Introduction to Cortical Auditory Evoked Potentials in Adults: Estimating Hearing Sensitivity

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Presentation of the first paper in the Special Issue of Seminars in Hearing:

The Use of Cortical Auditory Evoked Potentials in Diagnosis and Treatment of Hearing Disorders

Guest Editor: Bram Van Dun

Learner Outcomes (1st & 2nd papers)

As a result of this course, participants will be able to:

1. Describe the clinical uses and limitations of the N1-P2 cortical auditory evoked potential.

2. List the main stimulus and recording parameters for the adult N1-P2 cortical auditory evoked potential when used in the clinic to estimate the hearing threshold.

3. Identify the effects of hearing aid gain on the amplitude of cortical auditory evoked potentials in normal-hearing and hearing-impaired participants.
N1-P2 Generators

Heschl's gyrus

Human brain view of the transverse temporal lobe.

Inferior Portion of Lateral Frontal & Parietal Lobes Resected.

John A Beal, PhD
Dep't. of Cellular Biology & Anatomy,
Louisiana State University Health Sciences Center Shreveport
Exogenous -v- Endogenous?

- Exogenous: determined by the physical nature of the stimulus (also termed *obligatory*)
- Endogenous: related to the psychological significance of the stimulus to the subject (*T.W. Picton, 1988*)

- The N1-P2 is an *obligatory exogenous* evoked potential
Clinical Applications

Objective Threshold Estimation

- Suspected NOHL
  - Adolescents
  - Adult occupational deafness compensation cases
- Difficult to test cases
  - Down’s syndrome
  - Learning difficulties
  - Senility / dementia
Clinical Applications

Site of Lesion

– Cortical Deafness or Auditory Neuropathy

– Combine with PTA, ABR, OAE, reflexes
N1-P2: Typical adult waveform

Stim

- N1
- P1
- P2
- N2

CERA (μV)
N1-P2: Characteristics

- Frequency Specific
- Habituates
- Arousal-dependent (read a book)
- Late Maturation – children >8 & adults
- Input / Output Functions: as for ABR
N1-P2: Intensity Series
N1-P2: Amplitude I/O Function

N1-P2 Amplitude Input - Output Functions

-5 to +5
10 & 15
20 & 25
30 & 35
40 & 45
over 45

Sensation Level (dB)
Amplitude (µV)
1 kHz
3 kHz
8 kHz
Mean

1 kHz
3 kHz
8 kHz
Mean

Sensation Level (dB)
N1 & P2: Latency I/O Functions

Latency Input - Output Functions

Latency (ms)

Sensation Level (dB)

1 kHz
3 kHz
8 kHz
Mean

Latency Input - Output Functions

-5 to +5
10 & 15
20 & 25
30 & 35
40 & 45
over 45

P2

N1
N1-P2: Recording Parameters

- Timebase: 500 to 1000 ms
- Low Filter: 1Hz
- High Filter: 15Hz
- Rate: 0.5 - 1.0 /s
- Sweeps: 20 - 50 total (in 2-3 replicates)
- Electrodes: True Cz (+); A1 or A2 (-); Fz (Gnd)
- Artifact Rej: ±50 µV
N1-P2: Stimulus Parameters

- **Type:** Tone Burst
- **Freq:** Any (but smaller resp. at HF)
- **Rise/Fall:** 10ms (but minimum 10 cycles)
- **Plateau:** 50 - 200ms (but not 100ms)
- **Polarity:** Alternating (but doesn’t matter)
- **Mode:** AC or BC
Enhancing the response

- Use stimuli with greater spectral complexity (Bardy, Van Dun & Dillon (2016))
- Make the stimulus more “attention-grabbing”
  - Vary the inter-stimulus interval
  - Alternate / randomise the side of presentation
  - Vary the stimulus level or frequency
- But use sparingly otherwise the effect wears off
Masking

• Need: As for pure tone audiometry
• Type: Narrow Band Noise if available
• Level: \( D_m = D_s - \text{TTL} + 10 + \text{ABG}_{nt} \)

• where:
  • \( D_m \) is in effectiveness
  • TTL is 40 for TDH, 50 for inserts and 0 for BC
  • \( \text{ABG}_{nt} \) is estimated
Patient Conditioning

- Explain Tests (& then do PTA?)
- Point out Visual / Intercom Monitoring
- Patient to sit
  - quietly
  - alert
  - Reading
- Don’t reveal how the patient could disrupt the test
Test Procedure

• 1st Freq: 1kHz
  – start at 60dBHL (then up 20dB if no response)
  – down in 20dB steps to below threshold
  – up 10dB
  – Repeat until threshold criteria satisfied

• Other Frequencies
  – start at estimated true threshold + 20-30dB
  – as above
Waveform Assessment

• Use objective (statistical) detection if available

• For response presence (clear response, “CR”):
  – Similarity between replicates
  – Identifiable N1 & P2 with believable latencies & amplitudes
  – Signal/noise ratio of $\geq 2.5$ or $p \leq .05$

• For response absence (”RA”):
  – No likely response present
  – Residual noise <2 µV

• All other waveforms are “inconclusive” and cannot contribute to the definition of threshold
Threshold Estimation

• Use only waveforms meeting “CR” or “RA” criteria

• Threshold is normally taken as the lowest “CR” level, with an “RA” at a level no more than 10dB below

• If 10dB steps used, okay to interpolate, e.g.:
  – If the lowest level response is $\geq 5\mu V$: interpolate
  – If the lowest level response is $< 5\mu V$: that is threshold

• Report on waveform quality / repeatability

• Report threshold using “=”, “≤”, or “>” terminology
Accuracy

• **Bias:** Mean CAEP - PTA difference
  » typically 5-10dB

• **Dispersion:** Spread of CAEP - PTA differences
  » 95% within ± 15dB

• *BUT* occasionally very poor responses
  » >20dB error
Problems

- Electrodes - impedance & physical contact
- Patient Noise: whistling, humming
- Ambient Noise: Newspaper, hearing aid
- EMG: Muscle-related artefacts
- Drowsiness: Fatigue, Drug effects
- Habituation: Limit test session - re-book
Case study

- 54 year old male, history of noise exposure, claim via union
- PTA: flat 60-80dBHL pattern but no difficulty at interview
- Never sought a hearing aid
- Causation disputed by ENT experts; NOHL suspected
- CAEP test requested
- Non-organic behaviour evident during tymps & electrode attachment
Cortical ERA web site: www.corticalera.com

ERA Course web site: www.eratraining.co.uk
(Un)aided cortical auditory evoked potentials in normal-hearing adults and with a hearing loss

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\textsuperscript{1} The National Acoustic Laboratories

\textsuperscript{2} The HEARing Cooperative Research Centre
Presentation of the second paper in the Special Issue of Seminars in Hearing

The Use of Cortical Auditory Evoked Potentials in Diagnosis and Treatment of Hearing Disorders

Guest Editor: Bram Van Dun

Setting the scene

- Detection of hearing loss
- Need to evaluate the hearing aid fitting
- Objective hearing aid evaluation

- Assumption: cortical responses grow with gain
Normal-hearers & hearing aid amplification

- Billings et al. (2007; 2011):
  - Detrimental or no effect on cortical amplitude

- Marynewich et al. (2012) & Jenstad et al. (2012):
  - No effect on cortical amplitude
  - Differences exist between hearing aids

- Critical: Can we control all HA settings in clinic?
- More research needed!
Hard-of-hearing hearing aid wearers:

- Korczak et al. (2005):
  - Aiding substantially improves CAEP morphology
  - More likely to occur near threshold
- Billings et al. (2012):
  - CAEPs may be justified for inaudible vs audible
- Easwar et al. (2015):
  - Aiding increases number of envelope following responses
Hypotheses

Hearing aid amplification

• Does not increase cortical amplitudes in normal-hearers

• Does increase in people with a hearing loss

Cortical amplitude is related to:
- Stimulus audibility,
- Not only stimulus SNR or absolute level
Hearing aids and sensation level (1)
### Participants

<table>
<thead>
<tr>
<th></th>
<th>Number of subjects (M/F)</th>
<th>Mean age years (range)</th>
<th>4 FAHL (dB HL)</th>
<th>Ear of testing (other ear plugged)</th>
</tr>
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<tbody>
<tr>
<td>Normal-hearing</td>
<td>12 (3/9)</td>
<td>32 (23-48)</td>
<td>6</td>
<td>Alternating</td>
</tr>
<tr>
<td>Hearing-impaired</td>
<td>12 (6/6)</td>
<td>74 (47-83)</td>
<td>56</td>
<td>Closest to target range</td>
</tr>
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</table>
Stimuli

<table>
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<tr>
<th></th>
<th>Length (ms)</th>
<th>Main frequency (Hz)</th>
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<tbody>
<tr>
<td>/m/</td>
<td>30</td>
<td>250</td>
</tr>
<tr>
<td>/g/</td>
<td>21</td>
<td>1250</td>
</tr>
<tr>
<td>/t/</td>
<td>30</td>
<td>3250</td>
</tr>
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</table>

- Presented in free field
- Unaided:
  - 55, 65, and 75 dB SPL
- Aided: 55 dB SPL
Hearing aid

- Siemens Motion 101S BTE
- 3 different gains
- Foam mould, no vent

<table>
<thead>
<tr>
<th>Feature</th>
<th>Normal-hearing</th>
<th>Hearing-impaired</th>
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<tbody>
<tr>
<td>Compression ratio</td>
<td>2:1</td>
<td>NAL standalone</td>
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<tr>
<td>Compression kneepoint</td>
<td>NAL standalone</td>
<td>NAL standalone</td>
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<tr>
<td>Attack Release</td>
<td>Fixed 2-22 ms</td>
<td>Var 0-12 ms</td>
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<tr>
<td></td>
<td>Fixed 54-56 ms</td>
<td>Var 16-84 ms</td>
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<tr>
<td>Compression</td>
<td>Syllabic</td>
<td>Syllabic</td>
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<tr>
<td>Insertion gain</td>
<td>55, 65, 75</td>
<td>55, 65, 75</td>
</tr>
<tr>
<td></td>
<td>(average-based)</td>
<td>(match targets)</td>
</tr>
<tr>
<td>Programmes</td>
<td>Flat 0, +10, +20 dB</td>
<td>Prescribed gain, -10, +10</td>
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<tr>
<td>Microphone</td>
<td>Omni</td>
<td>Omni</td>
</tr>
<tr>
<td>Noise, wind &amp; fb reduction</td>
<td>Disengaged</td>
<td>Disengaged</td>
</tr>
</tbody>
</table>
CAEP recordings

- Electrode positions:
  - Using HEARLab system
  - Stimulus every 1125 ms
  - 70 presentations, test and retest
Amplification & CAEPs (1)

**Normal-hearing**

**Unaided**

Tested @ Stim level

- Red: 75 dB SPL
- Green: 65 dB SPL
- Blue: 55 dB SPL

**Aided**

Tested @ 55 dB SPL

**Hard-of-hearing**

**Unaided**

Tested @ Stim level

- Red: 75 dB SPL
- Green: 65 dB SPL
- Blue: 55 dB SPL

**Aided**

Tested @ 55 dB SPL

**Gain**

- Red: +20 dB Gain
- Green: +10 dB Gain
- Blue: 0 dB Gain

- Red: PG +10 dB
- Green: PG
- Blue: PG -10 dB
Amplification & CAEPs (2)

Normal-hearing

Output level: $p = 0.23$
Aiding: $p = 0.35$

Hard-of-hearing

Output level: $p < 0.0001$
Aiding: $p = 0.009$
Audibility and signal-to-noise ratio

\[ SL_{\text{max}} = 6.39 \text{ dB} \quad \text{(audibility)} \]

\[ \text{SNR}_{\text{max}} = 31 \text{ dB} \quad \text{(signal-to-noise ratio)} \]

Hearing loss
55 dB SPL
Prescribed Gain-10 dB
Subject 5, Sound g, Gain PG

\[ SL_{\text{max}} = 13.2 \text{ dB} \] (audibility)

\[ SNR_{\text{max}} = 31.5 \text{ dB} \] (signal-to-noise ratio)

Hearing loss
55 dB SPL
Prescribed Gain
Hearing loss 55 dB SPL
Prescribed Gain +10 dB

\[ \text{SL}_{\text{max}} = 24.7 \text{ dB} \quad \text{(audibility)} \]

\[ \text{SNR}_{\text{max}} = 30.1 \text{ dB} \quad \text{(signal-to-noise ratio)} \]
Subject 5, Sound g, Unaided 55 dB SPL

\[ \text{SL}_{\text{max}} = 4.77 \text{ dB} \] (audibility)

\[ \text{SNR}_{\text{max}} = 52.7 \text{ dB} \] (signal-to-noise ratio)

Hearing loss
Unaided
55 dB SPL
Subject 5, Sound g, Unaided 65 dB SPL

\[ SL_{\text{max}} = 14.8 \text{ dB} \quad \text{(audibility)} \]

\[ SNR_{\text{max}} = 62.7 \text{ dB} \quad \text{(signal-to-noise ratio)} \]

Hearing loss
Unaided
65 dB SPL
Subject 5, Sound g, Unaided 75 dB SPL

\[ SL_{\max} = 24.8 \text{ dB} \quad \text{(audibility)} \]

\[ SNR_{\max} = 72.7 \text{ dB} \quad \text{(signal-to-noise ratio)} \]
Normal-hearing
55 dB SPL
Prescribed Gain

$SL_{\text{max}} = 26.7 \text{ dB}$ (audibility)

$\text{SNR}_{\text{max}} = 26.7 \text{ dB}$ (signal-to-noise ratio)
Normal-hearing
55 dB SPL
Prescribed Gain +10 dB

\[ \text{SL}_{\text{max}} = 27.8 \text{ dB (audibility)} \]

\[ \text{SNR}_{\text{max}} = 27.8 \text{ dB (signal-to-noise ratio)} \]
Normal-hearing
55 dB SPL
Prescribed Gain +20 dB

\[ \text{SL}_{\text{max}} = 31.9 \text{ dB} \quad \text{(audibility)} \]

\[ \text{SNR}_{\text{max}} = 31.9 \text{ dB} \quad \text{(signal-to-noise ratio)} \]
Subject 9, Sound g, Unaided 55 dB SPL

\[ SL_{\text{max}} = 52.7 \text{ dB} \]  (audibility)

\[ SNR_{\text{max}} = 52.7 \text{ dB} \]  (signal-to-noise ratio)

Normal-hearing Unaided 55 dB SPL

Sound level (dB SPL) vs. Frequency (Hz)
Normal-hearing
Unaided
65 dB SPL

Subject 9, Sound g, Unaided 65 dB SPL

\[ \text{SL}_{\text{max}} = 62.7 \text{ dB} \quad \text{(audibility)} \]

\[ \text{SNR}_{\text{max}} = 62.7 \text{ dB} \quad \text{(signal-to-noise ratio)} \]
Normal-hearing
Unaided
75 dB SPL

\[ \text{SL}_{\text{max}} = 72.7 \text{ dB} \] (audibility)

\[ \text{SNR}_{\text{max}} = 72.7 \text{ dB} \] (signal-to-noise ratio)
Signal-to-noise ratio or audibility?

Normal-hearing

Hard-of-hearing
Audibility for both populations

(Picton 1977; Ross 1999)
Discussion

Results correspond to observations by

• Billings et al (2009; 2012)
• Korczak et al (2005)
• Easwar et al (2015)

• Papesh et al (2015):
  • Effects of background noise on CAEP amplitude
• Maamor et al (2017):
  • Effects of SNR on CAEP amplitude
  • Dependent on type of background noise
Conclusions

• Amplification increases audibility
  ✔️ for hard-of-hearing listeners
  ❌ not for normal-hearing listeners

• Amplification increases cortical response amplitudes
  ✔️ for hard-of-hearing listeners
  ❌ not for normal-hearing listeners

• Based on the relationship between CAEP amplitudes, audibility, and hearing aid gain
  – Evaluating hearing aids should be clinically possible in a population with a hearing loss.
  – When looking at DETECTION of speech sounds only.
Conclusions

- Participants
- The Hearing CRC

www.nal.gov.au
www.hearnetlearning.org.au
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References


The HEARing CRC Member Organizations

Core Members

<table>
<thead>
<tr>
<th>Australian Hearing</th>
<th>Cochlear</th>
<th>Macquarie University</th>
<th>Siemens</th>
<th>The University of Melbourne</th>
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Support Members

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<th>Acoustics Pty Ltd</th>
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<th>Audiology Australia</th>
<th>The Bionic Ear Institute</th>
<th>The children’s hospital at Westmead</th>
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<td>The Royal Victorian Eye &amp; Ear Hospital</td>
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<td>University of Wollongong</td>
<td>Walter+Eliza Hall Institute of Medical Research</td>
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