The Parallel Auditory Brainstem Response (pABR)

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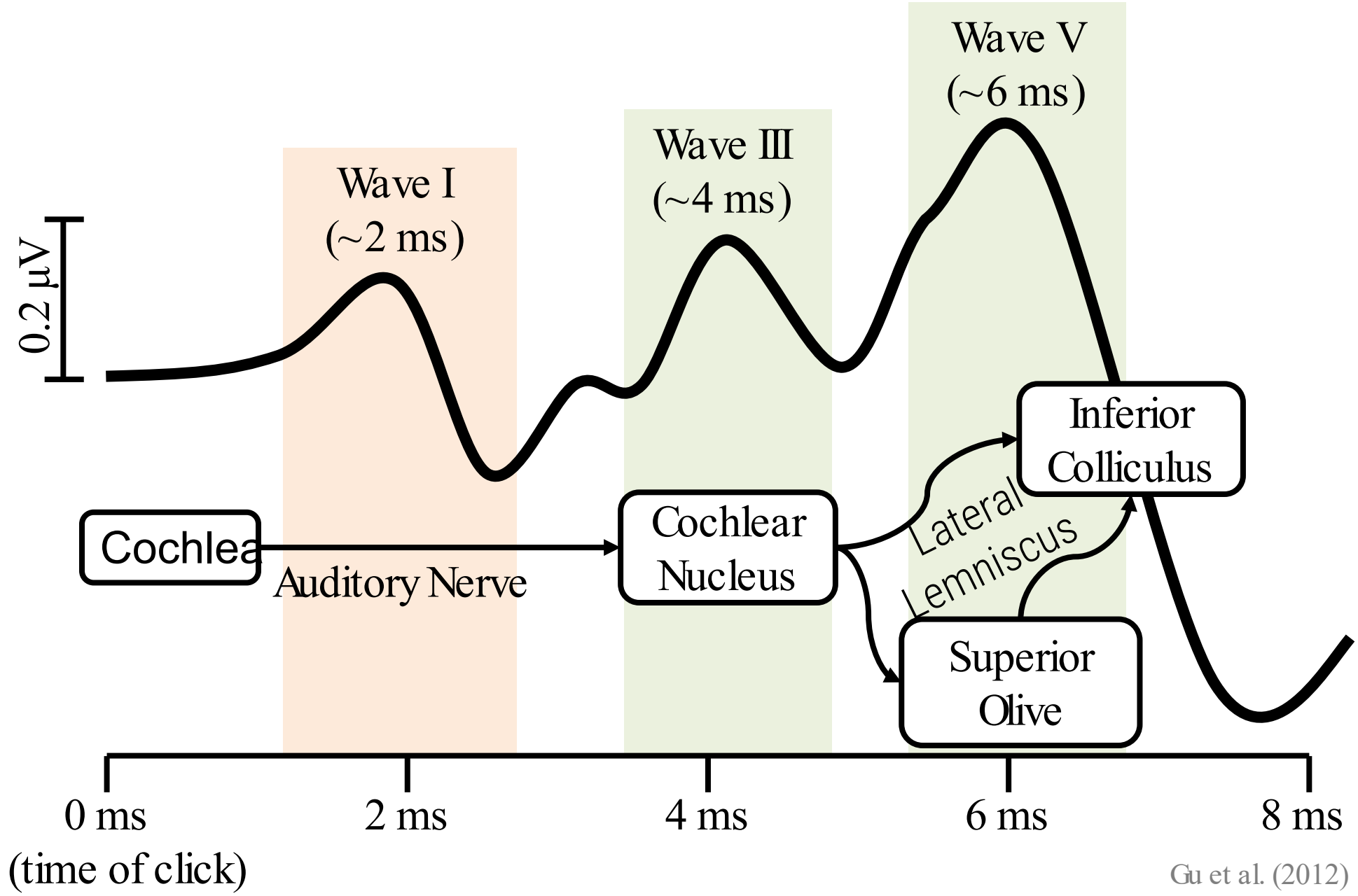
Dr. Thomas Stoll Penelope Corbett

Outline

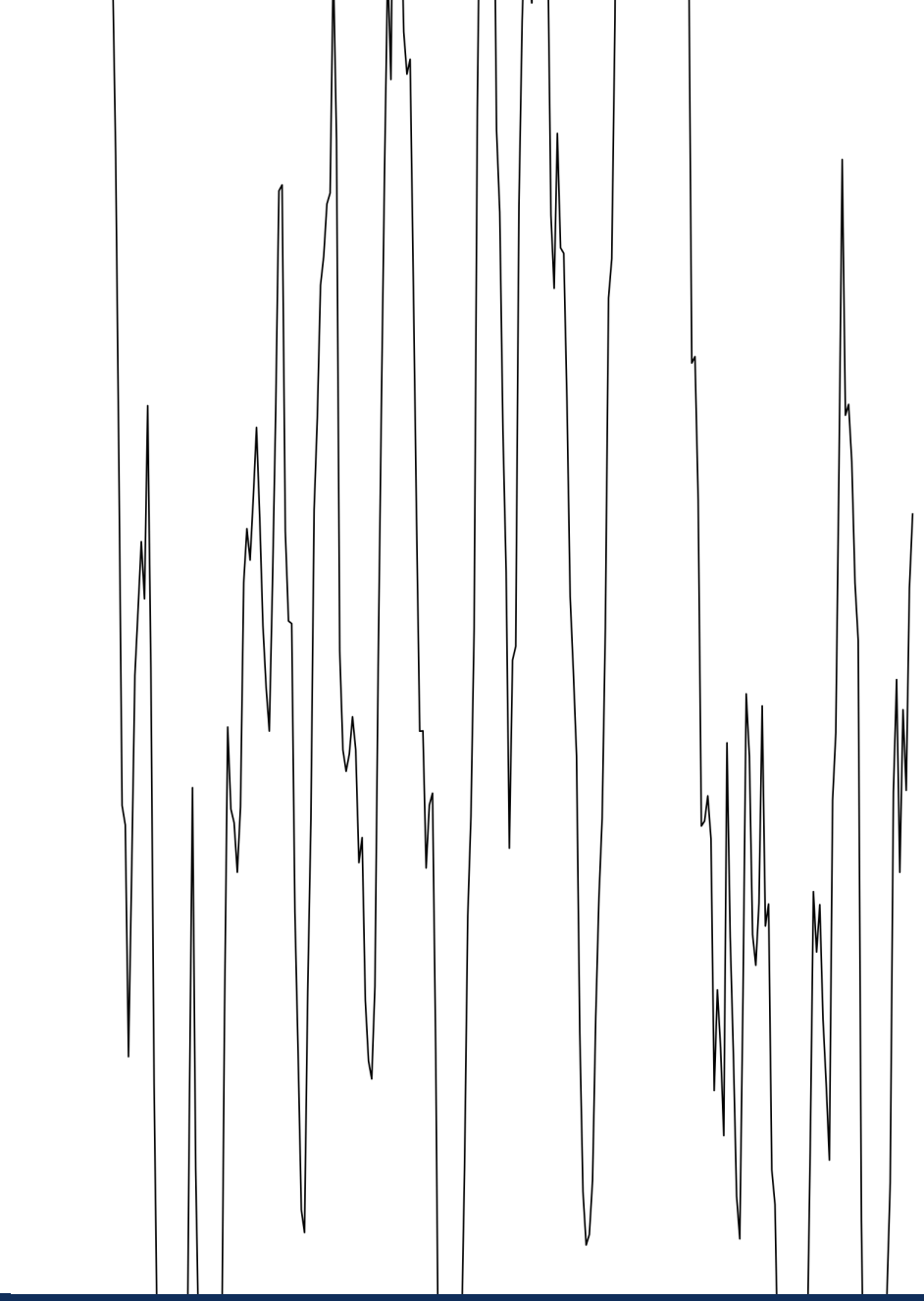
1. Why do we need the pABR?
2. How does the pABR work?
3. Is the pABR place specific?
4. What will the pABR look like in clinical use?
5. How does the pABR compare to the ASSR?
6. What future opportunities does the pABR provide?

Part 1

Why do we need the pABR?


Wave V
(~6 ms)
Wave III
(~4 ms)
Wave I
(~2 ms)
0.2 μV
Inferior
Colliculus
Lateral
Lemniscus
Cochlea
Auditory Nerve
Cochlear
Nucleus
Superior
Olive
0 ms
(time of click)
2 ms
4 ms
6 ms
8 ms

Gu et al. (2012)





ABR Pros and Cons

- ABR reflects synchronous activity in subcortical nuclei following a transient sound.
- Frequency-specific stimuli can be used to stimulate specific portions of the tonotopic axis.
- ABR is mostly unaffected by sleep, anesthesia, cognitive state.
- The ABR is *very small* compared to the ongoing noise in the EEG—many sweeps are needed.

Diagnostic ABR

- Diagnostic ABR uses frequency-specific stimuli to estimate hearing thresholds.
- Presence of a response indicates a sound at that frequency, level, and ear is encoded by the auditory system.
- Diagnostic ABR functions as an "objective" version of the pure-tone audiogram.

ABR problems

- Full tone burst ABR exam takes a very long time.
  - 2 ears, 4 frequencies, multiple levels = many measurements.
  - Measurements taken in serial, one at a time.
  - Sacrifices often made due to time constraints.

- Sometimes necessitates sedation to prevent movement artifacts.
  - Costly, time-consuming, increased risk (FDA, 2017).

Part 2

How does the pABR work?

Potential solution

- Record different frequencies and ears simultaneously **in parallel**

- Made possible by randomizing stimulus timing.
  - Mathematically disentangle separate responses.



clicks 500 Hz 1 kHz 2 kHz 4 kHz 8 kHz parallel

Periodic versus random timing

- Standard ABR stimulus trains are periodic, range from 10 to 80 clicks / s.

- Higher rates restrict analysis window.
  - Randomized sequences get around that.
    (e.g., Burkard et al., 1990; Thornton & Slaven, 1993; Delgado and Ozdamar, 2004).

- Independent randomized sequences allow simultaneous measurement.

pABR analysis paradigm

Goals

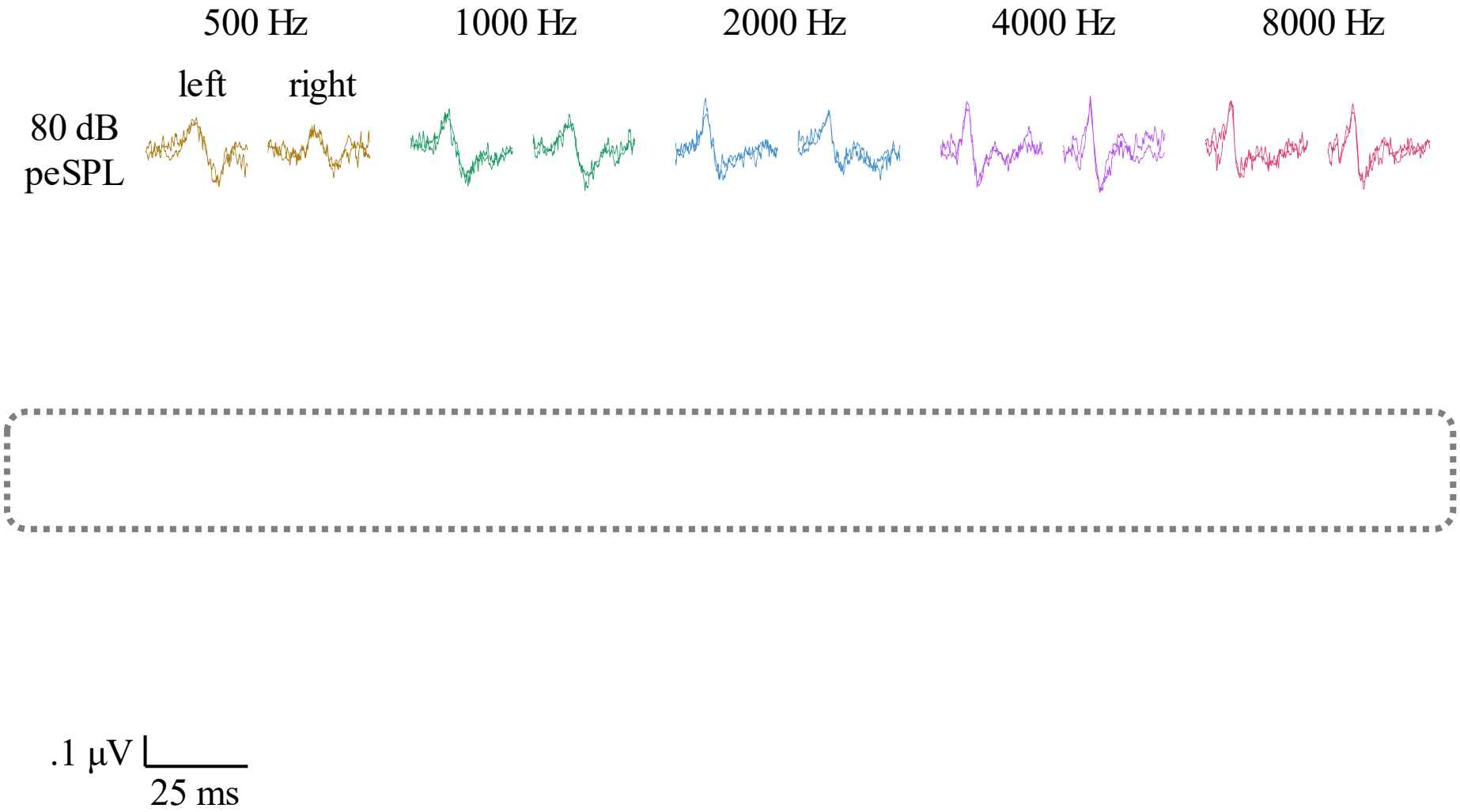
1. Decreased acquisition time
   - Testing all frequencies at once should speed exam

2. More accurate results
   - Faster test allows more data points, better SNR
   - Parallel presentation may improve place specificity on the cochlea

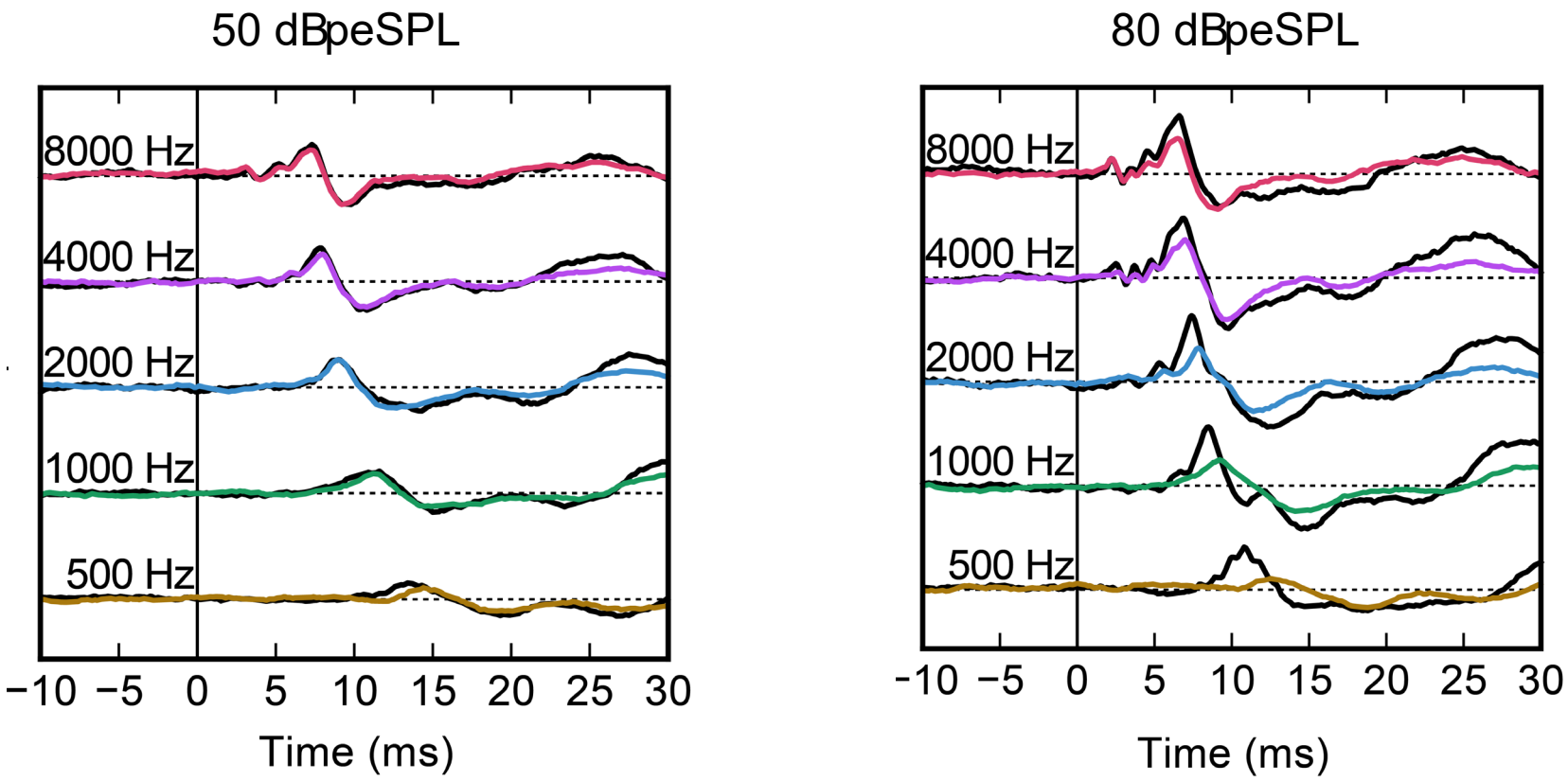
Part 2

Performance of the parallel ABR

Single subject intensity series

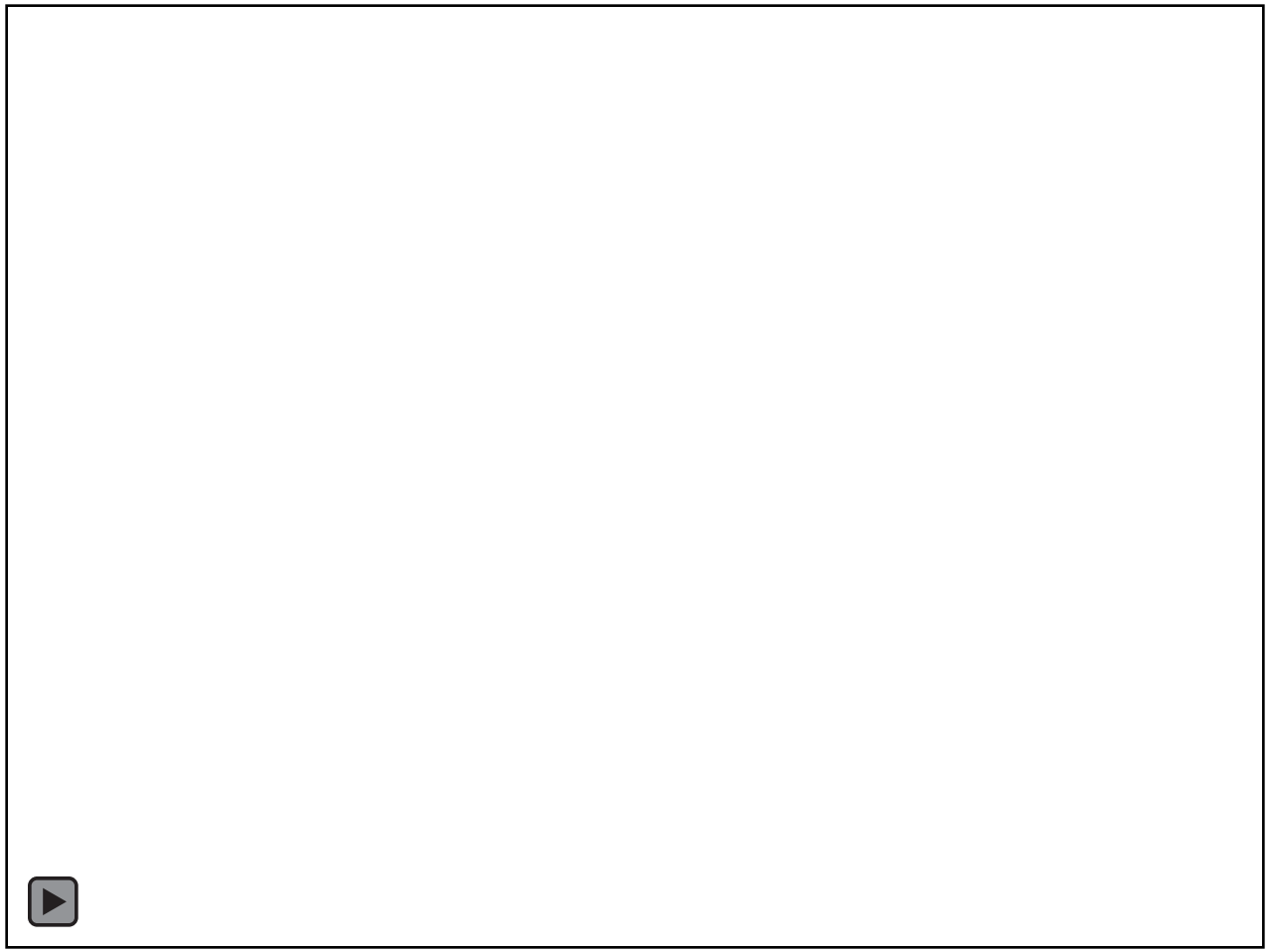


Parallel vs serial waveforms

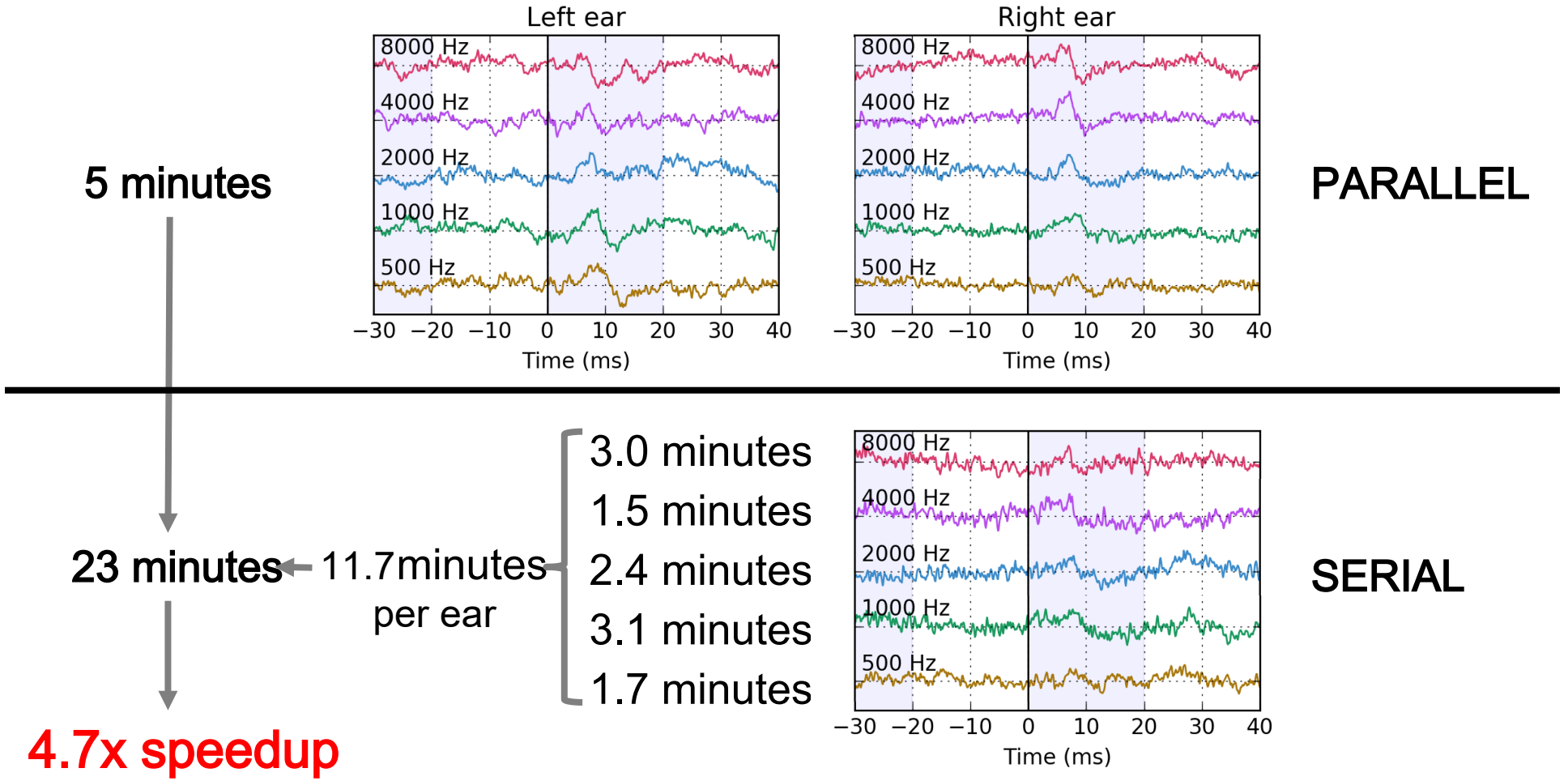


Polonenko & Maddox, 2019

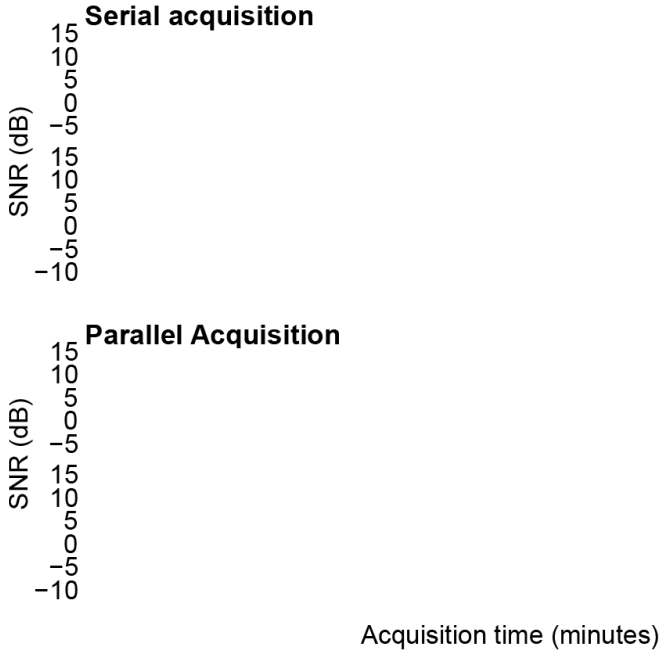
Sample acquisition at 50 dB SPL

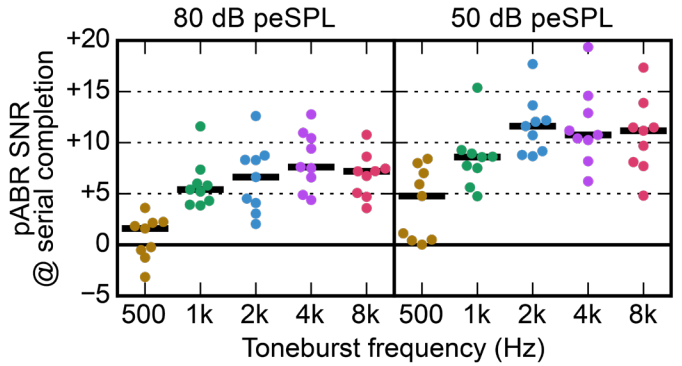


Sample acquisition at 50 dB SPL



Parallel ABR shortens acquisition





Median time-to-target-SNR improvement:

- **1.4x speedup** @ high intensity
- **3.0x speedup** @ low intensity

Polonenko & Maddox, 2019

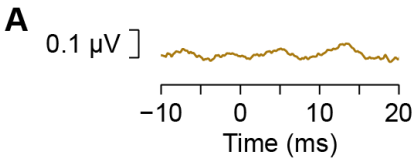
Parallel ABR shortens acquisition

- Speedup roughly 2x, depends on intensity

- Why isn't the speedup 10x?
  1. Parallel acquisition limited by the slowest channel
  2. Parallel acquisition gives slightly smaller responses

- True gains will depend on many factors
  - Must be tested in a clinic-like setting

Parallel ABR shortens acquisition



- Added context improves visual waveform detection (longer analysis windows for free)
- Non-measurement time highly reduced
  - No deciding which frequency to run next

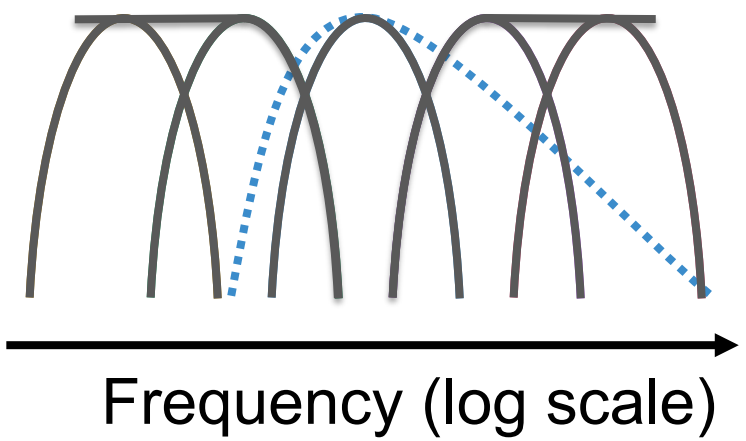
Polonenko &Maddox, 2019

Part 3

Is the pABR place specific?

Place specificity

Ideal diagnostic test would be highly place specific on the cochlea.



Central idea: different stimulus frequencies interfere with each other ~~and~~ *and this is a good thing*.

Place specificity

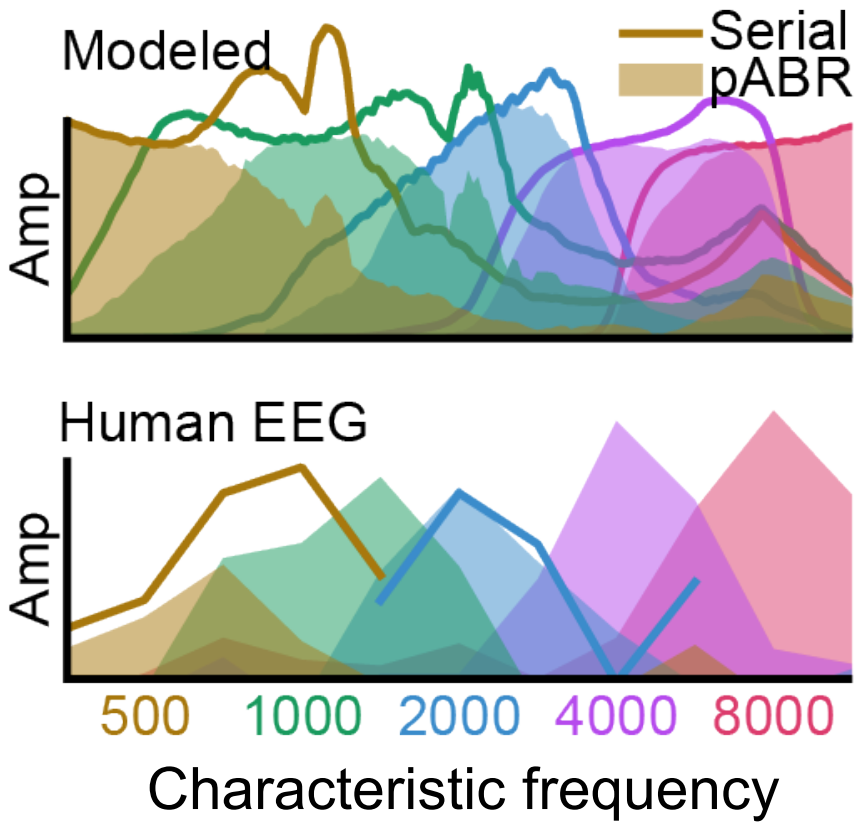
We cannot make recordings from specific places of the human cochlea

- No direct test of place specificity

- We can use modeled responses
- We can use derived-band responses

Standard versus pABR place specificity

- Modeling and EEG both show that the pABR is place specific
- Better place specificity at lower frequencies than standard methods
- Interference between stimuli on the cochlea is a good thing

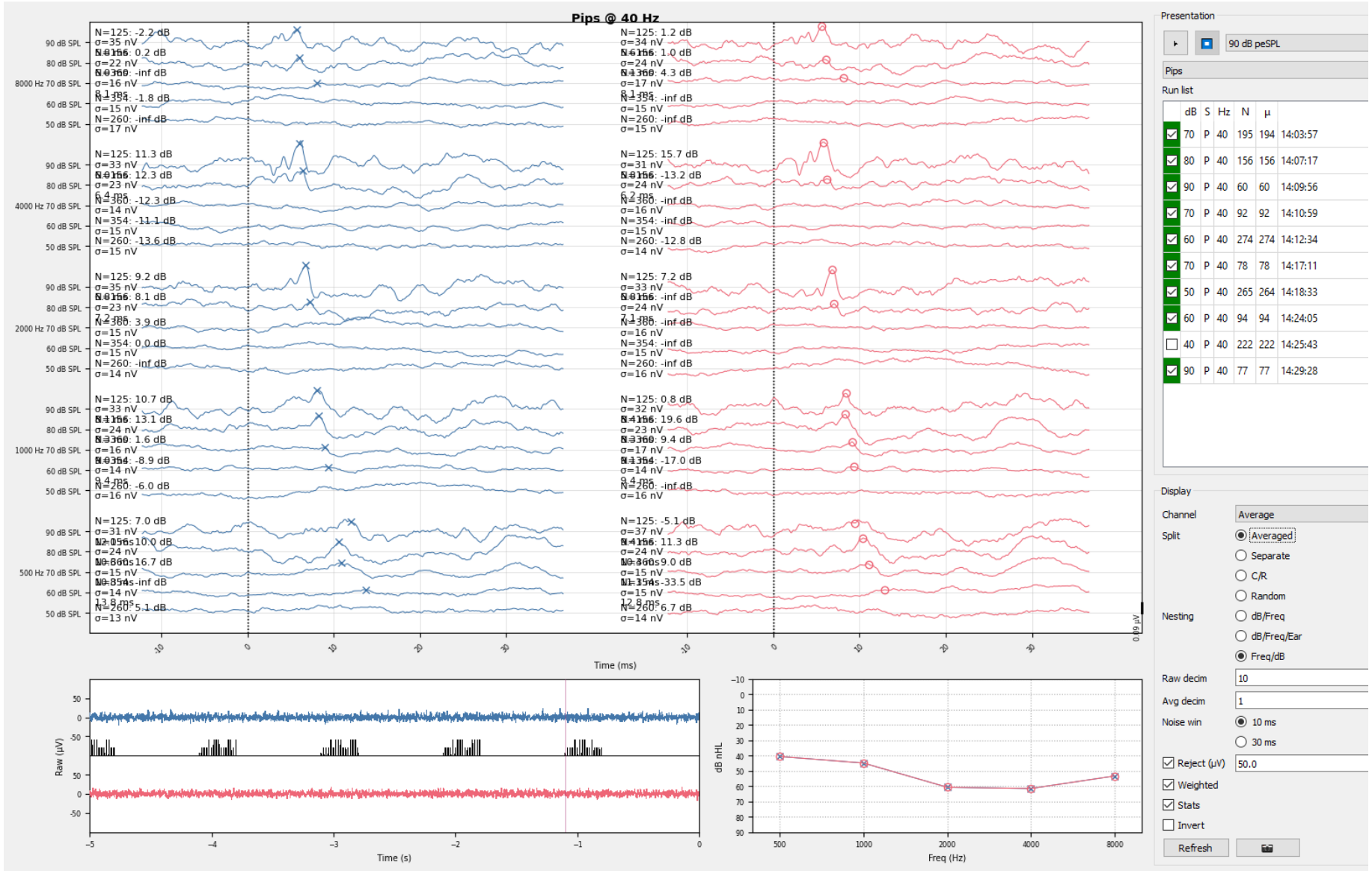


Part 4

What will the pABR look like in clinical use?

Practical considerations

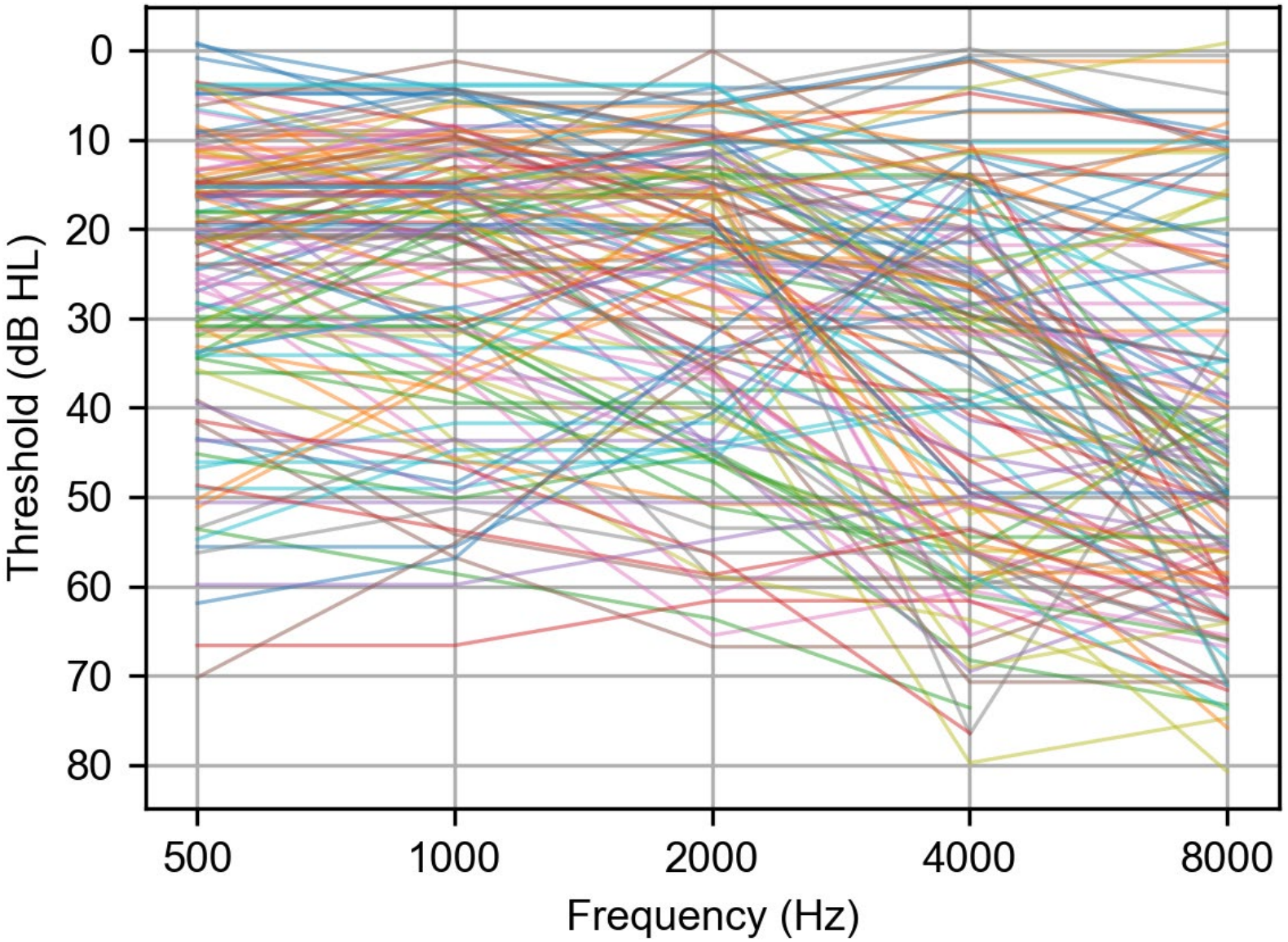
- Threshold search is totally different.
- No longer need to choose frequency or ear.
- Only search over level:
  - Start all exams at moderately high level (50 dB eHL)
    - Move to lower level if responses (20 dB eHL).
    - Move to higher level if not.


Pips @ 40 Hz
Time (ms)
Raw (µV)
Time (s)
dB nHL
Freq (Hz)
Presentation
90 dB peSPL
Pips
Run list
dB S Hz N µ
70 P 40 195 194 14:03:57
80 P 40 156 156 14:07:17
90 P 40 60 60 14:09:56
70 P 40 92 92 14:10:59
60 P 40 274 274 14:12:34
70 P 40 78 78 14:17:11
50 P 40 265 264 14:18:33
60 P 40 94 94 14:24:05
40 P 40 222 222 14:25:43
90 P 40 77 77 14:29:28
Display
Channel
Average
Split
Averaged
Separate
C/R
Random
Nesting
dB/Freq
dB/Freq/Ear
Freq/dB
Raw decim
10
Avg decim
1
Noise win
10 ms
30 ms
Reject (µV)
50.0
Weighted
Stats
Invert
Refresh

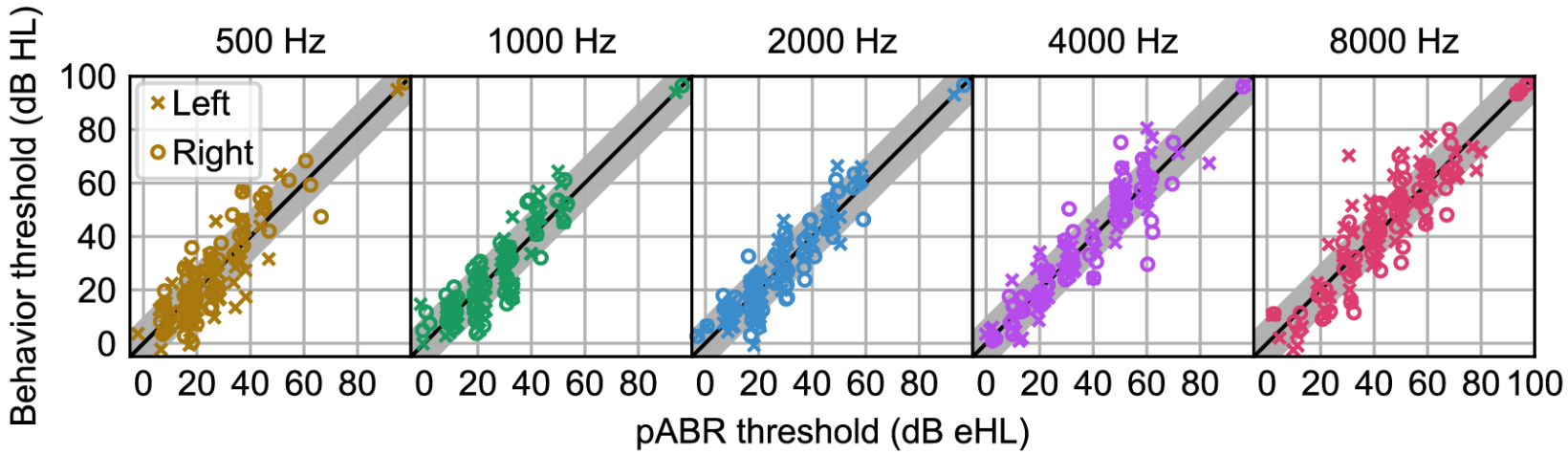
Is it accurate?

Design:

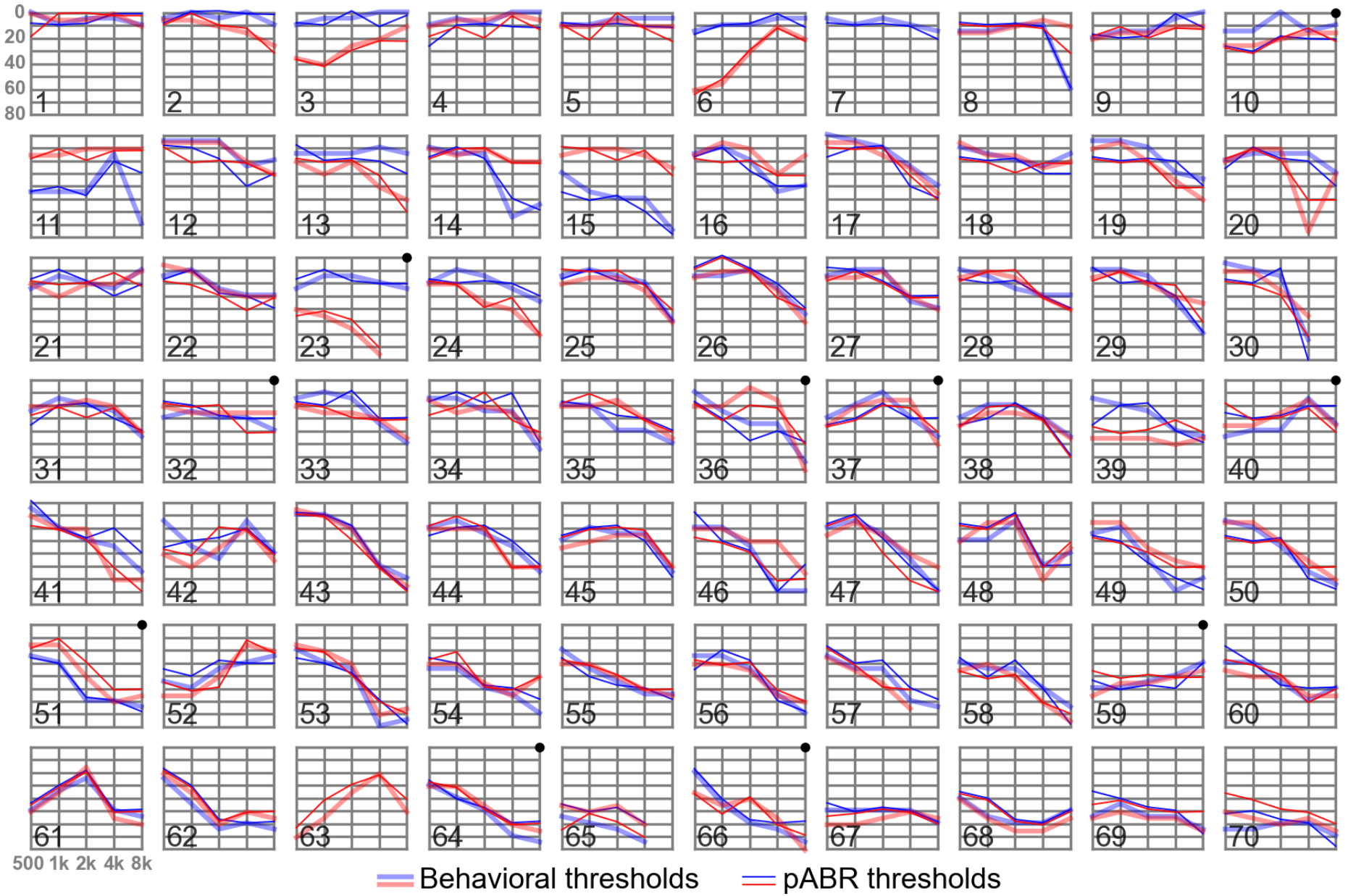
- 70 adult subjects with widely varying hearing loss configurations
- Measure behavioral audiogram
- Measure pABR thresholds
- In ten subjects:
  Compare pABR and standard ABR speeds


0
10
20
30
40
50
60
70
80
Threshold (dB HL)
500
1000
2000
4000
8000
Frequency (Hz)

pABR is highly accurate



- Overall pABR-audiogram correlation of 0.9 ± 0.02
- 79% of thresholds within one step size of 10 dB
  - 90% within 14 dB

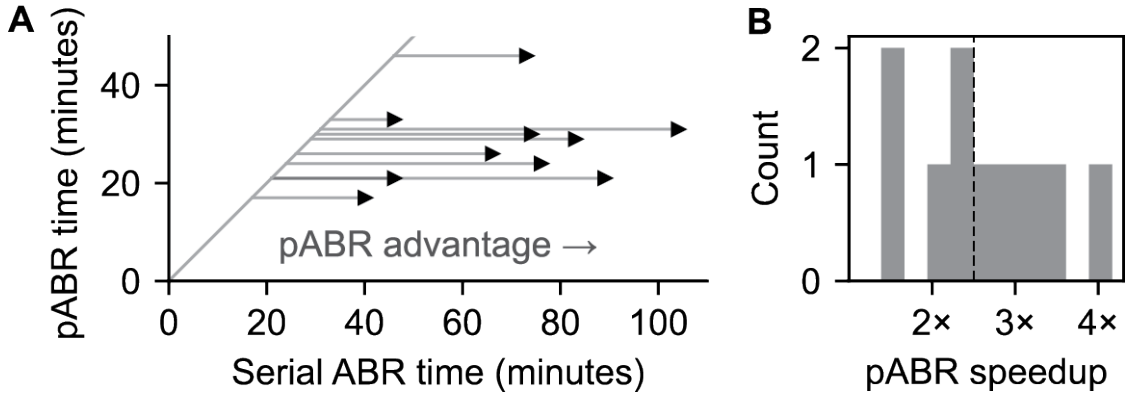

0
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50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
500 1k 2k 4k 8k
Behavioral thresholds
pABR thresholds

pABR is very fast

- Median to collect all 10 thresholds: 32 minutes
  - 3.2 minutes per *threshold*
- Median to confirm normal hearing: 11 minutes
  - 1.1 minutes per ear-frequency combination
- Much more complete information from exams of similar duration

pABR is very fast

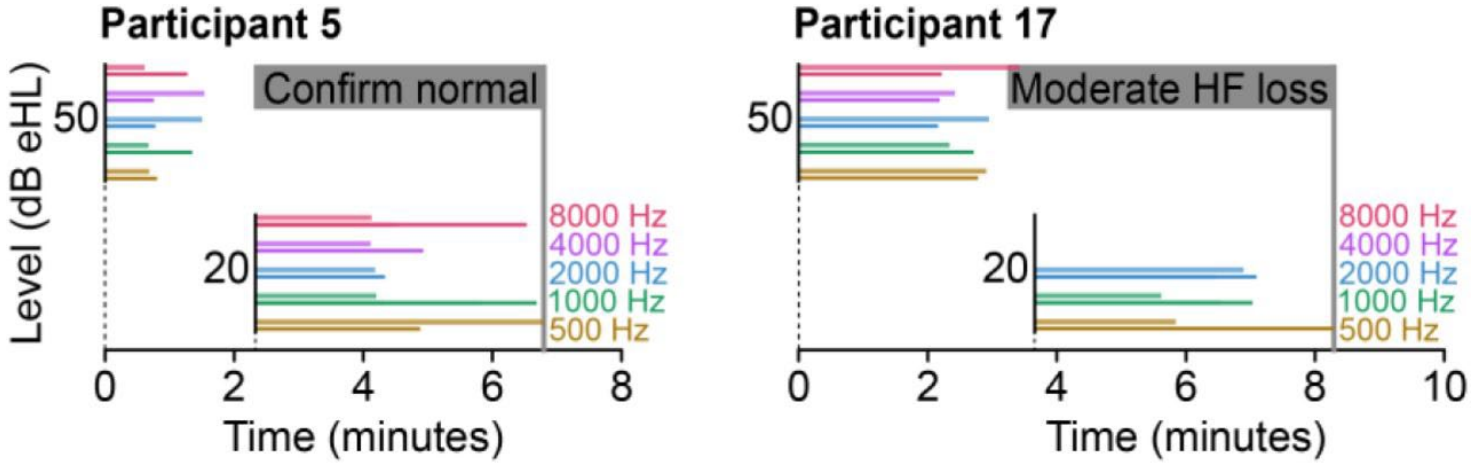
- 10 subjects invited back to do ABR again using standard system (Interacoustics Eclipse)
  - 8 thresholds measured: 500–4000 Hz in each ear



- pABR faster in every subject (28 min vs 70 min)
- Median speedup: 2.5×

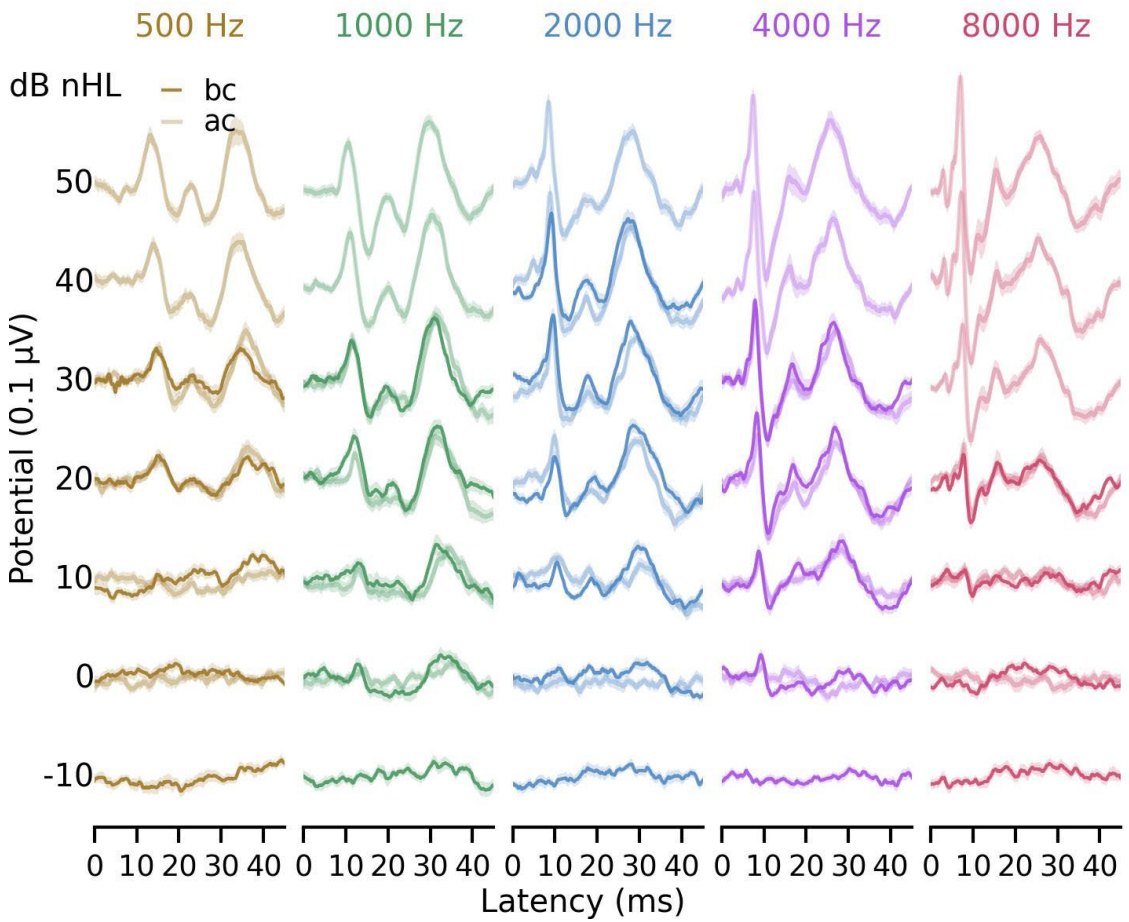
What if a session is cut short?

- Audiologists (and parents) know: *babies wake up*
  - Janssen et al (2010): 20% of natural sleep exams end before 24 minutes
- Standard ABR: only get some thresholds
- pABR: information for all ear-frequencies at some levels (threshold bracketing)

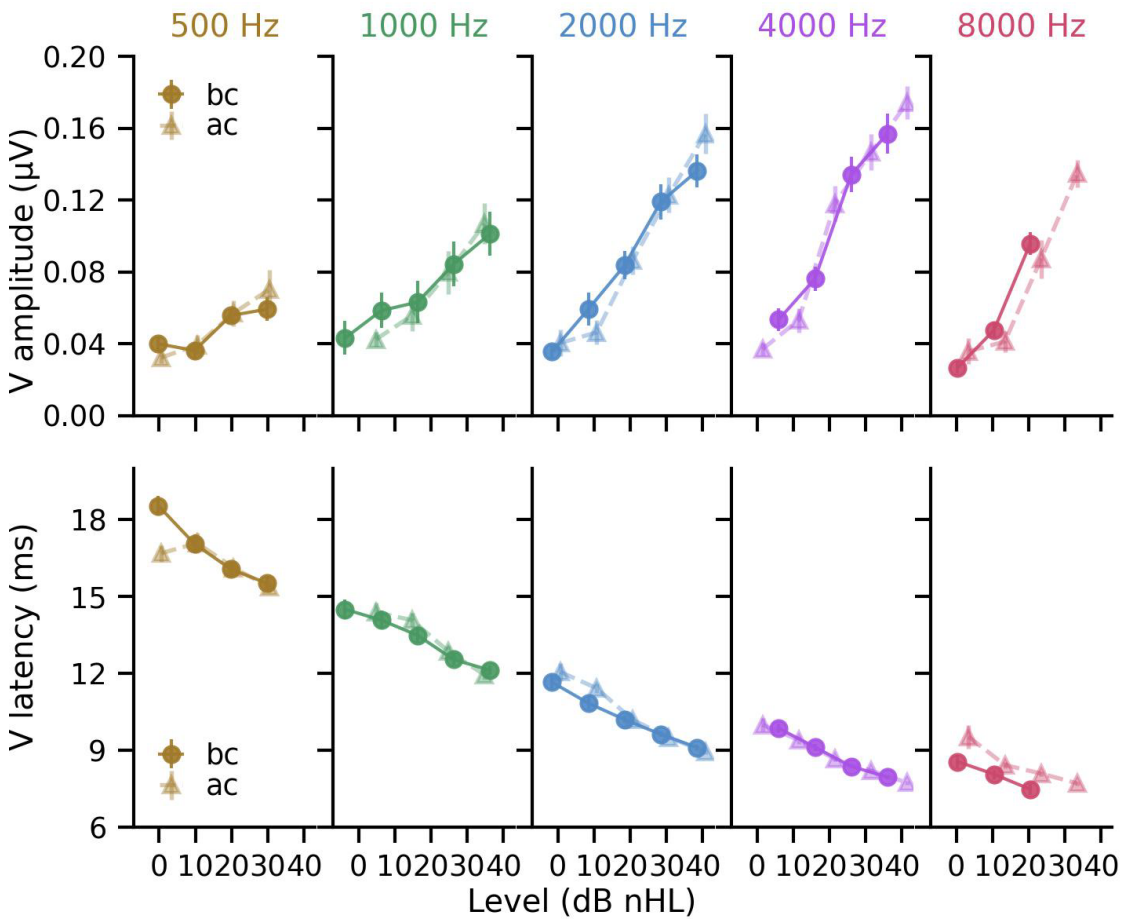


pABR can be used with bone-conduction

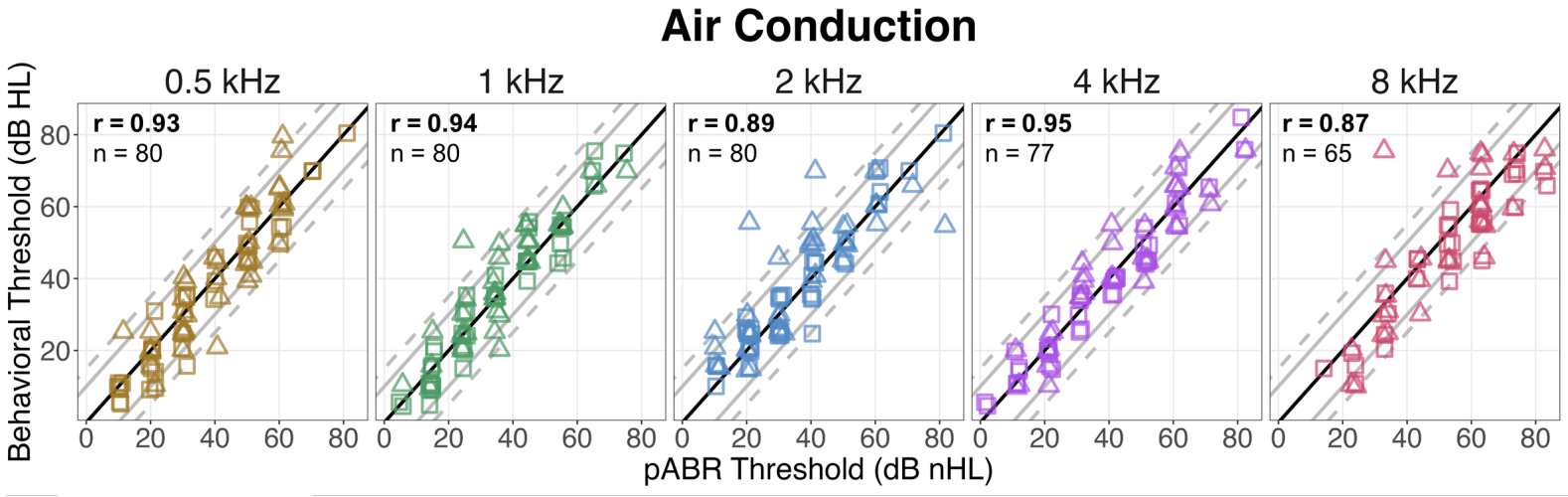
BC can be used with pABR up to 30 dB nHL

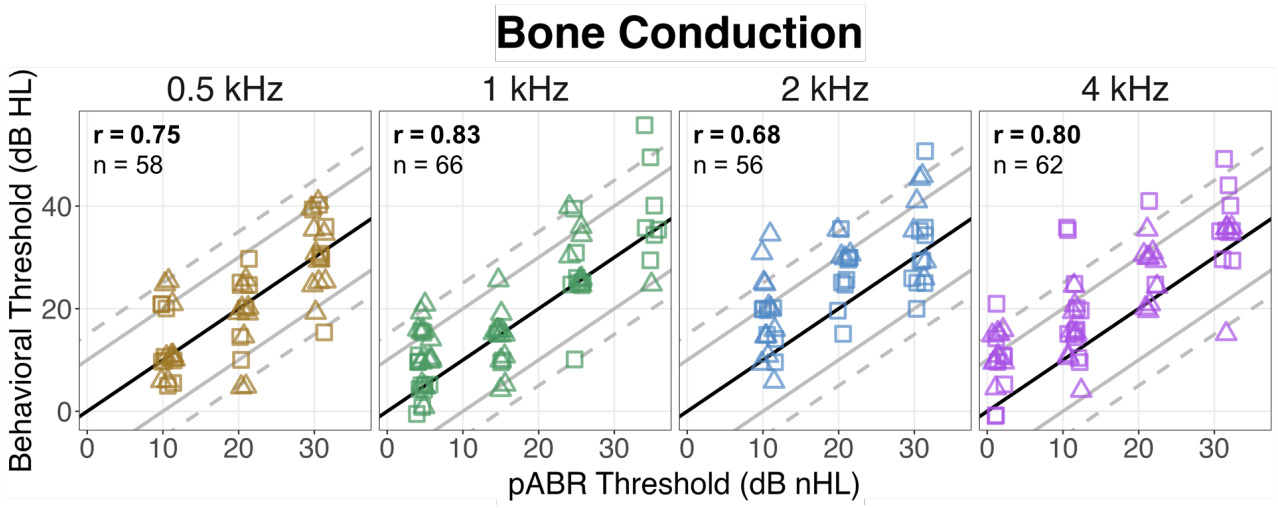


Wave V is similar for air- and bone-conduction



Accurate threshold estimates for AC and BC





Type of Hearing Loss

□ Sensorineural (N=20)

△ Conductive/Mixed (N=20)

* Not corrected to eHL yet

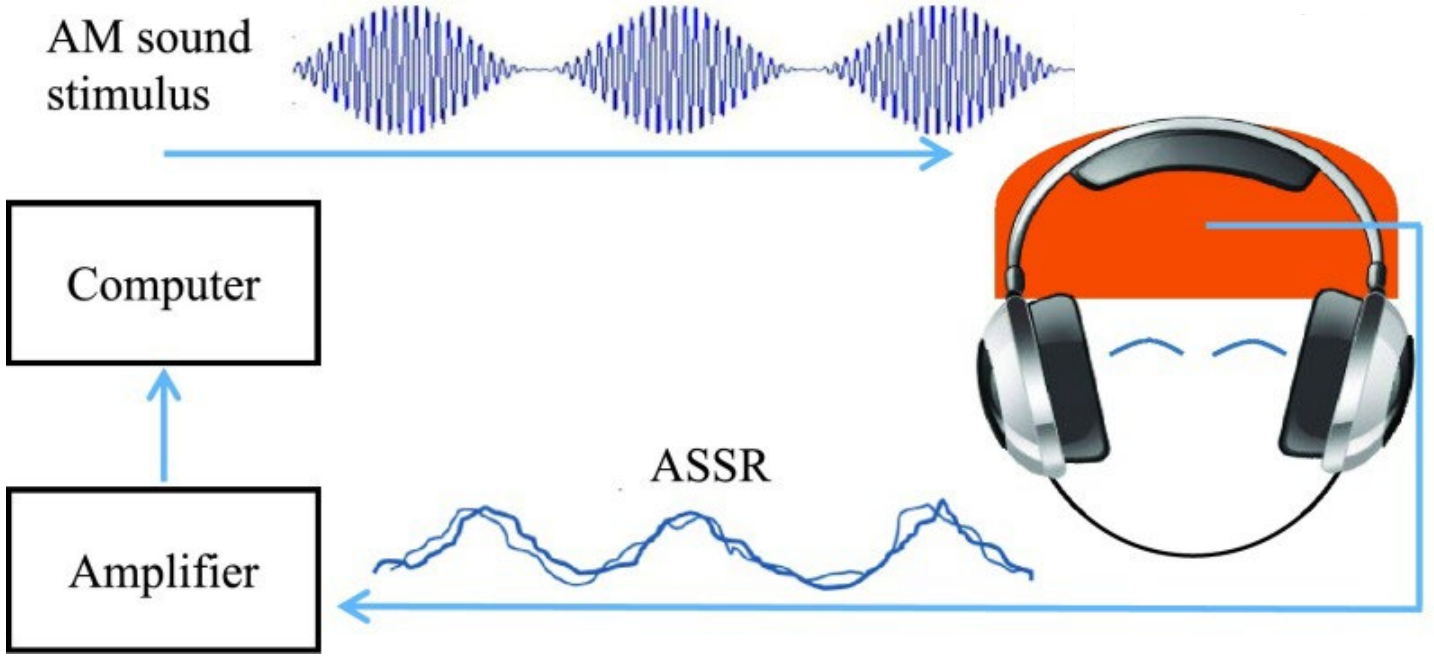
Part 5

How does the pABR compare to the ASSR?

Auditory steady state response

- The ASSR is an existing method that allows frequencies and ears to be measured simultaneously.
- Probe tones at audiometric frequencies are modulated at frequencies ~80 Hz.
- Presence of modulation frequencies in EEG can be used to estimate thresholds.

Auditory steady state response



Von Rosenberg et al, 2016

ASSR advantages

- ASSR shares many advantages of the pABR:
  - Multiple frequencies measured simultaneously (Lins &Picton, 1995)
  - Faster threshold determination (Sininger et al, 2019)
  - Good place specificity (Herdman et al, 2002)

ASSR disadvantages

- No waveforms
  - Cannot be used to diagnose auditory neuropathy spectrum disorders (ANSD)
    - Still need the ABR (JCIH, 2019)
  - Wastes expertise in interpreting responses
  - Cannot use later response components offered by pABR
- Can show spurious responses in people who are profoundly deaf (Swanepoel et al, 2008)
- Has seen limited clinical uptake

Related techniques have been used for recording transient evoked reponses. For example, Plourde et al. (1988) described how ''interweaving'' and ''overlapping'' can be used to record evoked potentials from concurrent trains of stimuli presented in different modalities or different locations within a modality. Recently, Fausti et al. (1994) have used a ''multiple-stimulus method'' to record auditory brain-stem responses to different high-frequency tone bursts. The steady-state techniques are more powerful since they are not restricted by minimum interstimulus intervals.

The pABR offers the combined benefits of the standard ABR and the ASSR and avoids their weaknesses.

Part 6

What future opportunities does the pABR provide?

Near-term next steps

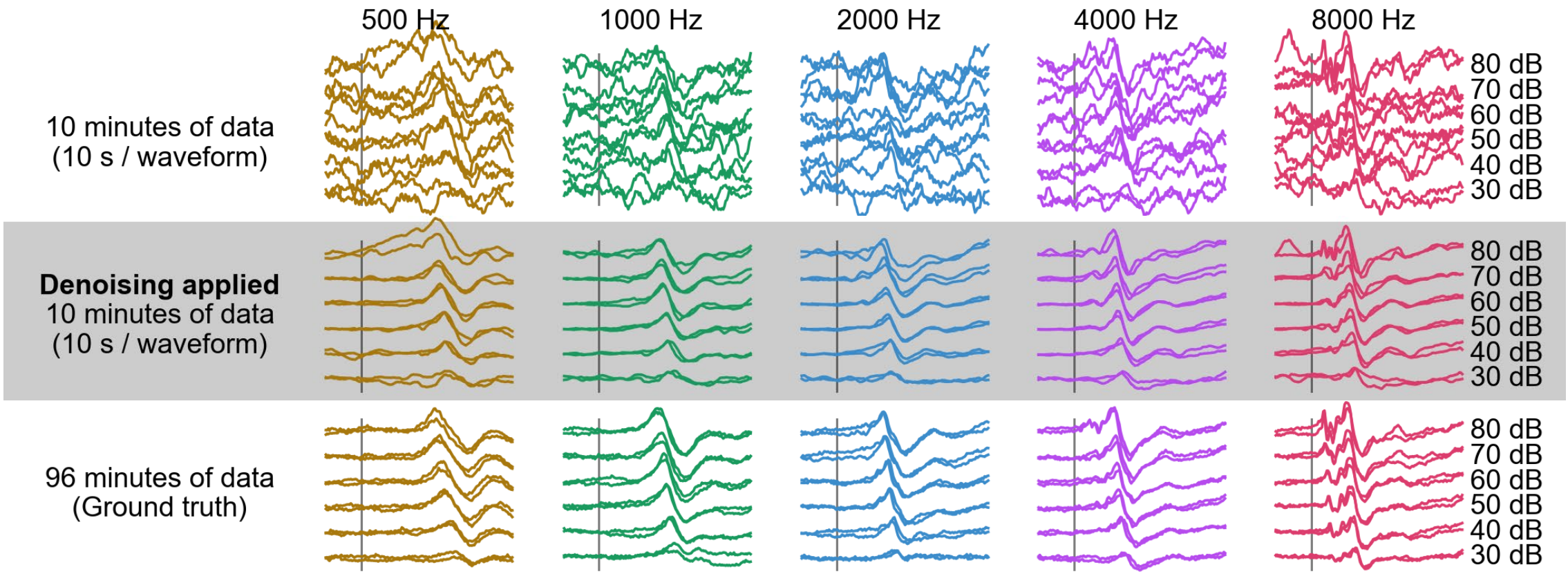
- Test in infants—stay tuned!
- Investigate use as a frequency-specific screener.
  - Collaborating with Seattle Children's.
- Develop pABR-specific denoising tool.

Longer-term possibilities

- Loss to follow-up after failed screen is 46% in Michigan (EHDI).
  - Highly variable from county to county (and state to state)

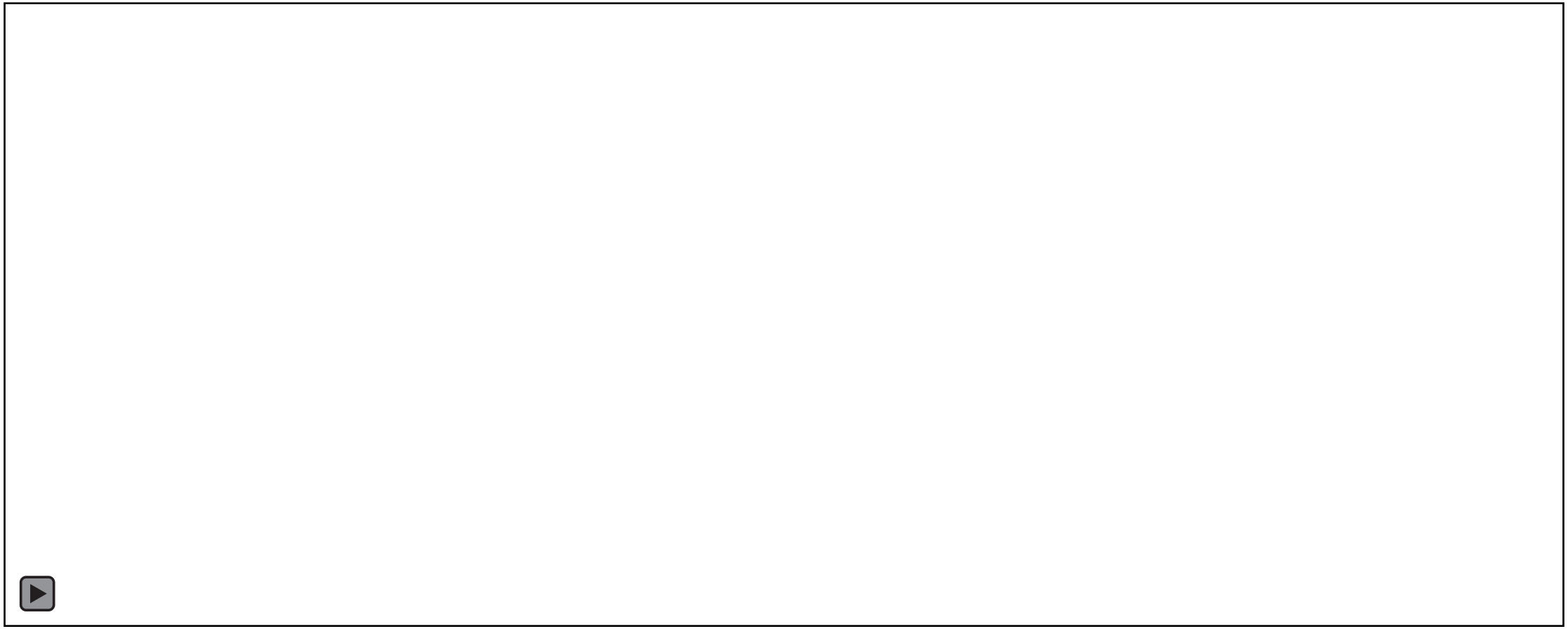
- In radiology: a technician makes measurements freeing the expert (possibly at another site) to diagnose and consult with patients.
  - Paradigm not currently possible for ABR—audiologist needed to guide the interactive threshold search.
  - Can we just record all waveforms for offline diagnosis?

Denoising based on the pABR



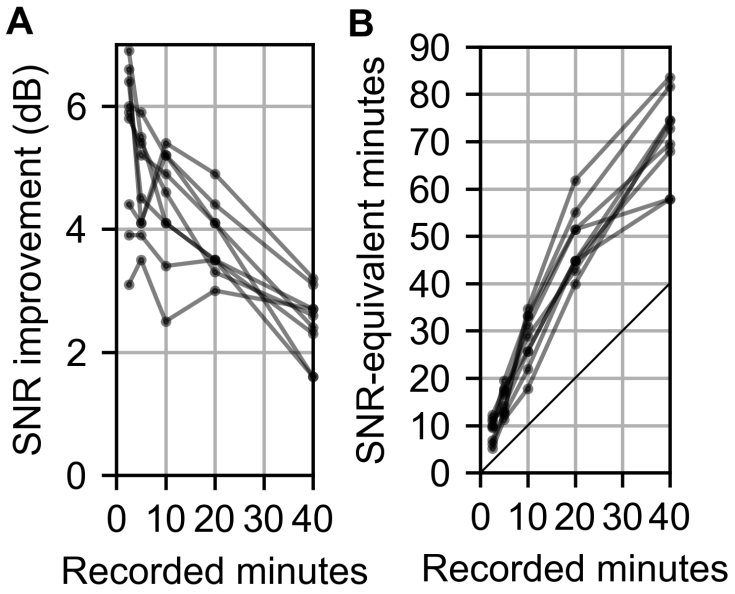
Maddox, 2025, patent WO2025072978A1

Denoising based on the pABR



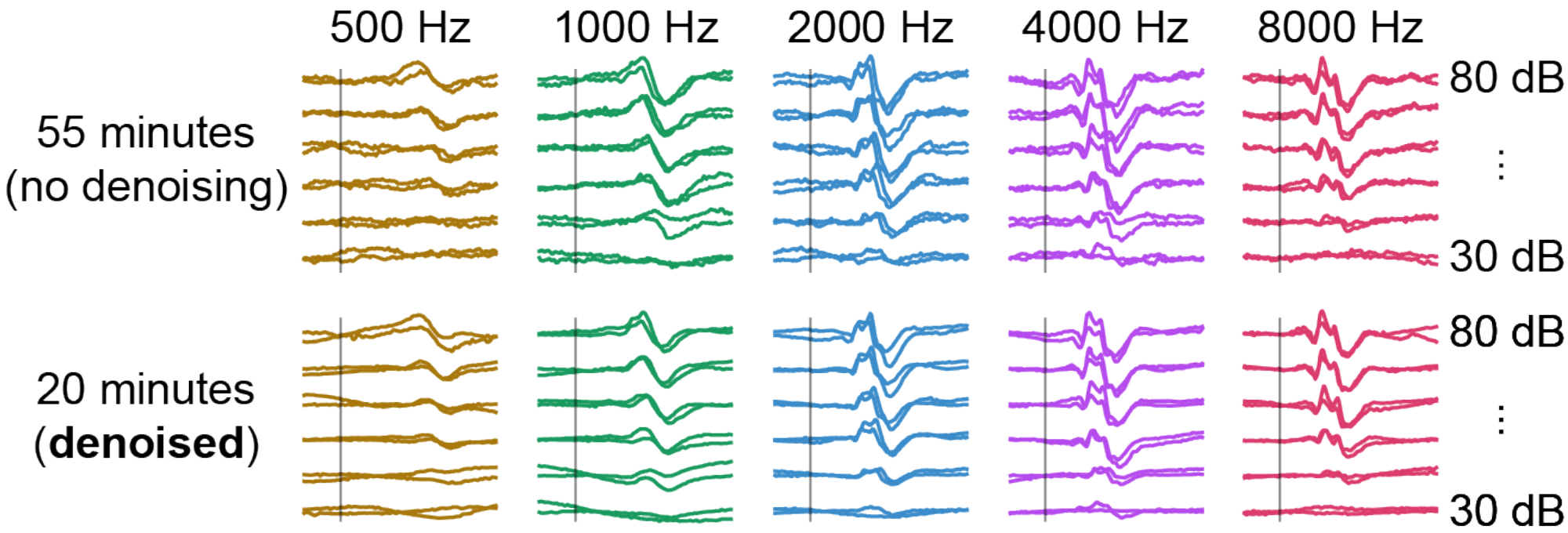
Maddox, 2025, patent WO2025072978A1

Denoising based on the pABR



- Denoising leads to drastic SNR improvements.
- Ability to collect 50 minutes worth of data in 20 minutes.
- Entire response series collectable in a single session.

Denoising infant pABR data



Concluding thoughts

Comparison with existing methods

- The pABR offers many advantages:
  - Simultaneous waveform collection across frequency, ear
  - Better place specificity at lower freqs, higher levels
  - Simplified threshold search (vary level only)
  - Possible use of later waves (MLR)
  - Bone conduction capabilities (ASSR struggles)
  - Denoising to eliminate threshold search (in progress)

- Main disadvantages:
  - Not available on current hardware

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