Dry and Water-Based EEG Electrodes in SSVEP-Based BCI Applications

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Abstract. This paper evaluates whether water-based and dry contact electrode solutions can replace the gel ones in measuring electrical brain activity by the electroencephalogram (EEG). The quality of the signals measured by three setups (dry, water, and gel), each using 8 electrodes, is estimated for the case of a brain-computer interface (BCI) based on steady state visual evoked potential (SSVEP). Repetitive visual stimuli in the low (12 to 21Hz) and high (28 to 40Hz) frequency ranges were applied. Six people, that had different hair length and type, participated in the experiment. For people with shorter hair style the performance of water-based and dry electrodes comes close to the gel ones in the optimal setting. On average, the classification accuracy of 0.63 for dry and 0.88 for water-based electrodes is achieved, compared to the 0.96 obtained for gel electrodes. The theoretical maximum of the average information transfer rate across participants was 23bpm for dry, 38bpm for water-based and 67bpm for gel electrodes. Furthermore, the convenience level of all three setups was seen as comparable. These results demonstrate that, having optimized headset and electrode design, dry and water-based electrodes can replace gel ones in BCI applications where lower communication speed is acceptable.

Keywords: Dry electrodes, Water-based electrodes, EEG, Signal quality, Brain-computer interface, BCI, Steady state visual evoked potential, SSVEP.

1 Introduction

Brain computer interface (BCI) technology has not yet reached wider adoption except for the few cases where it is used by severely impaired patients (for a recent review see [1]). A number of research groups are trying to bring this technology to a more advanced level, mainly focusing on the most convenient of brain sensing solutions - the electroencephalogram (EEG) - which measures electrical activity of the brain.

Despite numerous advances, both in technological and ergonomic aspects, all three predominant noninvasive BCI modalities, namely steady state visual evoked potential (SSVEP), motor imagery, and P300 are still bound to laboratory settings and do not show clear signs of being ready for wider commercialization in coming years. Among the many problems that EEG-based BCI systems face, the most important ones include:

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1. Cumbersome and inconvenient procedures to prepare the user before BCI operation, low comfort during the BCI operation, and issues in detaching the system at the end of the usage.
2. Lower accuracy of the BCI command classification algorithms, especially when deployed outside lab conditions, leading to a lower information transfer rate (ITR).
3. Long time required for the user to adapt and learn to use the BCI, including the time required for the BCI to learn specific user parameters, i.e., long calibration procedure.
4. Unpleasant and intrusive interaction with a BCI system that results in users being aversive to the use of BCIs.
5. High number of users that cannot learn to use the BCI, i.e., a so-called BCI illiteracy.

While the first problem is common to all BCIs, except that the number and positioning of electrodes used in a particular system can differ, the latter ones have different impact depending on the BCI modality. In addressing these problems, we consider the SSVEP BCI as a promising solution because, when compared to other BCIs, it can provide high level of detection accuracy (i.e., high ITR), requires short calibration time, and has low BCI illiteracy [2, 3].

The steady state visual evoked potential refers to the response of the cerebral cortex to a repetitive visual stimulus (RVS) oscillating at a constant stimulation frequency. The SSVEP manifests as peaks at the stimulation frequency and/or harmonics in the power spectral density (PSD) of EEG signals [4]. Because of their proximity to the primary visual cortex, the occipital EEG sites exhibit a stronger SSVEP response. SSVEP based BCIs operate by presenting the user with a set of repetitive visual stimuli (RVSi). In most of current implementations, the RVSi are distinguished from each other by their stimulation frequency [5–8]. The SSVEP corresponding to the RVS receiving user's attention is more prominent and can be detected in the ongoing (i.e., background) EEG. Each RVS is associated with an action or a command which is executed by the BCI when the corresponding SSVEP response is detected.

The majority of current SSVEP-based BCIs use stimulation frequencies in the 4 to 30Hz frequency range [9]. RVS at these frequencies, as compared to higher frequencies, have several disadvantages that underpin the fourth problem defined previously: they are prone to visual fatigue which decreases the SSVEP strength, they entail a higher risk of photic induced epileptic seizure [10], and they overlap with the frequency bands of spontaneous brain activity. Higher stimulation frequencies are, thus, preferable for the sake of safety and comfort of the BCI user [3].

The major aspect addressed in this paper is the first problem of the inconvenient and uncomfortable preparation, usage, and detachment of a BCI. This problem stems from the fact that EEG recording procedures remained very similar to that of the early EEG days. The EEG is recorded using Ag/AgCl electrodes that are in contact with the scalp through electrolytic gel [11]. The electrolyte serves two purposes, i) it bridges the ionic current flow from the scalp and the electron flow in the Ag/AgCl electrode and ii) 'glues' the electrode to the scalp. To further improve signal quality, the scalp is frequently cleaned and, especially in clinical applications, skin on the scalp is abraded.