Brain Computer Interface based on the Steady-State VEP for Immersive Gaming Control.

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ABSTRACT: This paper presents an implementation of an effective EEG-based Brain Computer Interface design as the control mechanism for an immersive 3-D game. The BCI is based on the application of the steady-state visual evoked potential (SSVEP) generated in response to phase-reversing checkerboard patterns. Real-time game control and signal processing is facilitated by a combined graphics/DSP/network communications framework. Three methods of feature extraction are compared in a series of offline classification tests. Despite the relatively uncontrolled environment in which the game was played, the performance of the BCI control was robust and relatively consistent across all subjects with 41 of 48 games successfully completed. Performance while playing the game is found to be an improvement on performance in the offline tests, the cause of which is attributed to the goal-driven nature of the game.

KEYWORDS: EEG, BCI, SSVEP, online classification, overt attention, rehabilitation.

INTRODUCTION

Performance of a BCI is normally assessed in terms of information transfer rate, which incorporates both speed and accuracy. One BCI solution that has seen considerable success in optimising this performance measure relies on steady-state visual evoked potentials (SSVEPs), a periodic response elicited by the repetitive presentation of a visual stimulus at a rate of 6-8Hz or more [1]. SSVEPs have been successfully utilised in both above-mentioned BCI designs – gaze direction within a matrix of flickering stimuli is uniquely manifest in the evoked SSVEP through its matched periodicity [2,3], and also the self-regulation of SSVEP amplitude has been reported as feasible with appropriate feedback [4].

In this paper the authors wish to address the application of the SSVEP-based BCI design to a real-time gaming framework. It is proposed that performance on the BCI game detailed below will be sensitive to neurological disorders such as Attention Deficit/Hyperactivity Disorder and thus may aid in its rehabilitation. Presented here is the performance of the real-time BCI game “MindBalance” when played by normal subjects.

The design of the MindBalance game was split into two parts. First a preliminary offline analysis was conducted to determine the most favourable signal processing methodology and to choose suitable frequencies. Once satisfactory offline analysis results were obtained, the full real-time game was assessed with the offline parameters and tested in a separate location.

METHODS FOR OFFLINE STUDY

Subjects: Five male subjects, aged between 23 and 27, participated in the preliminary study. All subjects had normal or correct-to-normal vision.

Experimental Setup: EEG was acquired from two Ag-AgCl scalp electrodes placed at sites O1 and O2. In the initial offline testing the subjects underwent 25-second trials in which they viewed each one of two bilateral checkerboard patterns phase-reversing at the two selected frequencies and this was repeated with positions reversed.

Feature Extraction: Three feature extraction methods were employed for comparison in the preliminary offline data : squared 4-s FFT, FFT of autocorrelation and autoregressive model parameters (a model order of 5 was empirically chosen).

Classification and Results: Linear discriminants were used as the classifier model for this study.

Feature	Sq-4s FFT	FFT of auto	AR
Best Average Performance	74.4%	77.3%	89.1%

Table 1: Comparison of features for offline data. Performance is defined as the ability to detect the correct stimulation frequency solely from SSVEP

METHODS FOR REAL-TIME BCI GAME

MindBalance – the Game: The object of the MindBalance game is to control the balance of an animated character on a tightrope using only the player’s EEG. A checkerboard is positioned on either side of the character. A screen-shot of the game can be seen in Figure 1.

Figure 1: The character loses balance during the game

Signal Processing and the C# Engine: In order to carry out this study, a programming engine and platform was required, capable of rendering detailed 3-D graphics while at the same time processing continuous EEG data to control a sprite within the game. This was accomplished using a combined graphics, signal processing and network communications engine implemented in C#.

Window Length	1 second		2 seconds	
Harmonics	1st	1st +2nd	1st	1st +2nd
Average Performance	76.7%	79.9	77.3%	89.5%

Table 2: Real-time performance during game.

DISCUSSION

Phase-reversing checkerboard patterns were found to elicit distinct SSVEP responses and were successfully used to make binary decisions in a Brain Computer Interface-controlled game. Two interesting observations, among many, were made during both the offline and online testing. Most notably, two investigators who themselves participated as subjects in the study achieved better performance both in terms of accuracy in the offline analysis and in terms of success in completing the game. This implies that either practice, or a goal-driven approach to stimulus fixation results in a more pronounced visual response. This may be thought of in terms of visual attention. Endogenous modulation of SSVEP response has been reported as possible in relation to both foveal fixated stimuli [4] and covertly attended stimuli in peripheral vision [5]. The improved discriminability of the SSVEP with increased perceived conscious effort may be related to the ability of the subject to focus selective attention on the fixated stimulus, as well as the ability to inhibit early processing of distractors in the peripheral visual field.

In post-experiment debriefing, subjects reported that feedback, particularly audio feedback during training, aided in the successful sustained fixation on a particular stimulus, and the inhibition of responses to distractions. Also, in the case of an error causing the character to drop to the second level of imbalance, subjects found it possible to adjust their fixation strategy, most notably through observing the checkerboard as a whole rather than specifically fixating on any individual elements or allowing perception of the phase reversal as a moving pattern.

In general, subjects performed better while playing the game than in the off-line tests. The results for the offline tests are shown in Table 1 and the results for the real-time performance during the game are shown in Table 2. This may be due to the greater length of trials in the offline tests, during which habituation to the visual stimuli without any perceived salience becomes an issue. It is also believed that feedback is a major factor in the degree of conscious compliance.

CONCLUSIONS AND FURTHER WORK

Results of the study indicate that successful binary control using Steady State Visual Evoked Potentials is possible in an uncontrolled environment and is resilient to any ill effects potentially incurred by a rich detailed visual environment as in the MindBalance game. The authors also propose to extend the results of the preliminary results of this study to covert visual attention, in which subjects direct attention to one of two bilateral stimuli without eye movement.

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