Prediction of the audiogram in adults & older children using the N1-P2 long latency response

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Summary of objective tests
(* = estimates threshold)

- tympanometry
- acoustic reflex threshold (ART)
- otoacoustic emissions (OAE)
- electrocochleography* (ECochG)
- auditory brainstem response* (ABR)
- auditory steady-state response* (ASSR)
- middle latency responses* (MLR)
- auditory cortical response* (ACR, CERA)
- late responses (P_{300}, MMN)

Electrocochleography

- 10 dB precision
- no masking required (even for bone conduction)
- some degree of frequency specificity
- no / poor objective scoring
- trans-tympanic recording
  - invasive – poor patient tolerance
  - requires involvement of surgeon
  - requires local or general anaesthesia
  - high ambient noise in theatre
- extra-tympanic recording
  - poorer recording conditions & precision

Auditory Brainstem Response

- 10 – 20 dB precision (poorer at low frequencies)
- applicable to all ages
- immune to mental state / sleep
- widely accepted / extensive clinical database
- some degree of frequency specificity
- no / poor objective scoring
- requires good patient relaxation

Auditory Steady-State Response

- 10 – 30 dB precision
  - less reliable in adults
- good frequency specificity (probably)
  - 500 Hz – 4000 Hz range
- can test several frequencies simultaneously
- excellent objective scoring tools
- requires very high level of relaxation
- problems with bone conduction artefacts
- limited clinical database
- detection algorithm differs across manufacturers

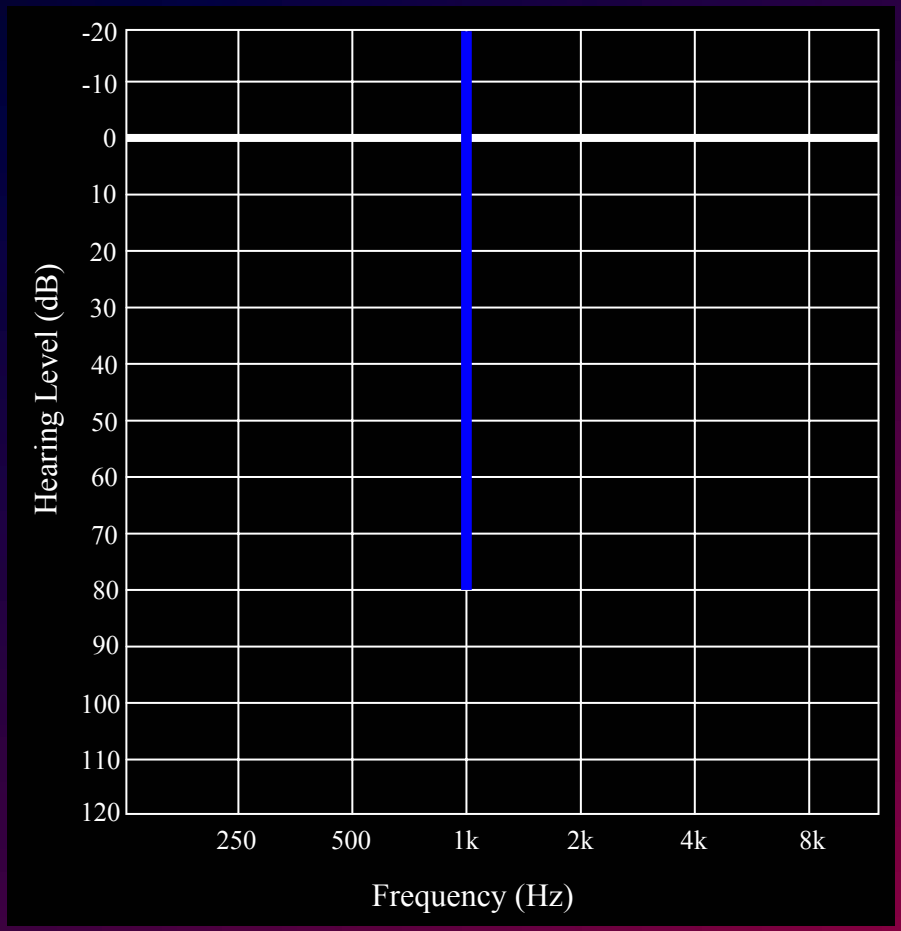
Middle Latency Responses

- 20 – 30 dB precision
- influenced by mental state / sleep / sedation
- not applicable to young children / infants
- no / poor objective scoring
- limited clinical database
- some degree of frequency specificity

N1-P2 Auditory Cortical Response

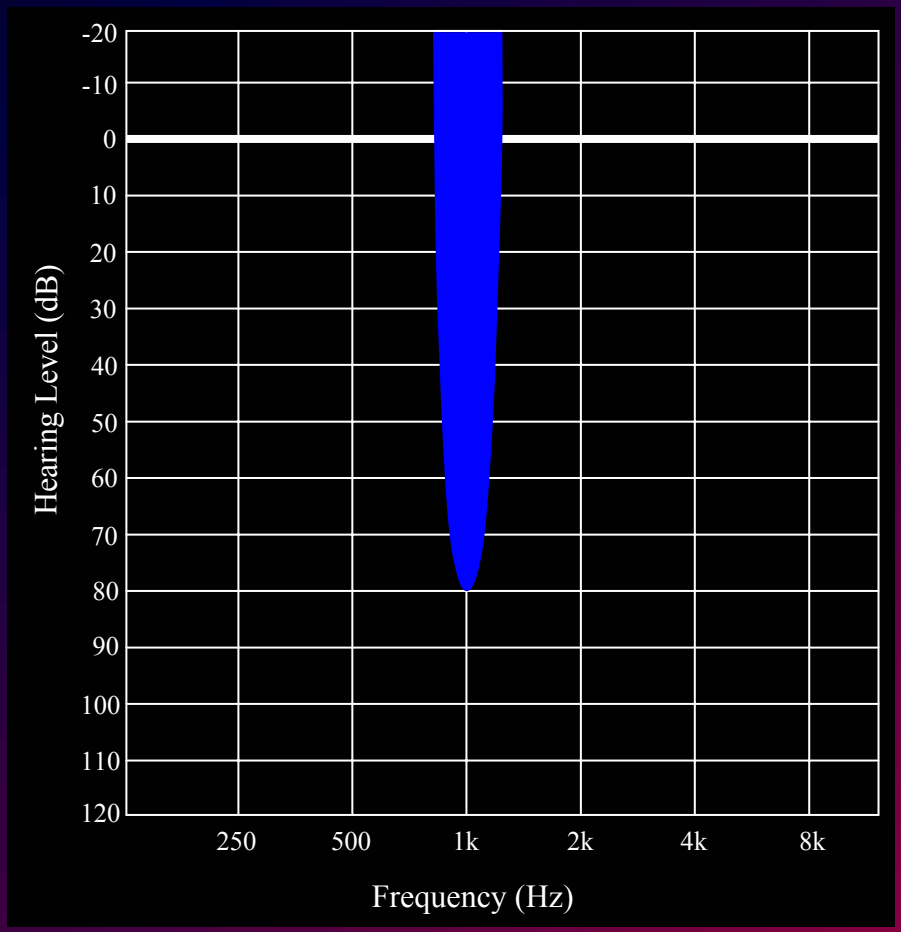
- 10 dB precision
- excellent frequency specificity (10 ms rise time)
  - 250 Hz – 8000 Hz range
- no requirement for patient relaxation
- quick (but only with appropriate software!)
- requires patient to remain awake / alert
- no / poor objective scoring
- not applicable to young children
- under-developed software on most systems
- little-known in USA

Stimulus spectrum
80 dBHL 1kHz Pure Tone (audiometry)



Ideal “line” spectrum

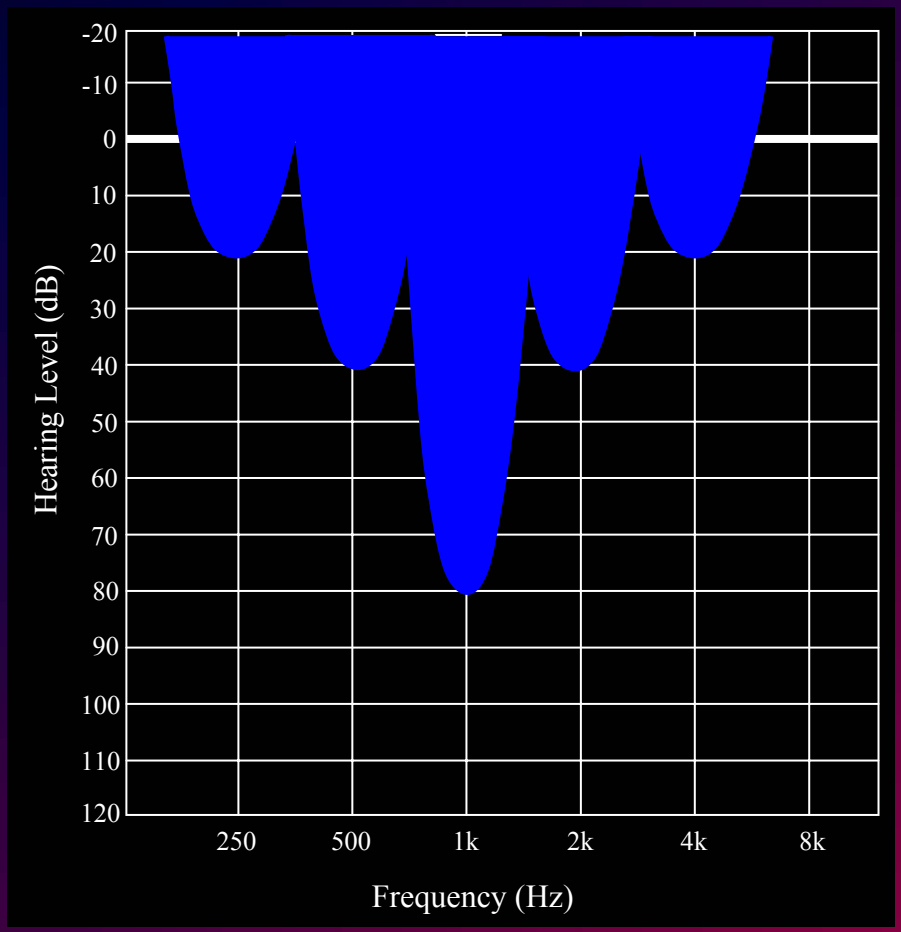
Stimulus spectrum
80dBHL 1kHz Tone Burst (CERA)



Almost ideal spectrum but a little spectral splatter

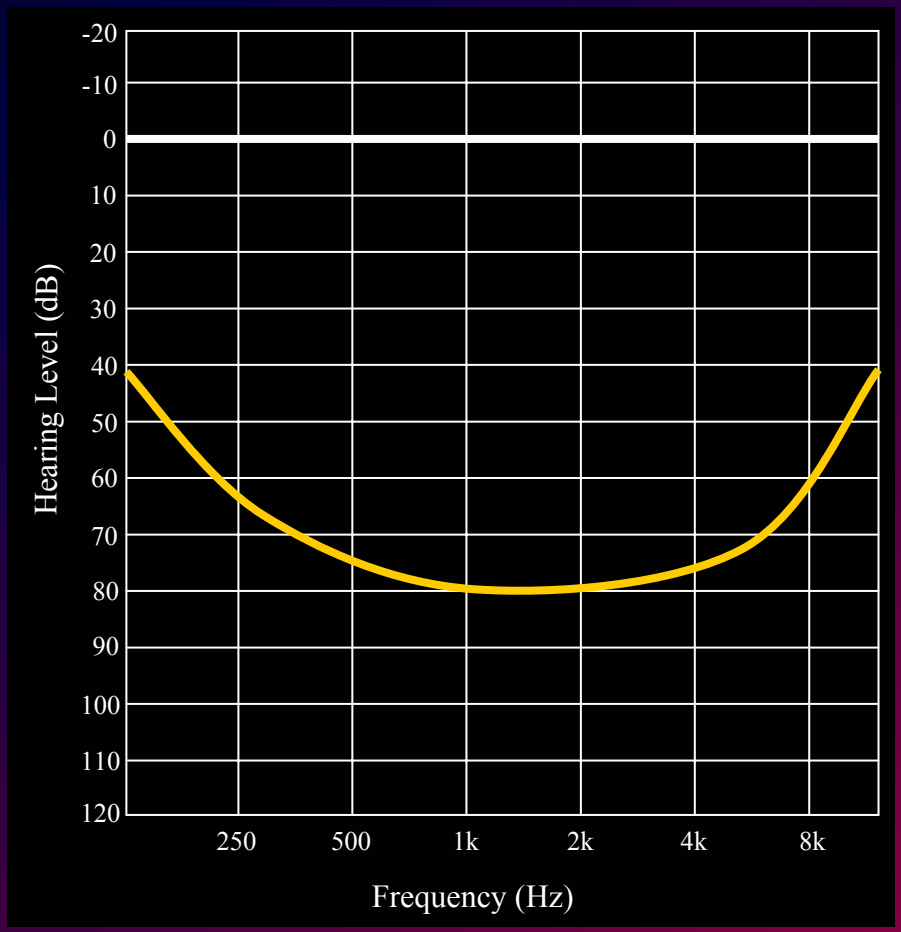
Stimulus spectrum

80dBnHL 1kHz Tone Pip (2:1:2) (ABR)



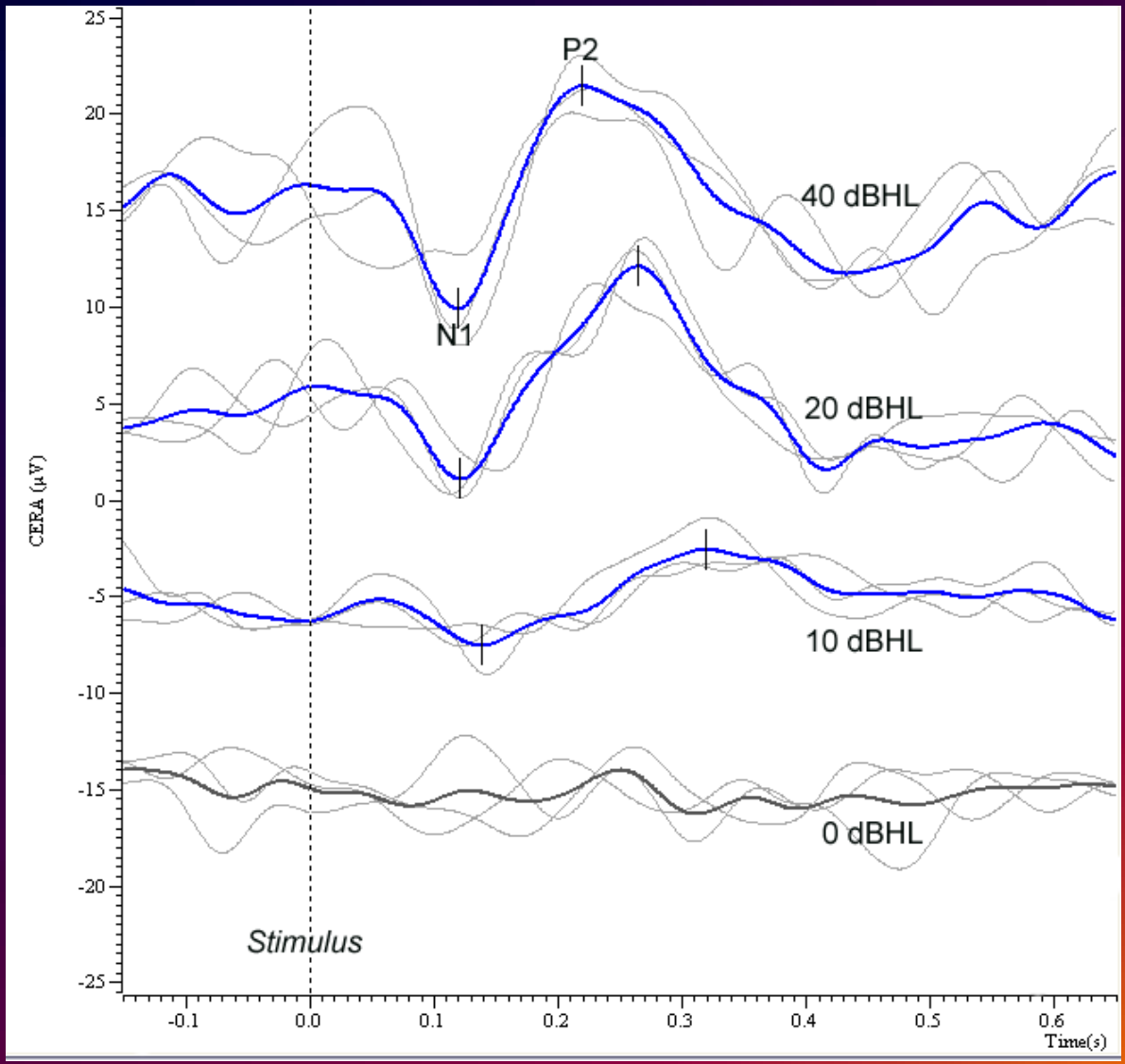
Considerable spectral splatter but still some frequency specificity

Stimulus spectrum
80dBnHL Click (ABR)



No useful frequency specificity

Typical CERA Responses



Early Research Findings 1

- 10s ISI required to avoid *any* rate-related adaptation (Appleby, 1964; McCandless & Best, 1964)
- Optimum ISI: 1 – 2 s (Rapin, 1964; Davis & Zerlin, 1966)
- Protracted averaging therefore leads to a smaller response (Henry & Teas, 1968; Nelson et al, 1969)
- *Conclusion #1: use a modest number of sweeps; if further averaging is required (near threshold), insert a 10s silent interval before averaging continues, allowing the response to recover*

Early Research Findings 2

- Varying the ISI may increase response amplitude

  (Rapin, 1964; Rothman, Davis & Hay, 1970)
- But some studies have failed to show this effect

  (Davis & Zerlin, 1966; Nelson et al, 1969)
- *Conclusion #2: Vary the ISI in the hope this will yield a larger response, and so a more accurate threshold estimate*

Early Research Findings 3

- Response amplitude is increased if the side of presentation is alternated (Butler, 1972, Lammertmann et al, 2000)
- Attention to the stimulus and general alertness yields a larger response (see Stappels, 2002, for a review)
- *Conclusion #3: Randomising the side of presentation should be a more "attention-grabbing" stimulus, giving a larger response*

Early Research Findings 4

- Response amplitude declines over time, reducing accuracy (Prosser et al, 1981, Roeser & Price. 1969)
- Test sessions involving 3 or 4 frequencies usually exceed one hour (Hyde et al, 1997)

- *Conclusion #4: increase accuracy by reducing test time – automate all predictable manual tasks*

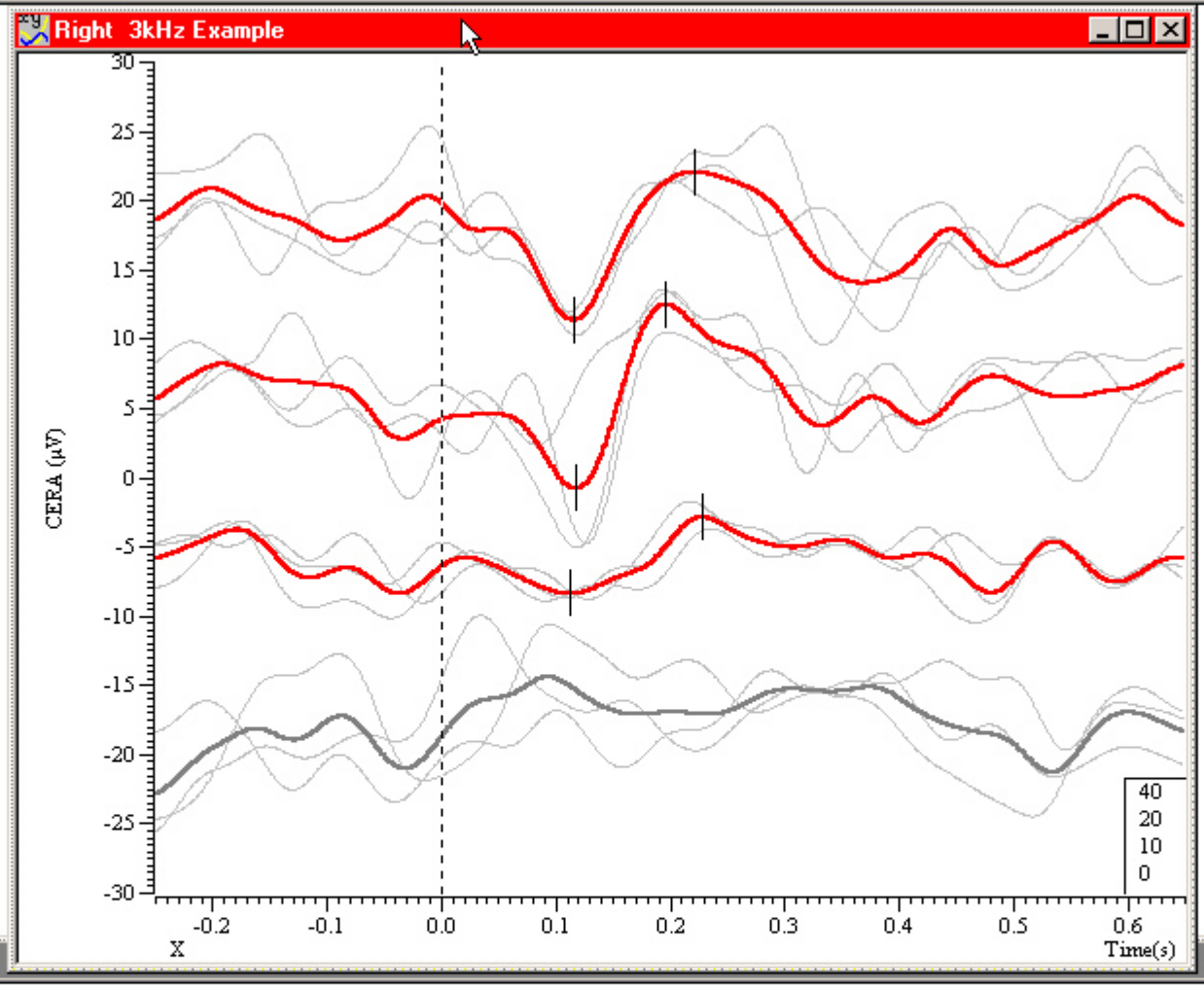
Why the poor reputation?

- Any test will perform badly if parameters are wrong
- A few studies have yielded poor results because:
  - filters were inappropriate
  - repetition rate was inappropriate
  - patient conditioning was inappropriate
- These poor results have been reflected in text books
  - educational courses now teach that this is a flawed test
  - this has led to little clinical demand
- Manufacturers have failed to provide time-saving software on commonly-available systems

Example
3 kHz masked bone conduction

Edit View Analysis Cursor Sample Script Window Help

Delete | Reprate/Vary | Set Up | Acquire Ave | Intensity | Next Freq/End Test | AmpGain | Patient



Results

r(kHz)	Bone Conduction Side	(dBHL)	SWPs	STATUS	N1(ms)	P2(ms)	AMP(µV)	CORREL.	Masking: (dB)	Masking: Side
3	Right	40	15	Y	115	222	10.7	0.86	50	Left
3	Right	20	15	Y	118	196	13.3	0.53	30	Left
3	Right	10	45	Y	113	228	5.5	0.78	20	Left
3	Right	0	30	N	0	0	0.0	0.33	10	Left

Test time:

4 minutes

Example
250Hz air conduction (both ears)

Test Parameters

Stimulus:	tone bursts, linear 10ms rise & fall, 60ms plateau
Stimulus frequencies:	250 – 8000 Hz
Inter-stimulus interval:	1.4 s ± 30% variation
Electrode montage:	+ve: Cz; -ve: linked mastoids; Ground: forehead
Filter settings:	1 Hz high pass; 15 Hz low pass
Number of sweeps:	30 per grand average with a
	a 10s silent interval half-way through
Number of replicates:	3 sub-averages, acquired simultaneously, cyclically
Timebase:	900 ms, 250 of which is pre-stimulus onset
Equipment:	Cambridge Electronic Design CERA system
	(www.ced.co.uk)

Study on speed & precision: Method

See Lightfoot & Kennedy, Ear & Hearing 2006: 27(5): 443-456

- 24 adult volunteers first underwent PTA then CERA (blind to PTA results)
- 15 M, 9 F, mean age 39 years, range 22 – 59 years
- Tests at 1, 3 & 8 kHz

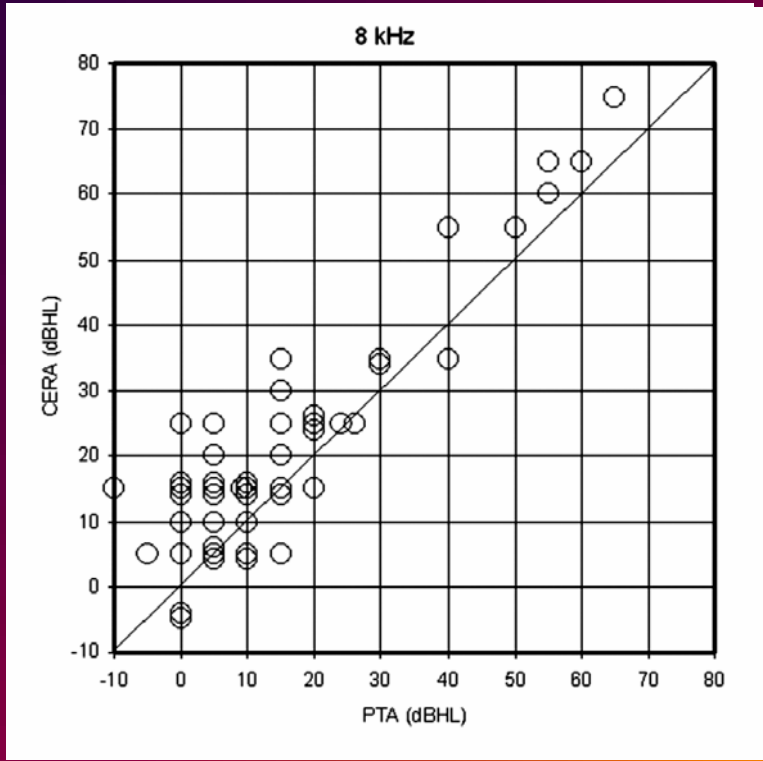
  (literature had suggested poorer accuracy at high freq)
- Protocol used:
  - 10s recovery period
  - variable ISI
  - random-ear stimulation

Speed & precision - results

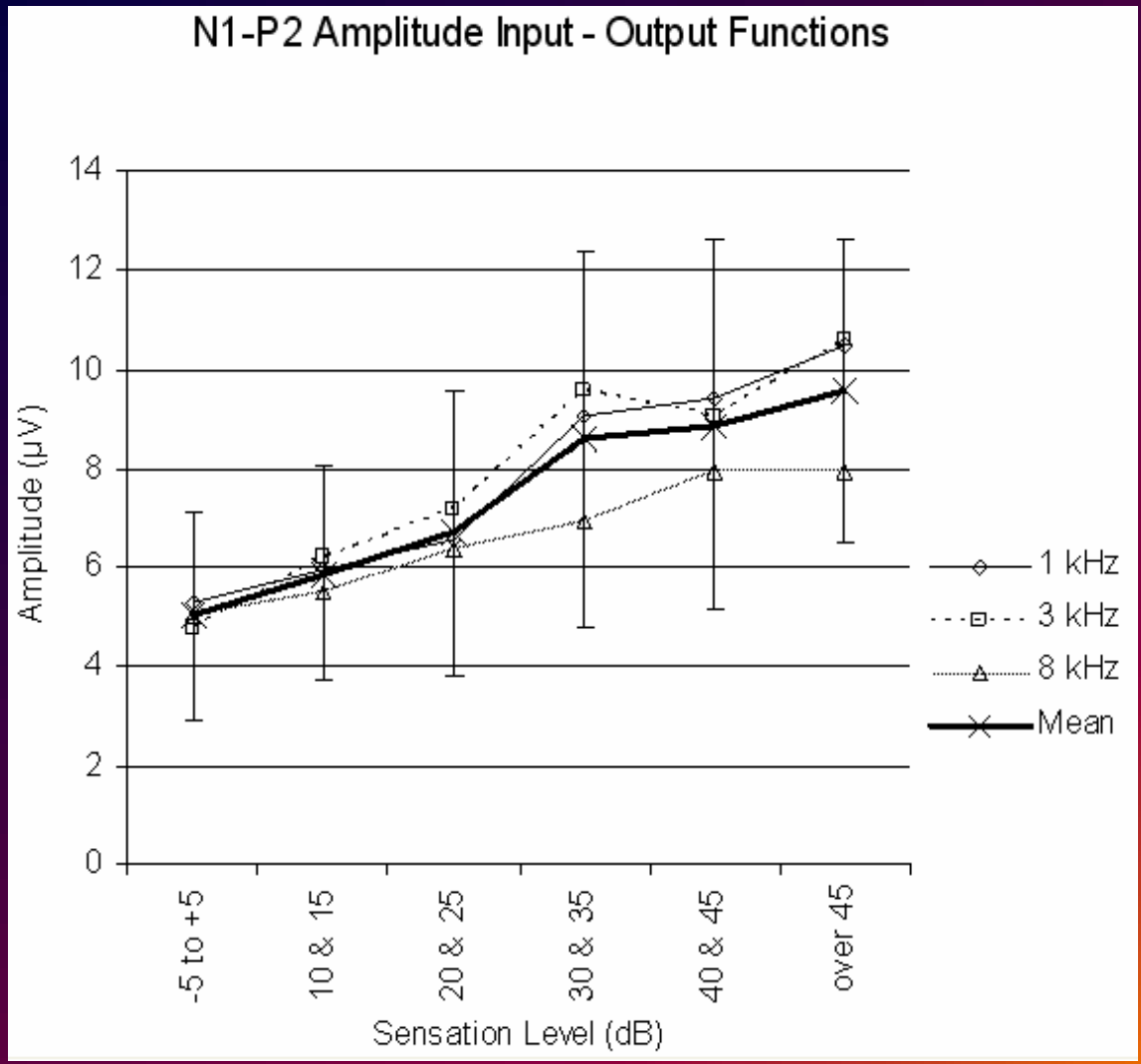
- 6 CERA thresholds took 20.6 minutes
  (average: 3.5 minutes / threshold)
- 6.5 dB average PTA - CERA bias
- after accounting for this bias:
  - 80% of thresholds were within ±10 dB
  - 94% of thresholds were within ±15 dB
  - 94% of 3-freq averages were within ±10 dB

Effect of frequency

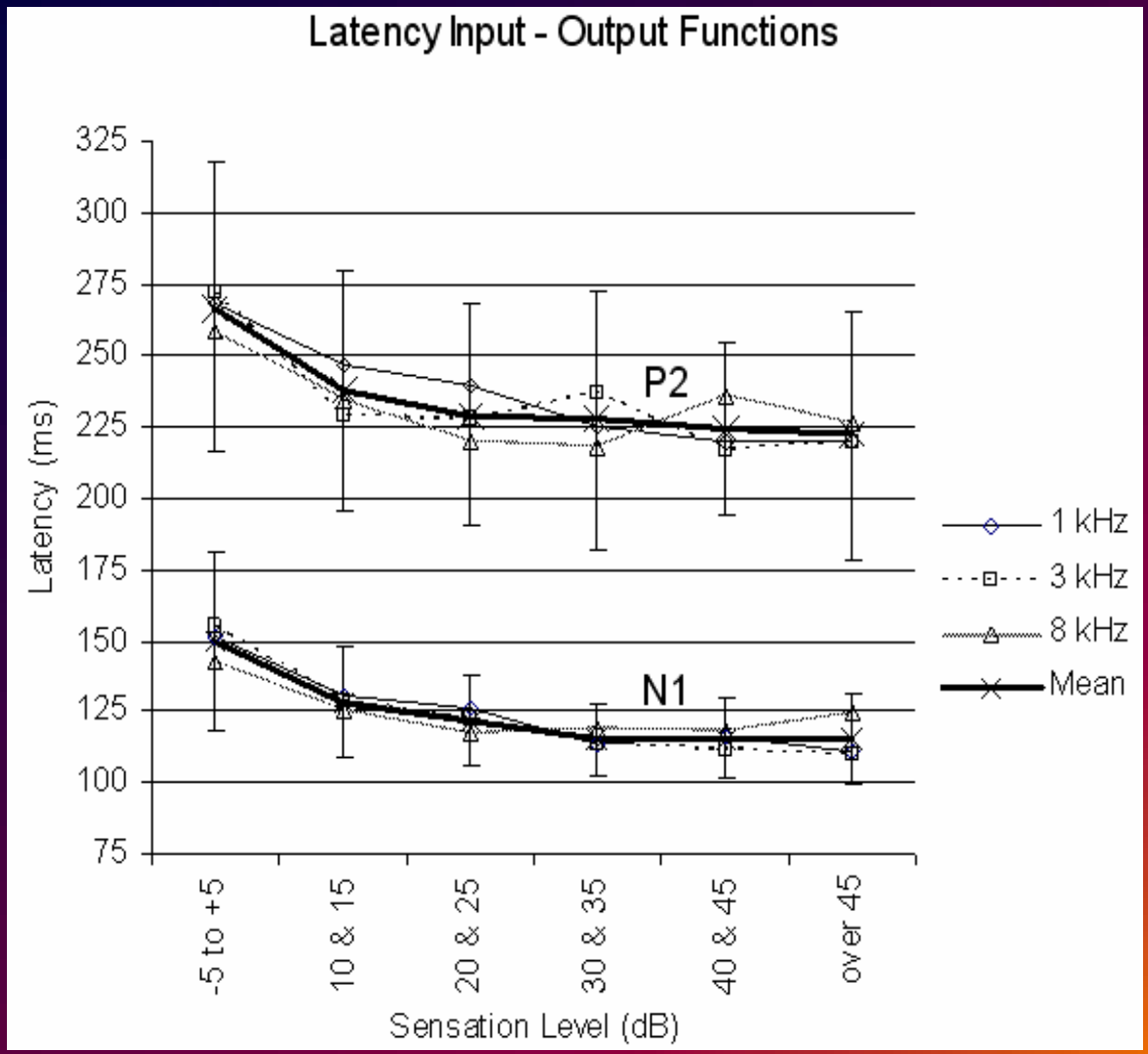
- PTA – CERA differences were not significantly different across frequency
- Previous reports may not have controlled for test order effects
- Recruiting losses lead to better CERA precision
- PTA – CERA bias falls to 4.5 dB for losses >30 dB



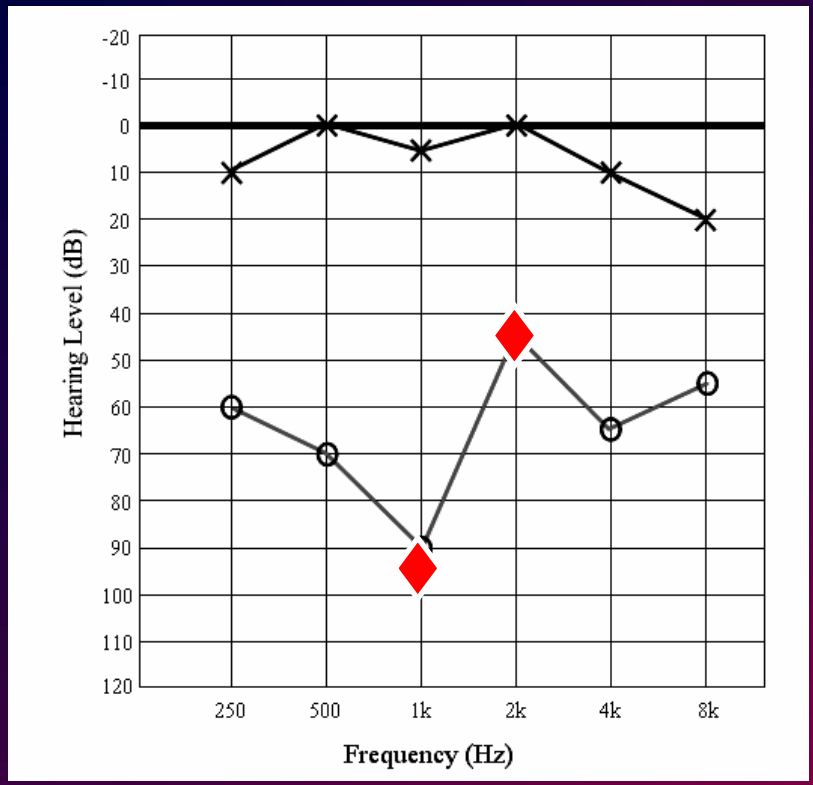
Input-Output functions

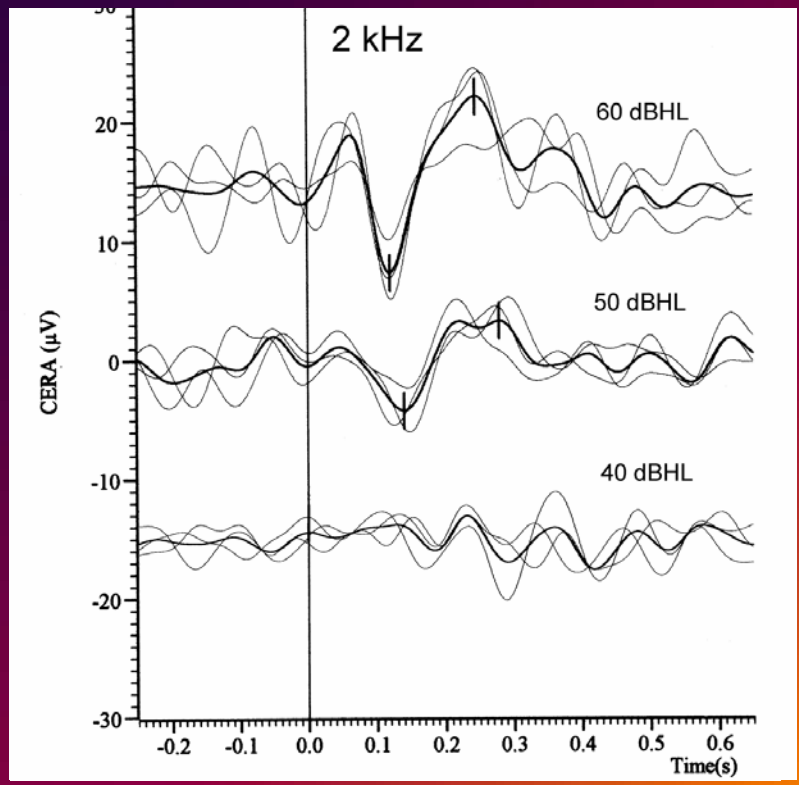


Input-Output functions



Frequency Specificity





Investigating stimulus features

- Following PTA & threshold CERA, subjects underwent CERA (3kHz, 25 dBSL) in a number of test conditions (A, B, C, D - order balanced across subjects) to identify any effect of:
  - fixed -v- 30% varying ISI
  - effect of 10s silent interval after 15 sweeps
  - effect of intensity in the opposite ear
  - effect of monaural -v- alternate -v- random ear presentation

Test Conditions

A: 30 stimuli delivered to the test ear at a fixed ISI (1.4 s) without a break, at 25 dBSL

B: as condition A but with a 10 s stimulus-free silent interval interposed after the first 15 stimuli

Test Conditions

C: as condition A but with a varying ISI (1.4 s ± 15%)

D: random pseudo-simultaneous binaural presentation 30 stimuli, variable ISI and a 10 s break after 15 stimuli. Non-test ear intensity: -10dBSL.
This will be referred to as $D_{25/-10}$

Test Conditions

$D_{25/25}$: As $D_{25/-10}$ but 25dBSL in each ear

$D_{25/40}$: As $D_{25/25}$ above, but with the non-test ear at 40dBSL

Test Conditions

D_{rnd} : As $D_{25/25}$ above, (random ear presentation) but at a fixed ISI

D_{alt} : As D_{rnd} above, but *alternating* ears

Results (paired T-tests on N1-P2 amplitude)

- Effect of 10s recovery period:
  - Conditions A & B: $p = 0.32$
  - No effect of 10s recovery
- Effect of varying ISI:
  - Conditions A & C: $p = 0.54$
  - No effect of varying ISI
- Effect of randomisation of ear
  - Conditions A & $D_{25/-10}$: $p = 0.000048$
  - Very significant effect

Results (cont)

- ***But:*** Condition $D_{25/-10}$ had a greater effective ISI because of the inaudible stimulus in one ear

- So, compare Conditions A & $D_{25/25}$: $p = 0.28$
  - No Effect of ear randomisation

Results (cont)

- Effect of non-test ear intensity
  - Conditions $D_{25/25}$ & $D_{25/40}$: $p = 0.66$
  - No Effect of opposite ear intensity

- Effect of random -v- alternating ear stimulation
  - Conditions D_{rnd} -v- D_{alt} $p = 0.44$
  - No difference between random & alternating ear

Conclusions

- None of the features had a significant impact on N1-P2 amplitude (& therefore test accuracy)
- Could be because:-
  - Sample size was too small to see the effects
  - Sweep number per average too small (poor S/N)
  - There is genuinely no effect, contrary to earlier work
  - The effect may disappear near threshold

Speculation

- This experiment took about 20 minutes
- The various stimulus conditions represented an ever-changing stimulus for the subjects
- So long-term habituation was not induced
- Therefore the conclusions suggest no *short-term* effect of stimulus features
- A different paradigm may expose longer-term effects of these stimulus features

Clinical Utility

- With an efficient protocol, CERA can be 2-3 times faster and much easier than “manual” averaging
- CERA is as accurate and more frequency specific than ABR in adults / older children
- CERA is accepted in UK courts as the definitive test upon which disability & compensation is based
- Special stimulus manipulation does not appear to be required
- Problem: efficient protocols are not available on standard systems – demand them!

Memorable Quotes:

- The N1-P2 response is *"the (threshold estimation) measure of choice for most older children and adults" David Stapells, in Katz 2002*

- *"This appears to be an uncommonly sensitive test which has been surprisingly little-used in the United States" Snyder, in Dobie 2001*

Thanks
for
listening!

More info at www.CorticalERA.com