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Cortical auditory evoked potentials (CAEPs) reveal changes in audibility with amplification: clinical implications

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Disclosure

• Employed at the National Acoustic Laboratories (NAL) Australia

• Funding for research,
  • Grants from the National Institutes of Health (NIDCD), USA
  • Grants from the National Health and Medical Research Council, Australia
  • Australian Government, Office of Hearing Services, HEARing CRC
Learning Objectives

• Describe how the presence of CAEPs and audibility relate to each other
• Describe how the use of nonlinear frequency compression in hearing aids affects audibility and the presence of CAEPs
• Describe clinical applications of CAEPs for hearing aid evaluation

Why do we measure cortical auditory evoked responses in infants with hearing loss?

• Because early detection makes early treatment possible; and
• Early intervention is effective in improving outcomes
Australia: National Figures for Age at First Hearing Aid Fitting
Source: Australian Hearing (2014) "Demographic Details of Persons under the age of 21 years with a Hearing Impairment who are fitted with a Hearing Aid or Cochlear Implant"
But how do we know if early fitting is effective?

Adjust hearing aids?

Refer for Cochlear implant?

Effect of age at cochlear implantation
Are the hearing aids effective?

**PEACH Plus**

Parents’ Evaluation of Aural/Oral performance of Children (PEACH)

Potential scenarios

- Progress
- Plateau
- Significant delay

Mean

+1 SD

-1 SD

PEACH score

0 10 20 30 40 50

Age (months)

0 20 40 60 80 100

4 months

8 months

Courtesy of Kirsty Gardner-Berry

Cortical auditory evoked potential (CAEP)

- Reliably present in awake infants
- More likely to correlate well with speech perception – desired outcomes
- Can be elicited by a range of sounds, including clicks, tone bursts, vowels, consonants
- Can be very frequency specific if needed
The Auditory Cortex

Grand Average; n = 16 nh infants

clker.com online shared image
Purdy et al. (2001) with permission
Measuring CAEPs in the clinic

- Three sensors are placed on the head: Forehead, Vertex, and Behind the ear.
- Baby sits on parent's lap or in a high-chair in front of the speaker.

Stimuli for measuring CAEP

- /m/, /g/, /t/, /s/ stimuli with corresponding waveform representations and frequency response graphs.

(ILTANS & NBF SPL)
There is some evidence to suggest that measures of CAEPs correlate well with functional performance ...

Functional performance vs number of cortical responses present

No. of CAEP present was positively associated with better functional performance as reported by parents

Infants with ANSD

No. of CAEP present was positively associated with better functional performance as reported by parents


Children with ANSD: CAEPs and speech discrimination ability

Children with CI (Sharma, 2002) and NAL aided hearing impaired infants/children (N=40) using speech stimuli presented at 65 dB SPL.

- **Children with normal P1 responses had higher IT-MAIS scores**

*Sharma et al. (2011) Int J Audiol 50:98-106*
In Summary

Why measure CAEPs?

• UNHS makes early treatment possible. Effectiveness of treatment can be evaluated using objective measures and subjective ratings to optimise outcomes.
• Measuring CAEPs is an objective clinical method of choice
  • Reliably measured in awake babies, including those with ANSD
  • Can be elicited by a range of sounds, including clicks, tone bursts, speech sounds
  • Correlates well with functional performance and speech perception

How do the presence of CAEPs and audibility relate to each other?

Qn: CAEPs relate to functional hearing. How does CAEP relate to audibility /sensation level?
CAEPs can provide some indication of audibility
- presence suggests detection
- absence suggests that the sensation level is <10 dB

22 infants with mild to severe hearing loss, <30 months old

<table>
<thead>
<tr>
<th>Sensation level (dB)</th>
<th>No. of detections</th>
<th>No. of data points</th>
<th>Sensitivity (%)</th>
<th>No. of subjects</th>
<th>95% Two-sided Cl (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;0</td>
<td>58</td>
<td>81</td>
<td>71.6</td>
<td>21</td>
<td>59.3–90.9</td>
</tr>
<tr>
<td>&gt;10</td>
<td>44</td>
<td>59</td>
<td>74.6</td>
<td>19</td>
<td>55.0–94.2</td>
</tr>
<tr>
<td>&gt;20</td>
<td>21</td>
<td>27</td>
<td>77.8</td>
<td>12</td>
<td>54.3–100.0</td>
</tr>
</tbody>
</table>

CI, confidence interval.

Detection rate of CAEP increases with audibility: SNHL,
Detection rate of CAEP increases with audibility: SNHL, ANSD

Limitations of CAEP testing

- Influenced by the state of arousal
  - CAEP morphology changes dramatically when the child falls asleep
  - Variable / unreliable morphology, especially in children
  - Test awake and alert, or at least in a constant state

- Low sensitivity of CAEPs in infants and young children at low sensation levels
  - State of arousal, cortical maturation, test condition, speech ability
  - Absence of CAEPs across the board is a warning sign
How does nonlinear frequency compression affect audibility? Presence of CAEPs?

Why evaluate non-linear frequency compression hearing aids?

- When hearing loss at high frequencies is severe, conventional amplification may not provide adequate audibility
- Frequency lowering schemes aimed to increase audibility of high frequencies
- Audibility of high-frequency sounds is important for
  - Spoken Language development
  - Speech perception

- Compresses and shifts frequencies above a cut-off frequency to a lower frequency region with better hearing
- Frequencies below the cut-off frequency remain unchanged

Frequency (Hz)

Level (dB)
CAEPs and NLFC hearing aids

N = 5 school-aged children

<table>
<thead>
<tr>
<th>Case</th>
<th>2 kHz NLFC SL (dB)</th>
<th>CAEP</th>
<th>2 kHz no-NLFC SL (dB)</th>
<th>CAEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30.29</td>
<td>Present</td>
<td>30.24</td>
<td>Present</td>
</tr>
<tr>
<td>2</td>
<td>19.36</td>
<td>Present</td>
<td>19.86</td>
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</tr>
<tr>
<td>3</td>
<td>13.1</td>
<td>Present</td>
<td>13.36</td>
<td>Present</td>
</tr>
<tr>
<td>4</td>
<td>9.68</td>
<td>Present</td>
<td>9.66</td>
<td>Present</td>
</tr>
<tr>
<td>5</td>
<td>0.02</td>
<td>Present</td>
<td>6.51</td>
<td>Present</td>
</tr>
</tbody>
</table>

- No change in calculated SLs
- No difference in detection of CAEPs

Qn. Use of tone-bursts for testing & relevance to speech?

CAEPs and nonlinear frequency compression hearing aids

- N=38 HI children (2.8-7.6 yrs)
- Stimuli: /ɡ/, /t/, /s/ presented in the free-field at 55 and 65 dB SPL
- Conventional hearing aids vs NLFC aids.

![Graph showing detection rate for /s/ at 55 and 65 dB SPL]  
Significantly higher detection rate for /s/ when NLFC activated

Qn. How does audibility (SL) relate to presence of CAEPs?  
Qn. Could there be differences other than NLFC that led to the difference detection rate of CAEPs?
Aims of the current study

1. How NLFC affects audibility?
2. How NLFC affects the presence of CAEPs to speech sounds?
3. How do audibility and presence of CAEPs relate to each other?

Participants

- N=27 children with sensory/neural hearing loss
- Mean age = 11.6 yrs (SD = 2.36), range 6.1-16.8 yrs
Calculation of stimulus audibility

**Stimulus audibility calculations:**

- Spectral characteristics of speech stimuli in 1/3 octave bands in the free field (dB SPL)
- 2 cc coupler measures at low and average input levels
- Real-ear aided gain for each individual
- Unaided hearing thresholds in respective frequency bands.

**NLFC activated:**

- The input frequency for gains measured at respective output frequencies was determined for each fitting by using the manufacturer’s software prior to calculating the aided audibility levels.
NLFC effects on audibility of /ɡ/ /t/ /s/ (n = 27)

On average, aided sensation levels were higher with NLFC enabled (p = 0.01).

<table>
<thead>
<tr>
<th></th>
<th>Sensation level (dB)</th>
<th>No. of participants</th>
<th>No. of detections (p &lt; 0.05)</th>
<th>No. of stimuli presented</th>
<th>% detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>/ɡ/</td>
<td>0 to 9</td>
<td>7</td>
<td>4</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10 to 19</td>
<td>16</td>
<td>43</td>
<td>47</td>
<td>95.9</td>
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<td>&gt;= 20</td>
<td>32</td>
<td>95</td>
<td>99</td>
<td>96.0</td>
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<tr>
<td>/t/</td>
<td>0 to 9</td>
<td>13</td>
<td>19</td>
<td>22</td>
<td>86.4</td>
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<tr>
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<td>10 to 19</td>
<td>18</td>
<td>45</td>
<td>49</td>
<td>91.8</td>
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<td>&gt;= 20</td>
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<td>65</td>
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<td>&gt;= 20</td>
<td>22</td>
<td>29</td>
<td>39</td>
<td>74.4</td>
</tr>
</tbody>
</table>
In summary,

- NLFC increased audibility, significantly for /t/ and /s/
- CAEPs were detected more often when NLFC was activated
- Higher sensation level was associated with higher detection rate of CAEPs

CAEPs can be used to evaluate the effectiveness of some signal processing schemes in hearing aids for providing audibility in young children
Clinical applications

Research and clinical data revealed..

• When hearing aids for children with mild to severe hearing loss are fit accurately according to the NAL-NL2 prescription

<table>
<thead>
<tr>
<th>phone</th>
<th>n</th>
<th>No. CAEP detected</th>
<th>No. stimuli presented</th>
<th>% detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>/ɡ/</td>
<td>48</td>
<td>138</td>
<td>146</td>
<td>96</td>
</tr>
<tr>
<td>/t/</td>
<td>46</td>
<td>110</td>
<td>122</td>
<td>90</td>
</tr>
<tr>
<td>/s/</td>
<td>42</td>
<td>64</td>
<td>83</td>
<td>77</td>
</tr>
</tbody>
</table>
Further, we found that ...

![Diagram showing the presence and absence of CAEPs for the sounds /s/, /t/, and /ɡ/]

When CAEP is present for /s/, it is also likely to be present for /t/ & /ɡ/.

When CAEP is present for /t/, it is likely to be present for /ɡ/.


The data support streamlining the clinical procedure of CAEP testing for hearing aid evaluation.
In principle,

- For aided testing of SNHL, flat and sloping audiograms
  - Start with /s/ -> /g/
  - Start with 65 dB
- For aided testing of SNHL, upward sloping audiograms
  - Start with /m/ - > /t/
- For unaided testing of ANSD,
  - Start with /t/ - > /m/
  - Make decisions about aiding

Case Study - SN

Background:
- Born at 38 weeks gestation
- Jaundice – phototherapy for 24 hours
- Maternal family history of hearing loss – mother, grandfather, uncles & cousins

Diagnostic assessment results

<table>
<thead>
<tr>
<th>Assessment Type</th>
<th>Results – Left Ear</th>
<th>Results – Right Ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click ABR</td>
<td>CM absent</td>
<td>CM absent</td>
</tr>
<tr>
<td>Tone burst ABR (dBnHL)</td>
<td>500 1k 2k 4k</td>
<td>500 1k 2k 4k</td>
</tr>
<tr>
<td></td>
<td>AC 30 30 45 50</td>
<td>AC 30 30 45 50</td>
</tr>
<tr>
<td>High Freq Tympanometry</td>
<td>Normal M/E function</td>
<td>Normal M/E function</td>
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<tr>
<td>DPOAEs</td>
<td>Absent</td>
<td>Absent</td>
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</tbody>
</table>
Case Study_SN

**Audiological management**
- Aided bilaterally at 6 weeks of age.
- Fitted to estimated audiogram of mild to moderate sloping hearing loss, based on the ABR results.
- Used NAL-NL2 prescription
- Verification method: Coupler gain and average RECD

**Evaluation methods:**
1. Cortical Auditory Evoked Potentials (CAEPs) assessment
2. Parent’s Evaluation of Aural/oral Performance (PEACH) questionnaire

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**Evaluation - Aided CAEPs assessment & PEACH**

Aided CAEPs assessment - for typical sensorineural hearing loss

*Testing sequence from left to right*

<table>
<thead>
<tr>
<th>/s/ @65</th>
<th>/s/ @75</th>
<th>/t/ @65</th>
<th>/t/ @75</th>
<th>/g/ @65</th>
<th>/g/ @75</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>

**Aided adjustment**
- MF /g/ (1k Hz)
- HF /t/ (4k Hz)
- VHF /s/ (6k Hz)

**Do** PEACH

<table>
<thead>
<tr>
<th>Results</th>
<th>Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>a PEACH: Age appropriate</td>
<td>Monitor</td>
</tr>
<tr>
<td>b PEACH: NOT Age appropriate (overall score below 2 SD)</td>
<td>Increase gain for low-level input &amp; repeat PEACH</td>
</tr>
<tr>
<td>c PEACH: Poor in quiet</td>
<td>Adjust Dir mic/noise reduction or FM/remote microphone</td>
</tr>
</tbody>
</table>

---

**Functional performance of children**

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**PEACH_SNHL table**

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Case Study  AS

- Male, born at 36 weeks gestation
- Jaundice, required phototherapy
- Complication: pulmonary hypertension required ventilation
- No family history of hearing loss
- Newborn hearing screening: bilateral referral

### Audiogram

<table>
<thead>
<tr>
<th>Axis</th>
<th>Left Ear</th>
<th>Right Ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click ABR</td>
<td>Cochlear microphonic</td>
<td>Cochlear microphonic</td>
</tr>
</tbody>
</table>
| TB_ABR (dBnHL) | 500 1k 2k 4k NR NR NR NR | 500 1k 2k 4k NR NR NR NR [
| * NR = No respon at 95 dB |
| High Freq Tymp. | Normal M/E function | Normal M/E function |
| TEOAEs | ✓ | ✓ |

### Unaided CAEPs assessment

<table>
<thead>
<tr>
<th>High Frequency</th>
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</table>

### Low Frequency

<table>
<thead>
<tr>
<th>Low Frequency</th>
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</tr>
</tbody>
</table>

Unaided PEACH results: Below 2 SD
Estimated audiogram

- Unaided CAEP detected for /m/ at 65 dB; /t/ at 75 dB SPL
- PEACH <2SD
- Fitted with hearing aids at 9 weeks corrected age

Aided CAEPs assessment at 13 wks

<table>
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<th></th>
<th>/m/65</th>
<th>/t/75</th>
<th>/g/65</th>
<th>/s/75</th>
<th>Aided adjustment</th>
<th>MF /g/ (1k Hz)</th>
<th>HF /t/ (6k Hz)</th>
<th>VHF /s/ (6k Hz)</th>
<th>Do PEACH</th>
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<td>+1.5 SD</td>
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</tbody>
</table>

Results Actions

- PEACH: Age appropriate
- PEACH: Age inappropriate (overall score below 2.5SD)  
  - Monitor: Increase gain for bilateral input & repeat PEACH
  - Ongoing concerns, discuss with EIA and case alert for CI referral
- No adjustment indicated

Functional performance of children
Last but not least, Paediatric referral for cochlear implant candidacy

Children with HL

3FA ≤ 60 dBHL

Fit HA

3FA ≥ 80 dBHL

- Monitor hearing And Progress with PEACH
- Evaluate aided performance with PEACH
- Measure aided corticals

- PEACH score below 2SD
- Absent aided corticals

With parent consent Refer for CI candidacy evaluation

No

Yes

60 < 3FA < 80 dBHL And HTL at 2 or 4 kHz > 80 dB HL

In summary,

- To check effectiveness of hearing aids for infants, use a test battery
  - Subjective parent reports AND
  - Objective measures of cortical auditory evoked potentials (CAEPs)
- Higher CAEP detection rate relates to better functional performance
- CAEP detection rate increases with sensation level
  - Sensory/neural hearing loss
  - Auditory neuropathy spectrum disorder
- Use of nonlinear frequency compression increases audibility
- Application in clinical procedure for
  - Evaluating the effectiveness of amplification
  - Determining the need to provide aiding in ANSD
  - Facilitating referral for cochlear implant candidacy referral
For more information

Cortical Auditory Evoked Potentials Reveal Changes in Audibility with Nonlinear Frequency Compression in Hearing Aids for Children: Clinical Implications


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Thanks for listening

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