Feasibility of Measuring Auditory Steady-State Responses in Children with a Cochlear Implant

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Introduction

Conventional CI fitting procedures depend on the **subjective feedback of the CI user**. However, this approach is difficult to use in CI users who are not able to give adequate behavioral feedback, particularly in young children and infants. An **objective method to determine the electrical stimulation parameters** could be a solution to be certain the child has proper access to sound after the fitting session. New advances show that **electrically evoked auditory steady-state responses (eASSRs)** measured with electroencephalography (EEG) have great potential as an objective fitting method for CIs, especially for clinically relevant stimulation parameters, i.e., high pulse rates (pps) and a monopolar stimulation (MP) configuration[1,2]. eASSRs are phase-locked responses from (sub-) cortical regions of the auditory cortex and can be elicited with amplitude-modulated (AM) stimuli[2,3]. Previous research confirms that AM stimuli elicit neural responses with a high signal-to-noise ratio (SNR) in adults[4]. Furthermore, it has been shown that this measure represents temporal envelope encoding across the auditory pathway[2]. Recent research in our lab shows that this approach is successful in adults with a CI, despite the **high stimulation artifacts** that corrupt the EEG[1].

However, measuring these responses in children with a CI is challenging. A successful **artifact removal method**, i.e., linear interpolation, enables the measurement of artifact-free responses with clinical CI parameters in adult CI users, with the majority of eASSR thresholds within the lowest quartile of the dynamic range[1]. The **threshold determination** based on the eASSRs has not been established for the pediatric CI population due to lack of appropriate artifact removal methods in children with a CI and several other factors that complicate data collection and analyses, e.g., smaller responses, smaller head, artifact topography, … The purpose of this study is to conduct a feasibility study and compare several artifact removal methods. Therefore, we measure eASSRs, with clinical CI parameters, in children with single-sided deafness who received a CI.

Methods

Experiment Protocol

- Children with single-sided deafness with implant from Cochlear Ltd. (n=3, 6y)
- Stimulus: Sinusoidal amplitude-modulated (SAM) 900-pps pulse train in MP mode
  - Fixed modulation depth of 50 current units (cu) → Based on average dynamic range (DR) in CI users[5,6]
- **Behavioral measurement: Fitting**

  Loudness growth functions (7-point categorical loudness scale)
- **EEG measurement:** SAM pulse trains recorded on electrode 10 with hyper-rate EEG sampling system[7]
  - Modulation frequency (f_m): 37 40 43 Hz & 82 89 96 Hz x 5 min
  - Electrode locations: Fpz, Fz, Cz (as reference electrodes), Iz, P9, P10, Mastoid Left, Mastoid Right

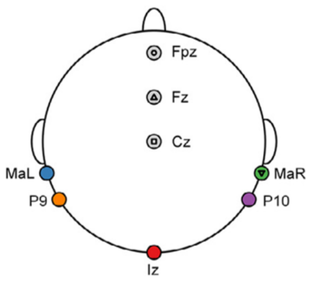

Figure 1: Recording electrode locations for EEG measurements.

Artifact removal

- EEG recording is contaminated with electrical artifacts[3,8,9]

Electrical artifacts were removed by means of linear interpolation (LI)[3] & system identification (SI)[8,9]

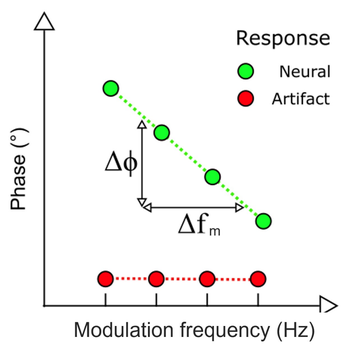

Figure 2: Phase slope as a function of modulation frequency. The green dots indicate a neural response, whereas the red dots indicate the response is artifact dominated. Artifact dominated responses have a phase of 0 degrees and no phase slope. For neural responses, there is a phase different from 0 degrees. Across neighboring modulation frequencies there is a downward phase slope, since phase decreases with increasing modulation frequency.

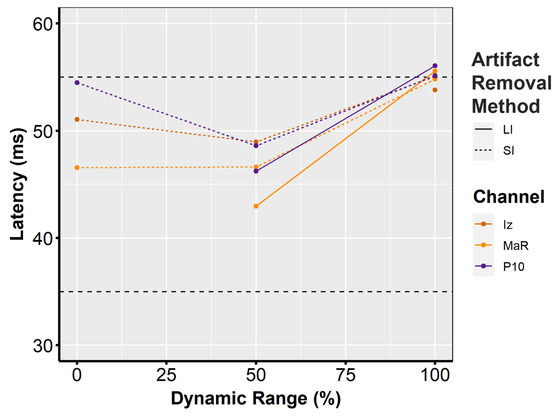

Figure 3: Latency as a function of dynamic range for Iz, MaR, P10 with reference Fz. Artifacts removed with LI are indicated with a full line, whereas SI is indicated with a dashed line. A latency is calculated from the phase slope for significant phases. For 40-Hz modulation frequencies we expect latencies between 35-55 ms (black dashed lines), which indicates a neural response. For LI, artifacts can only be removed until 50% of the DR, whereas for SI we can remove artifacts until the threshold level.

References

[1]Verwaerde et al. (2023). *In preparation.*
[2]Gransier et al. (2020). *Sci. Rep., 10.*
[3]Hofmann & Wouters (2012). *JARO, 13*, 573-589.
[4]Gransier et al. (2016). *Hear .Res., 335.*
[5]Rüegg et al. (2021). *J. Clin. Med., 10*, 324.
[6]Wathour et al. (2021). *Eur .Arch. Oto-Rhino-L, 278*, 4671-4679.
[7]Biosemi (2021). www.biosemi.com.
[8]Schott et al. (2022). *EUSIPCO, 1243-1247.*
[9]Schott et al. (2023). *IEEE.* Submitted.

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Results

LI vs SI

- Results are shown for best combination of contralateral/central electrode with reference electrode & blanking length of 1000 µs for LI
- Stimuli were presented at comfortable level based on SAM condition

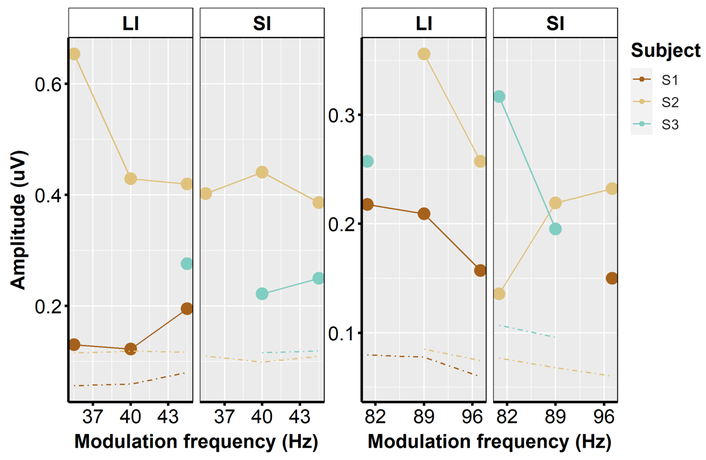

Figure 4: eASSR amplitude as a function of modulation frequency for both artifact removal methods. This figure shows only significant amplitudes across the neighboring modulation frequencies for both the 40-Hz range as the 89-Hz range for all three subjects. The dashed lines are the noise levels respectively.

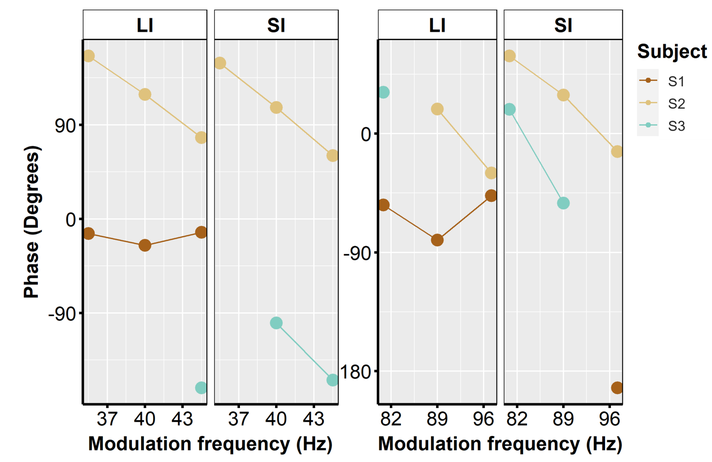

Figure 5: eASSR phase as a function of modulation frequency for both artifact removal methods. This figure shows the phase slope only for significant phases for all three subjects. A flat slope indicates that the responses are artifact dominated, whereas a downward phase slope indicates the presence of a neural response. For example, S1 has a flat phase slope for LI, yet for SI no significant neural responses were found. Therefore, SI has detected the presence of an artifact and correctly indicates there is no neural response. For S3, no significant responses are found with LI, whereas SI can detect significant neural responses for both modulation frequency ranges.

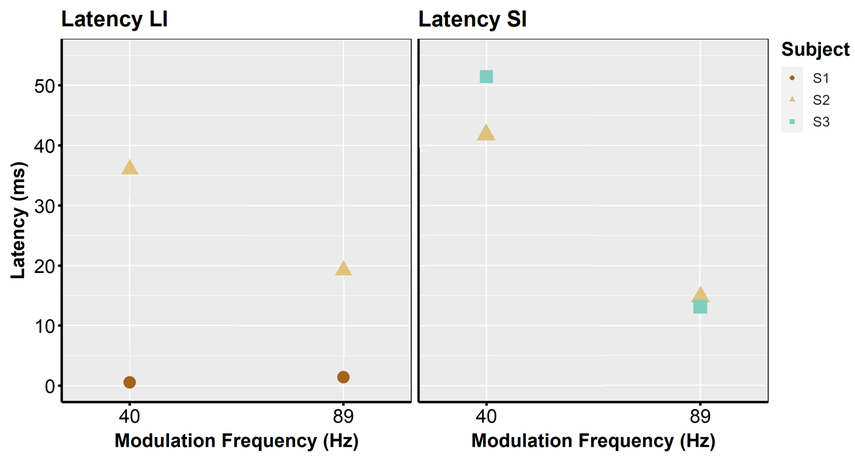

Figure 6: eASSR latency as a function of the modulation frequency range for both artifact removal methods. These latencies are calculated from the phase delay based on significant phases. A latency of approximately 0 ms indicates an artifact dominated response. For the 40-Hz frequency range the expected latency is 40 ms, whereas the expected latency for the 89-Hz range is around 15 ms. For LI not all artifacts were removed from the recordings. For SI, artifacts were removed, since latencies are within the expected range for each modulation frequency (i.e., 35-55 ms).

Conclusions

- eASSRs are promising metric to determine the pulse rate dependent stimulation levels in CI users and show their potential for an objective fitting routine
- System identification proves to be the best method for removing stimulation artifacts from the EEG recording in both adults and children with a CI
  - SI removes stimulation artifacts and correctly detects neural responses, where LI fails.
- Artifact-free neural responses are measured for contralateral/central electrodes in a clinically relevant setup (i.e., MP and 900 pps) with a hyper-rate EEG system[7] in children with a CI

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