Cortical auditory evoked potential recordings in cochlear implant users using the clinical HEARLab system

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Background

- **CAEP**: Cortical Auditory Evoked Potential
- Can be reliably generated in adults and children
- Feasible using speech stimuli
- Is useful for hearing aid fitting evaluation in infants and difficult-to-test people
Background

Sound presentation (about 30 ms long)
Starting from the clinical end

- Single-channel clinical CAEP recording system (e.g., HEARLab)

  Extending use towards cochlear implants (CIs)

- Other methods to fit CIs (e.g., ECAPs through NRT at Cochlear)
  - Not extremely reliable for fitting a CI
  - Behavioural component still required. Problematic for infants.
  - Only evaluates early part of auditory system

- Current research in CAEPs & CI varies in clinical applicability
  - Gilley et al (2006): use of 64 channel electrode cap + ICA
  - Friesen et al (2010): different interstimulus intervals
  - Mc Laughlin et al (2013): single channel high-sample
  - Visram et al (2015): 64 channel cap + direct stimulation + thresholds
Using CAEPs

• Determine Threshold- and Comfortable- levels for individual electrodes of the CI

• Evaluate and fine-tune CI fittings using broadband stimuli (e.g., speech) in the free field

• Both adults as (young) children
Problem

1125 ms CI artefact

grand average

ongoing EEG

CI artefact
Previous work

- **Hardware modification** (25 CI subjects)
  - Lowpass filter in the electrode connected to the scalp
  - Reduced artefact amplitude by a factor of 10

- **Assessment of CAEP presence** (34 CI subjects)
  - Variability between CI brands (range: 55 – 90%)

- **Assessment of excessive CI artefact presence** (same 34 CI subjects)
  - Variability between CI brands (range: 3 – 35%)

- (Un)reliable presence/absence of CAEPs and CI artefacts makes or breaks its clinical applicability.
- Currently only reliably usable in MED-EL devices.
So…. how to?

- Increase CAEP presence?
  - Longer stimuli (30 => 400 ms)?

- Reduce CI artefacts even more?
  - Alternative EEG scalp electrode locations?
  - Advanced signal processing?

- Do these interventions facilitate CAEP hearing threshold estimation?
  - i.e., aided thresholds from a CI user in the free field?
Methods

- **400 ms narrowband noise stimuli**
  - 125-500 / 500-2000 / 2000-8000 Hz
- **Stimulus levels**
  - -10 / 0 / 10 / 20 / 30 / 40 dB SL
- **Recorded with HEARLab system**
  - 120 presentations per recording
  - 1-2 seconds SOA
  - Through a loudspeaker

9 adults with Cochlear CI
Results: Alternative electrode channel

Narrowband noise 0.5 – 2 kHz, grand averages (9 CI adults)

- No artefacts!
- But also no CAEPs...
- Hence, forget about this channel.

Suggested alternative electrode channel

CI artefact onset
CI artefact offset
behavioural threshold

CI mastoid
Contralateral mastoid
Results: Threshold estimation (1)

- Determine difference between behavioural and CAEP threshold for same NBN stimuli
- Currently CAEPs are visually interpreted

<table>
<thead>
<tr>
<th>Narrowband N</th>
<th>125 – 500 Hz</th>
<th>0.5 – 2 kHz</th>
<th>2 – 8 kHz</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD (dB)</td>
<td>15.6 ± 12.4</td>
<td>15.6 ± 10.1</td>
<td>21.1 ± 11.7</td>
<td>17.4 ± 11.3</td>
</tr>
</tbody>
</table>

Contralateral side (opposite CI)

Subtract this value from the CAEP threshold to obtain (aided CI) behavioural threshold in the free field

In all (100%) cases (9 subjects x 3 stimuli):
- a threshold could be determined
- a CAEP was detected at 40 dB SL (a significant increase when compared with short stimuli ~ 70%)

However still a CI artefact present, especially the ipsilateral side.
- smart artefact removal
Results: Artefact removal (1)

Example for a single participant: Adult 3, Stimulus narrowband noise 2-8 kHz

Before artefact removal

Artefact removed, CAEP recovered

Artefact residual (no concern as outside CAEP range)

CAEP unaffected

CI artefact

CI mastoid

Contralateral mastoid

CI mastoid

Contralateral mastoid
Mc Laughlin et al (2013):
• CI artefact removal
• Specifically for one EEG channel (i.e., 3 electrodes)
• Assumes CI artefact relates to stimulus envelope

• Procedure:
  1) Take the stimulus envelope
  2) Filter with same filters as EEG recording device
  3) Fit bivariate polynomial to filtered stimulus envelope, averaged response, and time.
  4) Obtain estimated artefact
  5) Subtract from averaged response
  6) Obtain corrected response
Results: Threshold estimation (2)

Threshold: Difference between behavioural and CAEP threshold for same NBN stimuli (CI in free field)

**Before CI artefact removal**

<table>
<thead>
<tr>
<th></th>
<th>CI side</th>
<th>Contralateral side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold: Mean ± SD (dB)</td>
<td>18.9 ± 10.5</td>
<td>17.4 ± 11.3</td>
</tr>
<tr>
<td>Thresholds determined (%)</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>Artefacts present (no / small / LARGE)</td>
<td>7 / 3 / 17</td>
<td>18 / 5 / 4</td>
</tr>
</tbody>
</table>

‘More precise’ estimation of behavioural threshold (p = 0.032, two-tailed)

**After CI artefact removal**

<table>
<thead>
<tr>
<th></th>
<th>CI side</th>
<th>Contralateral side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold: Mean ± SD (dB)</td>
<td>17.0 ± 12.2</td>
<td>14.8 ± 9.4</td>
</tr>
<tr>
<td>Thresholds determined (%)</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>Artefacts present (no / small / LARGE)</td>
<td>20 / 5 / 2</td>
<td>23 / 4 / 0</td>
</tr>
</tbody>
</table>

Significantly less CI artefacts

Especially less large artefacts making CAEP interpretation difficult or impossible
Conclusions

Although this is a pilot in 9 CI adults (Cochlear)…

• Does CAEP presence increase through longer stimuli (30 => 400 ms)?
  • Yes, evidence seems to point this way.

• Can CI artefacts be reduced through
  • Alternative EEG scalp electrode locations? No, and contralateral side preferred.
  • Advanced signal processing? Yes, reduces artefacts significantly.

• Do these interventions facilitate CAEP hearing threshold estimation?
  • Yes, hearing threshold estimation seems to be feasible.
  • Artefact removal significantly improves thresholds in contralateral side only.

• This can all be done in a clinical one-channel recording device!
Future work

• Full automation
• Direct stimulation of CI electrodes to find CAEP thresholds (~T-levels)
References


Acknowledgements

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Please also visit:
- hearlab.nal.gov.au
- www.hearnetlearning.org.au
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