Compact Long-term 8-channel Electroencephalography with High Functional Sensitivity using Cooperative-sensor Technology with Dry Electrodes

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The ability to monitor brain activity from multiple head locations during daily life activities, outside the lab, could bring crucial value to neuroscientists and clinicians. CSEM is exploring its cooperative-sensor technology to enable wearable, long-term, high-quality electroencephalography with 8 channels.

The ability to monitor brain activity with tools such as **electro-encephalography (EEG)** in a seamless, long-term manner during daily life activities outside the lab/clinics could prove highly valuable to neuroscientists, clinicians and patients. However, **wearable EEG** is technically challenging for several reasons: (i) a high signal-to-noise ratio is required to measure electrical brain activity, (ii) the presence of hair makes it difficult to achieve good electrical contact, and (iii) the presence of wires and components on the head can be cumbersome and stigmatizing.

Building on its past experience in wearable systems for cardiac and muscle electrophysiology, CSEM has recently developed **ULTEEM**, a highly compact single-channel wearable EEG system that is beginning to demonstrate excellent signal quality in areas such as sleep monitoring. Nonetheless, certain applications, such as the study of epileptic spike propagation, network activity and connectivity, require monitoring multiple head locations at a time, as in so-called **multi-channel EEG**.

In this work, CSEM explored the feasibility and advantages of its **cooperative-sensor technology** to develop a compact multi-channel EEG system with high signal quality, low sensitivity to noise perturbations and low wire density (Figure 1). The system was implemented with 8 sensors connected by a 2-wire parallel bus, and a compact control unit to supply the sensors with power and synchronization signals, and to store measurement data. A dedicated app was developed to control the device via Bluetooth. The sensors were designed with standard snap connectors to allow compatibility with diverse electrode types. Two sensor configurations (i.e., positions) were considered: **"Wake"**, with the sensors uniformly arranged in a ring around the head, and **"Sleep"**, focused on frontal and fronto-temporal regions (Figure 1).

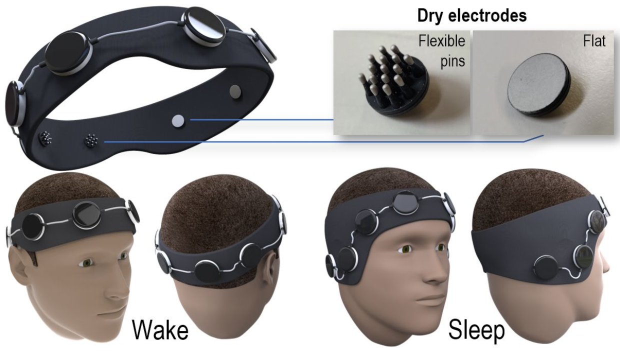

Figure 1: EEG prototype, with two different configurations ("Wake" and "Sleep"), here shown with dry electrodes (pin-type for hair, flat for skin).

Once tested for electrical safety, the system was tested in human volunteers for signal quality and functional sensitivity, as well as for the feasibility of EEG recordings with dry electrodes. In a first study focused on the **electrodes**, 4 participants were recorded in the "Wake" configuration while undergoing an alternated eyes open/closed protocol (15 s alternations) – known to increase alpha wave power (8–12 Hz) with eyes closed compared to open. The protocol was run using either dry electrodes (SoftPulse from Datwyler; pin type for posterior, flat type for anterior regions) or wet gel electrodes (NG Geltrodes, Neuroelectrics). Overall, both electrode types allowed a clear detection of alpha modulation (Figure 2a). On average for the group, the baseline noise observed with dry electrodes around the alpha peak was only 16% higher than with gel, while the peak amplitude was comparable.

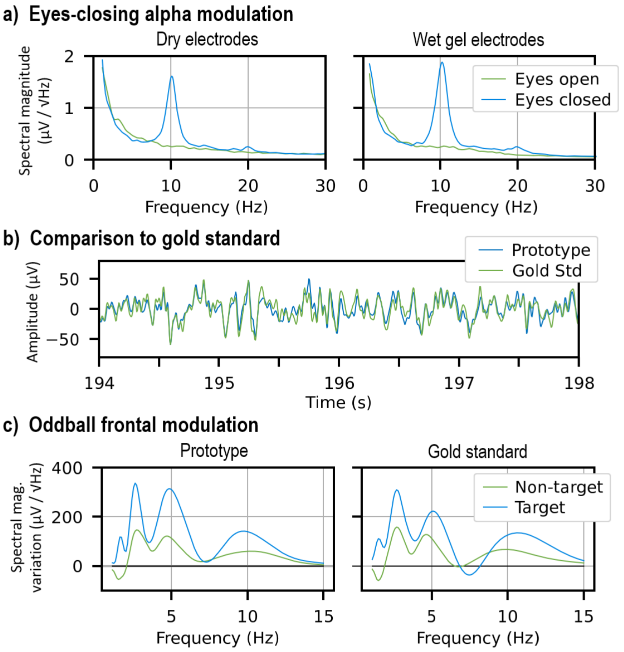

Figure 2: EEG signals recorded from human volunteers using different electrode types (a), and a concurrent gold-standard system (b,c).

In a second study focused on **functional sensitivity**, 2 participants were recorded with both the new prototype ("Sleep" configuration, dry electrodes) and a gold-standard commercial device (64-ch BrainAmp from Brain Products, passive wet gel electrodes), simultaneously. Besides eyes open/closing, an auditory oddball protocol was also run, where pure tones were played in succession – either a lower pitch (termed "non-target", more frequent) or a higher pitch ("target", rare). Overall, the signals measured by the prototype were highly similar to those of the gold standard (Figur 2b), with correlations of 0.89–0.98. Both systems showed similar modulations in the frontal brain response to target versus non-target stimuli (Figure 2c), namely an increase in theta waves (4–7 Hz), as reported in past studies.[1]

Altogether, the results obtained so far suggest that cooperative sensors can capture meaningful features of brain activity with high signal quality and low sensitivity to noise, even with fully dry electrodes. This project is conducted in close collaboration with Inselspital, Bern, and is partly funded by the Canton of Bern. CSEM thanks them for their support.

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[1] Cahn, *et al.*, 2013, *https://doi.org/10.1093/scan/nss060*