Hybrid oddball - SSVEP BCI

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Abstract

Objectives: blablabla blalabbla Steady-State Visually Evoked Potential (SSVEP)-based BCIs.

Results: blablabla blablabla SSVEP responses.

Conclusion:

1 Introduction

Brain-Computer Interfaces (BCIs) aim at decoding the brain activity in order to provide a direct communication channel between the brain and an external device. In this study, the brain activity is recorded using electroencephalography (EEG), which offer the advantage over other method (*e.g.* micro electrodes, fMRI ...) to be non-invasive and easy to set up.

Some of the earliest EEG-BCI systems were based on the P3 component of the Event Related Potential (ERP) (Donchin et al. 2000; Farwell and Donchin 1988). The P3 is a positive deflection in the EEG time-locked to salient stimuli presented in an oddball paradigm, typically evoked over the parietal cortex, and occurs between 200 and 500 ms after stimulus onset (Sutton et al. 1965). Although those BCIs rely mostly on the P3 component, other components (*e.g.*, occipital N1 and/or N200) may also be used for ERP detection (Bianchi et al. 2010; Kaufmann et al. 2011), for this reason we prefer here to use the term *oddball-based BCIs*.

Such system have been shown to work successfully on both healthy and disabled patient Krusienski et al. 2008; Sellers et al. 2010 CITE PLOS ONE PAPER, however, as they rely on several repetition of a stimuli sequence in order to increase the signal-to-noise ratio of the ERP, they remain slow and the communication speed decreases as the number of stimuli (*i.e.* number of choices available to the user) increases.

Other systems of interest are BCIs based on Steady-State Visually Evoked Potentials (SSVEPs). They rely on the psychophysiological properties of the EEG brain responses recorded from the occipital cortex during the periodic presentation of identical visual stimuli (*i.e.* flickering stimuli). When the periodic presentation is at a sufficiently high rate ($>$ 6 Hz), stable and synchronized neural oscillations at the stimulus frequency and its harmonics are evoked over the visual cortex (Herrmann 2001; Luck 2005; Regan 1966). Such BCIs are particularly attractive because SSVEPs have high signal-to-noise ratios and are less susceptible to eye movement and blink artifacts (Perlstein et al. 2003) as well as electromyographic artifacts (Gray et al. 2003). Several SSVEP-based BCIs have been successfully tested with healthy subjects (see Vialatte et al. 2010 for a review).

As for oddball-based BCIs, SSVEP systems have been successfully test on healthy subject (Allison et al. 2008; Friman et al. 2007) and only recently (to a lesser extend) with locdked-in patients (Parini et al. 2009) CITE PLOS ONE PAPER. on screen -¿ limited number of stimuli -¿ screen refresh rate, size of stimuli, distance between them and coamplification

Recently, the BCI community started to develop so-called hybrid BCIs, which combine different data acquisition techniques in order to improve the user experience of the system. As defined by Pfurtscheller et al. 2010, *"a typical hybrid BCI is composed of one BCI and another system (which might be another BCI), and must also achieve specific goals better than a conventional system"*. We focus here on the case where both system are BCIs. The improvement achieved by a hybrid system can be of different natures such as a higher accuracy, number of choice or selection speed, access to a no-control state, a better usability or higher number of person effectively able to use the system (Brunner et al. 2011).

2 Materials and Methods

2.1 Material

The EEG signals were recorded using a BioSemi Active Two system with 32 channels (following the 10-20 international system) at a sampling rate of 1024 Hz. Two additional electrodes were positioned on the right and left mastoids and the mean of the signals recorded at those two sites was used to reference the activity measured by the 32 EEG electrodes.

All stimulation employed MATLAB®, the stimuli were visually presented on a laptop's LCD screen (60 Hz refresh rate) and their display and timing used the *Psychophysics Toolbox Extensions* (Brainard 1997; Pelli 1997).

2.2 Experimental protocol

2.2.1 Experiment 1: studying the oddball ERPs

The aim of this first experiment was to study the effect of a flickering background on the typical ERP response associated to an oddball paradigm. N subjects participated in the experiment (age, gender).

As shown in Fig. 1, a typical *stimulation cycle*, started with a 2000 ms cue, indicating the participant his/her target item, followed by a 1000 ms pause during which the cue disappeared and all icons remained gray. The background rectangle started then to flicker and the oddball stimulation began 500 ms later. The oddball stimulation consisted of 10 *flashing sequences* during which each of the 6 icons was flashed one after another in random order for a duration randomly set between 200 and 300 ms. As usually done for oddball experiments, the participants were instructed to focus on their target symbol and count the number of time it flashes. A 1000 ms pause followed the oddball stimulation and preceded the next cue. An *experimental run* lasted approximately 4 minutes and consisted of 12 consecutive stimulation cycles, so that each of the 6 icons was cued twice (in random order).

As we aimed here at studying the effect of the flickering background on the oddball ERP response, we considered 5 experimental conditions. The first one (*baseline condition*) consisted of a run as described in the previous paragraph but in which no flickering background was displayed. The 4 other conditions (*hybrid conditions*) differed only by the frequency of the flickering background; the frequencies used were 8.57, 10, 12 and 15 Hz, corresponding to the division of the refreshing rate of the screen by 7, 6, 5 and 4, respectively.

For each of the 5 conditions, all subjects performed 3 runs, therefore the whole experiment consisted of 15 runs of approximately 4 minutes each. The order of the run was randomized for each subject and a 5 to 10 minutes pause was set up every 5 runs.

2.2.2 Experiment 2: studying the SSVEP responses

The aim of this second experiment was to study the effect of an oddball paradigm on the SSVEP responses. N subjects participated in the experiment (age, gender).

The experimental run was the same as described in sec. 2.2.1. Two experimental parameters were manipulated, the first one was the stimulation frequency; the same frequencies as for the first experiment were used (8.57, 10, 12 and 15 Hz). The second experimental parameter was the presence or not of the oddball stimulation sequence. When the oddball stimulation was displayed, the participants were instructed to count the number of flashes of the target icon, while when no oddball stimulation was displayed, their task was simply to focus on their target icon.

The experiment consisted thus of 8 runs of approximately 4 minutes each. The order of the run was randomized for each subject and a 5 to 10 minutes pause was set up after the first 4 runs.

2.2.3 Experiment 3: hybrid classification

This third experiment consists in a proof-of-concept for a hybrid oddball-SSVEP BCI. N subjects took part in the experiment.

Two rectangles flickering at 12 Hz and 15 Hz where simultaneously presented on the left and right side of the screen, respectively. Within each of those rectangles 6 items were presented so that 2 independent and simultaneous oddball paradigm could occur as shown in Fig. 2. The *stimulation cycle* was the same as described in sec. 2.2.1, icons from the left and right rectangles were always flashed simultaneously, however the order in which the icons would be flashed was set independently (and randomly) for each rectangle. An *experimental run* lasted approximately 4 minutes and consisted of 12 consecutive stimulation cycles, so that each of the 12 icons was cued once (in random order). Each subject participated in 8 consecutive runs with a 5 to 10 minutes pause after the the 4$^{\text{th}}$ run.

2.3 Data Analysis

2.3.1 Experiment 1: ERP classification

We first observed average responses to target (and non-target?) stimuli for each of the 5 experimental conditions. The EEG signals were filtered between 0.3 and 30 Hz (zero-phase 3$^{\text{rd}}$ order Butterworth filter) and epochs were cut from 200 ms before the stimuli onsets until 800 ms after. In order to ensure that none of the epochs used for averaging were corrupted by ocular artifact, we rejected, for each *experimental run*, the 15% epochs with the highest peak-to-peak amplitude (Luck 2005). We also visually inspected the filtered EEG traces to verify that no of ocular artifact could be seen within the 85% remaining epochs. For each participant, averaged ERPs were observed and compared with respect to the experimental condition. We particularly looked for differences between the baseline condition (pure oddball) and the hybrid conditions (4 other condition with flickering square) and within the hybrid conditions themselves for an eventual influence of the flickering frequency over the ERP response.

The second step was to compare classification accuracies. The EEG signals were filtered between 0.5 and 20 Hz (zero-phase 3$^{\text{rd}}$ order Butterworth filter), epochs were cut from each the stimuli onsets until 600 ms after and downsampled to 128 Hz. The resulting epochs were labeled to either *target epochs* or *non-target epochs* according to whether they corresponded to the EEG response to a target stimulus (flashing of a target symbol) or a non-target one (flashing of any non-target symbol). For each subject and experimental condition, we ran a 3-fold cross-validation where a linear Support Vector Machine (SVM) was trained (Keerthi and DeCoste 2006) on the data collected during 2 out of the 3 experimental runs and the performance was measured on the remaining run. We thus obtain for each subject and experimental condition 36 correctness values (0: wrongly detected and 1: correctly detected). The correctness values were computed for a number of repetitions N_r of the flashing sequence varying from 1 to 10. In order to mimic the behavior of a BCI, for each stimulation cycle and each icon, epochs were average over the N_r *first repetitions*.

The correctness data were analysed using R (CITE) and the R package *lme4* (CITE + languageR?). We used logistic linear mixed effect models (CITE) with the number of repetitions nested within subjects as random factors. As fixed factors, we considered the experimental condition, the number of repetitions and the interaction between those 2 factors. We used Non significant fixed effects The significance of the fixed factors as predictors for the correctness was established by means of likelihood ratio test (CITE).

2.3.2 Experiment 2: SSVEP response analysis

2.3.3 Experiment 3

3 Results

3.1 Experiment 1: studying the oddball ERPs

3.2 Experiment 2: studying the SSVEP responses

3.3 Experiment 3: hybrid classification

4 Discussion

5 Conclusion

Acknowledgments

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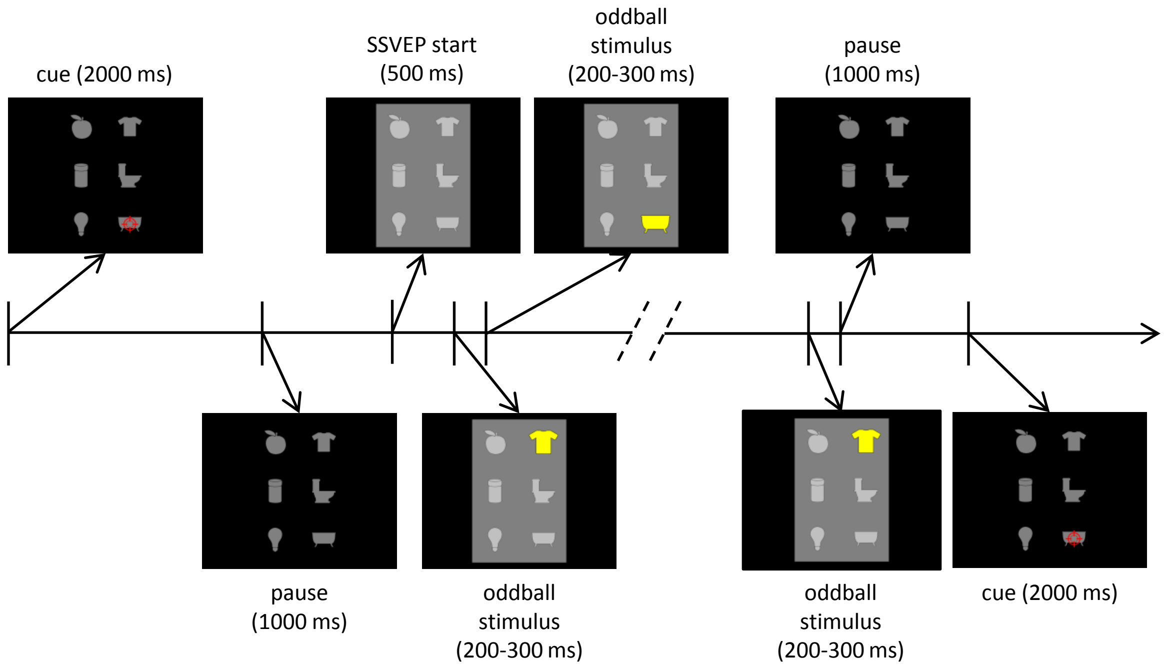

Figure 1: stimulation sequence

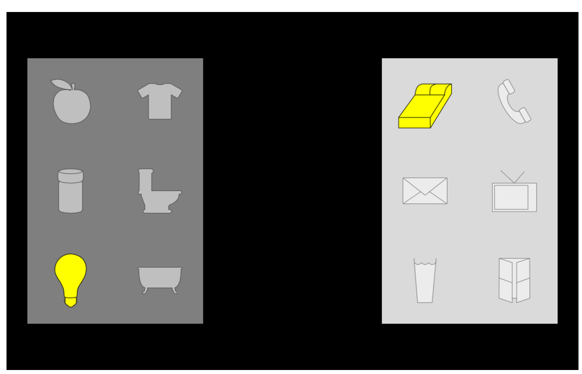

Figure 2: example of stimulus