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Cooperating Brains: Joint Control of a Dual-BCI

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Abstract. Pairs of participants simultaneously used EEG-based motor-imagery BCIs to jointly play a cooperative computer game. Here, we present this novel 'Dual-BCI' setup, including results on feasibility and user experiences, experiences on the design of Dual-BCI games, especially highlighting possible caveats and potential solutions. In addition, we investigated and compared the simultaneous classifier outputs from both participants and explored the use of both participants' brain signals for simulated online BCI. Importantly, the presented Dual-BCI scenario represents a promising tool for the investigation of brain-to-brain connectivity in human social interaction; see companion abstract [Görgen et al., submitted].

Keywords: EEG, Hyperscanning, Dual-BCI, Motor-Imagery, Social Interaction

1. Introduction

Despite abundant research with non-invasive BCIs, multi-brain BCI studies (BCI applications involving multiple users at the same time) are scarce. The few multi-brain BCI studies that have been conducted involve two participants simultaneously – but individually – controlling a *separate* part of an application (e.g. two-player 'Brain-Pong') [Müller et al., 2006; Göbel et al., 2004]. To the best of our knowledge, the present study is the first one investigating a *cooperative* BCI scenario, in which two participants jointly play a computer game cooperatively controlling a single game character. Here, we present first results on the feasibility and user experience of jointly and continuously controlled BCI applications. We give a detailed description of the Dual-BCI setup, the design of the continuous BCI game, potential caveats and possible improvements. Furthermore, we compare the simultaneous classifier outputs from both players and explore the integration of both participants' brain signals for multi-brain classifiers. In addition to the development of BCI games, one interesting application scenario for the Dual-BCI setup is its ability to serve as a framework for investigating neural brain-to-brain connectivity of inter-personal interaction: Using BCIs to control computers via brain activity alone, people can perform coordinated behavior without any muscular activity, a potential confounding factor of previous studies investigating brain-to-brain connectivity. Refer to our companion abstract [Görgen et al., submitted] for more details.

2. Material and Methods

Ten pairs of participants used motor-imagery to control a game character (a cowboy) in a two-dimensional cooperative maze game, where the cowboy moved around to collect a number of targets (fruits). Fig. 1 illustrates the Dual-BCI setup that we employed. EEG data was filtered using Common Spatial Pattern (CSP). The resulting CSP features were classified using Linear Discriminant Analysis (LDA), the output of which was used as control signal.

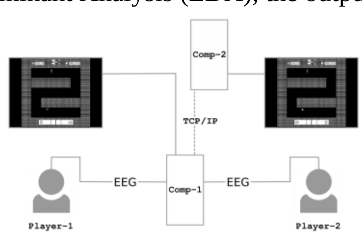
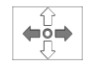
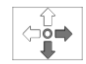


Figure 1. *The Dual-BCI setup: Two players are seated in front of separate monitors. Recording and processing of EEG data is performed by a single computer. All data needed to display the BCI feedback is sent via network to a second computer to display it to the second player.*

2.1. Conditions

Experimental conditions involve different levels of cooperation between both players (Table 1). The conditions are presented block-wise. Additionally, we employed a pure observational condition and a keyboard condition.

Table 1. *Experimental conditions: From top to bottom conditions require an increasing amount of cooperation between both players. The white (gray) circle in row one denotes the game character of player 1 (player 2). The other white-gray circles denote that both players control the same character. White (gray) arrows denote the control direction of player 1 (player 2). In conditions 1 & 2, the character was controlled in 1D (along the horizontal axis), in conditions 3 & 4 in 2D.*

Condition	*Description*	*Illustration*
Individual Control	Each player individually controls a different game character along one dimension (left/right)	
Same Dimension Control	Both players control the same character along the same dimension (left/right)	
Separate Dimension Control	Each player controls the same character along one dimension (left/right vs. up/down)	
Split Dimension Control	Each player controls the same character along one direction of each dimension (e.g. left/up vs. right/down)	

2.2. Data Analysis

Data analysis is currently in progress. It includes a descriptive statistical analysis of user questionnaires, which were used to collect subjective data on the user experience of the BCI game. Furthermore, we perform correlation analyses between subjective ratings and objective performance. We present detailed histograms of the continuous classifier outputs from both participants during different phases of the experiment and compare these to subjective experience and objective performance. Additionally, we will explore the use of both participants' brain signals for simulated online BCI in order to enhance performance using multi-brain classifiers.

3. Results

3.1. Feasibility

The Dual-BCI system has been tested successfully: Joint control of the cooperative BCI game by two participants using motor-imagery was accomplished.

3.2. Evaluation

Preliminary results show that participants preferred the cooperative 'separate dimension control' condition as compared to 'individual control' and the 'same dimension control' condition in terms of competence, immersion, flow, challenge, empathy and positive affect. This suggests that participants favor playing together and that user experience is enhanced in this cooperative setting. Drawbacks in the 'split dimension control' condition (e.g. level of control difficulty) lead to decreased joy of use in this condition. Descriptive analysis of the participants' continuous classifier outputs suggest bi-modal histograms for participants with good BCI control. Detailed results will be presented at the conference.

4. Discussion

We successfully establish a Dual-BCI setup in which two participants played a cooperative BCI game. To the best of our knowledge, this study provides first results on the feasibility of cooperatively continuous-controlled BCI applications by two persons. Thus, this work constitutes the foundation for further investigation on the benefits of mutli-brain BCIs. One promising application scenario of this approach is its capability of using it as a tool for investigating brain-to-brain coupling between people during human social interaction [Görgen et al., submitted].

Acknowledgements

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