Social interaction in a cooperative brain-computer interface game

by

Michel Obbink

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Examination committee:

Prof. dr. ir. Anton Nijholt
Dr. Mannes Poel
Dr. Job Zwiers
Hayrettin Gürkök, M.Sc.
Danny Plass-Oude Bos, M.Sc.

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Abstract

Does using a brain-computer interface (BCI) influence the social interaction between people when playing a cooperative game? By measuring the amount of speech, utterances, instrumental gestures and empathic gestures during a cooperative game where two participants had to reach a common goal, and questioning participants about their own experience afterwards this study attempts to provide answers to this question. Three selection methods are compared; point and click, BCI and timed selection which is a selection method similar in difficulty as BCI selection. The results show that social interaction changed when using a BCI compared to using point and click, there was a higher amount of utterances and empathic gestures. This indicates that the participants automatically reacted more to the higher difficultly of the BCI selection method. Participants also reported that they felt they cooperated better during the use of the point and click.

Preface

This master thesis is the result of the study performed during my graduation at the University of Twente in Enschede. This study has been partly published during the International Conference on Intelligent Technologies for Interactive Entertainment 2011 (Appendix E). There are a few people to whom I wish to express my appreciation.

First I wish to thank my examination committee: Prof. dr. ir. Anton Nijholt, Dr. Mannes Poel, Dr. Job Zwiers, Hayrettin Gürkök M.Sc and Danny Plass-Oude Bos M.Sc. With a special thanks to Hayrettin Gürkök and Danny Plass-Oude Bos for their continual input and support that significantly improved the quality of this work, and for the opportunities that I got to demonstrate and publish this research outside the university's boundaries.

Next I wish to thank my family as they supported me and made it possible for me to pursue the educational career of my own choosing. Another thanks goes to my co-students for all the cooperation and friendships developed during the last years. Especially Gido Hakvoort for his cooperation, input, help with annotation and the discussions on both our works, and together with his brother Michiel Hakvoort for the great times outside either of our studies.

Contents

Chapter 1

Introduction

1.1 Background

A brain-computer interface (BCI) is a means of interaction between humans and computers based on neural activity in the brain. It has fascinated people as it could enable whole new ways of controlling objects such as computers or wheelchairs. Since it has come into existence BCI research has mostly focused on helping disabled people, for example by controlling a wheelchair [22] or by helping them to communicate with the outside world through a word speller application [7]. Studies are currently considering applications for healthy users as well. Possibilities are applications such as virtual environment controllers [2] and games [21]. An advantage of games is that when one is integrating BCI into a game one could turn a disadvantage, the lower accuracy that is often associated with BCI, into a challenge that the gamer has to master [18]. As the Wii [19] and the Kinect [15] popularized new genres of games that could be controlled based on movement, BCI could trigger a new genre of games where mastering your brain waves is pivotal.

1.2 Motivation and Goals

There is already research being done on the interaction between humans and computers while using BCI, especially on the performance of different BCI methods and how to improve them [1, 4, 10, 14]. One of the current main problems in BCI research is moving BCI out of the laboratory setting into the everyday environment. For BCI to perform well in normal situations, it has to perform in situations where there is background noise, for example when the user is engaged in multiple tasks or when the user is communicating with other people. One drawback of BCI is that equipment for recording, such as electroencephalograms (EEGs), are very sensitive to noise, and this noise might result in artifacts in the signal [6]. This noise can be introduced by factors such as muscle movement of the person using the BCI equipment or electrical interference. As muscle movements generate artifacts users might be less inclined

to interact socially with each other for worry of decreasing BCI performance. The first research question therefore is if using a BCI influences the social interaction between people when playing a cooperative game. This would have consequences for cooperative applications if social interaction between users is proved to be substantially impeded. The second research question therefore is, if it has an influence on social interaction, does using a BCI also influence the cooperation between those people. The hypothesis is that using a BCI during selection will influence the social interaction between players in a cooperative game setting more than when not using BCI. This happens because the use of a BCI would require more concentration and time from the player than without.

1.3 Approach

This will be a comparison study, looking at the social interaction either using a BCI or not in a cooperative game setting. To make these conditions comparable an experiment has to be setup where the players have to perform a certain task, either by using a BCI or not. The composition of this task has yet to be determined as it is dependent on the BCI method that will be used.

Another important aspect is the social interaction. There are a few questions that need to be answered before the research questions can be answered. First of all during the experiment there must be social interaction, so it is important to know how social interaction can be stimulated during the the experiment. Secondly a method of measuring social interaction has to be found. This should be an objective method and result in quantitative data as this makes it possible to compare the different conditions. However, it will be interesting to gather information from the players themselves as well by means of a questionnaire, and compare this to the result of the analysis.

1.4 Structure of report

The second section of this paper describes related work on the stimulation and measurement of social interaction. The third section discusses the task that players have to perform, in the context of using a BCI, and the game environment around the task. The fourth chapter describes the methodology of the experiment that is performed. The fifth chapter presents the results of this experiment and in the sixth section these are discussed. Chapter seven finishes with the conclusion and possible future work.

Chapter 2

Related work

Social interaction is the first aspect that has to be considered. There are a few questions that have to be answered, such as how social interaction can be induced. If there is no social interaction during the experiment of this study, than no conclusions can be drawn. These conclusions have to drawn based on some kind of measurement. So the next important question that needs answering is how to measure social interaction with quantitative data. This chapter addresses these questions by looking at previous studies. Both studies in a general setting as well as those placed in a game environment are considered here.

2.1 What is social interaction?

Social interaction is the interaction between two or more humans. Language, both verbal and non-verbal, is used as a coordination device, or a way for two or more individuals to coordinate and reach a common goal [9], or as Clark calls it: joint activity [5]. As social interaction is an activity between humans, it must be observable through the human senses. Not all, but most social interaction can either be seen, for example gestures or facial expressions, or be heard in the form of a vocal expression. These vocal expressions can either be part of a formal language and be called speech or they are not and can be called utterances. As they are observable, it makes them recordable with camera and microphone.

2.2 Inducing social interaction

The first concern is that during the experiment there should at least be some social interaction. The experimental setup should stimulate the players to interact with each other. According to Fowler et al. [9] several studies have observed that humans have a tendency to cooperate and sometimes even imitate behaviour such as gestures, posture and verbal language. This suggests that while two users work together on a system towards the same goal, they will inherently interact with each other. For this purpose

	Speaker A's actions	Addressee B's actions
4	A is proposing joint project w to B	B is considering A's proposal of w
3	A is signalling that p for B	B is recognizing that p from A
2	A is presenting signal s to B	B is identifying signal s from A
1	A is executing behaviour t for B	B is attending behaviour t from A

Table 2.1: Clark's grounding table

the players, during the experiment in this study, play a game cooperatively, hence the players will have to work and interact together to achieve a common goal.

2.3 Measuring factors that influence social interaction

In this study a comparison is made, therefore the difference in social interaction between conditions is what is of consequence. However, human social interaction is both diverse and complex, therefore there is no fixed way to measure it. There are different possible ways to approach this problem. One way to measure the difference in social interaction is by looking at the moments where communication between two people goes wrong. For example, if people are distracted they might not pay attention to social cues of others and miss important parts of the communication between them. This influences the social interaction between them and therefore can be used as a measure. Clark [5] describes that communication can go wrong at different levels. As an example he gives the table 2.1 with the following description.

> *To succeed in their joint projects (level 4), A and B need to ground what A is to be taken to mean for B (level 3), and to do that, they need to ground what behaviour A is presenting to B (level 2), and to do that, they need to ground what behaviour A is executing for B (level 1). Dealing with all these levels is simplified by two properties of action ladders - upward completion and downward evidence.*

Meaning that for a joint action, or an act of communication to succeed both person A and person B must understand on these different levels of communication what has happened between them, otherwise parts of the communication might be missed or misinterpreted by the other person. Hence this understanding, or grounding, is crucial for successful cooperation.

2.3.1 Cognitive load

A different and a more indirect method is by measuring the cognitive load of an user. Yin and Chen [27] discuss several methods of measuring cognitive load during the performing of tasks and use measuring based on speech for their own research. Cognitive load is defined by Feinberg and Murphy [8] as the amount of mental energy

required to process a give amount of information. It can also be seen as the capacity of our working memory. The more events or elements that a person attends to at the same time, the higher the cognitive load will be. If the working memory is overloaded preforming this will affect the user's concentration, tasks will prove more difficult to complete and will take longer. Yin and Chen recording speech and looking at features such as the rate of pauses and rate of pitch peaks to make an automated measurement of the cognitive load. This measurement could be used to measure the cognitive load of the players and see if the cognitive load is higher when using the BCI selection method. As the working memory can only handle a very limited number of activities at once, a higher cognitive load might have influence on the cooperation between players. There are two levels of cognition: The higher cognitive level, with this complex tasks are performed and which has a very low capacity and the lower cognitive level, which handles familiar tasks. Through learning a complex task can become a familiar tasks and be handed from the higher cognitive level to the lower cognitive level. This is an interesting point, because this could mean that even though using BCI might have influence on the cooperation at the start as it is something new, with enough repetition it might become an automatic task, and stops influencing cooperation. This might be an interesting point for further research.

2.4 Measuring social interaction in games

There have been studies into social interaction within gaming contexts. However, most of these studies focus on social interaction in games played over the Internet. Most of these studies have been done on role-playing games, for example multi user dungeons (MUDs) or massive multiplayer online role playing games [17]. Muramatsu and Ackerman [16] examines the social world of a combat orientated MUD. A combat orientated MUD, in contrary to a social MUD, focusses more on the game and less on social aspect during game play. Therefore the social interaction between players is more directed at the game experience. Even if the social interaction is limited compared to social MUDs, there still is social activity, consisting out of conflict an cooperation. Sill for many participants it is the social activity that is the most important factor of playing. This is another indication that multiplayer games stimulate social interaction even if they are not designed as social games. In these MUDs all communication run trough text input however and is not ideal as this limits expressiveness of the players. In the game that is used during the current study, the participants need to be able to express themselves in more ways, and they do not have the time to type either commands, replies or other social interactions to each other as the speed is kept at a higher pace.

Lindley et al. [11] measured the engagement and social behaviour of two co-located players playing a game. The two players had to play the game Donkey Konga, which could be played with either a conventional controller or with special bongos. These bongos required the players to tap the them and clap their hands to the beat of the music. For analyses Lindley et al. treated a pair as a single unit, as they did not see an individual independent from its partner. They used definitions from the autism

diagnostic observation schedule (ADOS) [13] to code verbal and non-verbal behaviours. Verbal behaviour was either categorized as speech or utterances. They repeated the procedure for non-verbal behaviour, categorizing them between instrumental gestures and empathic gestures. Instrumental gestures are actions that convey a clear meaning, or are used to draw/direct attention. Gestures that could be in this category are: pointing, shrugging, nodding and moving head towards the other person. Empathic gestures are actions that convey emotion, such as placing hands in front of the mouth in shock or resting their chin on a hand. With the bongos the participants produced significantly more utterances, instrumental and empathic gestures. They showed that an alternative game controller such as the Bongos, makes participants produce more social interaction. This study is highly comparable to the current study as they're both comparison studies into different methods of control and both use a game environment to situate the experiment in.

2.5 Conclusion

Making the game naturally a cooperative game makes sure that cooperation and thus social interaction is induced between the two players. Several ways of measuring either social interaction or factors that have influence on social interaction have been found, such as cognitive load and annotating audiovisual tracks. However, non of these are in cohesion with BCI. The most interesting study [11] measures social interaction by annotating the recorded audiovisual tracks based on; speech, utterances, instrumental and empathic gestures, whitch results in quantitative results that can be used to make a comparison. Besides the way of measuring social interaction, the setup of the experiment is comparable to this study, as they have a comparative study between two different controllers in a cooperative game setting. However, in the current study the influence of a BCI on social interaction is compared to non BCI, this will most likely have a different effect as the Bongo's controller had in their experiment.

Chapter 3

Study environment

As this is a comparison study, a task will be performed by the players that can be done either with or without a BCI. This chapter defines this task together with the the game environment in which it is placed. It starts out by first looking at how a BCI could be used and what kind of task would be suitable. Once two BCI methods are selected that could be used a preliminary experiment determines which of these two is most suited to be used. Once the task and method is defined, the game environment where the task will be performed is described. Finally this chapter described how the task the players had to perform, with a BCI and without, is made part of the game.

3.1 Selecting brain-computer interface method

BCI is a means of interaction between human and computer based on neural activity in the brain. There are different ways in which a BCI can be used. In this study players will perform a task either with or without a BCI, therefore a way has to be found that can be achieved by both means. EEG is an accessible method that can be used for recording brain signals. EEG is a method that uses electrodes placed on the scalp to record electrical activity produced by the firing of neurons. One of the possible aspects that can be measured with EEG are event-related potentials (ERPs). An ERP is a response by the brain to an external event, for example a stimulus presented on a computer screen. Two well documented ERPs are the steady-state visual evoked potential (SSVEP) and the P300.

The SSVEP response is triggered when a user focusses on a stimulus that is flickering at a certain frequency. The SSVEP response is mostly visible between 6 Hz to 18 Hz and is recorded from the occipital region of the scalp [25]. Because the power of an SSVEP response shows only over a very narrow bandwidth that corresponds to the frequency of the stimulus [12], it is detectable with a fast Fourier transform (FFT).

As SSVEP, P300 occurs as a natural response to an external stimulus. However for P300 it is important that this is an infrequent stimulus. The less expected the stimulus is to the player, the higher the P300 response will be. Because of the low

probability that the target stimulus will be activated compared to the distractors an ERP component that occurs approximately 300 ms after the target stimulus is activated. P300 probably represents a summation of activity for various areas in the brain and is not a single event in a single part of the brain. A literature study into P300 and possible parameters was done in a preliminary study [20].

3.2 Selection task and game environment

When working on a computer or playing a computer game a conventional task is making a selection. With a common interface such as the mouse a selection is a matter of a mouse click on the right location. BCI could be suited to be used for a selection task. By using a set of frequencies for the objects that can be selected during the task for SSVEP or letting them blink in random order for P300 it is possible to distinguish the one the player was looking at from the others. However, for P300 there should be enough number of stimuli to make the activation of the target stimulus produce significantly enough feedback. On the other hand the amount of stimuli should be limited as more stimuli has it's disadvantages, such as a longer time that is needed to make a selection. There are however still some questions, such as which of these methods is most suited. The next chapter therefore describes a preliminary study looking at both SSVEP and P300 and some of the possible parameters.

The task that is used during the experiment consists of a selection task in a game environment. This makes it possible to compare the methods by either using just the mouse or a combination of mouse and a BCI. However, these methods are not comparable in difficulty. The method with a BCI will require more focus and time from the players than point and click. Therefore a third method, timed selection, is introduced as well. Timed selection is a selection method that should require a similar focus from the players at the selection as BCI selection, but without the need of using a BCI. This means there are the following three cases:

- Point and click selection
- BCI selection
- Timed selection (comparable to BCI selection)

Each of these methods is described in section 3.5 with a detailed description of the game. The game should be playable with each selection method.

The game environment that is chosen is a sheep herding game. The goal of this game is to lead a number of sheep to a pen. This is done indirectly by controlling herding dogs that have influence on the movement of the sheep. Because of this indirect control of the sheep, the players gain time to plan and anticipate the movement of the sheep. This makes it both easier for players when using BCI or timed selection to react to the game environment and helps them to cooperate with each other.

3.3 Finding BCI parameters for a game environment

The BCI selection can be performed with different methods. Two of these methods have been selected for comparison. To determine if either P300 or SSVEP will be used two preliminary studies were performed. One study [20] looked at P300 and the combination of two different parameters, the size of the stimuli and the length of the inter stimuli interval (ISI), or the pause between two activating stimuli. In this study two classification methods described by Farwell and Donchin are compared as well. This resulted in the comparison of the ISIs of 100, 200 and 300 ms and the sizes of 64 and 96 pixels resulted in the best combination of an ISI of 300 ms and a size of 64 pixels. However, both classification methods performed very poor, mostly just above the result of a random choice. This was probably due to the amount of stimuli. As described before, P300 performs better when there are more stimuli and during this experiment three stimuli were used, as this would keep the time needed to make a selection low.

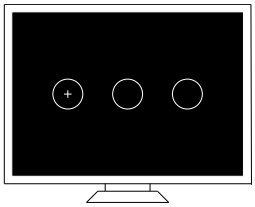


Figure 3.1: P300 pre-experiment setup, the plus indicated the stimulus the participant had to focus on

In the same setup Hakvoort et al. [10] tested SSVEP. This study made a comparison between two classification methods, canonical correlation analysis (CCA) and power spectral density analysis (PSDA) while looking at seven frequencies (6, 6.67, 7.5, 8.57, 10, 12 and 15 Hz) [26]. This resulted in a significantly better performance of CCA over PSDA. Hakvoort el al. recorded this data for same two sizes as the P300 experiment, 64 and 96 pixels. Every combination of three possible frequencies for both sizes where tested with CCA and with an average recall of 84.6% ($\sigma = 11.9$), the set of 7.5, 10 and 12 Hz was chosen to be used during the experiment of this study.

With P300 performing far worse compared to SSVEP when using three stimuli, the choice between SSVEP and P300 is quickly made. Hakvoort et al. [10] also describes that CCA performs better then PSDA on the data recorded during these pre-experiments and with an average recall of 84.6% ($\sigma = 11.9$), the set of 7.5, 10 and 12 Hz with SSVEP and the classification method CCA were selected to be used during this study.

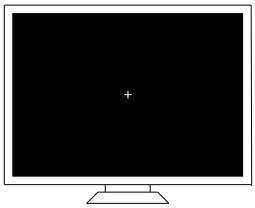


Figure 3.2: SSVEP pre-experiment setup, the middle plus is where the participant had to focus

3.4 The game Mind the Sheep!

Mind the Sheep! is the game that was built to perform the experiment of this study on. A custom game was built as this gives one more control over the inner workings of the game. For example, the different selection methods could be implemented into the game, and something less conventional to a game such as BCI can be integrated to the researchers needs. The task that should be performed within the game can be clearly defined and implemented without being restrained by third party engine limitations.

3.4.1 The GEHMI game engine

The first objective of the game was to build it such a way that could help with BCI research in general. To achieve this it was important that the game engine itself was separated from the game. Thereby other research groups can build their own type of game on the engine. Another aspect was that control modalities could abstractly be defined and easily incorporated into the engine. The setup therefore was so that everything should be modular, thus easily adjustable. With this setup other research groups can build their own experimental setting using the GEHMI engine and plug in their own modalities for control.

3.4.2 Modalities

For this study the modalities for mouse, keyboard and BCI were necessary. An abstract modality module was written that could implement any of these. Due to the abstract design, other study groups can implement other control modalities such as a speech recognition modality, a WiiRemote modality or other BCI control modalities.

3.4.3 The game

The game used in this study consisted of a playground representing a meadow (Figure 3.6). On this playground there were a few obstacles such as fences and vegetation (Figure 3.3 and a pen. The top-down view gave the participants the ability to plan around the obstacles, and communicate their plans to each other. The playground was populated with six herding dogs (three per player) and several sheep, depending on

Figure 3.3: Obstacle in the form of trees

the task. The goal of this game was to get all the sheep into the pen, in the shortest time, by giving the dogs move instructions. By setting a goal that participants had to reach, they had something to work towards together.

3.4.4 Agents

Sheep The sheep acted like a flock. This flocking behaviour was introduced by using the boids algorithm [24]. On default the sheep walk and graze around at random, some of them might start flocking. This flocking is based on the three boids rules that determine the movement vector for each sheep in the flock. When a dog approaches, they tend to flock more and move away from the dog.

Figure 3.4: Sheep, wandering around on the screen

Dogs In this setup there are three dogs for both players, the dogs can be moved to a location on the map by indicating this location with the mouse. The movement of the dogs is calculated by a A* path finding algorithm. When a dog is moving, sheep in

Figure 3.5: Two different dog styles, each player controls a different set

its path move away according to the boids prey-predator rule. The dog waits on the location that was indicated until a new instruction is given to this dog. By positioning dogs strategically a flock of sheep can be directed to the pen. Each herding dog will have a predefined name. This makes it easier for player to communicate about them to other players.

3.4.5 Multiplayer

A multiplayer version was needed to initiate the social interaction between players. Having multiple players also has the advantage that more data at the same time can be generated for later analyses. To start playing a multiplayer game, one first has to be start the game in server mode. When players join, they do this in a new instance of the game and enter a pre-game menu. Once both players have joined, one of the players start the game and at that moment the server generates the world. It sends the information about what map is used to the clients over TCP. As soon as this data is transmitted to all the clients they generate the world and its agents, once this is finished the game itself starts. During game play, all the game logic runs only on the server and the server sends regular updates with agent positions and angles to the clients over UDP. Once a client selects a dog and moves it, these coordinates are transmitted to the server over TCP who generates a path for that dog.

3.5 Selection

3.5.1 Point and click

The point and click method worked by first clicking the mouse on the dog that the participant wants to use. Once the dog is selected a small circle surrounds it as an indication of the selection. Now the participant can click on the location the dog has to move to and the dog starts moving.

Figure 3.6: A screenshot of the game containing 10 sheep and 6 dogs controlled by the players

3.5.2 BCI selection

To move the dog, the participant first moves his mouse cursor to the location the dog should move to. The participant presses and holds the left mouse button. From this moment the SSVEP method is active for the dog selection. The dogs are all highlighted with different frequencies. The participant then selects the dog that has to move to the indicated location by looking and concentrating on the blinking stimulus of the dog that should move. As the participant holds down the mouse button the SSVEP method continues to be active and the system acquires more samples over time. SSVEP detection has a higher accuracy over time, provided the attention of the participant is kept constant. On the other hand the participant may choose to release the mouse button sooner when a quick reaction is needed, but this decreased the chance of the correct dog being selected. So the trade-off between performance and reaction speed is up to the participant to make. If all went successfully, the correct dog moves to the location of the mouse cursor as soon as the button is released. If not, a wrong dog move to the indicated location. During the SSVEP stimulation the participant can still move the mouse cursor, altering the location the selected dog should move to.

3.5.3 Timed-selection

For the non BCI version the SSVEP method was replaced with a time based method. To give a herding dog instructions the first steps are the same as with BCI selection. The player moves the mouse cursor to a location on the map and presses down the left mouse button. From this moment the selector highlights the herding dogs one at the time, when the player releases the mouse button the currently highlighted herding dog is selected. Initially the selector highlights the next herding dog very quickly but this slows down as time wears on making the selection of a herding dog more accurate. Again the player has a choice between performance and reaction speed.

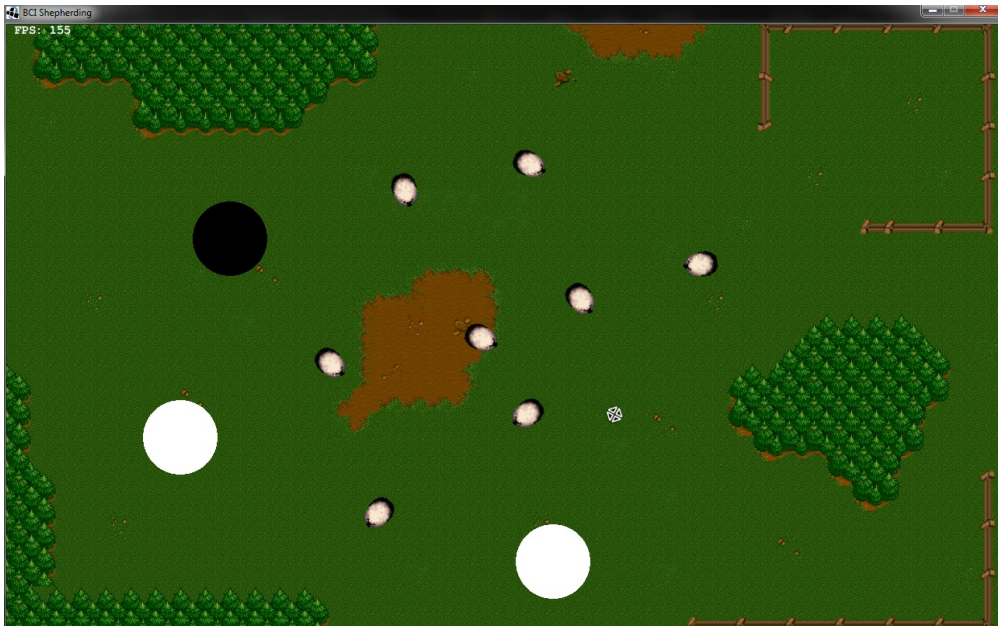


Figure 3.7: A screencapture of SSVEP

Chapter 4

Methodology of the experiment

4.1 Subjects

For this study 20 participants were tested, divided into 10 pairs. All participants were asked to bring a friend. If no friend was available they were teamed up with another participant. Pairs did not have to be equal in composition, because all the pairs performed each selection method. If the composition of a pair had influence on the interaction, it would have an influence on all methods. Therefore the composition of pairs has no effect on this study. The participants participated voluntarily in this study, and signed a consent form (Appendix D) for their participation. To motivate the pairs to do their best a small reward, a pair of cinema tickets, was promised to the pair that completed the experiment in the shortest time. The average age of the participants was $25.25(\sigma = 7.20)$ with the youngest being 18 and the oldest 54. Of the 20 participants 18 were male. Each participant had a normal, or corrected to normal eyesight, used a computer every day and at least some experience with computer games. None of the participants reported a history of epilepsy.

4.2 Experimental setup

The setup consisted of five computers: two for the participants to play on, two for the BCI acquisition and one for the recording and storing of audiovisual data. The participants were seated next to each other (Figure 4.1), so non-verbal interaction such as pointing was possible while playing the game. They both looked at their own LCD screens that were placed 50 cm apart from each other. This gave the participants the opportunity to turn their heads and look at each other's screen. As they had some freedom of movement and could move forward or backward in their chairs there was no fixed distance from participant to the screen. Any movement or speaking might impair

the accuracy of the SSVEP classifier due to muscle activity, introducing artefacts in the data, but it enables them to communicate more easily at will. The participants were notified in advance that this might be the case, but they had to decide for themselves if they heeded this notification or not. The BCI caps were placed at the start of the experiment and removed at the end of the experiment. A camera and microphone were pointed at the participants. This setup was placed between the participants and on a tripod so it recorded over the top of the LCD screens and captured the entire upper body of the participants, including their hands.

Figure 4.1: One participant pointing with one hand and clenching his fist while the other participant is looking on and holding his hand flat on the tabletop

Each pair started with a short training to learn the game and the three different selection methods. Once the training was finished they played three trials of the game, once with the point and click method, once with the BCI selection method and once with the timed selection method. Each trial took until they finished the task or a time limit of 20 minutes had passed. The trials happened in counterbalanced order for the pairs. Each trial was played on a pre-made map. However, the layout of these maps differed, because if the same map had been used for both trials the pair might have developed a strategy on the first map and deployed it again on the second map without having to discuss this. Thereby the social interaction of the latter trials may be influenced. The maps that were used therefore differed mainly on layout and obstacles. The combination of map and selection method was selected by counterbalancing each trial. During the whole procedure the experimenter stayed in the same room.

Once the experiment was completed the BCI caps were taken off and the participants were asked to fill in a questionnaire. Besides basic demographic information, the questionnaire asked them to think about the cooperation within the pair and rank both selection methods based on how they experienced it. It also asked them if they felt inclined to work together at all, to validate the setup of the experiment and it asked how

much difficulty they had selecting a dog with each method. This might provide some correlation between difficulty and certain behaviours that were measured. Finally, the participants were interviewed about their ranking of methods in the questionnaire. By doing an interview with the participants, more information could be gathered than by asking this in the questionnaire.

4.3 Data acquisition, processing and analysis

The SSVEP selection method used EEG signals that were acquired with a Biosemi ActiveTwo system, from five electrodes, $PO3$, $O1$, O_z, $O2$ and $PO4$, placed according to the 10-20 international system [23]. This data was digitized at 512 Hz sample rate, re-referenced to electrodes placed on the earlobes and analysed using CCA [3]. CCA has advantages over the commonly used PSDA method introduced by Cheng et al.[4], such as a better signal-to noise ratio and no need for channel selection. CCA tries to correlate the BCI signal to a set of reference signals based on the frequencies that are used. The frequency with the highest correlation to the reference signals is selected. The time it took to finish a trial was recorded.

The videos were annotated manually with the four behaviours that Lindley et al. [11] defined. These were speech, utterances, instrumental gestures and empathic gestures. Speech is the deliverance of formal spoken communication while utterances are all other sounds that were made by participants. Instrumental gestures are gestures that have a deliberate purpose to support cooperation, such as pointing and gazing to the others monitor. Empathic gestures are gestures that may convey the emotional state of a participant. Obvious gestures that could be thought of are gestures such as putting a hand in front of your mouth in shock, or more subtle such as increased repetitive, purposeless movement. The annotation itself was performed by the researcher as there were no resources to annotate all the data by a group of annotators. However, for gestures 10% of the data (the audiovideodata of one pair) was annotated by a seperate annotator to confirm the findings of the main annotator.

Every speech and utterance component in the audio data was marked from start to finish. The total length of both speech and utterances that participants produced per trial was used for analysis. These values were normalized to an number of seconds of either per minute, because all pairs finished in different times. A pair was considered as a single unit, thus this data was averaged over the pair. The same was done with instrumental gestures and empathic gestures. These were counted after the annotation. The total number of gestures per trial for both was normalized to a number of gestures per minute for each pair. Finally all these values were averaged over all pairs and for each of the selection methods to see the differences.

In the questionnaire participants were asked to rank the selection methods based on the level of cooperation the participants experienced. In a 7-point Likert scale they were asked if they felt the need to cooperate during the experiment to measure if this study was successful in inducing interaction between participants and about the difficulty of selecting the dogs with each method.

Chapter 5

Results

First it is important to see if this study was successful at inducing social interaction between participants. An item in the questionnaire asked whether the participants felt inclined to work together. Using a 7-point Likert scale 20 subjects answered with a mode of 7 (9 out of 20 answered with a 7). Testing these results with a Wilcoxon signed-rank test to a neutral result, with an average of 4, yielded $Z = -3.9811, p < 0.001$. Therefore the conclusion can be drawn that the experiment was successful in inducing cooperation within the pairs.

BCI tasks took on average 9.64 minutes ($\sigma = 5.85$) to finish while timed tasks took on average 11.52 minutes ($\sigma = 5.99$) and point and click tasks took on average 8.12 minutes ($\sigma = 5.07$) in seconds to finish. There was however no significant difference between any of the times as the deviation between pairs was very high.

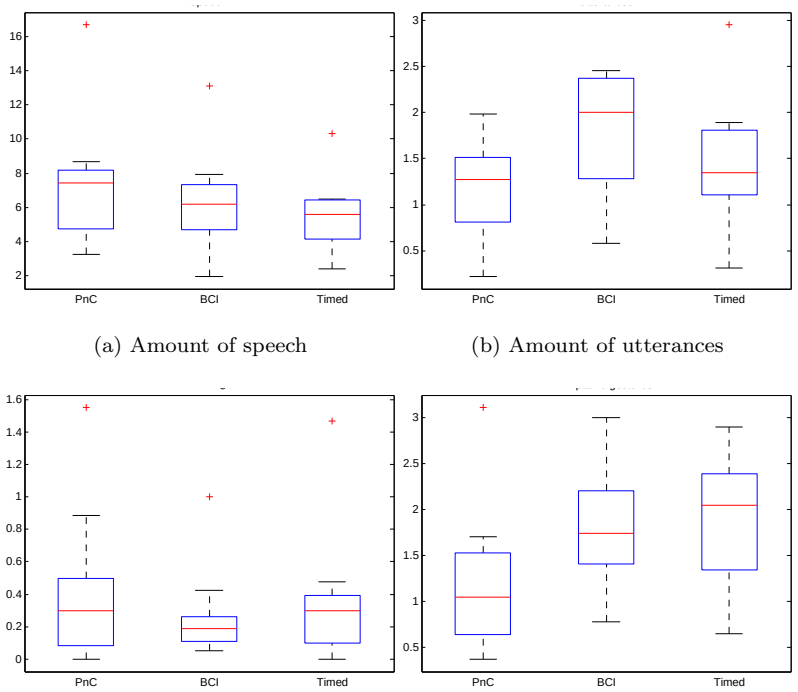
Table 5.1: An overview of all average values, and standard deviation within parentheses, over all the pairs for each of the behaviours for both the selection methods. For speech and utterances theses values are in seconds per minute and for instrumental and empathic gestures these values are number of gestures per minute.

	Point and Click selection	BCI selection	Timed selection
Speech	**7.56 (3.70)**	6.43 (2.92)	5.56 (2.15)
Utterances	1.18 (0.51)	**1.78 (0.63)**	1.43 (0.72)
Instrumental gestures	0.41 (0.49)	0.27 (0.28)	**0.42 (0.42)**
Empathic gestures	1.21 (0.80)	1.81 (0.70)	**1.88 (0.76)**

In table 5.1 the average values over all the pairs for all the four behaviours and both selection methods are reported. There was a higher amount of speech during the use of point and click selection compared to both BCI and timed selection. The amount of utterances was the highest during and empathic gestures during the use of BCI. Although this study reports the means, the analyses between the different selection methods uses the non-parametric Wilcoxon signed-rank test, because with the low amount of pairs a normal distribution cannot be guaranteed. Looking first at

speech the difference between point and click selection and timed selection is significant ($p = 0.0488$), this means that there was a higher amount of speech during the use of point and click. The difference of ($p = 0.0645$) shows that there is a potential trend, but no significant difference between the amount of speech with BCI and point and click. With utterances, the difference between point and click and BCI selection is significant ($p = 0.0059$) this means there is a higher amount of utterances when using BCI selection. There is no significant difference in the number of instrumental gestures between any of the three selection methods. As with utterances, there is a higher number of empathic gestures for BCI selection, between point and click and BCI selection ($p = 0.0039$). Using the Bonferroni correction, the significance boundary at $0.05/3 = 0.0167$ this means that only the significant differences are those for utterances and empathic gestures between point and click and BCI. Figures 5.1a to 5.1d show box plots of these results. For each plot, the central red line is the median, the edges of the box are the 25th and 75th percentiles, the whiskers of the plot extend to the most outermost data points that are not considered as outliers as these outliers are plotted individually as red plusses.

Looking at the results of the questionnaire (Appendix C) where the participants were asked to rank the different selection methods based on how well they cooperated during each trial. With this ranking participants reported that they cooperated significantly better using point and click over BCI selection ($p = 0.0047, z = -2.8301$). There is a trend that they cooperated better using point and click over timed selection ($p = 0.0343, z = -2.1170$), but using the Bonferroni correction this is not significant. They cooperated equally using BCI and timed selection ($p = 0.5453, z = -0.6049$).



(a) Amount of speech

(b) Amount of utterances

(c) Number of instrumental gestures

(d) Number of empathic gestures

Figure 5.1: Overview of boxplots for each aspect of the measured social interaction, with each a comparison between the three selection methods.

Chapter 6

Discussion

It was expected that due to the focus that was required for selecting a dog, the amount of speech and number of instrumental gestures would be lower during the use of BCI and timed selection. For BCI selection the participant's knowledge that speech and movement might disturb the EEG signal the amount of speech and the number of instrumental gestures would be lower. As cooperation is mostly done by speech and instrumental gestures it was expected that cooperation between participants would be reduced as well. When a wrong dog is selected it causes an unexpected situation, this triggers involuntary reactions from the participants in the form of utterances and empathic gestures. The amount of utterances and the number of empathic gestures were expected to be higher.

The participants indicated in the questionnaire that they found selecting with point and click significant easier then with both BCI ($Z = -3.7215, p < 0.001$) and timed selection ($Z = -3.9510, p < 0.001$). There was no significant difference in the difficulty between BCI and timed selection ($Z = -1.8396, p < 0.0658$). This makes sure that BCI and timed selection were comparable to each other.

No significant difference was found between point and click and either BCI or timed selection for either speech or instrumental gestures. For BCI selection with speech, this was mainly due to one of the pairs. Because of the novelty of the BCI method and the uncertainty of whether it would work or not, one of the participants, during the BCI trial, kept saying the name of the dog he wanted to select and then commenting on the result of the selection. Contrary to other pairs, this pair had a notably higher amount of speech during BCI compared to point and click. If this pair were not taken into consideration then there is a clear significant difference for speech during BCI or point and click ($p = 0.0078$). For instrumental gestures, this was because the low number of instrumental gestures. Some of the pairs produced no instrumental gestures at al during a trial.

There was a significant difference between point and click and BCI with utterances and empathic gestures. This shows that some aspects of social interaction do change with different selection methods. There were more laughs, groans, interruptions of speech and other sounds made during a BCI played game. This increase in the number

of empathic gestures and amount of utterances means that more unexpected events happened that the participants reacted on. These events are mostly the selection of a wrong dog and might imply the difficulty of the BCI selection. This does not mean that they produced less cooperation, but it was influenced as they had to adapt to new situations when a wrong dog was selected.

The amount of speech and number of instrumental gestures did not change significantly with the selection methods. Looking at the ranking of cooperation by the participants in the questionnaire, there is a significant difference between point and click and BCI selection, but not between point and click and timed selection. This means that participants said there was better cooperation when using point and click compared to BCI. This was also supported by some of the participants who voiced this during the interview afterwards. They said that at times they were too busy focusing on selecting the right dog and they did not pay much attention to what the other person was doing. As there is no significant difference between timed selection and both other methods it means that timed selection lays somewhere between point and click and BCI selection. The difficulty of timed selection did have some impact on the cooperation between the participants, but not as profound as BCI selection had. As BCI and timed selection had an equal difficulty this indicates that the novelty of BCI had some influence as well. However, the participants first had a training session and wore the BCI cap throughout the entire experiment to become familiar with BCI and the equipment.

The results from the audiovisual data indicate aspects of social interaction are affected by the higher difficulty and effort needed for BCI. The questionnaire and the interview support this, and indicate that the use of BCI noticeably influences the cooperation between participants in such a way that they cooperated better during the use of point and click.

Chapter 7

Conclusions

This study looked at the social interaction during a cooperative game using either BCI or not. In an experiment a comparison was made between three different selection methods: The first selection method was point and click with the mouse, as is used in many software applications. The second method was with a BCI, here participants had to focus on a stimulus to make a selection and the third method was timed selection, this method was included to simulate the BCI method in difficulty and required focus, but without a BCI itself. The research question, if using a BCI influences the social interaction between people when playing a cooperative game, has been tried to answer by measuring annotated audiovisual tracks of an experiment and a questionnaire and an interview after the experiment. The audiovisual tracks were annotated based on the speech, utterances, instrumental and empathic gestures the participants made. This experiment resulted in no significant difference in the amount of speech or the number of instrumental gestures. However, there was a trend towards more speech when using point and click compared to both BCI and timed selection, with an average difference of $1.13(\sigma = 1.83)$ and $2.01(\sigma = 2.68)$ seconds of speech per minute respectively. With an average difference of $0.60(\sigma = 0.53)$ seconds per minute, there was a significantly higher amount of utterances when using BCI compared to point and click. The number of empathic gestures when using BCI compared to using point and click was significant higher as well, with an average difference of $0.60(\sigma = 0.33)$ gestures per minute. The information provided by the questionnaire indicate this is possibly caused by the difficulty of BCI selection. However, timed selection is considered as difficult and does not show a significant higher amount of utterances or number of empathic gestures. This means that another aspect of BCI has an influence on the amount of utterances and empathic gestures as well. This may be the novelty of BCI when participants may involuntarily react more to events in the game. The questionnaire shows that participants cooperated significantly better during the use of point and click compared to BCI and that there is a trend that participants cooperated better during point and click compared to timed selection. This means that for BCI probably the combination of a difficult selection method and the novelty of the method influenced the cooperation. This implies that if BCI, or in this case SSVEP, gets developed

further and become more widespread in use, these influences may disappear over time.

For future work it would be interesting to see if using BCI over a longer period reduces this effect. This might change once the novelty of BCI wears off and the participant might become accustomed to the performing a certain task with BCI. Another interesting point would be to look deeper into the annotation and label each utterance and empathic gesture individually. This could provide more information on what kind of utterances and empathic gestures are more common during BCI. This would show for example if participants laugh or groan more during BCI.

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Appendix A

Questionnaire

BCI experiments Michel Obbink

Thank you for participating with this experiment. This experiment was conducted to find out more about the interaction and cooperation between players during the use of different selection methods.

During the experiment you have played with 3 different selection methods:

Point and Click - Clicking and selecting the dog with your mouse and clicking where you want it to move.

BCI selection - Clicking and holding the mouse button where you want the dog to move to, while looking at the flickering circles and releasing the mouse button to move it there.

Timed selection - Clicking and holding the mouse button where you want the dog to move to and releasing the mouse button when the dog you want to move is highlighted to move it there.

The next couple of questions will ask about your personal experience during the experiments.
If you have any questions do not hesitate to ask.

Rank the different selection methods

Rank them based on the cooperation

Rank 1:
During what method the cooperation between you and your teammate performed best?

	Best cooperation	Second best cooperation	Third best cooperation
Timed selection			
BCI selection			
Point and click selection			

Scale the rankings you just made

Grade the differences between the methods you rated in the previous question based on the cooperation between you and your teammate

There was much better cooperation with the method I placed at rank 1 compared to the one I placed on rank 2

	1	2	3	4	5	6	7	
Disagree very strongly								Agree very strongly

There was much better cooperation with the method I placed at rank 2 compared to the one I placed on rank 3

	1	2	3	4	5	6	7	
Disagree very strongly								Agree very strongly

There was much better cooperation with the method I placed at rank 1 compared to the one I placed on rank 3

	1	2	3	4	5	6	7	
Disagree very strongly								Agree very strongly

Cooperation

In this part you grade the level of cooperation between you and your teammate

I felt inclined to work together with my partner during this experiment

	1	2	3	4	5	6	7	
Disagree very strongly	○	○	○	○	○	○	○	Agree very strong y

I found it difficult to select a dog with Point and Click

	1	2	3	4	5	6	7	
Disagree very strongly	○	○	○	○	○	○	○	Agree very strong y

I found it difficult to select a dog with BCI selection

	1	2	3	4	5	6	7	
Disgree very strongly	○	○	○	○	○	○	○	Agree very strongly

I found it difficult to select a dog with Timed selection

	1	2	3	4	5	6	7	
Disagree very strongly	○	○	○	○	○	○	○	Agree very strongly

BCI experiments Michel Obbink

Demographic information

Surname; Initial(s)

Age

Mother tongue

Gender

Eyesight

- Normal
- Corrected to normal
- Impaired

Handedness
Right or left handed

- Left
- Right
- Both

Computer usage

- Every day
- Every 2-3 days
- Once a week
- More than once a month
- Less than once a month
- Never

BCI experience

- More then twice
- Twice
- Once
- None

Computer gaming experience

- Expert
- Moderate
- Novice
- None

Multiplayer gaming experience

- Expert
- Moderate
- Novice
- None

BCI experiments Michel Obbink

Other information

Substance consumption within 6 hours before the experiment

	None	1 unit	2 units	3 units	More
Alcohol					
Coffee					
High sugar content drink(e.g., coke)					
Tobacco					
Black Tea					
Energy drink					

Hours of sleeps before the experiment

Any drugs/medications used

Preferred address/number for contact

Other comments

Appendix B

Interview

After the experiments are done and both participants have filled in the questionnaire the experimenter asked several questions to the pair. These questions are not put in the questionnaire as they have the purpose to trigger the participants to speak more and describe in their own words how they cooperated and what kind of strategy they used with each selection paradigm.

* Ask about why the subjects ranked the methods as they did it as they did in the questionnaire at question 2 and what where the differences

* How would you define the strategy that was used during the use of paradigm [point and click/BCI/timed]

* Did the naming of the dogs had any influence on their cooperation?

* Did they have other comments

Appendix C

Questionnaire results

Experience	None	Novice	Moderate	Expert
General gaming	0	2	6	12
Multiplayer	0	6	6	8

Table C.1: Gaming experience

	1	2	3	4	5	6	7
Point and click	11	7	1	1	0	0	0
BCI selection	0	4	5	1	4	6	0
Timed selection	0	1	1	3	5	10	0

Table C.2: Results on statement if had difficulty selecting a dog on 7-point Likert scale

	Rank as first	Rank as second	Rank as third
Point and click	14	3	3
BCI selection	1	11	8
Timed selection	5	6	9

Table C.3: Results on participants ranking selection methods based on cooperation

Appendix D

Consent form

BCI research

Participant Consent Form

I have been asked to participate in a study conducted by Michel Obbink or *The Experimenter* of the University of Twente. My participation in this study is entirely voluntary. It is recommended that I read the information below and ask questions about anything I do not understand before deciding whether or not to participate.

PURPOSE OF THE STUDY

I understand that this study is designed to gain knowledge about physiological interaction with computer games and that its full purpose will be explained after the experiment. I understand that the entire process will involve up to two hours in which I have several opportunities for a break. I am advised to take a toilet break before the start of the experiment and the placement of the electrodes. Should I at any time during the experiment experience discomfort, then I should inform *The Experimenter* immediately.

PROCEDURES

If I volunteer to participate in this study, I will cooperatively play a game with another volunteer. During this time I will be asked to try to perform three tasks, I will try to perform these tasks to the best of my abilities. I understand that the whole experiment will be recorded with camera and microphone for later reference. I understand that *The Experimenter* will remain near me throughout the experiment and is available for questions at any time.

POTENTIAL RISKS AND DISCOMFORTS

I understand that EEG acquisition requires the placement of electrodes in combination with conductive gel on the scalp for the purpose of recording an EEG. There are few risks associated with this procedure. There is a remote possibility of skin irritation from the electrode gel used to attach electrodes. Techniques used to attach electrodes have been used at numerous research institutions for many years with no significant negative side effects reported.

I understand that I can remove the electrodes or the cap at any time if I desire and there is no risk of electroshock from this procedure. We do not expect any psychological, legal or financial risks for participating in the research, but as always, there may be possible unforeseeable risks that have not been identified. **Important:** If you have illnesses, are undergoing medical treatment or *are known to ever had an epileptic seizure*, please inform *The Experimenter* as soon as possible. For questions about this please contact *The Experimenter*.

RIGHTS OF RESEARCH SUBJECTS

I understand that the information filled in on the questionnaire is anonymised and can and will only be processed, published and presented in its anonymised form. All recorded data provided, e.g. the audio and video recording of me during the research study will not be disclosed to anyone outside the research team without written permission, except if necessary to protect my well-being, e.g., if I am injured and need emergency care or required by law. When the results of the research are published and discussed in conferences, no information will be included that reveals my identity. In any photographs, videos or audiotape records taken during the study my identity will be protected.

I may withdraw my consent at any time and discontinue my participation without penalty. I am not waiving any legal rights or remedies because of my participation in this research study.

SIGNATURE OF RESEARCH SUBJECT OR LEGAL REPRESENTATIVE

I have read and understand the information provided above. I have been given an opportunity to ask questions and all of my questions have been answered to my satisfaction.

BY SIGNING THIS FORM, I WILLINGLY AGREE TO PARTICIPATE IN THE RESEARCH IT DESCRIBES.

NAME (BLOCK CAPITALS): .....

Signed: ..... Date: .....

I, *The Experimenter*, confirm that I have fully explained the purpose and nature of the research study and the risks involved.

NAME (BLOCK CAPITALS): .....

Signed: ..... Date: .....

Appendix E

INTETAIN paper

Social interaction in a cooperative brain-computer interface game

Michel Obbink, Hayrettin Gürkök, Danny Plass-Oude Bos, Gido Hakvoort, Mannes Poel, and Anton Nijholt
mobbink@gmail.com, h.gurkok@utwente.nl, d.plass@cs.utwente.nl, gido.hakvoort@gmail.com, m.poel@utwente.nl, a.nijholt@utwente.nl

Human Media Interaction, University of Twente, Enschede, The Netherlands

Abstract. Does using a brain-computer interface (BCI) influence the social interaction between people when playing a cooperative game? By measuring the amount of speech, utterances, instrumental gestures and empathic gestures during a cooperative game where two participants had to reach a certain goal, and questioning participants about their own experience afterwards this study attempts to provide answers to this question. The results show that social interaction changed when using a BCI compared to using a mouse, there was a higher amount of utterances and empathic gestures. This indicates that the participants automatically reacted more to the higher difficultly of the BCI selection method. Participants also reported that they felt they cooperated better during the use of the mouse.

Key words: brain-computer interfaces, social interaction, games, cooperation

1 Introduction

A brain-computer interface (BCI) is a means of interaction between humans and computers based on neural activity in the brain. It has fascinated people as it could enable whole new ways of controlling objects such as computers or wheelchairs. Since it has come into existence BCI research has mostly focused on helping disabled people, for example by controlling a wheelchair [12] or by helping them to communicate with the outside world through a word speller application [5].

Studies are currently considering applications for healthy users as well. Possibilities are applications such as virtual environment controllers [1] and games [11]. An advantage of games is that when one is integrating BCI into a game one could turn a disadvantage, the lower accuracy that is associated with BCI, into a challenge that the gamer has to master [10]. This challenge could trigger a whole new genre of games where mastering your brain waves is pivotal.

One of the current main problems in BCI research is moving BCI out of the laboratory setting into the everyday environment. For BCI to perform well in

normal situations, it has to perform when there is background noise, for example when the user is engaged in multiple tasks or when the user is collaborating with other people. A drawback of BCI is that equipment for data acquisition, such as electroencephalographs (EEGs), is very sensitive to noise. Muscle movement of the person using the BCI equipment or electrical interference might result in artifacts in the signal. As muscle movements generate artifacts users might be less inclined to interact socially with each other for worry of decreasing BCI performance. This will have consequences for cooperative applications if social interaction between users is proved to be substantially impeded.

This study looks into the influence of BCI control on social interaction in a cooperative game setting. To cooperate with each other, users should be able to interact with each other unimpeded. To study this social interaction, an environment has been setup where a player can use either a BCI or a mouse. The task was comprised of the selection of objects. This means that a BCI could be tested against a normal point and click interface with the mouse. For the BCI selection method the classification method steady-state visually evoked potentials (SSVEPs) [14] is used. This is a method that uses a flickering stimulus to activate the part of the brain where visual information is processed. When showing a group of stimuli, the player can make a selection by looking at one of the stimuli. The different stimuli each flicker on a different frequency, in such a way the stimulus that the player focuses on can be distinguished from the others. By looking at the speech, utterances, instrumental gestures and empathic gestures that players produce while playing the game the influence of BCI on social interaction was analysed.

The second section of this paper describes how to induce and measure social interaction. The SSVEP method that is used during the experiment is explained as well. The third section discusses the methodology and the game. The fourth section presents the results and in the fifth section these are discussed. Section six finishes with the conclusion and possible future work.

2 Background

2.1 Inducing social interaction

The first concern in social interaction research is to induce the interaction among users. According to Fowler et al. [6] and Clark [4] language is used as a coordination device, a way by which coordination among two or more individuals can be achieved to reach a common goal, or as Clark calls it: joint actions. According to Fowler et al. several studies have observed that humans have a tendency to cooperate and sometimes even imitate behaviour such as gestures, posture and verbal language. This suggests that while two users work together on a system towards the same goal, they will inherently interact with each other.

2.2 Measuring social interaction

Lindley et al. [7] measured the engagement and social behaviour of people playing a game together. The game was Donkey Konga, which could be played with a conventional controller and with special bongos that required the users to tap the bongos and clap their hands to the beat of the music. They treated a pair of participants as a single unit, as they did not see an individual independent from its partner. They used definitions from the Autism Diagnostic Observation Schedule (ADOS) [9] to code verbal and non-verbal behaviours. Verbal behaviour was either categorized as speech or utterances. They repeated the procedure for non-verbal behaviour, categorizing them between instrumental gestures and empathic gestures. Instrumental gestures are actions that convey a clear meaning, or are used to draw/direct attention. Gestures that could be in this category are: pointing, shrugging, nodding and moving head towards the other person. Empathic gestures are actions that convey emotion, such as placing hands in front of the mouth in shock or resting their chin on a hand. With the bongos the participants produced significantly more utterances, instrumental and empathic gestures. They showed that an alternative game controller such as the Bongos, makes participants produce more social interaction. This research is highly comparable to the current study and therefore comparable measurement methods were used. With the four categories of verbal and non-verbal behaviour all possible events were captured and by looking at the time for speech it provides a method of measuring social interaction.

2.3 Steady-state visually evoked potentials

The SSVEP response is triggered when an user focusses on a stimulus that is flickering at a certain frequency. The SSVEP response is mostly visible between 6 Hz to 18 Hz and is recorded from the occipital region of the scalp [14]. Because the power of an SSVEP response shows only over a very narrow bandwidth that corresponds to the frequency of the stimulus [8], it is detectable with a fast-Fourier transform (FFT). SSVEP is an exogenous event-related potential (ERP), which means that it is an involuntary brain response to an external stimulus and these occur due to internal processing of external events.

An important issue that arose when building the SSVEP system was the set of frequencies that were used and how this was presented to the user. The work of Volosyak et al. [15] present a set of possible frequencies that could be used on an LCD screen. In a small pre-experiment trial performed with 7 participants every combination of their proposed frequencies were tested to select the three frequencies that were used in this study. With an average recall of 84.6% ($\sigma = 11.9$), the set of 7.5, 10 and 12 Hz was selected to be used.

3 Methodology

3.1 Participants

For this study 20 participants divided into 10 pairs, were tested. All participants were asked to bring a friend. If no friend was available they were teamed up with another participant. Pairs did not have to be equal in composition, because all the pairs performed each selection method and therefore if the composition of a pair had influence on the interaction, it had any influence on all methods and therefore it had no effect on this study. The participants participated voluntarily in this study, and signed a consent form for their participation. To motivate the pairs to do their best a small reward, a pair of cinema tickets, was promised to the pair that completed the experiment in the shortest time. The average age of the participants was $25.25(\sigma = 7.20)$ with the youngest being 18 and the oldest 54, of the 20 participants 18 were male. Each participant had a normal, or corrected to normal eyesight, used a computer every day and at least some experience with computer games. None of the participants reported a history of epilepsy.

3.2 The game

The game used in this study consisted of a playground representing a meadow (Figure 1). On this playground there were a few obstacles such as fences and vegetation and a pen. The top-down view gave the participants the ability to plan around the obstacles, and communicate their plans to each other. The playground was populated with three herding dogs and several sheep depending on the task. The goal of this game was to get all the sheep into the pen in the shortest time by giving the dogs movement instructions. By setting a goal that participants had to reach, they had something to work towards together.

Fig. 1. A screenshot of the game containing 10 sheep and 6 dogs controlled by the players

To move the dog, the participant first moves his mouse cursor to the location the dog should move to. The participant presses and holds the left mouse button.

From this moment the SSVEP method is active for the dog selection and the dogs are all highlighted with different frequencies. The participant selects the dog that has to move by looking and concentrating on the blinking stimulus of the dog that should move. As the participant holds down the mouse button the SSVEP method continues to acquires more samples over time. SSVEP detection has a higher accuracy over time, provided the attention of the participant is kept constant. On the other hand the participant might choose to release the mouse button sooner if a quick reaction is needed, but this decreased the chance of the correct dog being selected. So the trade-off between performance and reaction speed is up to the participant to make. If all went successfully, the correct dog moves to the location of the mouse cursor as soon as the button is released, if not a wrong dog moves to the indicated location. During the SSVEP stimulation the participant can still move the mouse cursor, altering the location the selected dog should move to.

The point and click method worked by first clicking the mouse on the dog that the participant wants to use. Once the dog is selected a small circle surrounds it as an indication of the selection. Now the participant can click on the location the dog has to move to and the dog starts moving.

3.3 Experimental setup

The setup consisted of five computers: two for the participants to play on, two for the BCI acquisition and one for the recording and storing of audiovisual data. The participants were seated next to each other, as can be seen in Figure 2, so non-verbal interaction such as pointing was possible while playing the game. They both looked at their own LCD screens that were placed 50 cm apart from each other. This gave the participants the opportunity to turn their heads and look at each other's screen. As they had some freedom of movement and could move forward or backwards in their chairs there was no fixed distance from participant to the screen. Any movement or speaking might have impaired the accuracy of the SSVEP classifier due to muscle noise which might have lead to artefacts in the data, but it enabled them to communicate more easily at will. The participants were notified in advance that this might be the case, but they had to decide for themselves if they heeded this notification or not. The BCI caps were placed at the start of the experiment and removed at the end of the experiment. A camera and microphone were pointed at the participants as can be seen in Figure 2.

Each pair started with a short training to learn the game and the two different selection methods. Once the training was finished they played two trials of the game, once with the SSVEP selection method and once with the point and click method. Each trial took until they finished the task or a time limit of 20 minutes had passed. Each trial was played on a pre-made map. However, the layout of these maps differed, because if the same map had been used for both trials the pair might have developed a strategy on the first map and deployed it again on the second map without having to discuss this. Thereby the social interaction of the latter trial may be influenced. The maps that were used for both methods

Fig. 2. One participant pointing with one hand and clenching his fist while the other participant is looking on and holding his hand flat on the tabletop

therefore differed mainly on layout and obstacles. The combination of map and selection method was selected by counterbalancing each trial. During the whole procedure the experimenter stayed in the same room.

Once the experiment was completed the BCI caps were taken off and the participants were asked to fill in a questionnaire. The questionnaire asked them to think about the cooperation within the pair and rank both selection methods based on how they experienced it. It also asked them if they felt inclined to work together at all, to validate the setup of the experiment and it asked how much difficulty they had selecting a dog with each method. This might provide some correlation between difficulty and certain behaviours that were measured. Finally, the participants were interviewed about their ranking of methods in the questionnaire. By doing an interview with the participants, more information could be gathered than by asking this in the questionnaire.

3.4 Data acquisition, processing and analysis

The SSVEP selection method used EEG signals that were acquired with a Biosemi ActiveTwo system, from five electrodes $PO3$, $O1$, O_z, $O2$ and $PO4$ placed according to the 10-20 international system [13]. This data was digitized at 512 Hz sample rate, re-referenced to electrodes placed on the earlobes and analysed using Canonical Correlation Analysis (CCA) [2]. CCA has advantages over the commonly used power spectral density analysis (PSDA) method introduced by Cheng et al.[3], such as a better signal-to noise ratio and no need for channel selection. CCA tries to correlate the BCI signal to a set of reference signals based on the frequencies that are used. The frequency with the highest correlation to the reference signals is selected.

The videos were annotated manually with the four behaviours that Lindley et al. [7] defined. These were speech, utterances, instrumental gestures and empathic gestures. Speech is the deliverance of formal spoken communication while utterances are all other sounds that were made by participants. Instrumental gestures are gestures that have a deliberate purpose to support cooperation, such as pointing and gazing to the others monitor. Empathic gestures are gestures that may convey the emotional state of a participant. Obvious gestures that could be

thought of are gestures such as putting a hand in front of your mouth in shock, or more subtle such as increased repetitive, purposeless movement.

Every speech and utterance component in the audio data was marked from start to finish. The total length of both speech and utterances that participants produced per trial was used for analysis. These values were normalized to a number of seconds of either per minute, because all pairs finished in different times. A pair was considered as a single unit, thus this data was averaged over the pair. The same was done with instrumental gestures and empathic gestures. These were counted after the annotation. The total number of gestures per trial for both was normalized to a number of gestures per minute for each pair. Finally all these values were averaged over all pairs and for each of the selection methods to see the differences.

In the questionnaire participants were asked to rank the selection methods based on the level of cooperation the participants experienced. In a 7-point Likert scale they were asked if they felt the need to cooperate during the experiment to measure if this study was successful in inducing interaction between participants and about the difficulty of selecting the dogs with each method.

4 Results

Before the results are analysed, it is important to see if this study was successful at inducing interaction between participants. An item in the questionnaire asked whether the participants felt inclined to work together. Using a 7-point Likert scale 20 subjects answered with a mode of 7 (9 out of 20 answered with a 7). Testing these results with a Wilcoxon signed-rank test to a neutral result, with an average of 4, yielded $Z = -3.9811, p < 0.001$. Therefore it can be concluded that the experiment was successful in inducing cooperation within the pairs.

Table 1. An overview of all average values, and standard deviation within parentheses, over all the pairs for each of the behaviours for both the selection methods. For speech and utterances theses values are in seconds per minute and for instrumental and empathic gestures these values are number of gestures per minute.

	BCI selection	Point and Click
Speech	6.43 (2.92)	7.56 (3.70)
Utterances	1.78 (0.63)	1.18 (0.51)
Instrumental gestures	0.27 (0.28)	0.41 (0.49)
Empathic gestures	1.81 (0.70)	1.21 (0.80)

In table 1 the average values over all the pairs for all the four behaviours and both selection methods are shown. There was a higher number of speech and instrumental gestures during the use of point and click selection, and a higher amount of utterances and empathic gestures during the use of BCI. BCI tasks took on average 9.64 minutes ($\sigma = 5.85$) to finish while point and click tasks

took on average 8.12 minutes($\sigma = 5.07$) in seconds to finish. This was however not a significant difference as the deviation between pairs was very high.

Using a Wilcoxon signed-rank test ($p = 0.0645$) shows that there is a potential trend, but no significant difference between the amount of speech with BCI and point and click, but ($p = 0.0059$) on utterances, it shows that when using BCI significantly more utterances were produced compared to using point and click. There was no significant difference between BCI and point and click for instrumental gestures ($p = 0.3223$). Looking at emphatic gestures, there are clearly significantly more gestures used while playing with BCI ($p = 0.0039$) compared to point and click.

5 Discussion

It was expected that due to the focus that was required for selecting a dog, and the participant's knowledge that speech and movement might disturb the EEG signal during the use of BCI selection, the amount of speech and the number of instrumental gestures would be lower. As cooperation is mostly done by speech and instrumental gestures it was expected that cooperation between participants would be reduced as well. When a wrong dog is selected it causes an unexpected situation, this triggers involuntary reactions from the participants in the form of utterances and empathic gestures. The amount of utterances and the number of empathic gestures were expected to be higher.

The participants indicated in the questionnaire that they found selecting with BCI more difficult than with point and click ($Z = 4.7013, p < 0.001$). However, no significant difference was found between point and click and BCI for neither speech nor instrumental gestures. For speech there was a trend towards significance.

The amount of speech and number of instrumental gestures did not change with the selection methods. In the questionnaire, participants were asked to rank how they thought they cooperated between different selection methods. They answered 17 out of 20 times that they cooperated better during the use of the point and click selection method. This was also supported by some of the participants who voiced this during the interview afterwards. They said that at times they were too busy focusing on selecting the right dog and they did not pay much attention to what the other person was doing. Further research with additional participants could reduce the effect of such an outlier that was found in the speech condition and provide proof with a significant difference.

There was a significant difference between point and click and BCI with utterances and empathic gestures. This shows that some aspects of social interaction do change with different selection methods. There were more laughs, groans, interruptions of speech and other sounds made during a BCI played game and here was a higher number of empathic gestures as well. This increase in the number of empathic gestures and amount of utterances means that more unexpected events happened that the participants reacted on. These events are mostly the selection of a wrong dog and implies the difficulty of the BCI selection. This does

not mean that they produced less cooperation, but it was influenced as they had to adapt to new situations when a wrong dog was selected.

The results from the audiovisual data indicate aspects of social interaction are affected by the higher difficulty and effort needed for BCI. The questionnaire and the interview support this, and indicate that the use of BCI noticeably influences the cooperation between participants in such a way that they cooperated better during the use of point and click.

6 Conclusion

This study looked at the social interaction and cooperation during a cooperative multi player game. A comparison was made between BCI selection compared to point and click selection. Measurements were taken from: audiovisual tracks, questionnaires and an interview. The audiovisual tracks were annotated marking the duration of speech and utterances, and the number of instrumental and empathic gestures. This experiment resulted in no significant difference in the amount of speech or the number of instrumental gestures, but there was a trend towards more speech when using point and click. There was a significantly higher amount of utterances and number of empathic gestures when using BCI compared to using point and click. This indicates that aspects of social interaction are affected by the use of BCI. The information provided by the questionnaire indicate this is caused by the difficulty of BCI selection and influences the cooperation in such a way that participants cooperated better during the use of point and click.

For future work it would be interesting to look deeper into the annotation and label each utterance and empathic gesture individually. This could provide more information on what kind of utterances and empathic gestures are more common during BCI. This would show for example if participants laugh or groan more during BCI.

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