Multi-Brain Games: Cooperation and Competition

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Abstract. We survey research on multi-user brain-computer interfacing applications and look in particular at 'multi-brain games'. That is, games where in one or other form the (EEG-) measured brain activity of more than one user is needed to play the game. Various ways of integrating and merging brain activity in a game context are investigated. Existing research games are mentioned, but the emphasis is on surveying BCI research that will provide ideas for future multi-brain BCI games.

Keywords: brain-computer interfaces, multi-brain games, social games.

1 Introduction

In previous years we have seen a growing interest in brain-computer interfacing (BCI) in the human-computer interaction (HCI) community. Before that, BCI was researched with the aim to help disabled persons and provide them, among other things, with a hands-free 'communication channel' to type messages, to control prostheses, or to navigate a wheelchair. Our research, instead, has focused on BCI for 'healthy' users, in particular on its use for games [1,2]. There are good reasons to do so. In games and entertainment applications we are not limited by thoughts and concerns that relate to patients and disabled persons. We can use our fantasy and can allow situations and events in non-real-life situations, happening in virtual worlds. We can allow cooperation and competition with multiple and distributed users and we can allow interaction modalities and effects that are unusual but can be believable, depending on the design of the game. Gamers don't behave as disabled people in need. They have different motivations and expectations. That introduces problems and new challenges. Game designers have to design for challenges or otherwise to make use of the existing challenges in a meaningful manner, rather than to avoid them.

In 2012 a roadmap for BCI research appeared [3]. The roadmap was initiated by the FP7 research program of the European Union. Unfortunately, the roadmap stayed close to traditional BCI research. It hardly took into account new research opportunities coming from embedding BCI research in HCI research, in particular multimodal interaction [4,5] and artificial intelligence research. The problems (or

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challenges) that were identified in the roadmap (reliability, proficiency, bandwidth, convenience, support, training, utility, image, standards and infrastructure) do also rise when we look at BCI for games, entertainment and artistic applications. However, they can be dealt with in a different way. A game is about challenges and an interactive art installation may be provocative and surprising rather than that it acts according to our expectations; teasing, frustrating [6] and deceiving. Hence, rather than being effective in a traditional sense, such applications are about manipulating experiences [7], and in particular hedonic experiences [8].

A bottleneck that prevents wide-spread use of BCI is the set-up encumbrance. A standard configuration requires an EEG cap with several electrodes, it has to be positioned on the head of the user, gel is required between scalp and electrodes to get good signals, and only after ten or more minutes of preparation time the user is physically connected to the BCI device. Presently so-called "dry" electrodes that don't require conductive gel and wireless connections have been introduced, reducing set-up time. Attractive headsets are now becoming available from BCI game companies. The other bottleneck is reliability. People can be trained to use a BCI, but not everybody can perform in a satisfactory way. BCI signals are subject-dependent and even for one subject there is variability depending on mood, emotions and fatigue. For certain applications repeated trials are needed in order to be able to make a decision about a mental state or to be able to map detected brain activity to appropriate control or communication commands. However, also for this bottleneck there are positive developments such as progress in signal analysis, artifact removal methods, and machine learning. Moreover, for some applications, as we will discuss in this paper, rather than recognizing brain activity of one user and deciding how to use it, we can have recognition of brain activity of many collaborating users involved in the same task. Maybe this multi-brain computer interfacing can lead to more reliable decisions and certainly it can lead to new and interesting applications of BCI.

Both for traditional BCI and multi-brain BCI it is useful to distinguish between active and passive BCI. Active BCI requires real-time or near real-time BCI. There is voluntary control of brain activity, meant to control an application. In a passive BCI situation the brain activity of a user is monitored. The user is not necessarily aware of it and does not attempt to steer it. This information can be used to adapt the environment, but not necessarily in real-time.

In this paper we discuss and survey applications and ideas on multi-brain-computer interfaces, with the aim of using these ideas in future multi-brain BCI games. In section 2 section we look at some research and applications in which information from multiple brain activity measurements is used to make decisions or to analyze multi-party interaction performance. Section 3 is about two important characteristics of games: competition and collaboration. Section 4 attempts to make clear that current BCI research makes it possible to talk about future BCI games that require input from brain activity of multiple users. Finally, in section 5, we present some conclusions.

2 Using BCI from Multiple Brains

Before looking more closely to what we call multi-brain games it is useful to have some remarks about BCI applications. We look at some examples where BCI is used in the context of information extracted from multiple brains. Clearly, gamers use their brains to compete and to collaborate, hence, whenever more than one player is involved in a game we can talk about multi-brain games, but, of course, it is better to speak of multi-user or multi-party games. Brain activity from multiple persons is measured and analyzed for neuromarketing purposes. An interesting example is neurocinematics [9] where similarities in spatiotemporal responses across movie viewers are studied. Future applications may require real-time processing of such brain activity in order to have collective or individual decisions about the continuation of a movie while watching.

There is certainly more research in which multibrain activity is investigated, where the immediate goal is not yet real-time applications, but where real-time applications, also in the context of games, can be foreseen. Mostly, at this moment in this research no active BCI control by users is present. There is, for example, measuring and analyzing of brain activity of persons engaged in the same task. There is the general aim of researching how this engagement shows in their brain activity. But there can be an added aim to learn from this and maybe support and improve this joint activity. This can then be done off-line, taking care of better conditions for future joint activity. And one step further, doing this analysis and interpreting the information real-time, that is, when the joint activity takes place, and then using this information to guide the users in their activity.

Whenever there is joint activity, the assumption is that there is some activity synchrony visible in the brain activity of the participants. Clearly, a conversation is a joint activity and coordination and nonverbal synchrony, including mimicking, is a well-known phenomenon. As reported in [10], there is also a spatiotemporal coupling of the speaker's and the listener's brain activity. In this research fMRI is used to record brain activity, hence, rather far away from the applications we have in mind. Nevertheless, the results support our idea that brain activity from different persons can be measured, analyzed and integrated in order to be used as a source of information to guide behavior and to control or adapt an environment in which the persons perform their activity. As is the case in other research on speaker-listener synchrony, the tighter the coupling between activities, the more successful is the joint task. As a possible application, can we off-line improve the conditions that lead to more synchrony? How do we model a social robot or an embodied agent such that its awareness of this synchrony can be used to have real-time adaptation of behavior?.

From this two-person activity we can move to multi-party or team activity. What kind of brain activity can we detect and integrate when we have a team of ‘players’ (not necessarily players in a game, but, more generally, persons involved in a joint activity). Can we get information about progress (successful collaboration) and use this information to improve conditions for such team activity? And, as a next step, based on real-time analysis and integration, being able to support and improve the joint activity? For example, during a meeting, can we decide and make group members aware that there is a convergence or divergence of opinions? In a multi-user game with participating teams, and when obtained real-time, such information can certainly help to win the game. Clearly, game, entertainment and artistic environments can be designed in such a way that each kind of combination of one and more persons, individual and joint voluntary control of brain activity and other, not consciously produced brain activity, can get a role in the environment.

Chris Berka and her colleagues [11] have a research program that aims at studying team cognition using BCI. They use wireless EEG headsets to measure attention, engagement and mental workload of the members of a team that has to play a serious game: a submarine piloting and navigation simulation. The aim is to achieve measures of the quality of the team performance and use these measures to adapt and rearrange tasks and responsibilities for more optimal team performance. At this moment this adaptation and rearrangement is not done in real-time. In a multi-user entertainment game such information can also be used to remove team members or to rearrange tasks among team members for a next game session. But obviously, real-time adaptation would be much more useful.

In this example [11], team members do not manipulate their brain activity. Brain activity is monitored; hence we have a passive multi-brain BCI application. Rather than monitoring one individual engaged in a task, a group of collaborating persons (the team) is monitored with the aim to achieve and maintain 'neurophysiologic synchrony' (a positive team rhythm). While in this case the team effort concerns a serious game (a simulation of a critical real-world situation), the application could as well be a multiplayer entertainment game with competing teams and where optimal team performance is a goal as well.

Knowing about a collective mental state of a group of users can find interesting applications in game, entertainment and artistic applications. Being able to improve, in real time, decision processes by measuring and aggregating activity of all the brains of people involved in the decision making, as can be the case in multi-user games that allow the forming of teams makes it also possible to issue commands to a game as the result of volatile team brain activity. We will return to this in section 4 of this paper.

3 Competition and Collaboration with BCI

Competition and collaboration are important characteristics of games. For that reason we now look at research in which BCI is studied from a competition and collaboration point of view. Other characteristics of games and how they relate to BCI can be found in [8]. A viewpoint in the examples that we discuss in this section is that at least two players are involved. And that at least one of them has his or her brain activity measured and it plays a role in the game. This can be to control the game (active BCI) or to adapt the game (scenario, levels, and environment) to the user. The user does not consider these game changes as unnatural and is not necessarily aware (and hence does not try to influence it) that game changes are caused by his or her brain activity.

As a side note, notice that we consider these issues in the context of human-*computer* interaction. Hence, one of the partners involved in a game may as well be an artificial agent (physically or virtually embodied agent, e.g., a social robot or a virtual receptionist) or the environment or a device that acts and is supposed to interact in a humanlike way. As an example we can mention the study of [12] where a humanlike robot teacher has access to the brain activity (attention/level of engagement) of a student and adapts his behavior to this activity by raising his voice or have more expressive gestures. In a competitive game environment knowledge about brain activity of a human opponent may give an unfair advantage to such an artificial agent. But that is also the case in a competitive game where a human player has access to the (interpretation of) brain signals of a competitor without having his own brain activity being exposed.

Obviously, when more than one person is involved in a BCI game, the social setting will have impact. Are players co-located or distributed? Is there an audience? What does the audience see and is there interaction between audience and players? In [13] the aim of the research was to investigate the use of BCI in a social setting (a small group of friends or relatives) and in particular the presence and the role of bodily actions of one of the group members playing a simple commercial BCI game while others are watching. In this game the BCI control is obtained from brain activity related to relaxation and concentration. Players used bodily actions (gestures, gaze, and facial expressions) to achieve a desired mental state. But they also used bodily actions to indicate their thoughts to the spectators in the group.

Interactions between co-located BCI gamers have been studied in [14]. We designed a game for research purposes: Mind the Sheep! (MTS!). It can be implemented as a single-player game, a cooperative multi-player game and, although we didn’t experiment with that, a competitive multiplayer game. Moreover, it allows both BCI and non-BCI play for players. In our study we introduced a two-player cooperative version of this game to study social interaction between players. Both co-located players wear an EEG cap. The game visualization consists of a 2D map that contains simple representations of a meadow, a sheep pen, dogs and sheep. Players select and move dogs around to herd and eventually fence the sheep in. A dog can be selected with BCI (SSVEP evocation). The players can cooperate through gestures and speech to develop and execute a joint strategy. But of course, they see also at the screens what actions the other player takes. There is no integration of brain signals. If one player stops, the other can continue but may take more time to finish the task.

It is more usual to have two-player games where the players compete, each player volitionally using his or her brain activity to compete. This competition point of view where only BCI as input modality to a game is used, can be illustrated with two more examples from earlier research. Consider a BCI version of the well-known Pong game, a virtual tennis game that can be played by two gamers that control their bats (up and down) to hit a tennis ball back to their opponent. Motor imagery (imagine hand movements) has been used to implement a BCI version of this game [15]. That is, individual motor imagery controls the bats, and there is no processing that looks at - or compares - the brain activities of the individual players.

This is different in what was probably the first competitive BCI game, Brainball [16]. In this game we have two players competing. They are expected to compete by relaxing and their performance is measured by EEG. The player who is the best in relaxing wins. The game is made interesting by visualization of the players' performances that control a ball moving on a table between the two players that are seated on the ends of this table. This visualisation has impact on their performance and makes the game also attractive for an audience that can decide to support or disturb relaxation of a player. Clearly we need real-time BCI measurement and control of this rolling ball. Brain activity of the players is compared and the difference determines the direction of the ball (moving into the direction of the player who is less relaxed). Hence, this is a different kind of competition, from the point of view of processing brain activity, than in the BrainPong example.

There are of course more examples where players manipulate their brain activity in order to play a particular BCI game. Our interest is in games where players have to compete or collaborate to play a certain game using brain activity. Relaxing to issue a command in a competitive environment has also been done in the 'Mexican Stand-off' [17]. This is a two-player game where the gamers relax in order to perform: that is, to fire a gun and kill an opponent. But certainly, being able to look at and experience the performance of their opponent, a gamer can try to increase his or her performance by comparing it with the performance of the opponent. Depending on the visualization or other information communicated to the gamers, such a stand-off game can be compared with a relaxation-based BrainPong game.

Less obvious is a cooperative two-player game where one player's brain activity is used to support the second gamer in his or her task. This second gamer does not necessarily use BCI. In [18] the authors look at games where players have different roles. One player is physically active while a second player uses his or her mastery of brain activity to provide favorable conditions for the performance of the first player. As mentioned in this paper, new games can be designed where a player's (traditional) game controller input can be modulated by collaborating BCI input, or where game activity is modulated by joint authority over game control input. Clearly, this includes a situation where brain activity of both players is measured and used in the collaborative control of a game. But it also allows games where there is competitive control over a game object. The authors introduce a Multi-User Video Environment (MUVE) that has been designed with both cooperation and competition in mind. Brain activity of one or more players can be used to disturb the physical control input of an opponent or opponents (or the other way around) and competition can be based on BCI input only.

4 Toward Multi-brain Games

We now have seen various possibilities for BCI input to games where players compete or collaborate. Usually this concerns two players, but suggestions that involve generalizations to more players are sometimes given. Moreover, the social setting of a game and associated social interactions emerged as an interesting research issue.

Interestingly, in what appears to be the oldest BCI game (BrainBall), there is a volitional contest by both players to control the same object in the game. In the other examples players use their brain activity to perform their own task in a collaborative or competitive game (MTS!, BrainPong), or they try to influence (in a collaborative or in a competitive way) the performance of the other player (MUVE). More subtleties in these distinctions can be introduced, e.g. by looking at dimensions such as social interaction and audience involvement and the role of passive BCI in these games. And, of course, we need to look at the consequences of having more than two players involved in multi-party and multi-brain games.

When looking at a possible definition of multibrain computer interfacing it now should be clear that it is unwise to be restrictive. Clearly, two or more persons need to be involved. Brain activities of two or more persons have to be integrated in the application. But, not necessarily at the same time and not necessarily in a synchronous way. In traditional multimodal interaction research we have one person interacting with an application using different modalities. The modalities can complement each other and fusion of the different modalities helps to solve ambiguities and can lead to more robustness. Usually three levels of fusion are distinguished, the data level, the feature level and the decision level. Fusion is meant to make the interaction effort stronger, to make clearer what is intended by an individual user.

We can also speak of fusion at different levels in the case of a cooperative game. For example brain activity of two or more players can be combined to have them make a particular decision in a game or to have them lift a spaceship in a virtual game environment, a task that would have been much more difficult if only brain activity of one player could be used. This is not some peculiar property of the brain activity modality. Lifting hand and arm gestures, facial expressions, or gaze behavior of two or more gamers could be implemented to have the same result. Or, any combination of different modalities that are used by different persons.

In the case of brain activity, comparable brain activity seems to be the most obvious first choice for data level fusion. But that may change in the future when we learn more about dependencies between different BCI paradigms. In a cooperative game situation fusion at the level of decision making can mean making a joint decision or doing a joint activity, but it can also mean a division of labor where players take responsibility for subtasks that help in reaching their joint goal.

Also in a competitive game where two or more persons are involved we can talk about fusion of information coming from different modalities and coming from different participants. Again, for the sake of discussion, let us focus on the brain activity modality. When we have competing players, rather than 'adding' information, on whatever level, we let the system (interface, game) compare ('subtract') information and make decisions that benefit the 'winner' or 'winners' who have outperformed with their joint brain activity the losers. Deciding when and how a team of BCI gamers has outperformed another team for deciding about or doing a particular activity can again be done at the data, feature and decision level. However, it should be mentioned that at each level different information is available to guide decisions. As an example, at the decision level we can use common sense and domain knowledge and we know about methods from artificial intelligence research that help us to represent and to reason about such knowledge. At every level of fusion, methods are available that take into account level context.

All these observations make it more difficult to get closer to a definition of multibrain games. Or, less difficult, to a decision that we should accept that there cannot be one definition and that multibrain games are just games in which measured brain activity of two (or more) gamers can be used to control commands or will be used to adapt a game to its users. Fusion of modalities of one user is an issue, but also fusion of modality information coming from different users (competing or collaborating) is an issue. There is another issue, when we talk about fusion, who is taking care of it? In traditional human-computer interaction a multi-sensor system provides input to computing power and intelligence that makes decisions. In games, but not only in games, human decision making can be used about to decide about how to integrate and fuse information, including brain activity information, coming from different modality sources and from different users.

An interesting example is the Multimodal Brain Orchestra (MBO) presented in [19]. This orchestra has four performers and a conductor. Two of the four performers can use P300 to trigger emotionally classified discrete sound events. Two other performers use SSVEP to modulate articulation and accentuation of an earlier recorded MIDI sequence. The conductor uses a WII-mote as a baton and can decide when the sound events have to be triggered and he can decide about tempo modulations. Hence, evoked brain activity from different performers is directed by the conductor. There is feedback from the music and visualization. In this example there is, if we understand it well, no 'adding up' or otherwise processing of joint activity at the level of brain signals or features extracted from brain signals. There is a human decision about the fusion of the classification results (SSVEP and P300).

Having now discussed the different ways brain activity from two or more sources can be integrated (and not claiming completeness), we now look at research that has been done in the past and that supports our ideas about having multibrain BCI games in the near future by demonstrating that brain activity of multiple persons can be used in applications. Some examples, not really aimed at collective decision making or performing an action through collective brain activity were already mentioned in section 2. Knowing about a collective mental state of a group of users can find interesting applications in game, entertainment and artistic applications. But even more interesting is being able to improve, in real time, decision processes by measuring and aggregating activity of all the brains of people involved in the decision making process, as might be the case in multi-user games that allow the forming of teams. Teams allow some kind of 'collective wisdom' to make decisions. Real-time decision making by a team of users rather than an individual user has been investigated in [20]. In this research twenty users had to make perceptual decisions, that is, deciding when confronted with a series of pictures whether a particular picture was a face or a car. Prediction of a decision based on aggregated brain activity turned out to be possible and, compared with an individual user, both the decision accuracy and decision speed could be improved. Clearly, applying such research results in a multi-player game context can make those games more interesting to play. Collaborative brain-computer interfaces have also been studied by Wang and colleagues [21]. It is investigated how EEG data from twenty users can be used to predict and decide about movements. Clearly, this is the kind of information that can be used in a multi-player game that allows the forming of teams and can have team performance included in the game, rather than just have input from individual players only.

We conclude with the currently nicest example of a multi-brain game, "BrainArena" [22], that in a simple setting illustrates some of the ideas mentioned above. It is a simple football game with a ball and goalposts displayed on a screen in front of the two players. There exist two versions of the game, a collaborative and a competitive one. The players wear EEG caps and use motor imagery (imaging left or right hand movement) to get the ball rolling in the direction of the goalposts. In the competitive version their actions are opposed and the player with the best performance wins, in the collaborative version the brain activities are merged and players steer the ball in the desired direction. Hence, in the competitive version it can be seen as a motor imagery version of the earlier mentioned BrainBall game. It can also be compared with a motor imagery version of BrainPong, but in that case each player has its own object (a bat) to control, while in BrainArena they compete to control an object (the ball).

5 Conclusions

We discussed the use of BCI as an input modality in a multiparty context. We discussed the various ways brain activity can be integrated in game contexts. We also focused on integrating brain activity from multiple persons. It is clear that many problems related to BCI in general have to be attacked. It can also be concluded, as we did in [1], that it is possible to design multiparty games in which multi-brain activity is included, and it can be done in such a way that is introduces interesting challenges to the gamers, rather than shortcomings of technology. Team decisions or team leader's decisions in a MMORPG (Massively Multiplayer Online Role-Playing Game) can be based on collective thoughts of a team or a sub team. Obviously, synchrony of thoughts is a problem here. However, natural game events can trigger joint and synchronized event related brain activity among team members. The potential role of 3rd party team communication software such as TeamSpeak should be considered. And again, perfectness would be unnatural. A 'synchronized kill' in the "Ghost Recon, Future Soldier" game does not have to be perfect. Joint brain and synchronized brain activity can be triggered because of various artificial stimuli that are designed in the game. There can be natural moments to take an explicit vote on how to continue or make an otherwise important decision. But fast decision making based on merging of brain activities of a large team, accepting that not yet everyone in the team is ready for it, is also natural.

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