

Innovations in the Electrophysiologic Assessment of Infant Hearing



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Long Term Goals of Research



- Apply knowledge of auditory system function and development to provide
 - Cost-effective
 - Sensitive
 - Specific
 - Efficient
- tools for infant auditory assessment.

Why these goals?



- Electrophysiologic methods must be used to determine hearing sensitivity in the first few months of life.
 - Ear and frequency specific estimates of hearing threshold are crucial to EHDI planning.
 - Electrophysiologic test results are usually the sole indicator of an infant's hearing levels until the infant is developmentally and motorically able to provide a behavioral response.
 - ✦ 6-9 months of age for typically developing infants, later for those with developmental delays.

The Auditory Brainstem Response



- The auditory brainstem response has been used for infant assessment for the past 35 years.
- Threshold estimates from ABR tests are used to fit hearing aids when behavioral testing is not possible.

The Problem



- The ABR is a very small “brain wave” compared to the electrical energy produced by the brain.
- Interference from muscle movement (even blinking or swallowing) can compromise the ability to get valid threshold estimates.
- It is usually necessary to have the infant sedated for a full diagnostic ABR test to be completed.

Costs of Sedated ABR



- There are high costs associated with sedated ABR:
 - Expense of administering sedative (nurse or nurse/anesthetist)
 - Expense of monitoring state of the infant
 - Risk of respiratory and/or cardiac distress and failure
 - Risk of undiagnosed hearing loss (with cascade of poor outcomes) when parents opt out of testing due to fear regarding the procedure.

Improving the ABR test



- Question:
- Are there methods or technologies that could be used that would significantly decrease test duration so that evaluations could be completed during
 - brief periods of quiet sleep
 - Quiet wakefulness
- Such methods/technologies would need to
 - Reduce the effects of infant movement on ABR
 - Improve the amplitude of the response relative to the noise from infant movement.

Innovations



- Three methods are being evaluated as “Innovations in the Electrophysiologic Assessment of Infant Hearing”, research supported by the Association of University Centers on Disability (AUCD).
- 1) Advanced signal processing as implemented on the Vivosonic Integrity ABR System
- 2) New stimulus: “Chirp”
- 3) New response paradigm: cortical evoked steady-state response.

Vivosonic Integrity





What's different about Vivosonic?



Innovation

- A Kalman (adaptive) filter
- An in-situ amplifier
- Blue-tooth communication for data transfer

Benefit

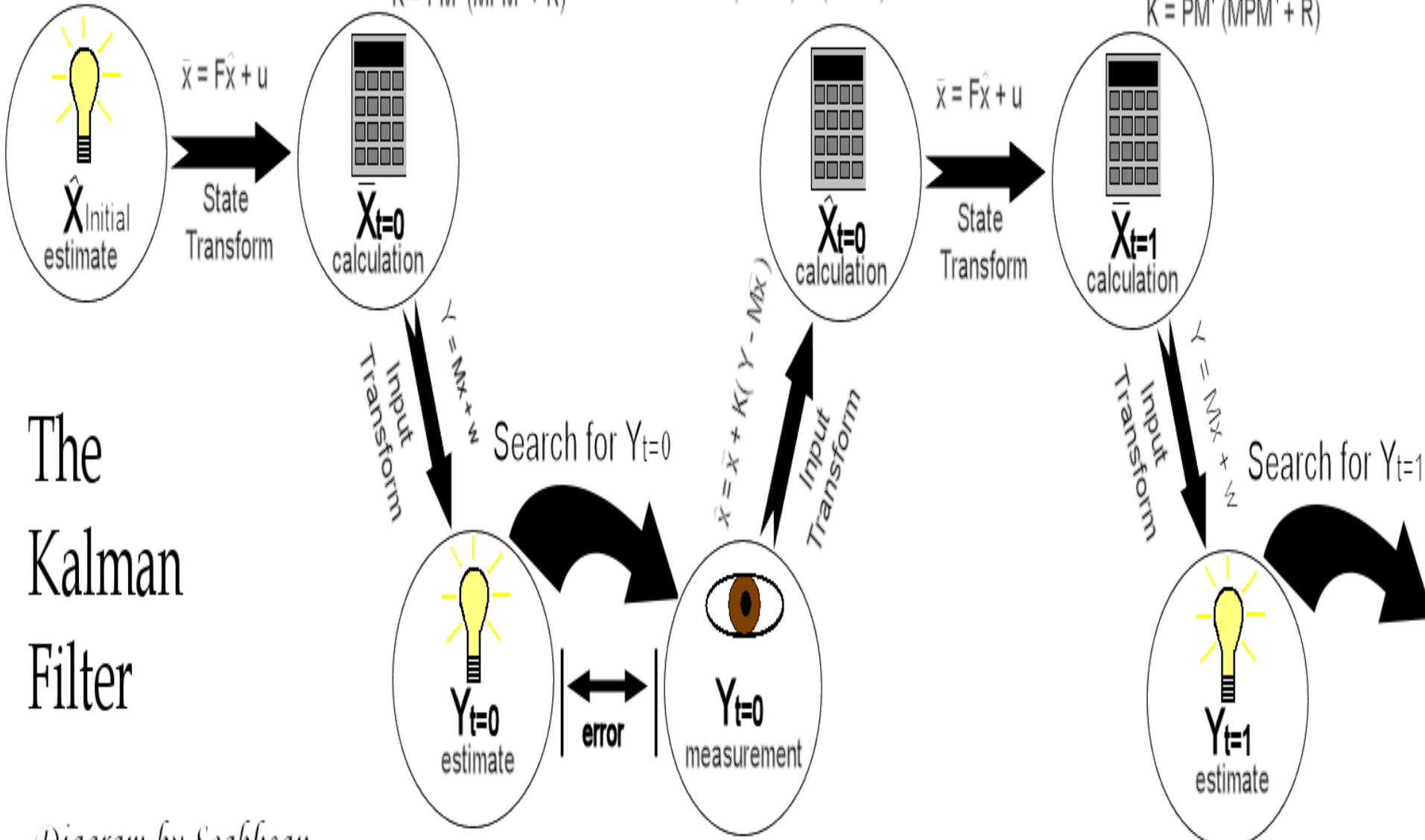
- “smart” filter, adapts to noise conditions and weights data appropriately for averaging.
- “Amplitrode”- combined electrode and amplifier.
- Patient is not tied to the computer. Parent can rock or walk around with baby during data acquisition.

Update P (Error Cov Matrix)
 $P = (I - KM) \bar{P} (I - KM)^T + KRK^T$

Project P ahead
 $\bar{P} = FPF^T + Q$
 Update K (gain)
 $K = \bar{P}M^T (M\bar{P}M^T + R)^{-1}$

Update P (Error Cov Matrix)
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Project P ahead
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The Kalman Filter

Diagram by Seabfican

The Kalman filter is an algorithm that uses a series of measurements observed over time, containing noise (random variations) and other inaccuracies, **and produces estimates of unknown variables** that tend to be **more precise than those based on a single measurement alone**

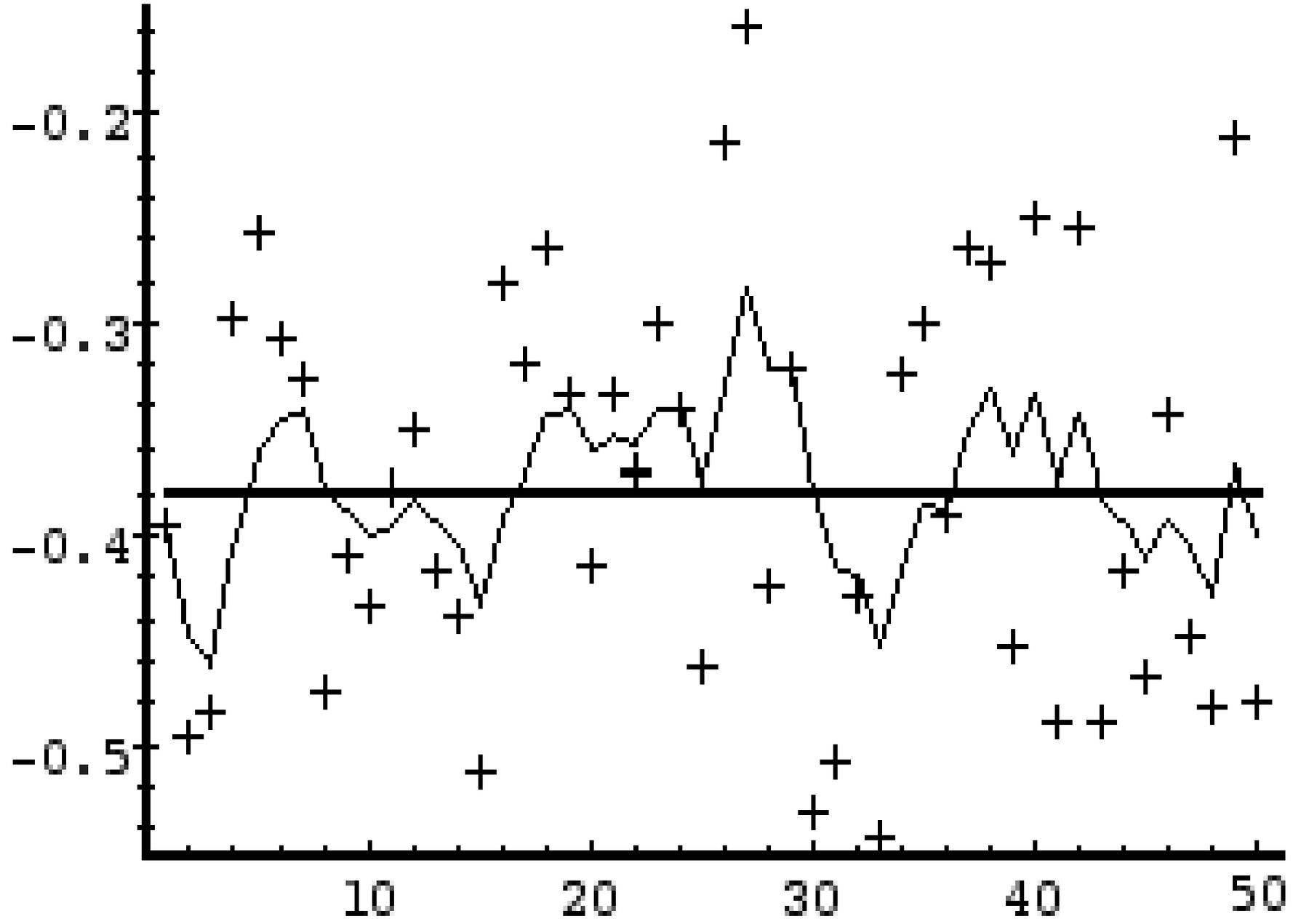
The Kalman filter has numerous applications in technology. The Kalman filter is a widely applied concept used in signal processing.

The algorithm works in a two-step process:

Prediction: the Kalman filter produces estimates of the current state variables, along with their uncertainties.

Updating: estimates are updated using a **weighted average**, with more weight being given to estimates with higher certainty.

Voltage



Response-to-Noise Ratio



- In conventional ABR tests,
 - EEG amplification,
 - averaging, and
 - amplitude-based artifact rejection
- are used to improve the ABR-to- noise ratio.

- Use of a Kalman filter has potential of reducing ABR averaging time by 75% compared to conventional methods (Chan et al 1975).

Experiment 2: Independent Verification



- Our first experiment was designed to determine if there was a difference in the ABR latency and amplitude when obtained using "experimental" (Vivosonic) technology, compared to conventional technology.
- Normally hearing adults were tested in 3 conditions:
 - Quiet, relaxation
 - Reading aloud
 - Making random motor movements
- The threshold, latency and amplitude of the ABR were evaluated as a function of recording method and listening condition.

Experiment 2: Clinical Verification



- The “experimental” system that employed the kalman-filter was used in a clinical setting.
- The audiologist using the system was not asked to vary her test protocol in any way, except for initiating ABR measurements while the infant was still awake.
- The presence and latencies of the ABR responses obtained during wakefulness were measured.
- The number of sweeps, needed to obtain a waveform was quantified.

Experiment I Methods

Independent Verification



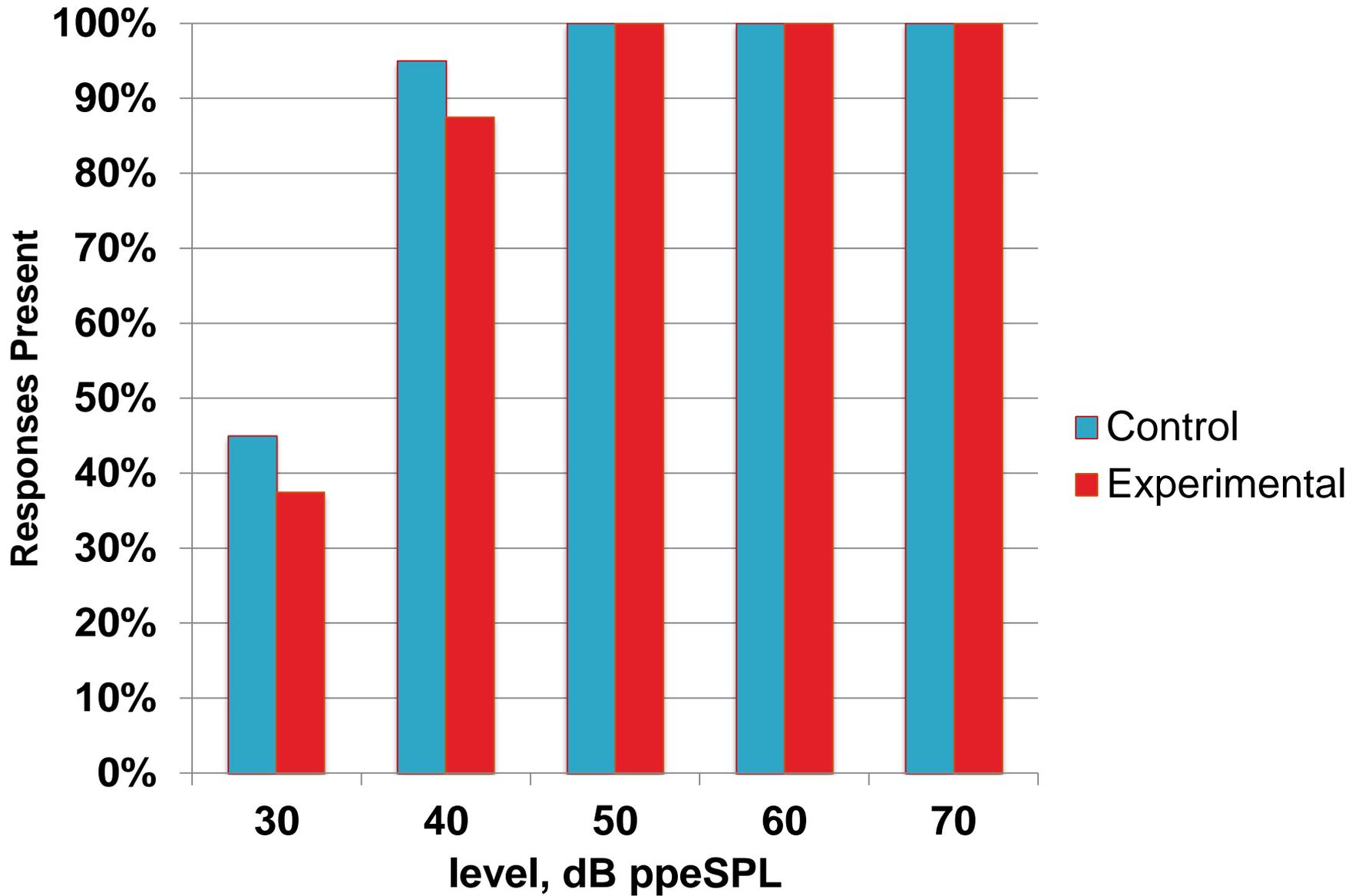
- 40 normally hearing young adults
- **Stimulus:** 100 μ s click presented at a rate of 27.7/s
- **Acquisition parameters**
 - Cz-A2 electrode montage, A1 ground for conventional (control) recording performed with an Intelligent Hearing systems Smart-EP system
 - Fpz-A2 electrode montage, Fp ground for experimental (Vivosonic) recording, according to manufacturers recommendation
 - EEG filter at 100-3000 Hz for both instruments.
 - Amplitude based artifact reject level set at 20% for conventional (control) recording.
 - Kalman filter as implemented in Vivosonic Integrity ABR system for "experimental" system.

Procedure

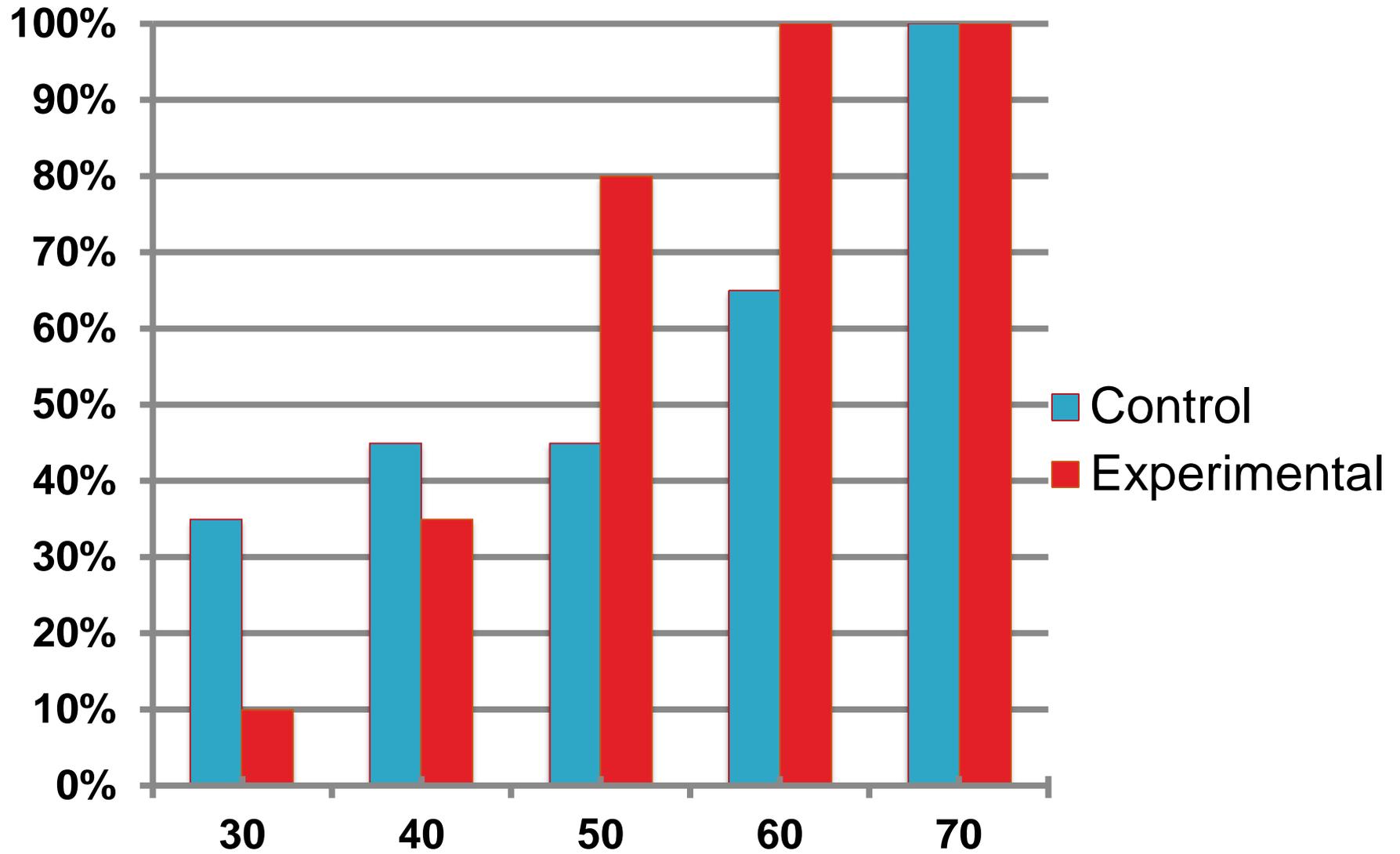


- 3 test conditions were performed for each subject using both instruments with order of device randomized across subjects
- **Quiet condition:** ABRs were obtained at each 10 dB decrement from 90 dB ppeSPL until no response was evident. 2000 sweeps were averaged for each trial and responses were replicated at each level.
- **Steady state noise condition.** Subjects read aloud from a magazine while ABR recordings were obtained. Test levels were at 70 dB ppeSPL and decremented in 10 dB and then 5 dB steps as threshold was approached. Each waveform was recorded for 3 minutes. The lowest level at which a response was obtained was replicated.
- **Intermittent noise condition.** ABR traces were recorded while the subject performed motor tasks on cue (i.e. humming, writing in the air, or naming objects) every 30 seconds. Starting at 50 dB ppeSPL, ABRs were averaged for three minutes at each 10 or 5 dB decrement as threshold was approached. The lowest level at which a response was obtained was replicated.

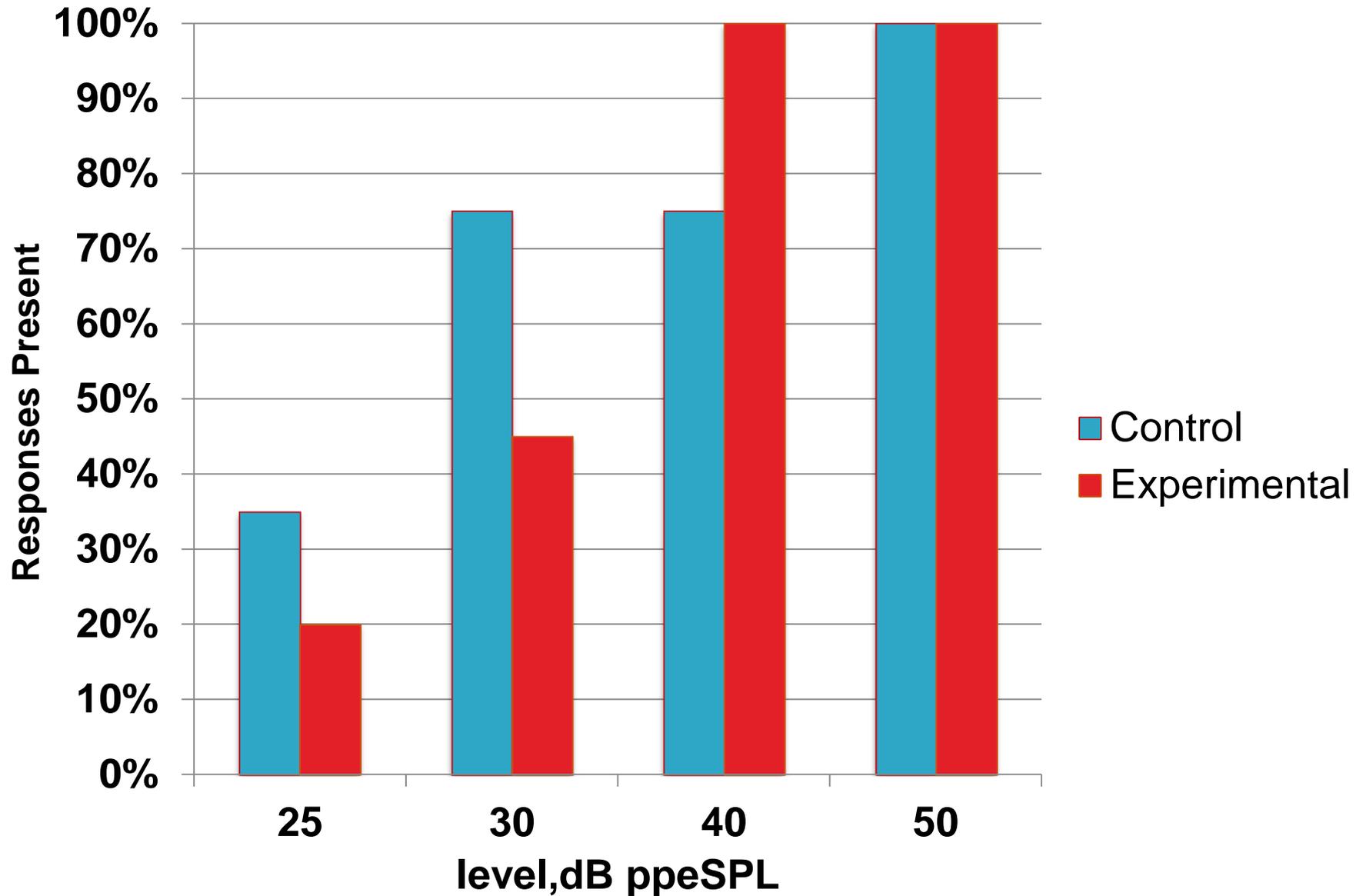
Quiet

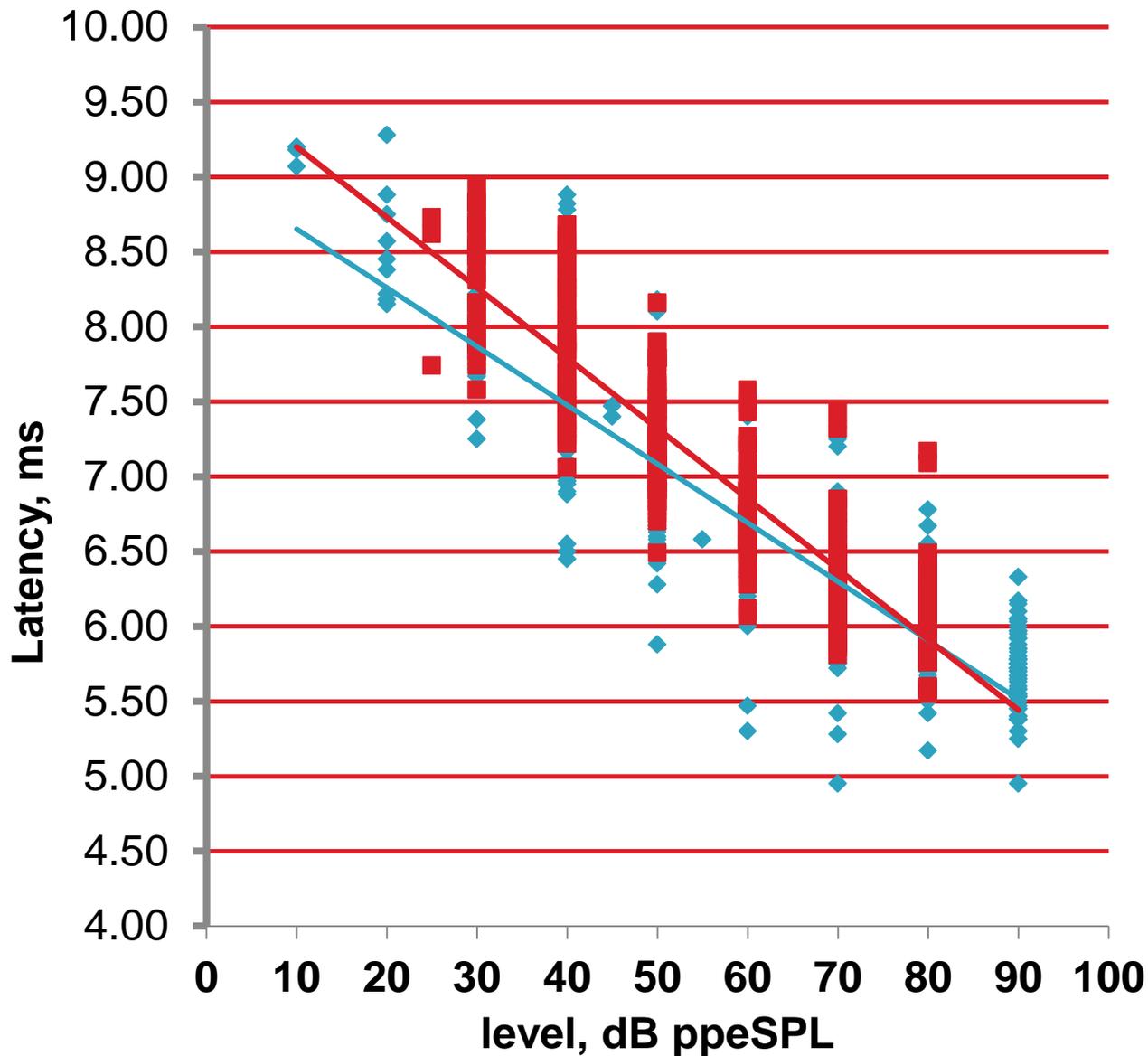


Reading Aloud: steady-state noise



Intermittent Movement





Quiet

◆ Control

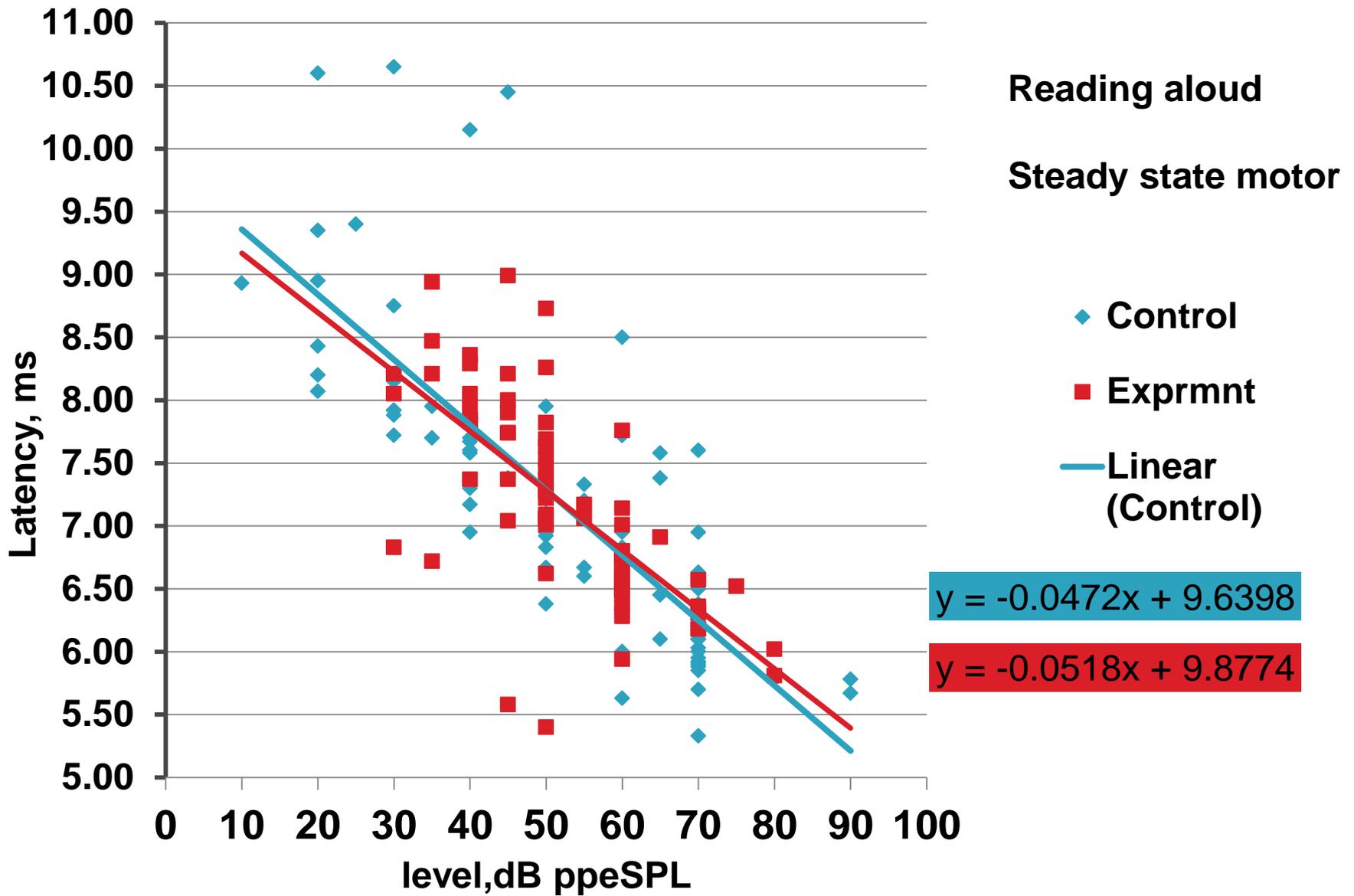
■ Exprmnt

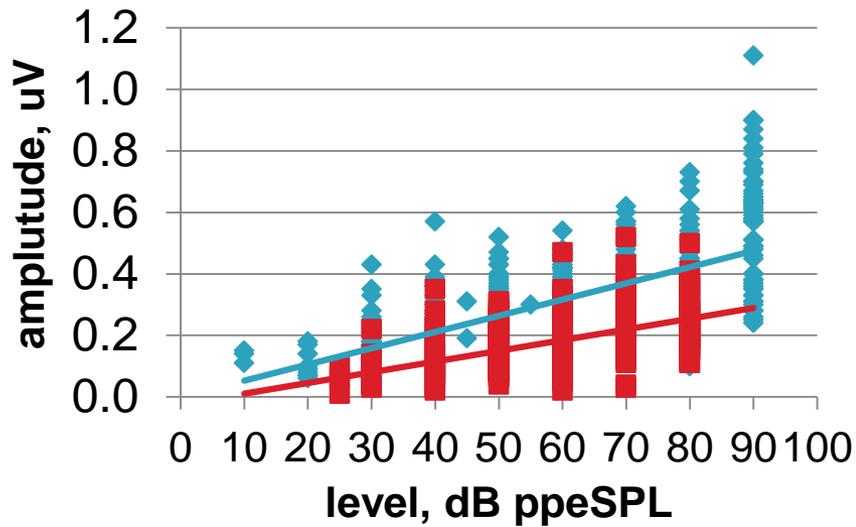
— Linear (Control)

— Linear (Exprmnt)

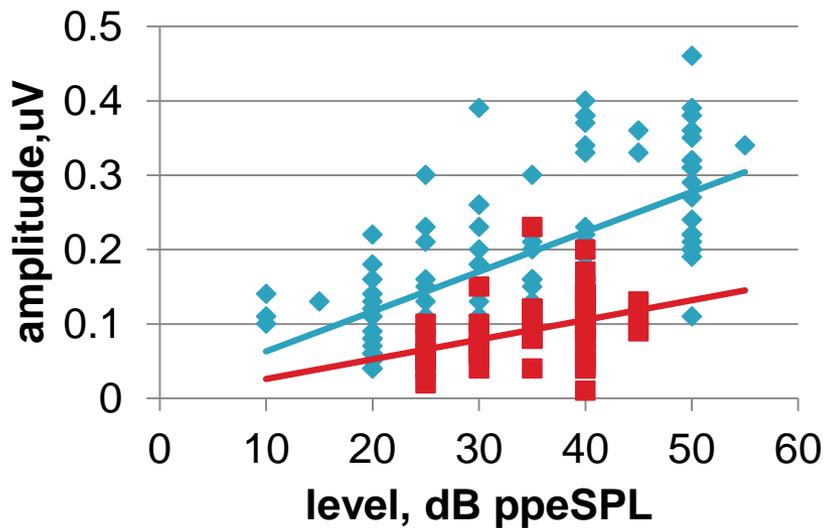
$$y = -0.047x + 9.6692$$

$$y = -0.0392x + 9.0453$$





Quiet



Intermittent Noise

Summary of Experiment I



- In quiet, conventional signal processing and innovative signal processing are equivalent in terms of being able to obtain a wave V at low stimulus levels.
- In steady state induced motor noise, a 25-35% advantage for "experimental" methods is obtained at 50 and 60 dB ppe SPL (30 and 40 dB nHL).
- In intermittent induced motor noise, there is a 25% advantage for experimental methods at 50 dB dB ppeSPL.

Summary of Experiment I



- ABR wave V latencies are prolonged for "experimental" system compared to conventional.
- Amplitudes are smaller for ABRs obtained with the experimental system compared to a conventional system.

Discussion



- kalman-filter *+in situ* amplifier method (Vivosonic) had 25-35% better probability of ABR response present in motor noise conditions at near threshold levels.
 - ✦ Advanced signal processing methods are designed to extract response from noise.
 - Conventional methods are also reasonably robust for the conditions tested.
 - Advantages may be increased for other band-pass settings
 - This is being tested in a controlled-lab setting.

Discussion



- Latencies prolonged for "experimental" method compared to conventional method.
 - Calibration?
 - Filtering can also induce some phase shifts
 - wave I – wave V IPLs were WNL
- Amplitudes smaller for "experimental" method
 - Amplitude of ABR is always contaminated by noise
 - Need to equate amplitudes on the basis of the noise floor.
 - Noise can inflate ABR wave V amplitudes

Experiment II: Clinical Verification



- **Purpose: move the system from the lab into the clinical setting**
- **Verify that the recordings made during infant wakefulness were comparable to those obtained in the lab setting with adults.**

Participants



- **Most infants referred to Tucson Medical Center for “natural sleep” ABR evaluation were under 6 months of age.**
 - Clinical verification study undertaken in 35 infants
- **Very few children, at our facility, are seen for ABRs between the ages of 6 months and 18 months of age.**
- **Older children are scheduled for ABRs under general anesthesia.**

ABR Evaluations using Vivosonic



- Treated as “typical” diagnostic ABR evaluations
- Compared to traditional equipment, using the Vivosonic involved the following:
 - Averaging began prior to baby falling asleep
 - Less “pausing” when child became somewhat active (e.g. sucking, slight motor activity).

Family and Baby Arrive



- **Consent signed**
- **Case history obtained**
- **Otoscopy**
- **OAEs and 1000 Hz tympanometry (if possible to help determine starting levels for ABR)**
- **Apply electrodes and insert earphones placed**

ABR Recording and Stimulus Parameters



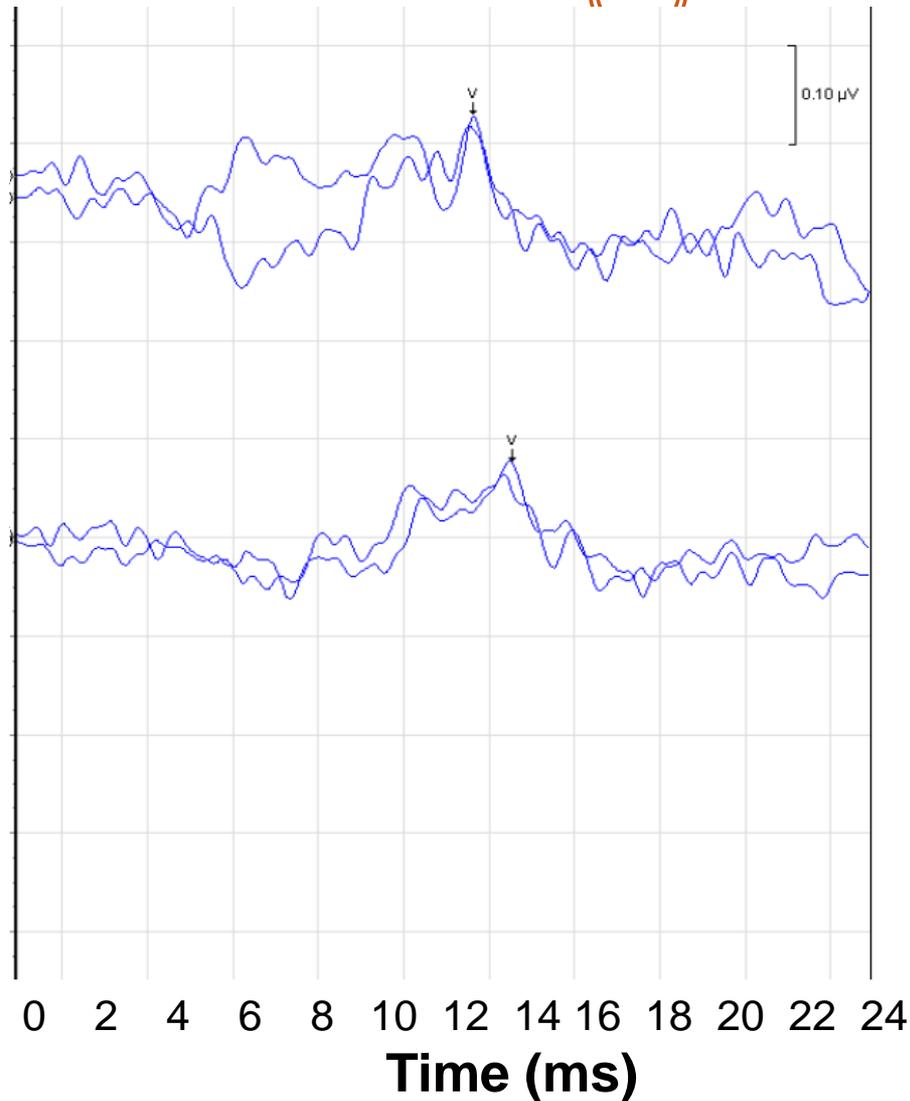
- Clicks
- Rate of 37.7/sec
- High pass filter of 30 Hz
- Low pass filter of 1500 Hz
- High frequency filter rolloff of 12 dB/octave
- Low frequency filter rolloff of 24 dB/octave
- Recording window: typically 20 ms

Stop criteria



1. How quiet is the ongoing EEG during the run?
2. Visual inspection of the averaged waveform (does it look noisy)?
3. Is there a wave V response (e.g. peak present and/or V trough deeper than other perturbations during recording)? Is the response in the latency range expected?
4. If on 2nd run...is there replication?

Examples ABRs recorded at 20 dBnHL



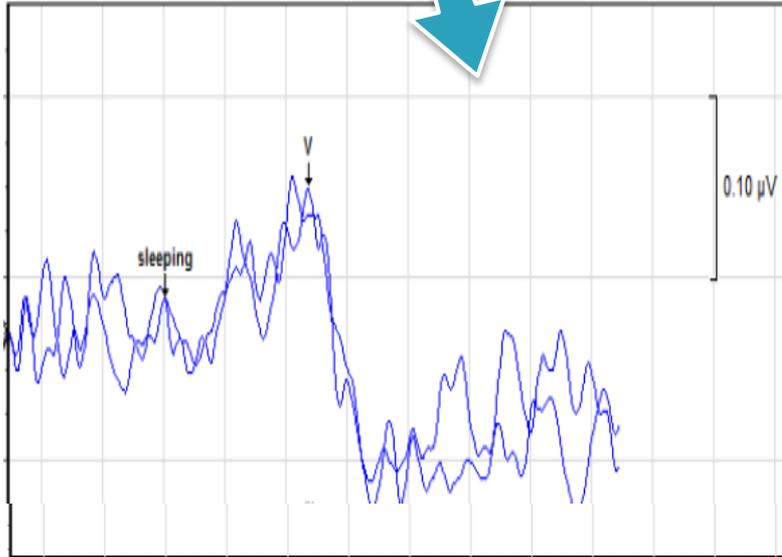
- Ongoing EEG was very quiet-no need to invoke Kalman Filter
- Clear peak and trough
- Replicated waveforms

Sleeping

vs.

Awake

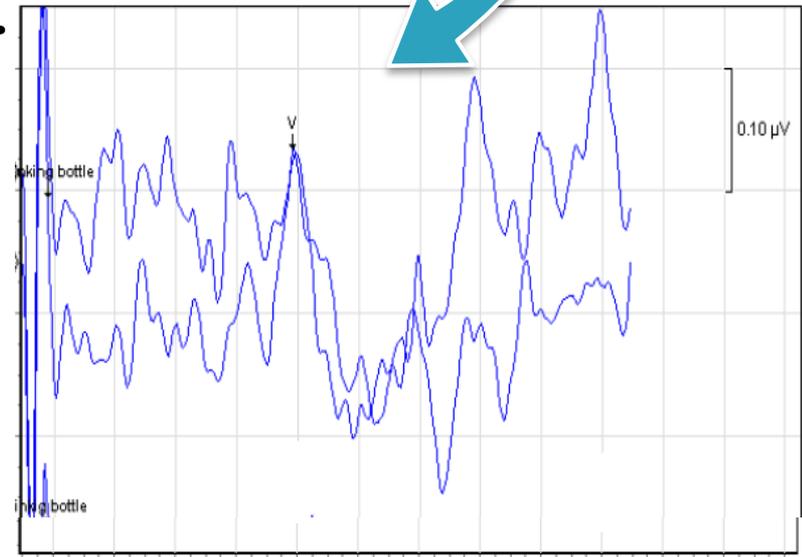
20
dBnHL



0 2 4 6 8 10 12 14 16 18 20
22 24

Time (ms)

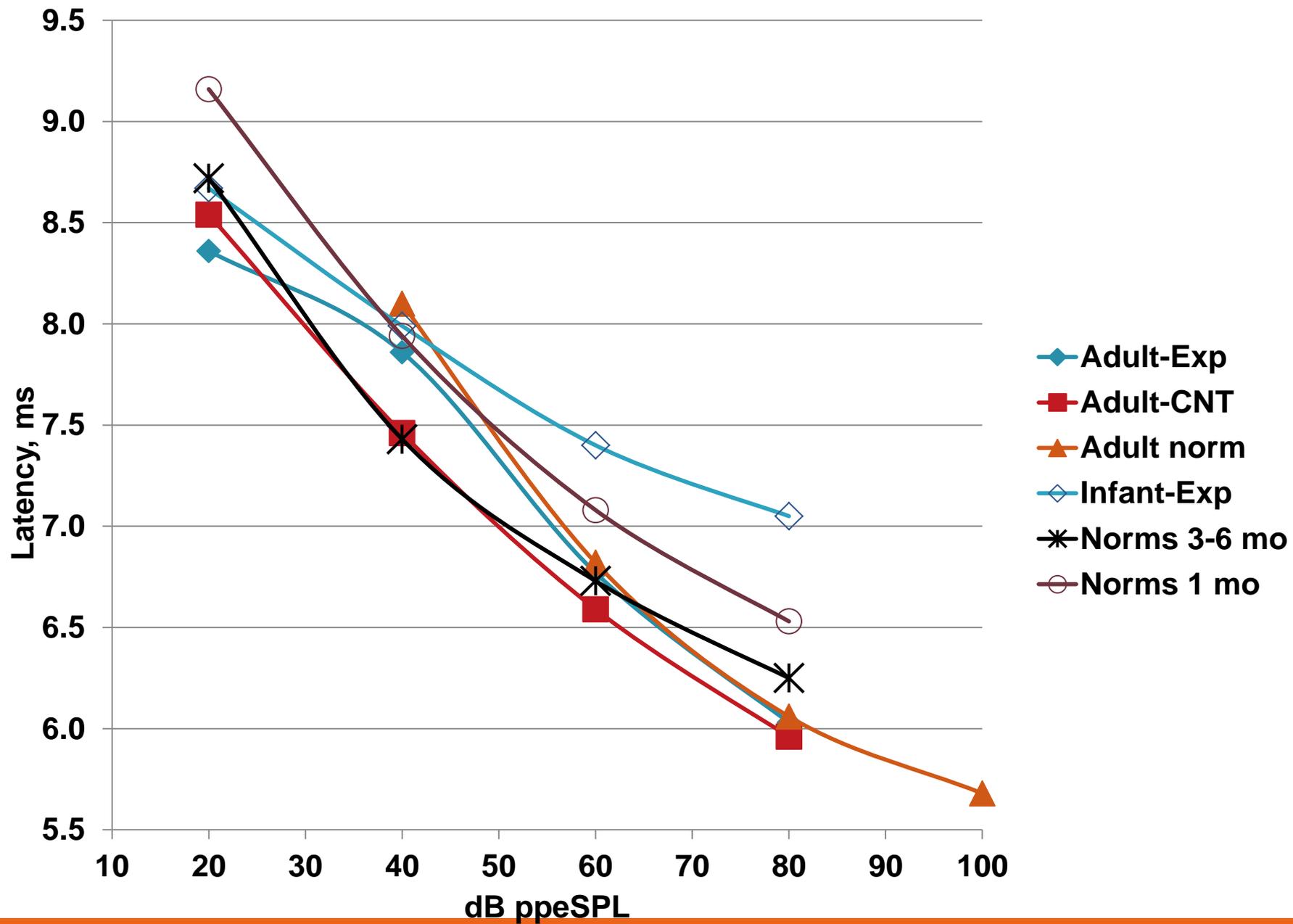
**299 and 331
equivalent sweeps**



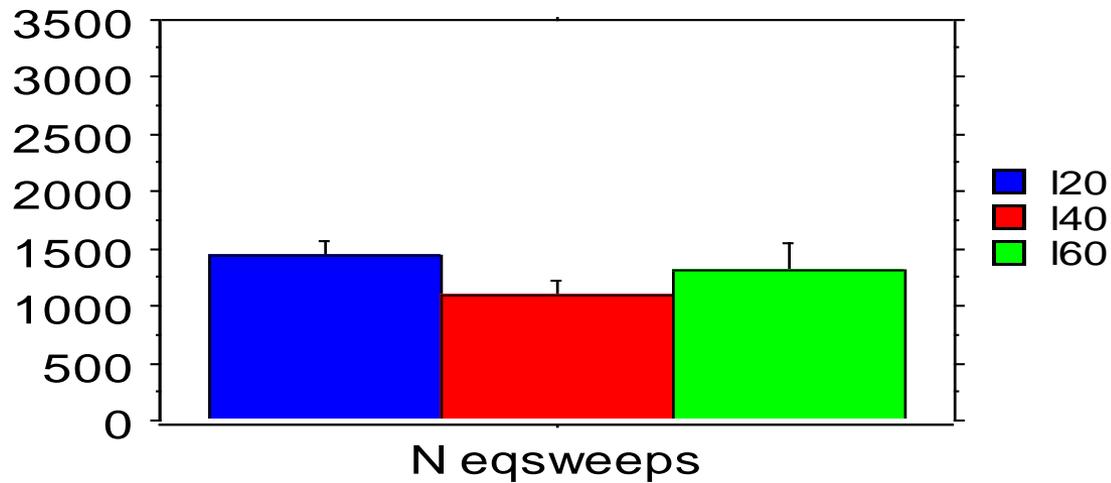
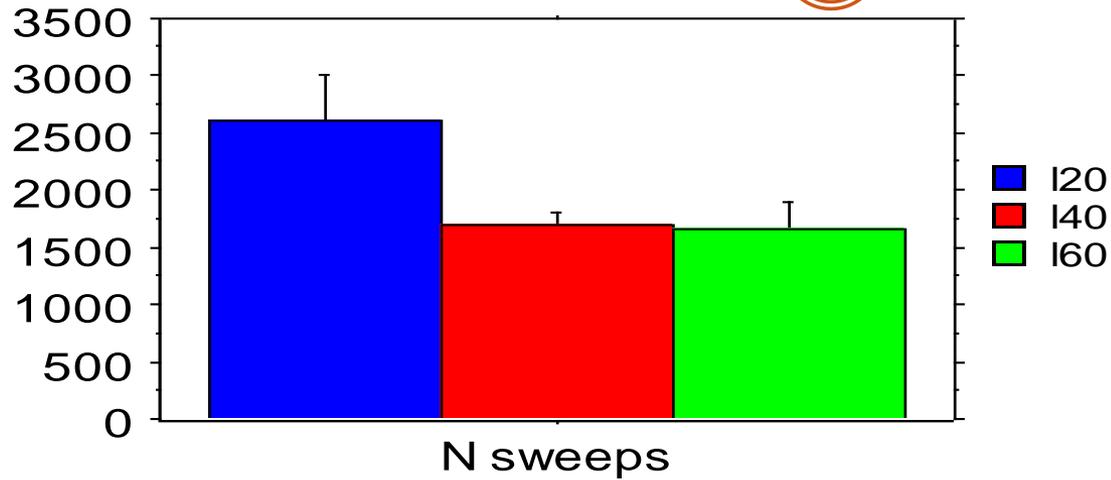
0 2 4 6 8 10 12 14 16 18 20
22 24

Time (ms)

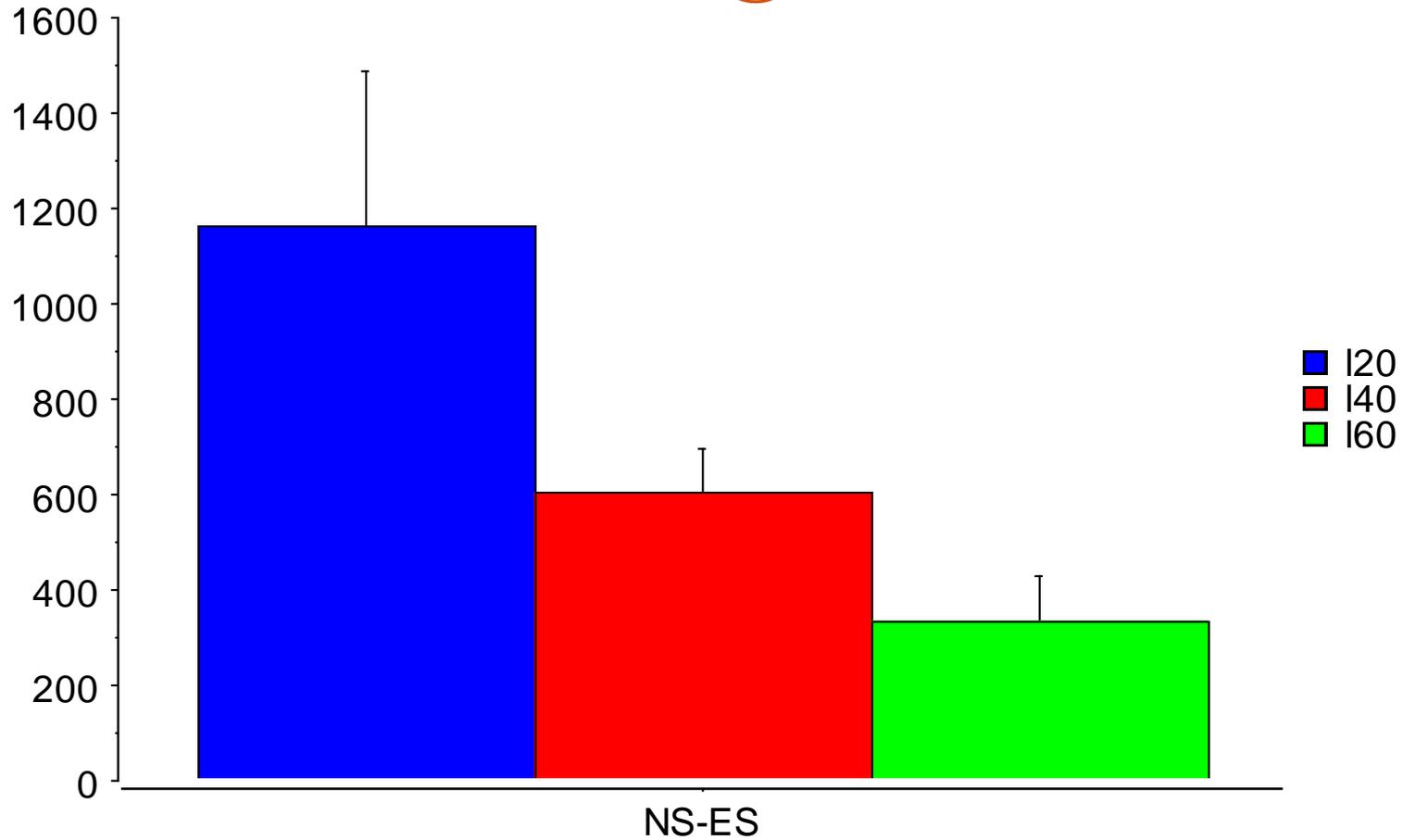
**2257 and 1006
equivalent sweeps**



Number of Sweeps (averages)



N Sweeps minus Equivalent Sweeps



Discussion



- Clinical verification indicated that the Vivosonic system could be used to obtain ABRs at near threshold levels in infants who were awake during testing.
- Clinician subjectivity regarding “acceptable noise level” during testing will affect results.
- On-line measures of response and noise levels are needed to provide clinicians the tools they need to make accurate estimates of thresholds from ABR tests.