Cooperating Brains: Dual-BCI as a New Paradigm to Investigate Brain-to-Brain Coupling

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Abstract. Recently, BCI research has started to provide new, elementary insights not only into brain control but also into the basis of neurocognitive processes. Here, we describe a novel BCI paradigm, 'Two-Person-BCI' or 'Dual-BCI', where the joint brain activity of two participants controls a computer. This can serve as a promising new research paradigm for the emerging field of brain-to-brain coupling. The main hypothesis underlying this field is that people's ability to coordinate their brain activity forms the elementary basis for communication, thus creating a so-called 'shared space' [Gallese, 2003]. A key feature of our new Dual-BCI paradigm is that it allows people to coordinate their behavior without using muscular activity. Here, we will show why Dual-BCI is an especially promising paradigm for investigating brain-to-brain coupling, we will describe analysis methods that can be used to detect different types of neural coordination between brains, and provide preliminary results from a first experiment where the paradigm has been applied; see also the companion abstract [Schultze-Kraft et al., submitted].

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

1. Introduction

For a long time neuroscientists have struggled to understand the neural basis of human communication. Traditional approaches that aim to understand the neural basis of human communication have recorded the brain activity of one person at a time (for an overview, see [van Overwalle et al., 2009]). In contrast to the traditional approaches, a fundamental hypothesis of the new field of Two-Person Neuroscience is that the coordination of brain processes between individuals is a central factor for enabling communication. Since the emergence of this new field the number of studies is steadily increasing, and the first results confirm this hypothesis (e.g. [Anders et al., 2011; Kuhlen et al., 2012]).

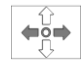
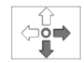
A critical limitation of the studies conducted so far is that all of them require some form of motor activity for communication/coordination of behavior. Thus, it remains an open question to which degree the obtained results rely on muscular motor activity and/or neural processes underlying those. That is, it would be important to disentangle coordinated neural activity that is simply the result of coordinated behavior from that which is crucial to establish coordination in the first place. To investigate this question, we conceived a new paradigm that allows coordinated behavior, but that does not require any kind of muscular activity: The 'Two-Person' or 'Dual-BCI' setup. In this setup, two participants coordinate their behavior to jointly control a virtual character. Critically, they control the character via BCIs, thus avoiding any kind of muscular activity, because BCIs circumvent the traditional brain-muscle-pathway; instead, they provide steering commands to the computer directly via thoughts. In the remainder of this paper, we will shortly describe the setup of an Dual-EEG-BCI study that we are currently conducting, explain which analyses methods we are going to use, and discuss why we believe the Dual-BCI Setup to be a promising tool to advance our understanding of the neural basis of human communication.

2. Material and Methods

2.1. Dual-BCI Setup & BCI game

In the experiment, 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); more details in [Schultze-Kraft et al., submitted]. To be able to test whether neural coordination – if existing – changes with the amount of cooperation that is needed to play the game, we used different experimental conditions that involved different levels of cooperation between both players (Table 1). The conditions are presented in successive blocks, were each block lasts about 10 minutes, depending on how fast participants reach the goal of each level.

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 control direction of player 1 (player 2).*

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)	

2.3. Data Analysis

A battery of different methods will be used to test the hypothesis that brain activity coordinates while people are communicating, and to identify which features of brain activity are coordinated, if coordination is present. These analyses will include, among others, canonical correlation analyses, between-brain phase locking values, between-brain- and granger-SPoC [Dähne et al., 2012], and frequency band power correlations.

3. Results

At the time of this writing, data recordings are currently in progress. Participants were successful in playing the game in cooperation, showing that they are able to coordinate their behavior as required [Schultze-Kraft et al., submitted]. First results on brain-to-brain coupling will be presented at the conference.

4. Discussion

We introduced 'Dual-BCI' as a new tool to investigate brain-to-brain coupling in Two-Person Neuroscience. An especially attractive feature of Dual-BCI is that it allows investigating coordinated behavior without requiring any form of muscular activity. We believe that the Dual-BCI has the potential to open up a new branch within Two-Person Neuroscience and, more general, will help to continue establishing BCI as a method within the neurosciences.

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References

Anders S, Heinzle J, Weiskopf N, Ethofer T, Haynes J-D. Flow of affective information between communicating brains. *Neuroimage*, 54(1):439–446, 2011.

Dähne S, Nikulin V, Höhne J, Haufe S, Meinecke F, Tangermann M, Müller K-R. Optimal Spatial Filters for Correlating Band Power with Cognitive Function. In *Proceedings of the HBM Conference 2012*, Beijing, China, June 2012.

Gallese V. The manifold nature of interpersonal relations: the quest for a common mechanism. *Philosophical transactions of the Royal Society of London*. Series B, Biological sciences, 358(1431):517–528, 2003.

Kuhlen AK, Allefeld C, Haynes J-D. Content-specific coordination of listeners' to speakers' EEG during communication. *Front Hum Neurosci*, 6*:*266, 2012.

Schultze-Kraft R, Görgen K, Wenzel M, Haynes J-D, Blankertz B. Cooperating Brains: Joint Control of a Dual-BCI. *Conference Contribution, International BCI Meeting 2013, Pacific Grove, California, USA, 2013*, submitted.

Van Overwalle F, Baetens K. Understanding others' actions and goals by mirror and mentalizing systems: A meta-analysis. *Neuroimage*, *48*(3):564–584, 2012.