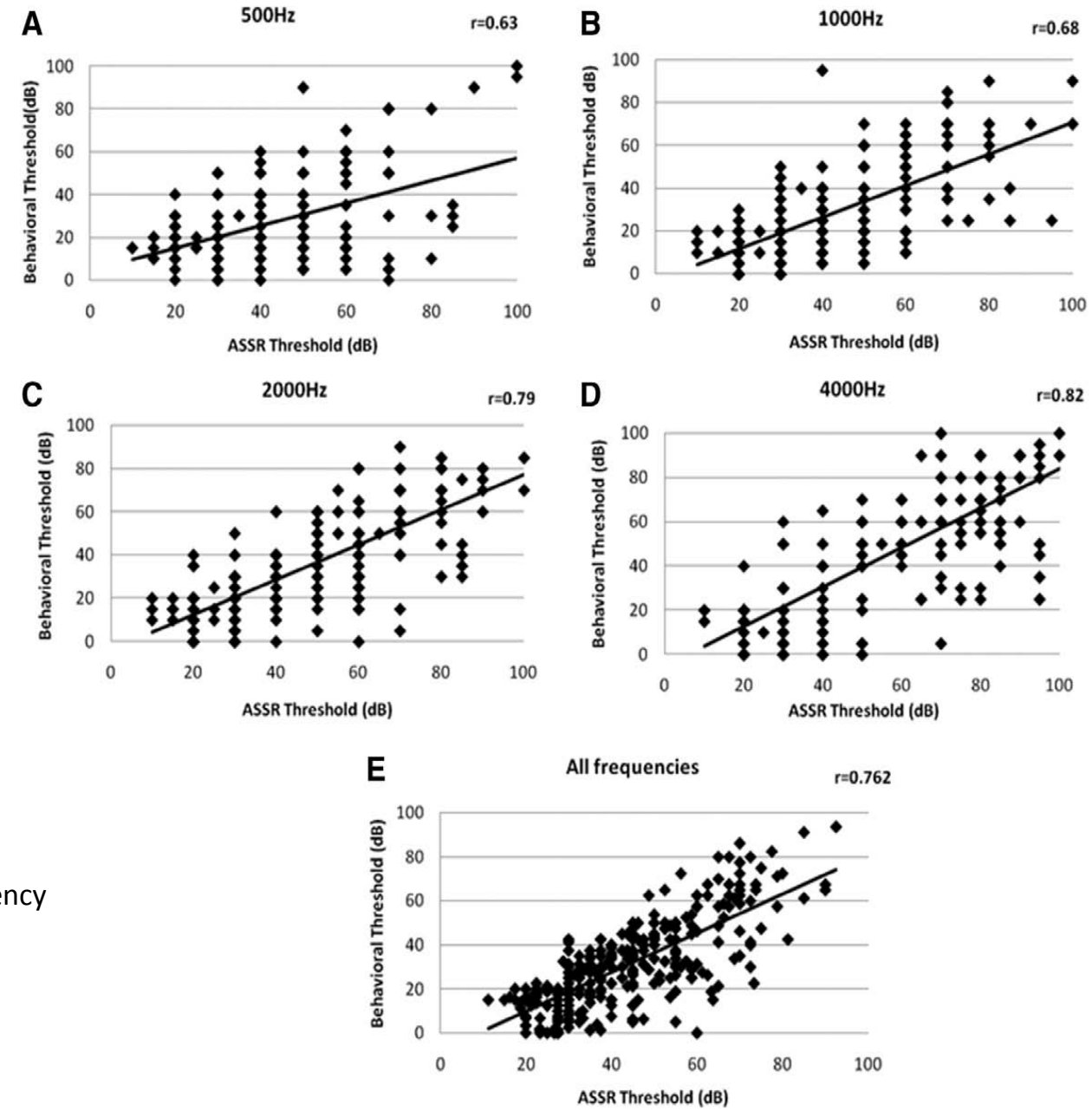
Open Circles ABR, closed are ASSR. Blue Star is ABR threshold from Sininger et al on Normally Hearing Newborns at 0-1 week.



ASSR Thresholds were determined by Phase Coherence only at the modulation frequency

Thresholds determined using ASSR by Audera in 2006 were <u>unacceptably</u> high demonstrating that the technique could not meet the then standard of TB ABR!!

Unacceptable Behavioral Prediction from ASSR



Attias et al., 2014
Adult Data
Used Amplitude of Mod Frequency (80-90 Hz) F test.

How are ASSR and ABR Alike, Different?

ABR and ASSR both look at the same brainstem neural activity.

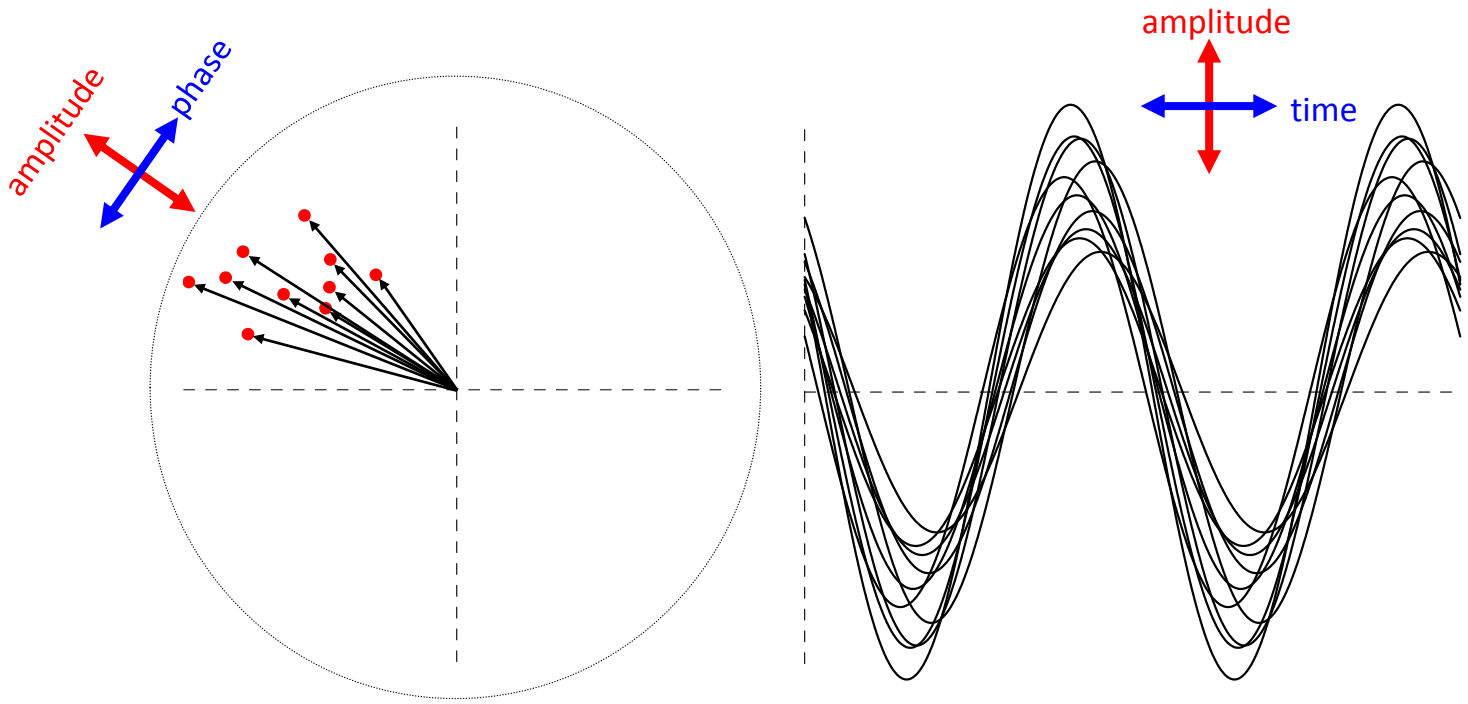
ASSR modulates the stimulus at a known frequency.

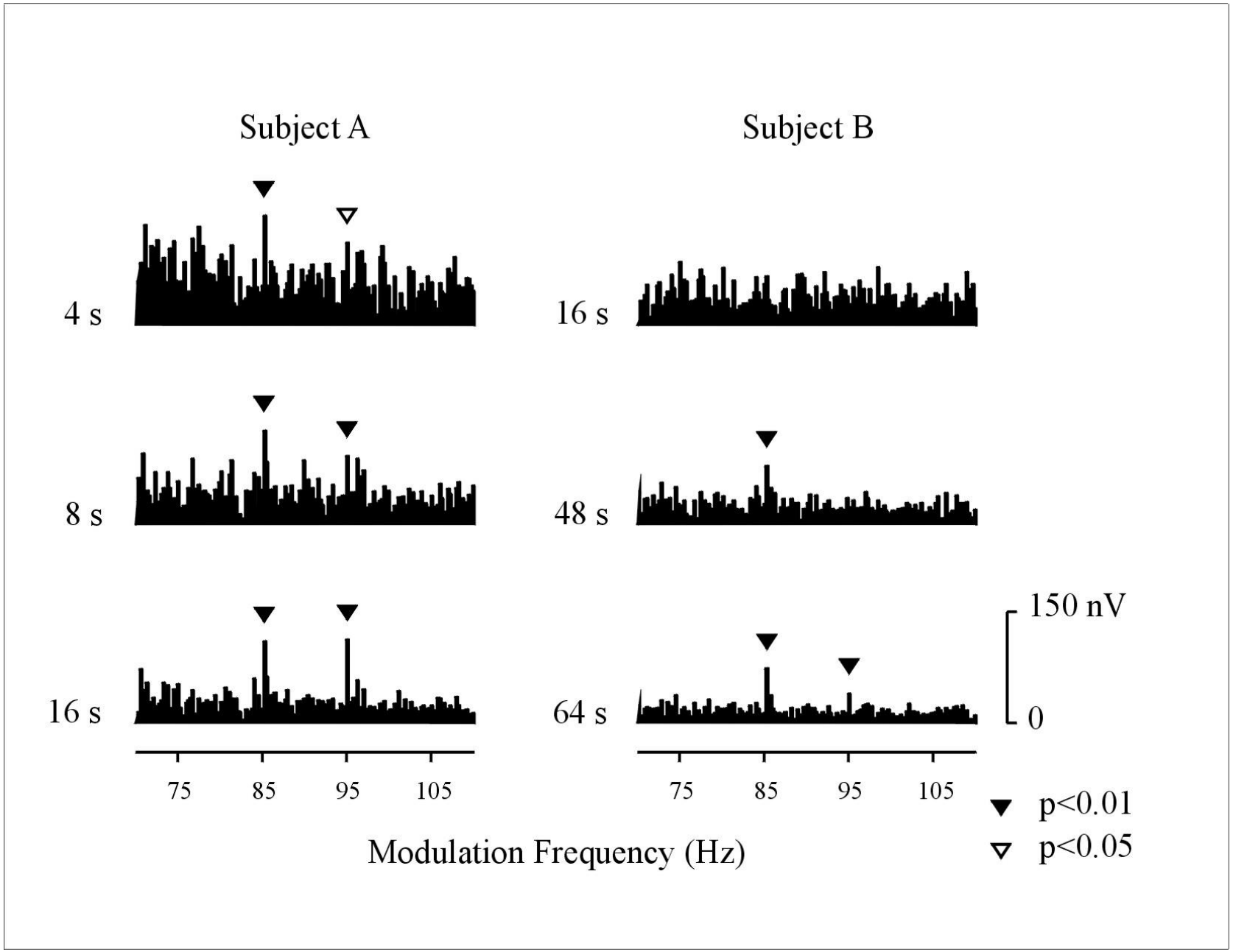
Response detection then searches for evidence of that frequency in the ongoing EEG.

If the neurons are activated by the stimulus, there will be a spike in the frequency response of the EEG at the modulation frequency and the phase of the EEG will be synchronized with the stimulus onset.

ASSR technique is solid but “Response Detection” had been under-developed.

Traditional ASSR Detection Searches for Significant Amplitude and/or Phase Coherence of the Modulation Frequency




Subject A
Subject B
4 s
16 s
8 s
48 s
16 s
64 s
150 nV
0
75
85
95
105
75
85
95
105
p<0.01
p<0.05
Modulation Frequency (Hz)

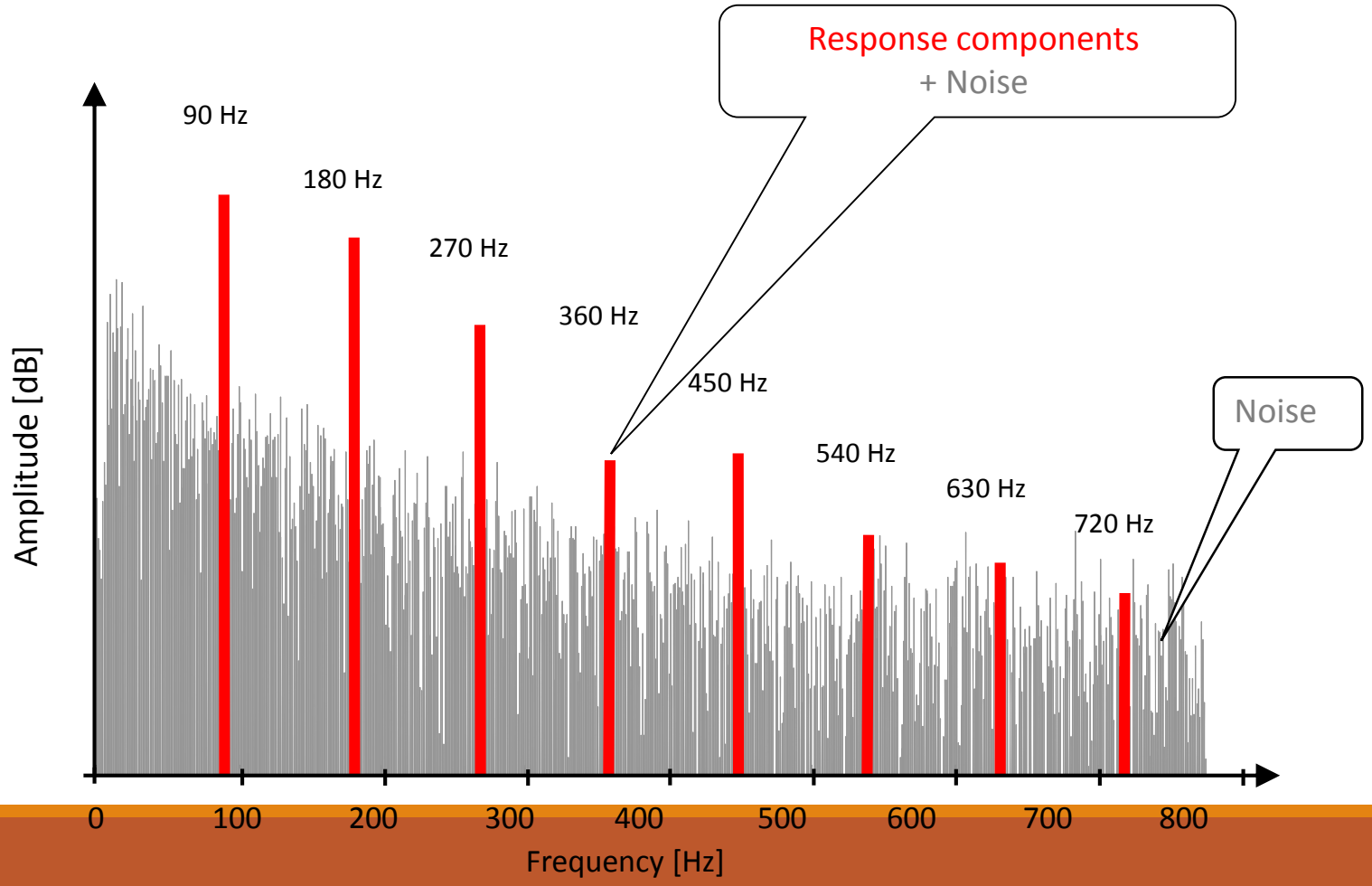
How is the "Next Generation" ASSR Different than the First Generation??

Next Generation uses BOTH amplitude and phase information for detection.

Next Generation uses the fundamental and 20+ harmonics for response detection.

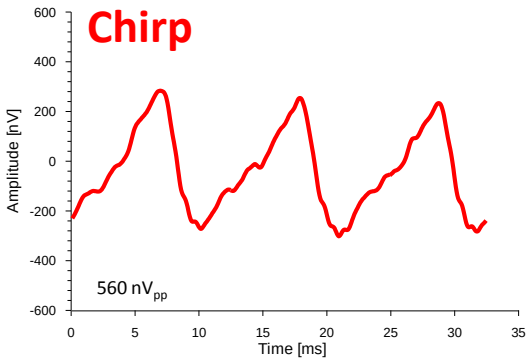
Next Generation ASSR uses Narrow Band CE-Chirps.

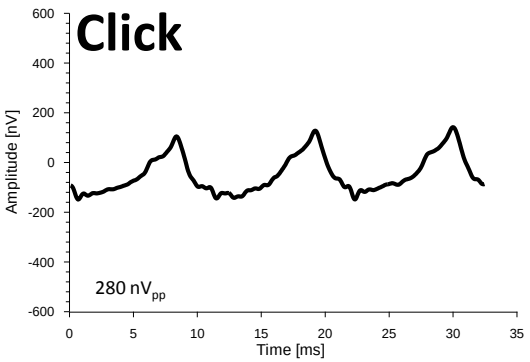
Next Gen ASSR uses Response Detection (Phase and Amplitude) at Fundamental and 12 Harmonics Compared to Fundamental Alone



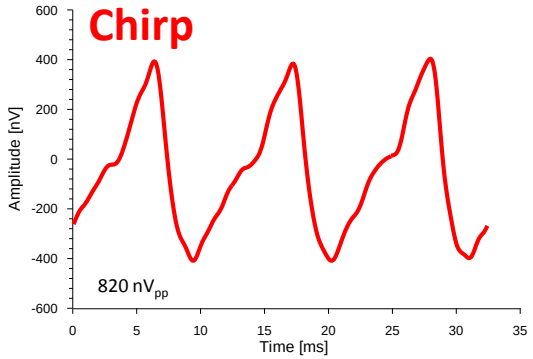
Next Gen ASSR uses Narrow Band CE-Chirps as Stimuli Known to produce Larger Amplitude Responses And Lower Thresholds

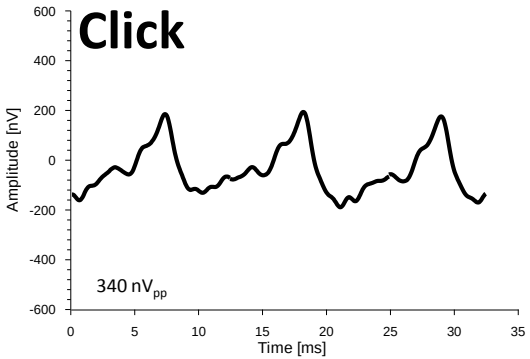
30 dBnHL





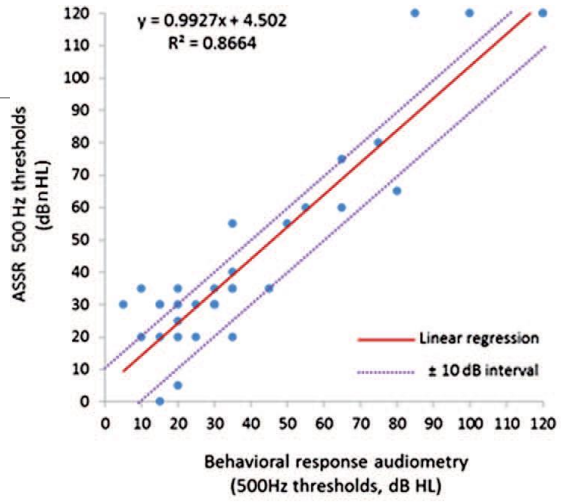
50 dBnHL



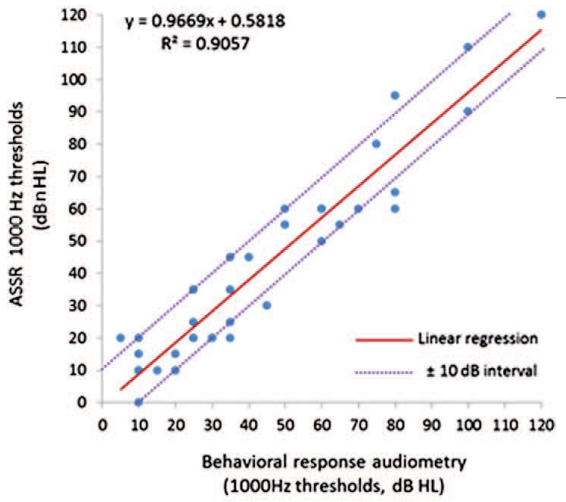


F. Venail et al. Narrow band CE-Chirps evoked ASSR in Children International Journal of Audiology 2014; Early Online: 1–8

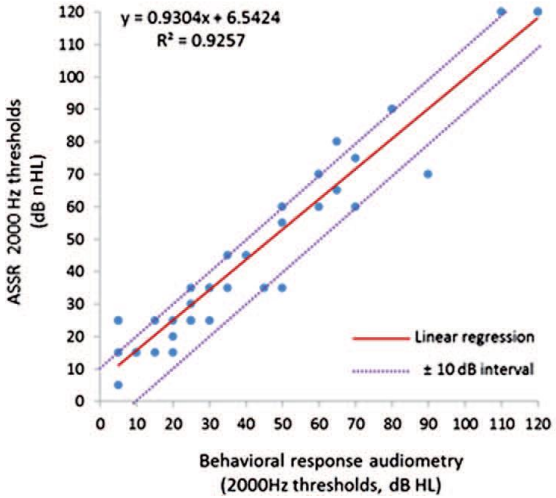
500 Hz



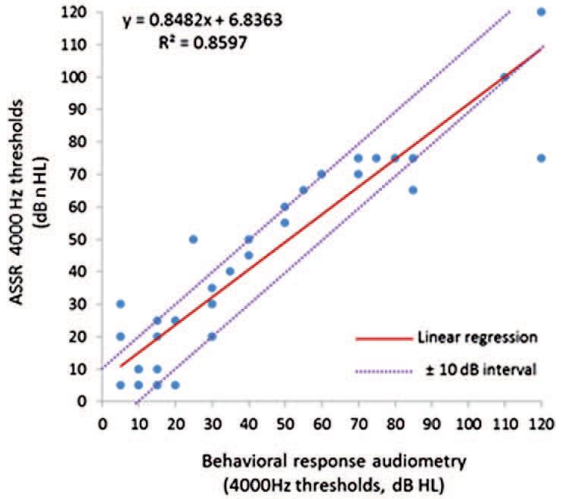
1000 Hz



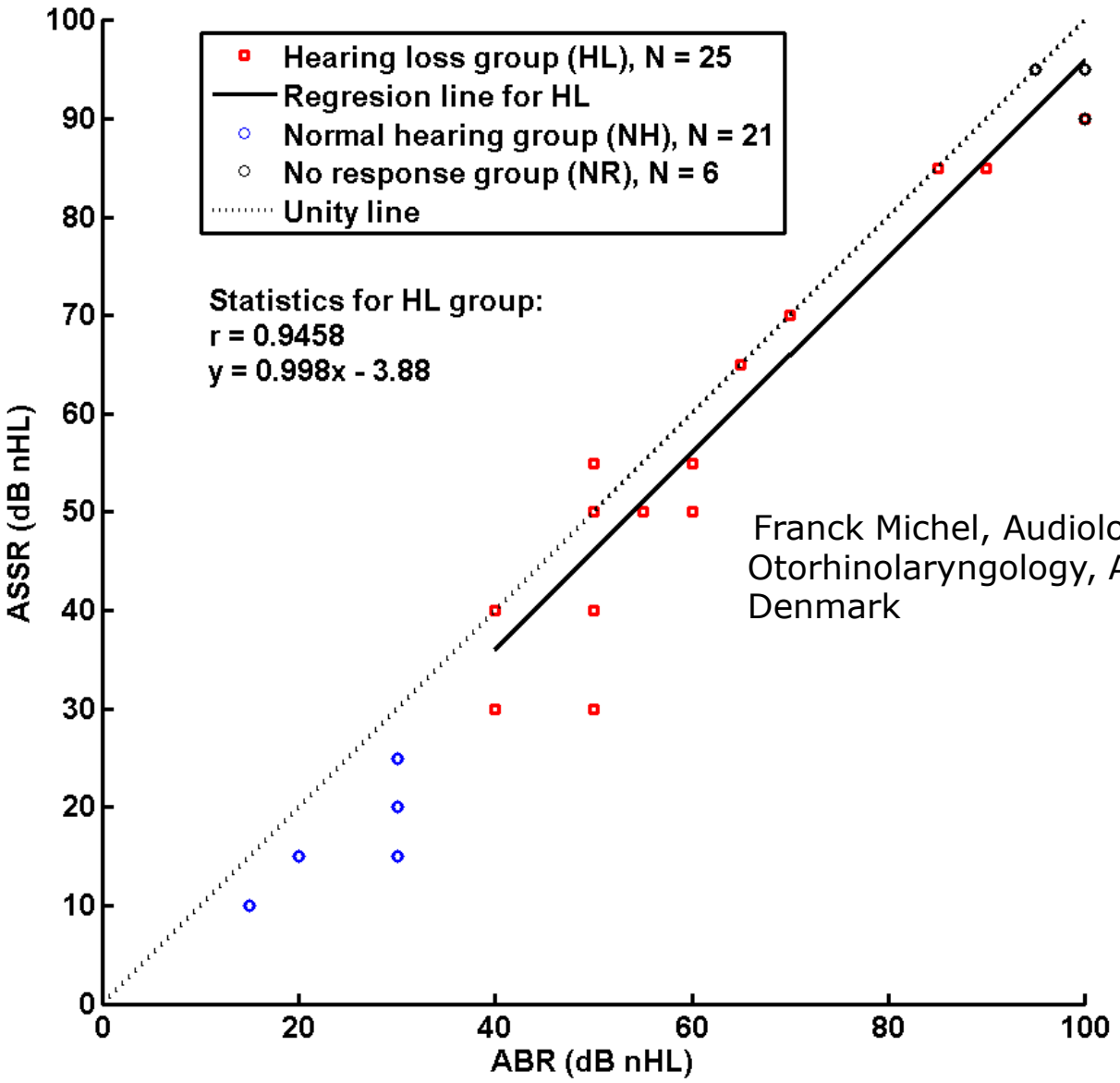
2000 Hz



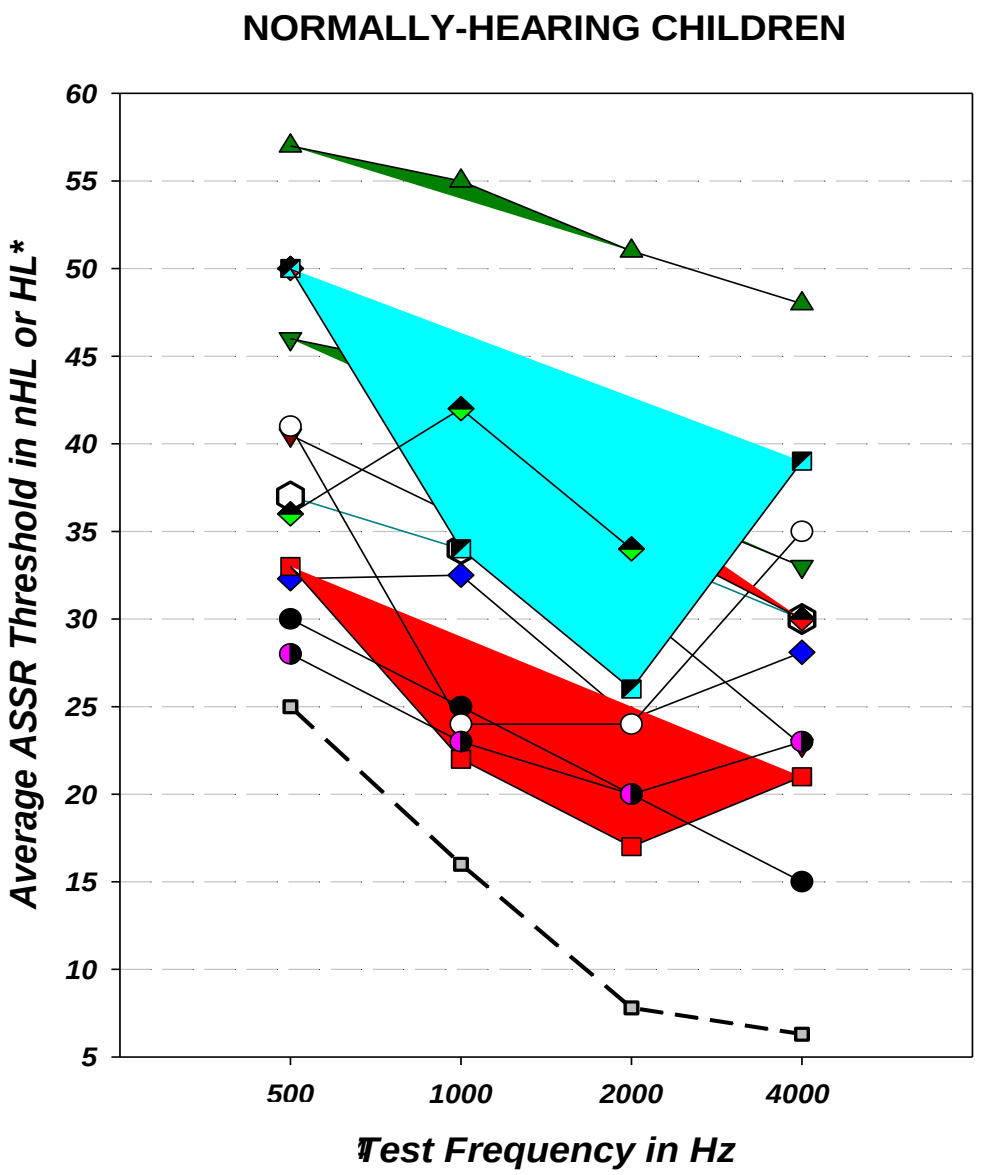
4000 Hz



Comparison of threshold estimation in infants with hearing loss or normal hearing using Auditory Steady-State Response evoked by narrow band CE-chirp and ABR evoked by tone pips: results for 2000 Hz



Franck Michel, Audiology Clinic, Department of Otorhinolaryngology, Aarhus University Hospital, Denmark



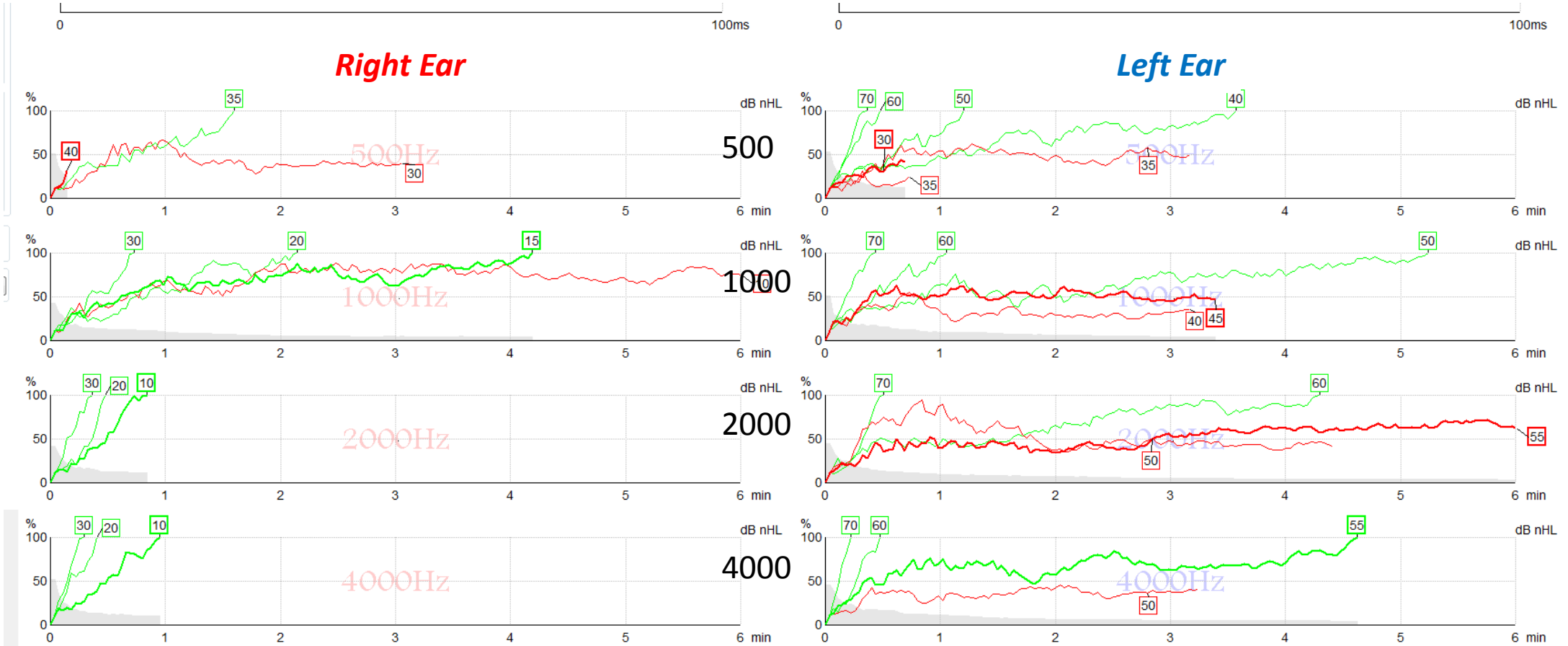
Strength of the Next Generation Detection is Demonstrated by Lowest Threshold for Normally Hearing Children

- *Rodriquez & Lewis, 2014*
- *Rance et al., 2005**
- *Lins et al 1996 **
- *Savio et al., 2001 (0-1 month)**
- *Swanepoel & Steyn, 2005**
- *Van Mannen & Stapells, 2009**
- *Michel & Jorgensen, 2017*
- *Savio et al., 2010 7-12 mo**
- *Rickards et al., 1994**
- *Rance & Rickards 2002**
- *Cone-Wesson & Rickards, 2002**
- *Levi et al., 1995**
- *Casey & Small, 2014**

33 Minutes, 23 seconds

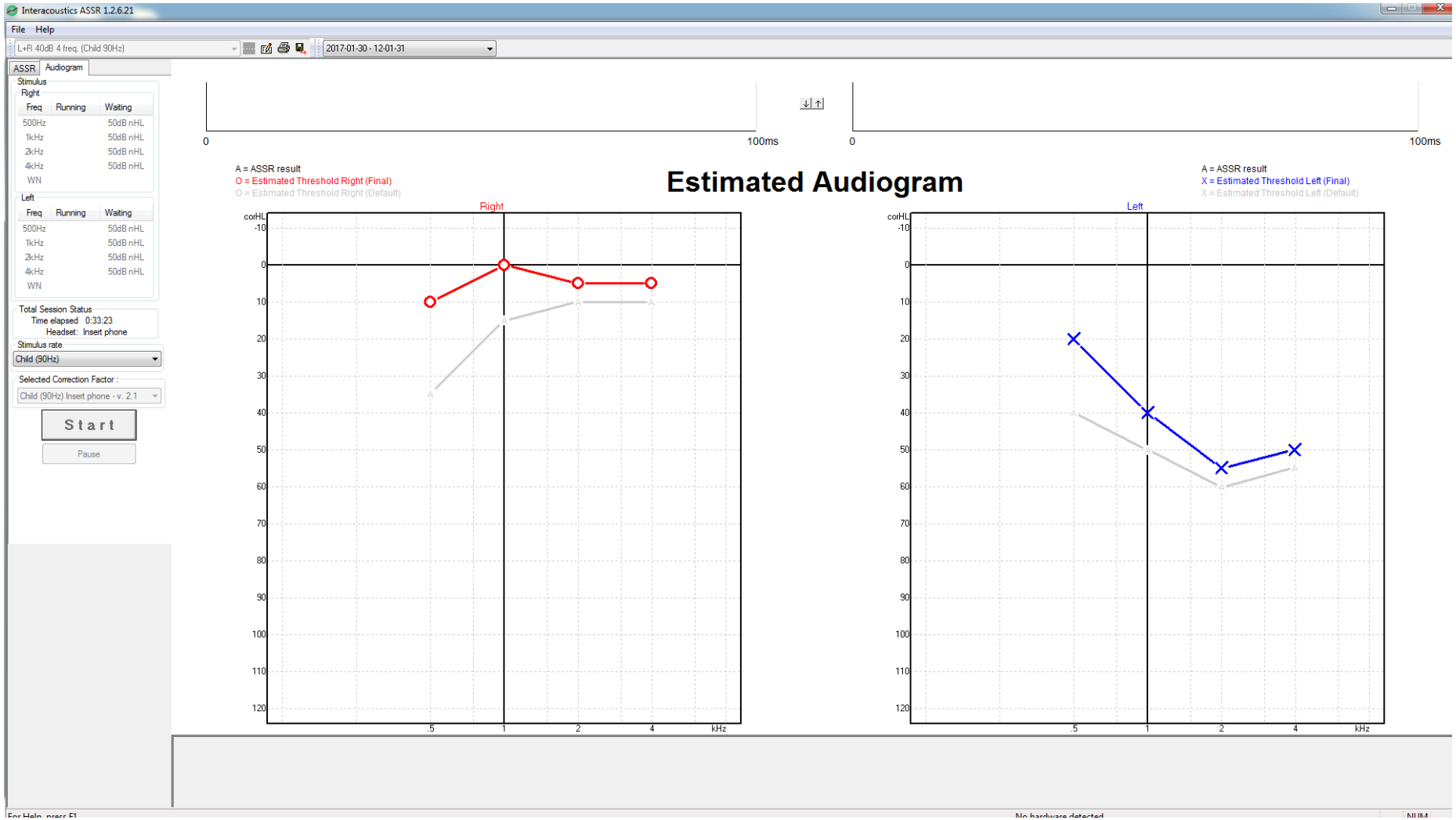
ASSR

Subject 3513 9 Months



dB nHL	500Hz	1kHz	2kHz	4kHz
10		75% 9nV	100% 27nV	100% 24nV
15		100% 10nV		
20		100% 15nV	100% 33nV	100% 32nV
30	40% 12nV	100% 24nV	100% 36nV	100% 41nV
35	100% 17nV			
40	31% 65nV			
45				
50				

dB nHL	500Hz	1kHz	2kHz	4kHz
10				
15				
20				
30	42% 32nV			
35	50% 13nV			
40	100% 12nV	35% 13nV		
45		47% 11nV		
50	100% 20nV	100% 10nV	42% 12nV	41% 11nV


Interacoustics ASSR 1.2.6.21
File Help
L+R 40dB 4 freq. (Child 90Hz)
2017-01-30 - 12-01-31
ASSR
Audiogram
Stimulus
Right
Freq Running Waiting
500Hz 50dB nHL
1kHz 50dB nHL
2kHz 50dB nHL
4kHz 50dB nHL
WN
Left
Freq Running Waiting
500Hz 50dB nHL
1kHz 50dB nHL
2kHz 50dB nHL
4kHz 50dB nHL
WN
Total Session Status
Time elapsed 0:33:23
Headset: Insert phone
Stimulus rate
Child (90Hz)
Selected Correction Factor :
Child (90Hz) Insert phone - v. 2.1
Start
Pause
0
100ms
0
100ms
Estimated Audiogram
A = ASSR result
O = Estimated Threshold Right (Final)
O = Estimated Threshold Right (Default)
Right
corHL
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
.5
1
2
4
kHz
A = ASSR result
X = Estimated Threshold Left (Final)
X = Estimated Threshold Left (Default)
Left
corHL
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
.5
1
2
4
kHz

Questions?