Cortical Response Applications for Audiometric and Audibility Assessment

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Agenda

I. Background and introduction; underpinnings of threshold estimation and audibility testing with CAEP
II. Review of stimulus and recording parameters and considerations
III. Information about new and existing commercial systems related to CAEP testing; brief strengths and limitations
IV. Threshold estimation using CAEP, relevant literature and clinical examples
V. Audibility measures using CAEP, relevant literature and clinical examples
VI. Summary, Q & A
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Background and Introduction

Where It All Began

• Davis and colleagues recorded first human EEG in 1934
• Wife, Pauline Davis, discovered N1 potential in ongoing EEG in 1939
• Built his own signal averaging computer in 1963
• Relentless pursuit of “evoked response audiometry” technique in infants and young children beginning around 1965

Father of Auditory Evoked Responses
Davis, P.A. (1939)

Davis, Mast, Yoshie, & Zerlin (1968)
In Current Clinical Practice

• Widespread
  – Click and Toneburst ABR

• Not as Widespread
  – ECochG
  – ASSR
  – MLR
  – LLR (CAEP)
  – P300
Table 5  Administration of Electrophysiologic Tests (n = 212)

<table>
<thead>
<tr>
<th>Test</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evoked otoacoustic emissions</td>
<td>33</td>
</tr>
<tr>
<td>Electrocochleography</td>
<td>25</td>
</tr>
<tr>
<td>Auditory brainstem response</td>
<td>65</td>
</tr>
<tr>
<td>Middle latency responses</td>
<td>9</td>
</tr>
<tr>
<td>Late evoked responses</td>
<td>2</td>
</tr>
<tr>
<td>40-Hz potential</td>
<td>1</td>
</tr>
<tr>
<td>Mismatch negativity (MMN)</td>
<td>1</td>
</tr>
<tr>
<td>Cognitive (P-300) response</td>
<td>5</td>
</tr>
<tr>
<td>Electronystagmography</td>
<td>47</td>
</tr>
<tr>
<td>Other</td>
<td>7</td>
</tr>
<tr>
<td>Do not test</td>
<td>25</td>
</tr>
</tbody>
</table>

N = 212

Martin et al (1998); JAAA

With Permission from Herbert Jay Gould, Ph.D. (in Atcherson & Shoemaker, 2012)
• Except for Wave I, no 1-to-1 relationship between peaks/valleys and auditory structures
  – Assumptions*:
    • Valleys = cell body activity (stationary sources)
    • Peaks = traveling action potential activity (moving sources)
    • Straight or bending pathways
    • Changes in conduction medium
    • Multiple generators beyond cochlear nucleus
• Parallel and crossed pathways
• Open and closed fields
• Changes from action potentials to post-synaptic potentials as we advance to the cortex

*See Moore (1987); Moller (1994); Eggermont (2007); Picton (2011)

First Things First
• Names: cortical auditory evoked potentials (CAEP), late auditory evoked potentials (LAEP), late auditory response (LAR), late-latency response (LLR); cortical event-related potential (CERP)
  – For this presentation, I will use CAEP which seems to be the most common and recent convention for the two measures discussed today

• Both exogenous and endogenous components (some more than others)

• Patient state needs to be awake and alert
Family of CERPs

- Occur between 50 and 250 ms (generally cannot see MLR and earlier waves)
- All "classic" components are obligatory
  - P1 (aka Pb or P50)
  - N1 (approximately 100 ms)
  - P2 (approximately ~180 ms, seen as early as 150 ms)
- Generators
  - Typically the auditory and association cortex, but not solely
  - May be influenced by reticular activating system and frontal cortex

CAEP

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  - P1 (aka Pb or P50)
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Ponton et al. (2002)

White & Atcherson (2011)
P1 Biomarker of Auditory Development

Sharma et al. (2005)
Sharma et al. (2005)

CAEP Clinical Applications

**Neurodiagnostic**
- Cortical lesions
- Auditory processing deficits
- Auditory Neuropathy Spectrum Disorder (ANSD)
- Possibly tinnitus

**Other**
- Audiometric threshold estimation
- Audibility assessment (detection)
- Discrimination
Target Clinical Uses

- Biomarker of maturation (or lack thereof)
- Unaided versus aided
  - Benefit of amplification/implant devices
  - Signal processing features
- Threshold estimation (Cortical Evoked Response Audiometry; CERA)
  - Medico-legal cases (noise-induced hearing loss)
- Alternative response when ABR is absent
  - ANSD
  - Severe degrees of hearing loss

CAEP Stimulus and Recording Parameters
Test Protocol for CAEP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Recommendation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transducer</td>
<td>ER-3A Inserts, Loudspeaker</td>
<td>Threshold estimation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Audibility</td>
</tr>
<tr>
<td>Mode</td>
<td>Monaural; Soundfield</td>
<td>Depends on purpose of CAEP</td>
</tr>
<tr>
<td>Stimulus Type</td>
<td>100 µsec Click, ~50 msec tone burst, Speech stimuli</td>
<td>Depends on purpose of CAEP</td>
</tr>
<tr>
<td>Rate</td>
<td>0.7 to 1.7/sec</td>
<td>High rates attenuate</td>
</tr>
<tr>
<td>Intensity</td>
<td>Variable</td>
<td>Depends on purpose of CAEP</td>
</tr>
<tr>
<td>Sweeps</td>
<td>200 to 500</td>
<td>Few as 50; as much as 1000</td>
</tr>
</tbody>
</table>

Test Protocol for CAEP

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Recommendation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Window</td>
<td>500 msec or more</td>
<td>Add -100 msec pre-stimulus; consider stimulus duration</td>
</tr>
<tr>
<td>Amplification</td>
<td>50,000x</td>
<td></td>
</tr>
<tr>
<td>Artifact Rejection</td>
<td>±100 µV</td>
<td>May adjust specific to patient</td>
</tr>
<tr>
<td>Notch Filter</td>
<td>Off</td>
<td></td>
</tr>
<tr>
<td>Filter Settings</td>
<td>0.1 to 100 Hz</td>
<td>Online filtering</td>
</tr>
<tr>
<td></td>
<td>1 to 30 or 40 Hz</td>
<td>Offline filtering</td>
</tr>
<tr>
<td>Ocular Channel</td>
<td>Yes, if possible</td>
<td>At least one above or below 1 eye</td>
</tr>
<tr>
<td>Replication</td>
<td>Minimum of 2 runs</td>
<td>May be helpful to average replicated runs for analysis</td>
</tr>
</tbody>
</table>
CAEP Electrode Montage

- Montage:
  - (+) Non-inverting (active) at Cz or Fz
  - (-) Inverting (reference) at earlobe(s) or mastoid(s)
  - Ground (depends on the montage, if single channel – earlobe/mastoid, if multi-channel Fpz)
  - Ocular electrodes for eyeblink detection/rejection

- Selection of reference site will influence results
  - Non cephalic site? Nape of Neck
  - Linked earlobes? Not always recommended

New and Existing CAEP Systems
What’s Out There?

• Most commercial auditory evoked potential systems permit CAEP recordings
  – Too numerous to name all

• HEARLab System (Frye Electronics)
  – Aided Cortical Assessment
  – Cortical Threshold Estimation

• CERA (at Royal Liverpool University Hospital)
  – Research system developed and used by Dr. Guy Lightfoot and colleagues

HEARLab

• Developed by National Acoustics Laboratory
• Manufactured by Frye Electronics, Inc.
• FDA approved since April 2013
• Cortical potential testing (P1/N1/P2)
  – ACA = aided cortical assessment (main feature)
  – CTE = cortical threshold estimation
• Uses statistical procedure (Hotelling’s $T^2$) and $p$-value to objectively determine if response is present
This is a research system developed by Dr. Guy Lightfoot and colleagues. His website discussed many potential advantages for the CAEP, makes comparisons with ABR, demonstrates how the CAEP stimulus and recording parameters can be optimized, and have video examples. Uses cross-correlation, calculates SNR, and yield $p$-value for likelihood of response.
http://www.corticalera.com (Dr. Guy Lightfoot’s website)
EXAMPLE AT 0.5 AND 1KHZ WITH PROFOUND HEARING LOSS

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.
EXAMPLE AT 0.5 AND 4 KHZ WITH MODERATE HEARING LOSS

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.
<table>
<thead>
<tr>
<th>Hearing Level (dB HL)</th>
<th>Worst Match</th>
<th>Frequency (kHz)</th>
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<tbody>
<tr>
<td>50</td>
<td></td>
<td>1.25</td>
</tr>
<tr>
<td>110</td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>100</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>2.0</td>
</tr>
<tr>
<td>40</td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>30</td>
<td></td>
<td>8.0</td>
</tr>
</tbody>
</table>

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.
Best Match

Frequency (kHz)

Hearing Level (dB HL)

0 10 20 30 40 50 60 70 80 90 100

0.125 0.25 0.5 1 2 4 8

Number of Patients (n = 6)

Frequency (kHz)

0 dB 5 dB 10 dB 15 dB 20 dB 25 dB

HEARLab to Behavioral Threshold Difference

Number of Patients (n = 6)

0 1 2 3 4

0.5 1 2 4

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.
HEARLab to Behavioral Threshold Difference

Raven E. Brasseux, Audiology Capstone Project (2013)
Research Advisor: Samuel R. Atcherson, Ph.D.

CAEP Audibility Assessment
ACA Example (Audibility)

Atcherson, Nicholson, Franklin, & Smith-Olinde (unpublished data)
Figure 1. The unsubtracted (left column) and subtracted (right column) waveforms recorded in three different stimulus presentation setups: soundfield-only (SF), soundfield and direct audio input with microphone (SF-LM), and direct input (DI). The CI artifact is clearly seen in the unsubtracted waveforms at stimulus onset (0 ms) and offset (800 ms). For unsubtracted waveforms, thick lines show responses to 3000 ms ISIs and thin lines show responses to 500 ms. Subtracted waveforms are all quite similar despite some differences in the CI artifact magnitude seen in the unsubtracted waveforms. All waveforms were recorded at Cz.
Summary

• Most commercial systems (at the very least) will allow you to record CAEPs, and optimized systems with objective statistical tools can improve detection
• Know and understand the vary stimulus and recording parameters, and patient effects
• Lots of potential clinical uses for CAEP, but more research is required, and should not discourage clinical use
• Stay Tuned...with the literature
Acknowledgments

• Raven E. Brasseux (Au.D. Class of 2014)
  – Capstone project

• Sarah W. Kennett (Au.D. Class of 2014)
  – Au.D./Ph.D. student and Graduate Research Assistant

• Colleagues:
  – Nannette Nicholson, Ph.D.
  – Cliff Franklin, Ph.D.
  – Patti Martin, Ph.D.
  – Laura Smith-Olinde, Ph.D.

Recommended Reading

Questions?

Auditory Electrophysiology: A Clinical Guide
Samuel R. Atcherson
Tessa M. Steedly

THANK YOU!!

WHAT?!

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Update on Auditory Electrophysiology: Evidence-Based Clinical Applications

Application of ABR in Objective Assessment of Infant Hearing
James W. Hall III, PhD

Clinical Applications of Electrocochleography in Audiology Today
James W. Hall III, PhD

Neurodiagnostic Auditory Evoked Responses Applications
Samuel R. Atcherson, PhD

Cortical Response Applications for Audiometric and Audibility Assessment
Samuel R. Atcherson, PhD

www.audiologyonline.com/electrophys2013