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Towards Implicit Control Through Steady-State Somatosensory Evoked Potentials

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Abstract. We present a reliable reactive BCI based on steady-state somatosensory evoked potentials (SSSEPs). As the stimulation frequencies are higher than 40 Hz this system ensures no interference with BCIs relying on ERPs or SMR. Hence, the presented system can be combined with other BCIs broadening the bandwidth of communication.

Keywords: Reactive BCIs, steady-state somatosensory evoked potentials (SSSEPs), Hybrid BCIs

1. Objective

The study presented here aims at extending the scope of interaction with Brain-Computer Interfaces (BCIs), by introducing a BCI system which does not interfere with most of the established BCI systems. This is done by using a BCI based on steady-state somatosensory evoked potentials (SSSEP) working with signal frequencies of more than 40 Hz, hence lying above those frequencies generally associated with human cognition [Ward, 2003]. Additionally, the presented BCI is a reactive BCI (rBCI) [Zander and Kothe, 2011], aiming to provide a solution for implicit control over a Human-Machine System [Rötting et al., 2009] and thus to reduce cognitive demands for human-machine interaction. As a consequence, the presented BCI system may possibly be combined with other BCIs, such as a motor imagery BCI, and can thus add degrees of freedom to interaction with future BCI systems.

2. Approach

Reactive BCIs usually make use of two different types of features in the EEG. They are either based on detection of changes in or appearance of event related potentials (ERPs) typically caused by appearance of stimuli relevant to the user or on the detection of steady-state evoked potentials (SSEPs). The latter are potentials which are evoked from perceiving a stimulus that is modulated in a specific frequency, leading to differences in the spectral domain of the EEG of that same frequency. Prior work in the field of rBCIs is mainly based on visual stimulation, such as the P300 Speller [Farwell and Donchin, 1988]. Also, most of the work with SSEPs was based on visual input [Lalor et al., 2005; Müller-Putz and Pfurtscheller, 2008] whereas some work also included tactile [Brouwer and van Erp, 2010] or auditory [Nijboer et al., 2008] stimuli, thus providing a proof of concept that this approach can potentially be transferred between modalities. As the visual and the auditory domain of users in Human-Machine Systems usually are occupied during operation, we investigate rBCIs that rely on tactile stimulation. Our approach transfers the knowledge gained from the rBCIs mentioned above to this modality and investigate the reliability of the resulting implicit control. We modulate specific frequencies in the EEG by steady-state somatosensory evoked potentials (SSSEPs) with auditory speakers as tactile stimulators. The frequency domain of the tactors is kept above 40 Hz and thereby excludes (1) interference with typical BCI-applications that are based on evoked potentials since those usually consist of waves within a lower frequency band (0.5 Hz–5 Hz) and (2) covering of the frequency domain which is generally assumed to be related to cognition [Ward, 2003].

3. Method

Data sets from 8 participants were included in the preliminary analyses. EEG was recorded using 64 impedance-optimized electrodes (BrainProducts, Gilching, Germany). Tactors used for the experiment were developed by Eagle Science (Haarlem, The Netherlands) and are based on auditory speaker modules. Compared to tactors that are driven by unbalanced motors, the stimulation with auditory based tactors is very precise and well adjustable regarding the frequency and amplitude of the vibration. Two tactors were placed on the participants' palms of the left and right hand. The used form of stimulation was derived from Tobimatsu et al. [1999]: Each tactor was vibrating with a carrier-frequency of 128 Hz sine modulated with a sine of 41 Hz on one hand and 59 Hz on the other one. Prime number frequencies were used for modulation to reduce overlapping frequencies. Each trial started with the presentation of a randomly selected letter from the set 'L', 'R' at the center of the screen for 2 s.

Hereafter, the letter was replaced by a fixation cross for 3.8 s. Simultaneously the tactors started vibrating and participants were asked to focus their attention on the vibration on the left hand side if the initial letter had been 'L' or on the vibration on the right hand side if it had been 'R'. After 2.8s of the stimulation period the amplitude was reduced by half for 0.125 s (amplitude twitch, similar to [Müller-Putz et al., 2006]). Participants completed 120 trials, 60 for each tactor. A linear weighting was derived for each class respectively (attention on left or right tactor) by averaging differences between the estimated power of the frequencies of 41 Hz and 59 Hz and normalizing it by the respective averaged bandpower derived from the two seconds of data before the stimulus. For classification, features were extracted by a similar procedure. Again, but here on single trial data after the amplitude twitch, bandpower was estimated for both frequencies, and normalized by the bandpower of the prestimulus data. The resulting vectors were each linearily combined with both weight vectors, resulting in a 4 dimensional feature space. Single-trial offline classification was performed with BCILAB [Delorme et al., 2011], generating a regularized linear discriminant analysis for each participant by crossvalidating the trials along the aforementioned approach.

4. Results

The estimated accuracy was 65.5 % (SD: 3.7 %) on average across subjects.

5. Discussion

For each participant the classification accuracy was reliable, but probably not sufficient for useful control. This hints to a problem caused by instability of the feature vectors and non-stationarity of the signal for which a solution needs to be found. Future research should focus on new types of feature extraction dealing with this problem. Improvement of the linear weighting to a spatial filter could be a solution, which would have to be tested on data from a higher number of participants. A hybrid application combining the approach described here with e. g. a motor imagery BCI should be promising to increase the bandwidth of information transfer in BCI-based applications.

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