Frequency Following Responses in Cochlear Implant Users

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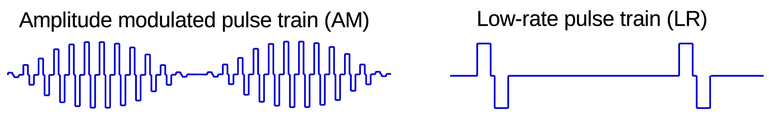
Introduction

- Frequency following responses (FFRs) reflect phase-locked neural activity to periodic sounds.
- FFRs are used to study auditory temporal processing
  E.g. Changes with ageing (Clinard et al., 2010), effects of auditory training (Anderson et al., 2013), neural plasticity (Tzounopoulos and Kraus, 2009), etc.
- Also, FFRs have been proposed as an objective measure for hearing aid fitting (Aiken and Picton, 2006; Choi et al., 2013)
- It is challenging to measure FFRs in CI users, mainly due to the large artefacts CI-stimulation causes in the EEG signal.
- This poster presents successful electrically-evoked FFR (EFFR) measurements in 4 CI users with Cochlear devices.

Methods

Stimuli



- Two stimulus types: AM (900 pps carrier) and LR
- Two frequencies to measure EFFRs: 80 and 100 Hz/pps + cortical EASSR measurement as reference: 40 Hz/pps
- Bipolar stimulation with polarity alternating over epochs (± 1 s segments) for (2 x) 300 epochs (± 5 min)
- Level: comfortable loudness (C-level)

Measurement set-up

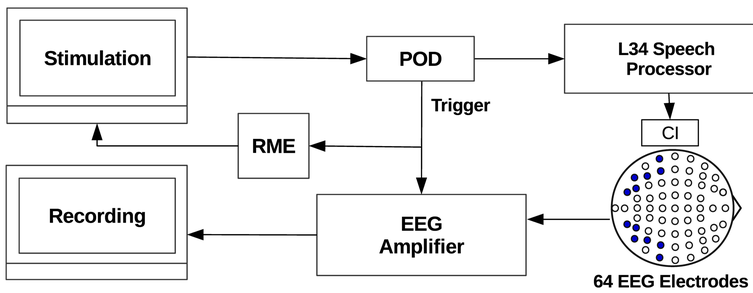


Figure 1: **Schematic representation of the measurement set-up.**
The EEG amplifier is a Biosemi ActiveTwo EEG Recording System with a sample rate of 8192 Hz.The subject is seated in an electrically-shielded sound-proof booth.

Artefact suppression

Linear interpolation (LI) (Hofmann and Wouters, 2010, 2012)

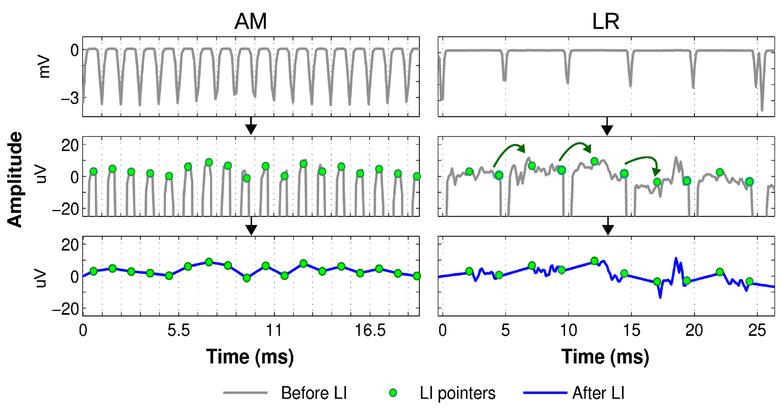


Figure 2: **Visualisation of artefact suppression**
AM: 900 artefacts/s, each interpolated over 1100 μs ($\approx$ 900 Hz sampling).
LR: less artefacts (e.g. 40 pps: stimulation artefact every 25 ms, power-up artefact every 4.9 ms) but interpolation over 2500 μs needed to remove artefact tail.

Signal processing

- Subtracting reference channel Cz from other EEG channels
- Averaging 12 EEG channels at the back of the head
- Rejection of epochs with large muscle artefacts
- Hotelling T^2 test ($\alpha = 0.05$) based on FFT spectrum

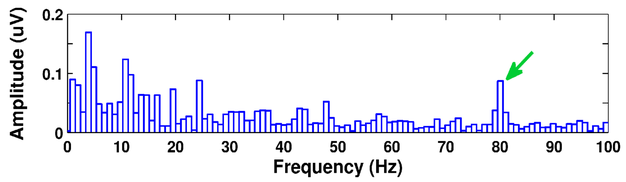


Figure 3: **Example FFT of EFFR for the 80 Hz AM stimulus**
Responses show as a spectral peak at the bin of the stimulus frequency (arrow). The bin width of the FFT spectrum is 0.97 Hz (1.024 s epoch duration).

Results

Significant EFFRs were found for AM and LR stimuli

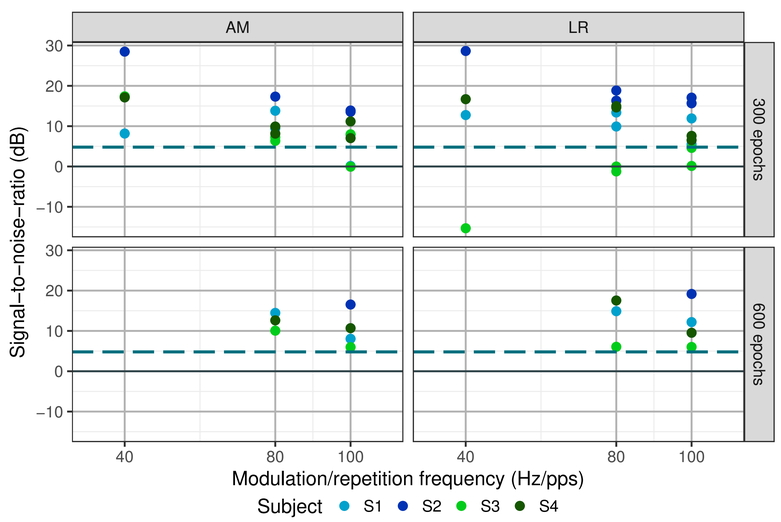


Figure 4: **Signal-to-noise-ratio and significance of responses**
The dots in the upper plots each represent a 300 epoch measurement, in the lower plots this is 600 epochs. The dashed lines show the SNR required for a significant response (Dobie and Wilson, 1996): 4.8 dB (300 epochs), 4.76 dB (600 epochs)

EFFRs follow the stimulation frequency

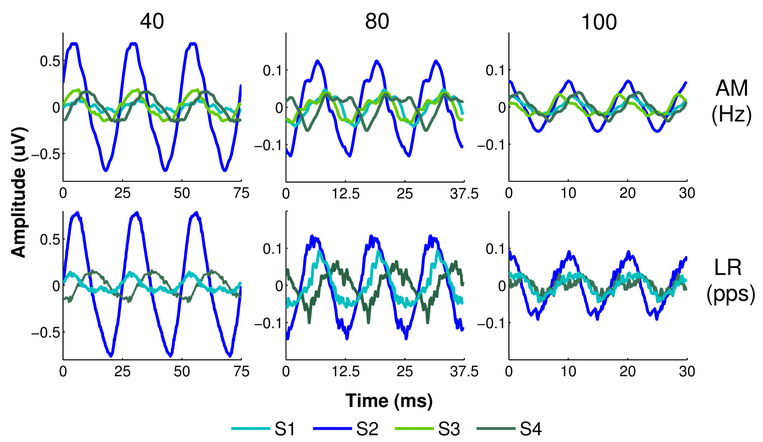


Figure 5: **Visualisation of averaged responses in the time domain**
For each condition, three average stimulus periods are presented. All waveforms are based on 300 epoch measurements. Low-rate stimulation results for S3 are not shown as responses were not significant within 300 epochs.

Phase delay increases with stimulus frequency, indicating reliable artefact suppression

- Neural processing → fixed time delay stimulus vs. response.
- Phase delay of responses increases with stimulus frequency.
- Phase delay of artefact infected responses is fixed at 0° or 180°.

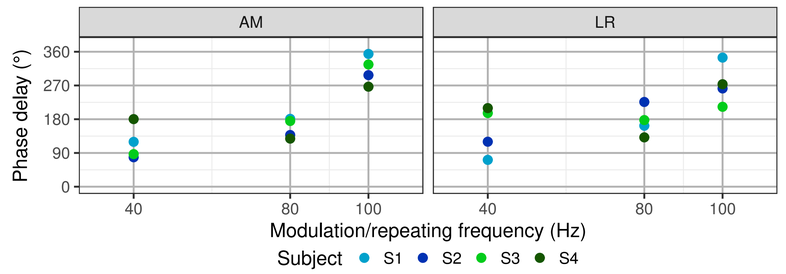


Figure 6: **Phase delay of measured responses**
If available 600 epochs measurements are shown and otherwise 300 epochs. Phase delays were converted to fit within the same 360-degree range.

Discussion

- Significant electrically-evoked FFRs were measured in all CI subjects, both with AM and LR stimuli.
- Phase delay of the responses increases with stimulus frequency, indicating adequate artefact suppression (Gransier et al., 2016).
- In most cases, significance was reached after 5 min.
- Future work could include EFFR measurement for more complex time-varying stimuli and the development of an objective fitting measure based on EFFRs.

Conclusions

In this work, we investigated the feasibility of measuring EFFRs in CI users. Results show that significant responses can be measured in all subjects for both amplitude-modulated and low-rate stimuli.

Acknowledgments & References

This research is funded by the Flanders Innovation & Entrepeneurship (formerly IWT), project 50432. The help provided by Robin Gransier during data collection is greatly appreciated.

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