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Introduction to Cortical Auditory Evoked Potentials in Adults: Estimating Hearing Sensitivity & the Effects of Aiding

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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 (1\textsuperscript{st} & 2\textsuperscript{nd} 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.

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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
Dept. 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
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: Latency I/O Function
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: \[ D_m = D_s - TTL + 10 + ABG_{nt} \]

• where:
  • \( D_m \) is in effectiveness
  • TTL is 40 for TDH, 50 for inserts and 0 for BC
  • \( ABG_{nt} \) 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 60dBL (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 ≥2.5 or p ≤ .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 ≥5µV: interpolate
  - If the lowest level response is <5µV: 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
(Un)aided cortical auditory evoked potentials in normal-hearing adults and with a hearing loss

Bram Van Dun¹,², Anna Kania¹,², Harvey Dillon¹,²

¹ The National Acoustic Laboratories
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
Background (1)

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!

Background (2)

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)

[Diagram showing the relationship between internal noise and amplified signal]
Hearing aids and sensation level (2)

Normal hearing

Unaided

Aided

Input-referred

Aided

Output-referred

Speech

audibility

Threshold

HA Noise

SPL

Speech

Threshold

HA Noise

Hard-of-hearing

Unaided

Aided

Input-referred

Aided

Output-referred

Speech

Threshold

Threshold

HA Noise

Speech

Threshold

Threshold

HA Noise

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>
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</thead>
<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>
</tbody>
</table>
### Stimuli

<table>
<thead>
<tr>
<th></th>
<th>Length (ms)</th>
<th>Main frequency (Hz)</th>
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</thead>
<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>
</tbody>
</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></th>
<th>Normal-hearing</th>
<th>Hearing-impaired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression ratio</td>
<td>2:1</td>
<td>NAL standalone</td>
</tr>
<tr>
<td>Compression knee point</td>
<td>NAL standalone</td>
<td>NAL standalone</td>
</tr>
<tr>
<td>Attack Release</td>
<td>Fixed 2-22 ms</td>
<td>Var 0-12 ms</td>
</tr>
<tr>
<td></td>
<td>Fixed 54-56 ms</td>
<td>Var 16-84 ms</td>
</tr>
<tr>
<td>Compression</td>
<td>Syllabic</td>
<td>Syllabic</td>
</tr>
<tr>
<td>Insertion gain</td>
<td>55, 65, 75 (average-based)</td>
<td>55, 65, 75 (match targets)</td>
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<tr>
<td>Programmes</td>
<td>Flat 0, +10, +20 dB</td>
<td>Prescribed gain, -10, +10</td>
</tr>
<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

Tested @ Stim level

- 75 dB SPL
- 65 dB SPL
- 55 dB SPL

Gain

- 20 dB Gain
- 10 dB Gain
- 0 dB Gain

Tested @ 55 dB SPL

Unaided

Aided

Hard-of-hearing

Tested @ Stim level

- 75 dB SPL
- 65 dB SPL
- 55 dB SPL

Gain

- PG +10 dB
- PG
- PG -10 dB

Tested @ 55 dB SPL

Unaided

Aided

Continued
Amplification & CAEPs (2)

Normal-hearing       Hard-of-hearing

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

Output level: $p < 0.0001$
Aiding: $p = 0.009$

Audibility and signal-to-noise ratio

$SL_{max} = 6.39 \, \text{dB}$ (audibility)
$SNR_{max} = 31 \, \text{dB}$ (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)
- \( \text{SNR}_{\text{max}} = 31.5 \, \text{dB} \) (signal-to-noise ratio)

Hearing loss
55 dB SPL
Prescribed Gain

Subject 5, Sound g, Gain PG+10

- \( SL_{\text{max}} = 24.7 \, \text{dB} \) (audibility)
- \( \text{SNR}_{\text{max}} = 30.1 \, \text{dB} \) (signal-to-noise ratio)

Hearing loss
55 dB SPL
Prescribed Gain+10 dB

CONTINUED
Hearing loss
Unaided
55 dB SPL

\[ SL_{\text{max}} = 4.77 \text{ dB} \quad \text{(audibility)} \]

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

Hearing loss
Unaided
65 dB SPL

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

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

\[ SL_{\text{max}} = 24.8 \text{ dB} \quad \text{(audibility)} \]
\[ \text{SNR}_{\text{max}} = 72.7 \text{ dB} \quad \text{(signal-to-noise ratio)} \]

Normal-hearing
55 dB SPL
Prescribed Gain

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

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

\[ \text{SNR}_{\text{max}} = 27.8 \text{ dB} \quad \text{(signal-to-noise ratio)} \]

Normal-hearing
55 dB SPL
Prescribed Gain+20 dB

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

\[ \text{SNR}_{\text{max}} = 31.9 \text{ dB} \quad \text{(signal-to-noise ratio)} \]

CONTINUED
Subject 9, Sound g, Unaided 55 dB SPL

\[ S_{L_{\text{max}}} = 52.7 \text{ dB} \quad \text{(audibility)} \]

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

Normal-hearing
Unaided
55 dB SPL

Subject 9, Sound g, Unaided 65 dB SPL

\[ S_{L_{\text{max}}} = 62.7 \text{ dB} \quad \text{(audibility)} \]

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

Normal-hearing
Unaided
65 dB SPL

CONTINUED™
Signal-to-noise ratio or audibility?

**Normal-hearing**

- $P2-N1$ Amplitude (μV) vs. Signal-to-Noise Ratio (dB)
  - $r^2 = 0.0022$, $p = 0.58$

- $P2-N1$ Amplitude (μV) vs. Audibility (dB)
  - $r^2 = 0.0021$, $p = 0.58$

**Hard-of-hearing**

- $P2-N1$ Amplitude (μV) vs. Signal-to-Noise Ratio (dB)
  - $r^2 = 0.13$, $p = 0.0001$

- $P2-N1$ Amplitude (μV) vs. Audibility (dB)
  - $r^2 = 0.45$, $p = 0.0001$
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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The CRC Programme supports industry led end-user driven research collaborations to address the major challenges facing Australia.
References


