Envelope-following responses in cochlear implant users: Effects of temporal envelope modulation complexity

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Electrically evoked auditory steady-state responses (EASSRs) are potentially useful neural responses for quantifying temporal envelope modulation (TEM) encoding of the auditory pathway in CI users [Luke et al. (2015) - 10.1016/j.heares.2015.02.006]. Unfortunately, they are difficult to detect in electroencephalography (EEG) recordings due to the electrical stimulation artifacts of the CI. A recent artifact removal approach has shown good detection results, even with clinically relevant stimulation parameters, but has practical limitations, such as requiring more than one EEG recording of different EASSRs [Schott et al. (2023) - 10.1109/TBME.2023.3316838].

It is hypothesized that increasing the complexity of the TEMs of the stimulation, i.e., using temporal envelopes with time-varying modulation frequency, has benefits in a clinical setting. For instance, using a CI stimulation with time-varying modulation frequency removes the necessity of more than one EEG recording to detect envelope-following responses.
Interestingly, the systematic increase of TEM complexity has been proposed in a stimulation framework for normal hearing subjects to assess the envelope processing in the auditory pathway [Gransier Wouters (2021) - 10.1016/j.heares.2021.108374]. It has been shown, that it may be useful for identifying differences in temporal envelope processing among various listener groups with distinct auditory processing deficits [David et al. - 10.3389/fneur.2022.852030]. However, its applicability to CI users has not yet been tested, mostly due to the challenges posed by the CI stimulation artifacts.

In this work, we created different CI stimulation paradigms using TEMs of higher complexity, i.e., systematically and randomly changing modulation frequency, and investigated the effect.
First, we analyzed, whether an increased complexity in TEMs has benefits for the CI stimulation artifact removal and response detection. For this, we created a hybrid dataset of EEG recordings with real CI stimulation artifacts and simulated neural responses.
Second, we recorded EEG from 4 CI users, using stimuli with different TEMs, and investigated, whether envelope-following responses can be evoked and detected with the different stimulation types.

Preliminary results suggest that CI stimulation using TEMs with time-varying modulation frequency are beneficial for artifact removal and response detection. From a technical standpoint, these stimuli are superior over conventional stimuli, used to evoke EASSRs, as they can reduce clinical testing time, and can be detected in an online routine.
Moreover, envelope-following responses can be reliably evoked and detected in all CI users using TEMs of varying complexity. From a neurophysiological perspective, these findings demonstrate that the proposed stimulation framework is also applicable to CI users.

Acknowledgement

This work was funded by Cochlear Technology Centre Belgium and the Flanders Innovation & Entrepreneurship Agency through VLAIO research grant HBC.2019.2373.