Recording cortical auditory evoked potentials (CAEPs) with a single-channel clinical device in cochlear implant users

Bram Van Dun[1,2], Nicky Chong-White[1,2], Robert Cowan[2,3]

[1] The National Acoustic Laboratories (Sydney), [2] The HEARing Cooperative Research Centre (Melbourne), [3] The University of Melbourne (Melbourne)

Abstract

Introduction

Cortical auditory evoked potentials (CAEPs) are used as an objective electrophysiological measure to clinically evaluate aiding in hearing-impaired individuals. However, the clinical application of CAEPs to cochlear implants (CIs) is in some cases impeded by the presence of an electrical artefact.

Objectives

The aim of this study is to evaluate whether a clinical single-channel CAEP recording system can be modified for testing with CI users in the free field to determine their aided thresholds.

Patients & Methods

Long (400 ms) narrowband noise stimuli (each 2 octaves wide starting from 125 Hz) were used to record CAEPs in 9 adult Cochlear CI users at 6 different levels ranging from -10 to 40 dB SL in the free field through a loudspeaker at 0 degrees azimuth. Initially three EEG channels (Cz – ipsilateral mastoid, Cz – contralateral mastoid, Cz – AF7 or AF8) were recorded to allow selection of the most promising one. Using recently developed artefact reduction techniques in the literature (Mc Laughlin et al., 2013), it was evaluated whether CI artefacts could be reduced. An electrophysiological detection threshold was derived based on the CAEPs that were evoked at different presentation levels, and behavioural detection thresholds were determined for the same stimuli.

Results

CI artefacts can be reduced by using long stimuli in combination with the polynomial fitting technique presented in Mc Laughlin et al. (2013). Placing the active electrode on contralateral mastoid (with the reference electrode on the vertex) is preferential. Artefact reduction significantly improves threshold estimation at the contralateral mastoid only. Estimated behavioural thresholds using CAEPs have acceptable correction means and standard deviations. CAEP presence increases when using longer stimuli (when compared to 30 ms speech sounds).

Conclusion

Hearing threshold estimation in CI users seems to be feasible using a clinical one-channel recording device! The next step will focus on threshold estimation on directly stimulated CI electrodes, aiding with the objective fitting of these devices in the clinic.

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

Starting from the clinical end

- Single-channel clinical CAEP recording system (e.g., HEARLab)
  - ⇨ Extending use towards cochlear implants
- Other methods like ECAPs (through e.g. NRT)
  - Not so reliable
  - Only evaluates early part of auditory system
- Current research varies in clinical applicability
  - Gilley et al (2006): use of 64 channel cap + Independent Component Analysis (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 stim + thresholds

Longterm clinical aim

Using CAEPs

- Determine T- and C- 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

Previous work (not yet published, using short speech stimuli, 30 ms)

- 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 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.

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 threshold estimation?
  - i.e., aided thresholds from a CI user in the free field?

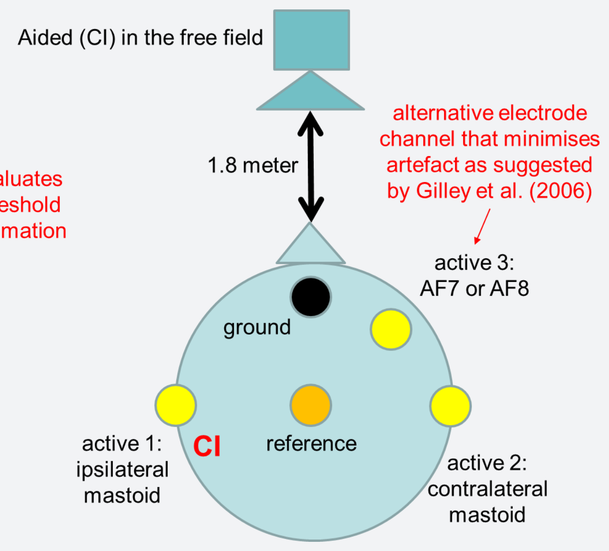
References

Friesen, L. and T. W. Picton (2010). "A method for removing cochlear implant artefact." Hearing research **259**: 95-106. Gilley, P. M., A. Sharma, et al. (2006). "Minimization of cochlear implant stimulus artifact in cortical auditory evoked potentials." Clinical neurophysiology **117**(8): 1772-1782. Mc Laughlin, M., A. Lopez Valdes, et al. (2013). "Cochlear implant artifact attenuation in late auditory evoked potentials: A single channel approach." Hearing research **302**: 84-95. Visram, A. S., Innes-Brown, H., El-Deredy, W., & McKay, C. M. (2015). "Cortical auditory evoked potentials as an objective measure of behavioral thresholds in cochlear implant users." *Hearing research* **327**: 35-42

Methods

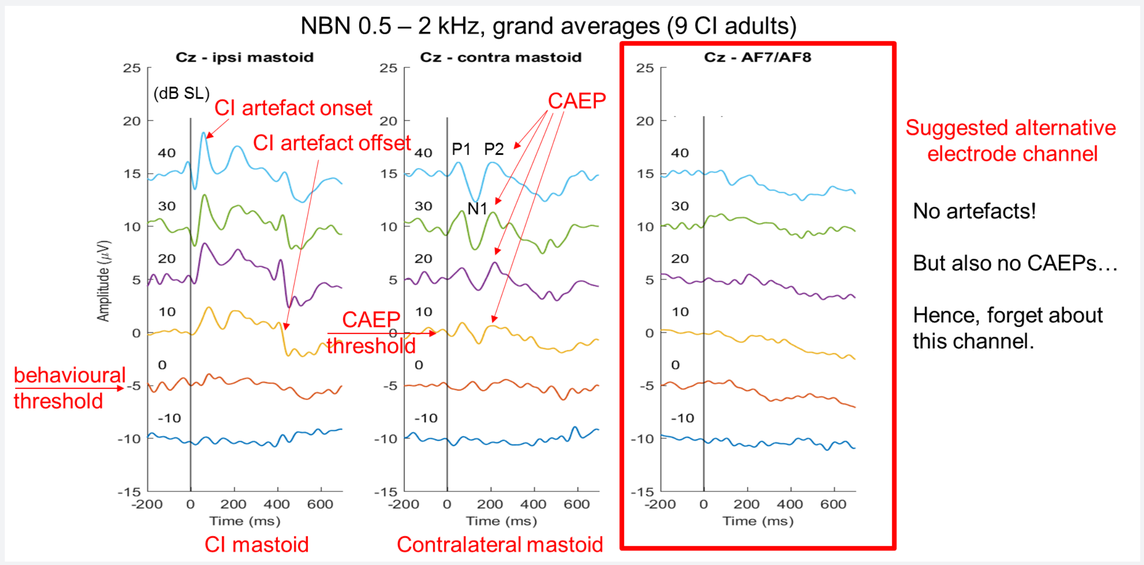
- longer stimulus
- 400 ms narrowband noise stimuli
  - 125-500 / 500-2000 / 2000-8000 Hz
- Stimulus levels
  - -10 / 0 / 10 / 20 / 30 / 40 dB SL ← evaluates threshold estimation
- Recorded with HEARLab system
  - 120 presentations per recording
  - 1-2 seconds SOA
  - Through a loudspeaker

9 adults with Cochlear CI



Results

Alternative electrode channel



Threshold estimation (before artefact reduction)

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

NBN	125 – 500 Hz	0.5 – 2 kHz	2 – 8 kHz	ALL
Mean ± SD (dB)	15.6 ± 12.4	15.6 ± 10.1	21.1 ± 11.7	17.4 ± 11.3

Contralateral side (opposite CI)

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

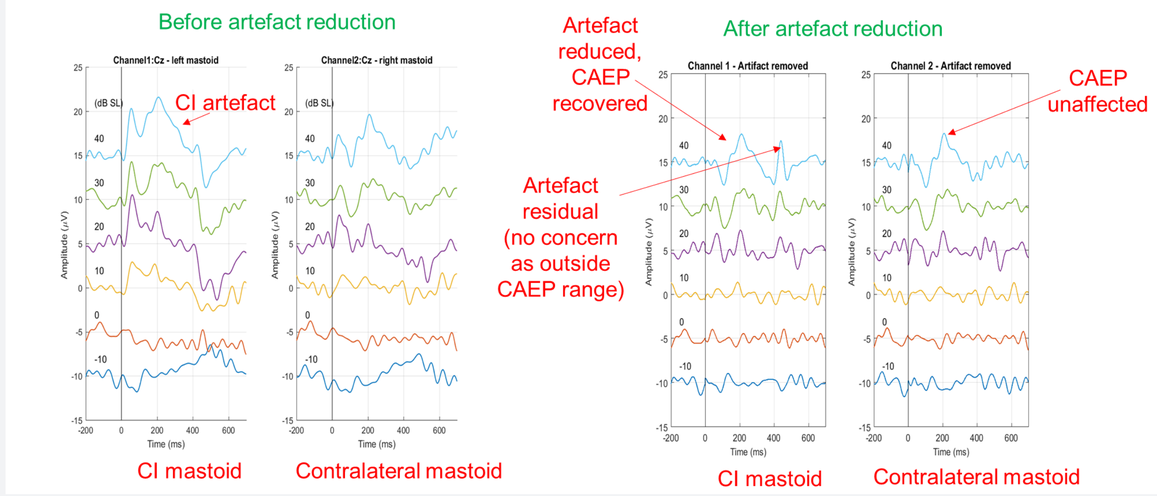
In all (100%) cases (9 subjects x 3 stimuli):
- a threshold could be determined
- a CAEP was detected at 40 dB SL (a significant increase when compared with short stimuli ~ 70%)

However still a CI artefact present, especially the ipsilateral side.

⇨ smart artefact reduction

Artefact reduction

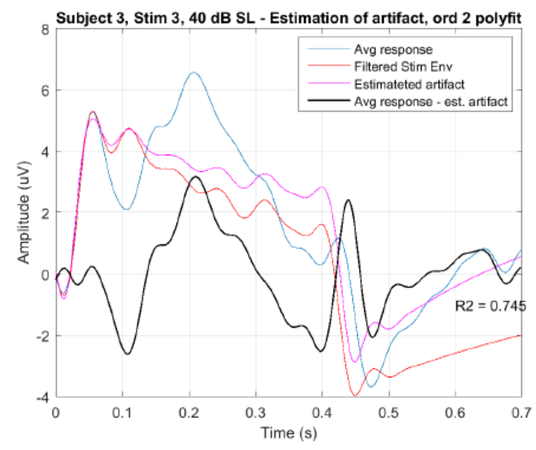
Example for a single participant: Adult 3, Stimulus NBN 2-8 kHz



Mc Laughlin et al (2013):
- CI artefact reduction
- Specifically for one EEG channel
- Assumes CI artefact relates to stimulus envelope

- Procedure:

1) Take the stimulus envelope
2) Filter with same filters as EEG 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**



Threshold estimation (after artefact reduction)

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

Before CI artefact reduction

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

Significantly less CI artefacts

Especially less large artefacts making CAEP interpretation difficult or impossible

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

After CI artefact reduction

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

Conclusions

- 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 reduction significantly improves thresholds in contralateral side only.