Monaural Electroencephalogram towards Brain-controlled Hearing Aids

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Reliable long-term electroencephalography (EEG) monitoring in- and around-the-ear could open remarkable new possibilities for medical devices as well as consumer products such as true wireless stereo earphones. Potential applications that can be unlocked with a single-ear wearable device include, yet are not limited to, brain-steered hearing aids, sleep monitoring, auditory attention decoding, temporal lobe epilepsy monitoring, and cognitive load/fatigue monitoring. Preliminary results with our novel single-ear EEG prototype show clear brain responses to auditory stimulation.

Target speaker identification, along with speech enhancement algorithms, improves the performance of hearing aids, in particular for so-called cocktail party scenarios. While hearing aids are optimized to amplify the human speech and suppress background noise, in multi-speaker conditions, further processing to identify the attended speaker and to amplify only their speech is needed. Recently, it has been shown that electroencephalography recordings (EEG) can be analyzed to identify the target speaker.

For hearing aids to benefit from this progress, there is a need for miniaturized EEG solutions which allow reliable, long-term, high-quality recordings without compromising everyday comfort.

To bridge this gap, we developed a new wearable device (ULTEEMear) in a compact form factor compatible with hearing aids and truly wireless stereo (TWS) earphones—wherein a physical connection between the two ears is not needed. The device was developed based on CSEM's proprietary active dry electrode technology,[1] allowing clinical-grade EEG acquisition and using Daetwyler Switzerland Inc.'s SoftPulse™ flexible dry electrodes; one in-ear and two flat electrodes that sit behind the ear outside hair region. Figure 1 displays the device worn by a subject on the right ear and its key features.

Figure 1: ULTEEMear single-ear single-channel EEG acquisition device in a hearing-aid-compatible form factor. The device is equipped with state-of-the-art connectivity solutions (BLE, USB) and exhibits a clinical-grade EEG recording quality (ISO 80601-2-26 compliant).

For a first evaluation of the functional sensitivity of ULTEEMear, a healthy subject underwent an auditory stimulation protocol while wearing the in-ear device. The EEG was recorded at 256 Hz, with an integrated bandpass filter of 0.5–40 Hz.

The protocol comprised 60 seconds of stimulation followed by silence; the stimulation consisted of repeated 100 ms bursts of white noise alternated with 100 ms of silence, to elicit steady-state evoked potentials (SSEP) in the auditory cortex at a repetition rate of 5 Hz. To avoid any signal contamination, the sound was delivered via audio speakers that were not in electrical or physical contact with the subject. Additional variants with different burst/silence duration (e.g., 125 ms) were also tested, to evaluate their impact on the fundamental frequency of the SSEP. After acquisition, the signals were analyzed with wavelet-based time-frequency decomposition and with the Welch method for average spectral estimation.

The time-frequency decomposition showed a clear EEG power peak at the fundamental stimulation frequency, which appeared quickly following the onset of the stimulation period and disappeared with its conclusion; higher frequency activity above 10 Hz was also stronger during the stimulation period (Figure 2a). The average signal spectrum for the 60 s stimulation period displayed the same clear peak at the stimulation frequency, and additionally enabled the distinction of several harmonics (Figure 2b). When computing the signal spectrum on less data (only the first 10 s), to further challenge sensitivity, the estimate showed stronger variability, yet the fundamental frequency and several harmonics (e.g., 15 Hz, 25 Hz) could already be clearly discerned (Figure 2c). Additionally, for protocols employing a different stimulus repetition rate, the fundamental peak moved accordingly to the respective frequency, as expected.

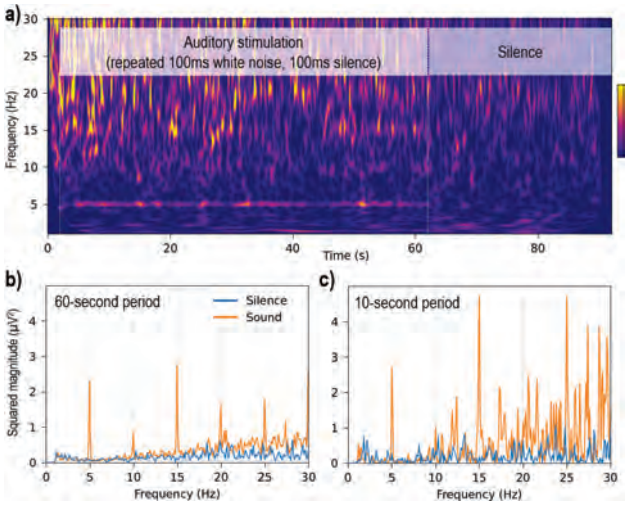

Figure 2: In-ear EEG response to auditory stimulation at 5 Hz repetition rate: (a) time-frequency decomposition, (b) average spectra during full 60-s stimulation period, and (c) first 10 s of stimulation.

In conclusion, this initial development and tests suggest a promising level of functional sensitivity for compact in-ear EEG with dry electrodes. Additionally, a third-party evaluation of our device for focus decoding shows equivalent performance when benchmarked against a commercially available 4-channel EEG headphone.

• Daetwyler Switzerland Inc

[1] G. Yilmaz, A. Seiler, O. Chételat, K. A. Schindler, Ultra-Long-Term-EEG Monitoring (ULTEEM) Systems: Towards User-Friendly Out-of-Hospital Recordings of Electrical Brain Signals in Epilepsy, Sensors 24 (2024) 1867.