Gaze-independent visual brain-computer interfaces
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Abstract. One goal of Brain-Computer Interface (BCI) research is to enable paralyzed patients to communicate. For the popular Matrix Speller, recent studies have shown that the spelling accuracy breaks down when the user is not allowed to fixate the target symbol. This observation raises the need for BCI spellers that work effectively for patients with serious oculomotor impairment. Here we will present three visual spellers based on covert spatial attention and non-spatial feature attention. Results with 13 healthy participants demonstrate that these spellers obtain a similar spelling performance during center fixation as the original Matrix Speller with target fixation.

Keywords: Covert attention, feature attention, mental typewriter, BCI, EEG

1. Introduction

A brain-computer interface (BCI) based on event-related potentials (ERPs) exploits the fact that the neural processing of a stimulus is modulated by attention. In particular, attention to an event can enhance the positive and negative peaks of the ERP time-locked to this event. ERP-based BCIs attempt to detect these modulations to infer the stimulus that the user intended to choose. Often, the BCI is implemented in an oddball paradigm, wherein rare target events are interspersed with frequent nontarget events. The first such device was the Matrix Speller introduced in [Farwell & Donchin 1988]. In this classical speller, a symbol matrix is shown on a screen and rows and columns of that matrix are randomly intensified. After averaging across few repetitions of the brain activity that is elicited by intensifications of rows and columns, the BCI system can detect the target ERPs and thus conclude the symbol attended by the user. In Farwell and Donchin's study, healthy participants were able to communicate at an average speed of 2.3 symbols/min.

Recent studies [Treder & Blankertz 2010, Brunner et al 2010] have shown that this performance of the Matrix Speller crucially depends on the fact that participants actually fixate the target symbol with gaze. In order to enable patients with oculomotor impairment to communicate via an visual ERP-based speller, a novel design is required. Here, we propose three variants of such spellers, which all proved to be successful in a study with 13 participants.

2. Material and Methods

Thirteen participants (8 males and 5 females), aged 16-45 years (mean 27), took part in the experiment. Concurrently with 64 channel EEG recording (BrainAmp and ActiCap by Brain Products), an Intelligaze IG-30 (Alea Technologies) eyetracker, sampling at 50 Hz, was used to register eye movements and to interrupt and repeat trials in which deviations from center fixation were detected.

Visual stimulation was achieved using three variations of the ERP Hex-o-Spell introduced in [Treder & Blankertz 2010]. It allows to choose one out of 30 different symbols comprising the letters of the English alphabet, punctuation and a backspace symbol that could be used to erase the previous symbol. The Hex-o-Spell is a two-stages speller, wherein a symbol group (e.g., "ABCDE") is selected at the first stage. Upon selection of a group, the symbols of that group are expanded on the other discs so that, at the second stage, the target symbol can be selected. The specific design of the three spellers is shown in Fig. 1.

The order of the three spellers was randomized across participants. For each speller there was initially an offline run which was used to calibrate the classifier [Blankertz et al, in press]. Then two runs followed in which participants could write phrases online. For the first run one a phrase was given, in the second one users could freely select what to write.
3. Results

The spelling accuracies using 10 repetitions of the six stimuli for Hex-o-Spell, Cake Speller and Center Speller were 90.4%, 88.0% and 97.0% respectively. Note, that the participants were instructed to correct their spelling mistakes using the backspace symbol of the speller such that the final phrase were in most cases error free. For the results reported here, each wrong selection during the process of spelling was counted. The spelling speed was on average about 2 characters/min, but an offline analysis indicated that the number of repetition can be reduced for most participants without significant loss in accuracy, which leaves room for improvement for the future.

4. Discussion

Our results are a proof of concept: It is possible to realize high-accuracy, fast-paced visual spellers that have a large vocabulary and that are independent of eye gaze. The accuracy of the Center Speller is about 10% higher than what was obtained in [Acqualagna et al, 2010] using a rapid serial visual presentation (RSVP) approach and the selection procedure is faster in the Center Speller (120 stimuli at 200ms ISI vs. 300 stimuli at 133ms ISI in the RSVP-Speller).

The significance of the results presented here is that they broaden the scope of visual spellers from simply recovering eye gaze to recovering attentional focus independent of eye gaze.

References

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