Embodiment in Brain-Computer Interaction

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ABSTRACT

With emerging opportunities for using Brain-Computer Interaction (BCI) in gaming applications, there is a need to understand the opportunities and constraints of this interaction paradigm. To complement existing laboratory-based studies, there is also a call for the study of BCI in real world contexts. We present such a real world study of a simple BCI game called MindFlex®, played as a social activity in the home. In particular, drawing on the philosophical traditions of embodied interaction, we highlight the importance of considering the body in BCI and not simply what is going on in the head. The study shows how people use bodily actions to facilitate control of brain activity but also to make their actions and intentions visible to, and interpretable by, others playing and watching the game. It is the public availability of these bodily actions during BCI that allows action to be socially organised, understood and coordinated with others and through which social relationships can be played out. We discuss the implications of this perspective and findings for BCI.

Author Keywords

Brain-Computer Interaction, gaming, embodied interaction

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

ACM Classification Keywords

Human Factors

INTRODUCTION

The concept of Brain-Computer Interaction (BCI) in which measurements of brain activity are used to control interactive systems has been with us for decades. Initially, the key focus of this kind of interaction technique was to offer new interaction modalities for people with disabilities such as those with motor control impairments. For example, BCI techniques have been used to control cursors, keyboard entry or navigation for wheelchairs [2, 25, 33, 26]. More recently, though, with advances in non-invasive BCI technology and the development of more practical BCI headsets, there is now a realistic possibility for using such technologies for a wider variety of applications and for users with no physical disabilities [1, 23]. In the last few years, one such area to which researchers have turned their attention has been the use of BCI as a technique for gaming [e.g. 5, 10 22, 15, 7, 16]. Some notable examples from the research literature include Brainball [12, 13], MindBalance [16], and "Use the force" [17, 20]. At the same time, we are also now beginning to see the first commercial BCI-based games with offerings from NeuroSky and Emotiv. These organisations offer both headsets and development kits for the creation of new games and applications based on BCI technology. This is likely to accelerate development of BCI games for fun and educational purposes.

Accompanying such developments, there is an increasing need to further understand the opportunities and constraints of BCI as an interactional paradigm within the context of gaming [22, 23]. That is, it raises questions such as: what are the capabilities and limitations of these techniques within the context of gaming; in what ways should BCI techniques be combined with other interaction modalities for engaging gaming experiences; and what new paradigms need to be developed that go beyond the emulation of basic games controllers [17]?

In deepening this understanding, as with any other area of HCI, there is a need to adopt a broad set of techniques capable of addressing both micro and macro levels of analytic enquiry, from questions of fine-grained interactional efficacy to larger questions of the value and use of these systems in real world social contexts. Inevitably, because of the pragmatic considerations associated with BCI research, to date there has been tendency to focus on issues amenable to analytic enquiry within laboratory settings by individuals using the headsets. These studies yield important results, but are only a part of the story. As Lécuyer et al suggest, there is a need to begin complementing this strand of work with other types of HCI and CSCW enquiry [17]. That is, they argue for more ethnographic and real world studies of BCI for gaming and other application scenarios. Such studies will help in an understanding of this technology since games are, in the main, social, as indeed are many of the other contexts in which BCI might be deployed.

With this in mind, in this paper, we discuss findings from a real world study of a BCI-controlled game played as a social activity in the home. This study draws on the philosophical and analytic concerns found in CSCW where techniques for analysing the social in all its embodied forms

CHI 2011, May 7-12, 2011, Vancouver, BC, Canada.

are well developed [e.g. 6, 28]. Before presenting the study, we first wish to establish some more context with respect to BCI and embodied interaction.

BCI AND EMBODIED INTERACTION

On the face of it, it is perhaps rather curious to align BCI with embodied interaction. After all, on the surface, the magic of BCI stems from the apparent disembodiment of action, where thoughts alone can have impact in the world. Inherent in the BCI paradigm and in its treatment in the literature is a focus on the internal workings of the brain and how detectable patterns of brain activity can be reliably interpreted to control artefacts in the digital domain. In this respect, the BCI paradigm begins to bear some resemblance to early approaches in HCI that were dominated by cognitive theories and abstract representations of the brain's internal processes as opposed to specific concerns with the external world, and the ways in which actions were situated. However, as HCI matured, this approach was subject to a number of critiques both in practical and philosophical terms. In part, these critiques arose out of the turn to the social as HCI shifted focus away from simply addressing individual interaction with computers to the more collaborative interaction possibilities being realized with emerging CSCW technologies. With this shift came new concerns and approaches driven by the practical concern of how to think about groups of people interacting through technology rather than just about individuals. But, accompanying this were related philosophical issues. In particular, there were concerns about the abstract nature of cognitive theories and the inherent "invisibility" of these processes. This led to a greater emphasis on examining what was observable – namely social action and the ways it is situated within a particular context [e.g. 8, 30]. It is this perspective we bring to bear in the work we report here.

Of additional import with these critiques and new approaches to HCI are philosophical foundations associated with them. These raise intriguing and challenging questions with respect to BCI because of the extent to which they concern themselves with the "embodiment" of action. Notions of embodied action in HCI [e.g. 5, 28] essentially draw on the philosophical foundations of phenomenologist thinkers such as Husserl, Heidegger and Merleau-Ponty. These authors take as their starting point that consciousness and perception are active, interpretive and embodied, arising from our presence and action in the world. This particular stance of embodied interaction is of significance for a number of reasons that relate to our concerns and methodological orientation in this paper. Firstly, it articulates an inherent relationship between actions in the world and our internal cognitive and conscious experiences. Secondly, it argues that through our actions we are able to create shared meanings with other people - the public availability of these actions to the perceptions of others allows action to be socially organized, understood and coordinated with others.

Where these arguments lead us to then are the important concern with the bodily actions that accompany brain-computer interaction. While BCI technologies have done more to reveal the internal workings of the brain and render them interpretable (albeit by machines), the inherent relationship with bodily actions in the world suggests our understanding of Brain-Computer Interactions lies also with an understanding of these actions in the world. This relationship has implications both for the pragmatics of BCI control as well as how these interactions are experienced socially. For example, from a pragmatic perspective, bodily movements and muscle artefacts can influence EEG signals [e.g. 21]. Within a social context, too, these accompanying actions are of additional significance. The work done to render the internal states of the brain and any intentionality visible and interpretable by others present, through actions, gestures, expressions and utterances, is a key component in the organisation of social conduct around these kinds of interactions [14]. Further, this is of importance to how social meaning is created through these technologies and how particular social relationships are played out both for those playing as well as those watching.

In order to explore these issues, we present a real world study of people using a simple BCI-based game called MindFlex®. MindFlex was a useful candidate of study for our purposes for a number of reasons. First, it is one of only a few BCI applications readily and commercially available for real world deployment. Second, gaming offers the necessary kind of social context through which we could study the social organisation of action with BCI.

RELATED WORK: BCI AND GAMING

While the use of steady state visual-evoked potentials and motor imagery-based BCIs have been demonstrated in other contexts, the demands of gaming present different challenges that motivate the recent crop of games-related research [7, 23]. There are questions for example, as to how things such as audio and visual stimulation in video games might impact on performance and motivation in positive and negative ways by dividing resources [e.g. 16]. A number of research initiatives in recent years have begun to explore the use of simple BCI controls in game-like scenarios. Typically, the applications provide the user with a small set of commands and controls somewhere in the region of one to three [17]. For example, there have been several attempts to demonstrate the use of BCI techniques for navigating in game-like virtual environments [e.g. 19]. The concern of this research, though, was not focussed on the gaming experience per se. Rather, they wanted to demonstrate how feedback provided by the 3D virtual world could improve motivation and performance over simple 2D feedback. What this does show, though, is the susceptibility of BCI performance to certain factors and parameters within game-like settings.

Other researchers have more explicitly attempted to create engaging game situations within the particular control constraints of BCI to understand the efficacy of the interaction within this context. In the MindBalance game, players' EEG readings are used to provide binary control over an animated character that is balancing on a tightrope [16]. As the character walks towards the player, it stumbles either leftwards or rightwards off the tightrope. The aim of the game is to correct the character's balance by focusing on the checkerboard on the opposite side of the screen to the direction of falling. This work is important for us in a number of ways. First, it points to an idiomatic approach to BCI game design. That is, the game mechanic would be relatively trivial for other more traditional games controllers but presents an engaging challenge within the context of EEG-based control. Second, the study quantitatively demonstrated that such binary control was feasible within the visually stimulating environment of the game and importantly that this success could be achieved using techniques requiring little training – an especially important consideration for use of BCI in gaming.

The MindBalance study, for good reason, like much BCI research, was conducted in closely controlled environmental conditions. As we have discussed, some authors have made explicit calls to conduct additional BCI research for gaming in more demanding real world contexts. This was one of the motivations underlying the work of the group at INRIA in their development and explorations of the "Use the Force" game [17, 20]. In this game, BCI techniques were used to control the virtual take-off of a spaceship using real or imaginary foot movements. One thing of significance was that it was conducted outside of a controlled laboratory environment in a public exhibition space with a large number of participants. This context enabled the researchers to take on some of the challenges associated with BCI in more real world environments and the distractions associated with these. In spite of these challenges, the experiments reported that a significant number of participants were able to successfully control the spaceship with BCI. The work also highlighted some of the cognitive strategies employed by participants in their control of the ship. This is an issue we return to later in the study presented here, albeit within the social context of game play. Of importance with this work though, as the authors argue, is that the environmental context of the study paves a way for more ethnographic enquiry into BCI, a key motivation for the work presented here.

Perhaps one of the most intriguing and imaginative pieces of work in BCI gaming is that which has looked at Brainball [12, 13]. What is notable about this research is that it is less focused on demonstrable efficacy of the BCI technique within the gaming domain and more on the creation of an engaging experience within the constraints and affordances of the BCI technology. In this game, two players at either end of a game table control a ball on the table. The aim of the game is to score a goal by moving the ball into the opponent's goalmouth by relaxing more than your opponent. With greater relative relaxation, the ball moves towards the opponent's goalmouth. Notwithstanding the imaginative concept behind the game itself, the research on it highlights a number of important issues. For example, and as articulated by several authors, play is as much a social and collaborative experience as it is an individual experience [e.g. 29, 31, 32]. It is the social aspects of games through which play becomes meaningful – an opportunity for people to come together with social purpose: for competition, for identity work and for other forms of social occasioning. The playing of BrainBall was very much a social occasion; in part because it involved multiple players in competition, but also because the playing of the game became an event, attracting both players and audience. The notion of audience in relation to BCI is of interest to us because it suggests engagement with a game is not just about a player's experience but also how it can be watched and enjoyed [27].

While the BrainBall work points to a number of issues relevant to our discussion, the evaluation part of the research does not share the same analytic concerns as our own. The research discusses some high level feedback about people's response, but there is very little in the way of detailed interaction analysis that contributes to our understanding of the physical manifestations of behaviour using BCI in social settings – the *physical* and *social* features of playing the game in a real-world setting.

THE STUDY

MindFlex® game

Figure 1. The MindFlex® Game Board

The MindFlex® Game is a commercially available BCI game and, as such, is amenable to use in a real world study. MindFlex uses a wireless headset with single electrode at the front and two clips that attach to each earlobe. The headset is based on Electroencephalography (EEG) technology that measures electrical signals from the brain to determine relative levels of concentration. The aim of the game is to move a floating ball around an obstacle course assembled on the game board (see Figure 1). As the player concentrates, electrical signals from the brain activate a fan on the game. Higher levels of brain activity, or "concentration", increase the fan strength, thereby blowing the ball higher. To lower the ball, players must relax, reducing concentration and brain activity. With the ball raised, a second control knob is turned by hand to move the fan source round the game board. This allows the floating ball to be moved around the obstacle course as the player raises or lowers the ball over encountered obstacles.

Participants

Sixteen participants took part in the study, made up of four distinct groups of people who knew each other. For each group there was a "host" participant responsible for assembling the group of people with whom they wanted to play the game just as they would if playing any other game at home. A social group had to consist of at least two people. The groups, then, consisted of different family members and friend relationships as determined by the group host. The groups were as follows:

Group 1 – One female (early 30s) and one male (early 40s), in a relationship and cohabiting.

Group 2 – Father (early 40s) playing with his three children – boy (7), girl (16), boy (18).

Group 3 – Married couple (50s), daughter (14), her two stepsisters (18, 20), the boyfriend (20) of one of the stepsisters. One of the stepsisters had learning difficulties.

Group 4 – Mother (50), father (52), son (14), daughter (12).

Method

Host participants were given the MindFlex® game to take home for approximately 1 week. They were asked to play the game at home with other people they knew. It was up to them to decide when, where, with whom, and how often to play the game, just as with any other game. Participants were given a camcorder and asked to video themselves when they played the game in a social setting. The groups were fluid in that some people would join or leave the group at particular points during any game play; this fluidity being a natural component to the play context. After finishing with the game, participants returned it and the video recordings of their sessions. In total, there was approximately 4 hours worth of video data collected from the sessions. The video sessions were subject to a detailed interaction analysis by the researchers, that focused on the physical manifestation of behaviour around the game, looking in detail at bodily action, gestures and utterances occurring during game play. This was oriented to players, as well as co-presents others who were watching or even collaborating. The aim of this analysis was to describe the embodied nature of the interactions and collaborations, and how they were coordinated. Further, it aimed to show how social meaning was created and relationships played out through these embodied interactions.

FINDINGS

In presenting the findings, we draw on a series of vignettes and video sequences that illustrate key manifestations of the embodied nature of BCI. We begin with a discussion of the body in achieving focus and controlling concentration and relaxation. Next, we consider notions of intentionality including difficulties arising from lack of bodily manifestations of intentionality and the efforts to make intentionality visible. We then explore extraneous gestures people employ to accompany BCI creating enhanced narrative around the game and with a view to facilitating their engagement. We then look at the ways players create performance through their body during BCI. We examine too, the playful role of spectators in interacting with the players and the social and interactional implications of this.

Bodily Orientation and Focus

In our observations, the proxemic arrangement of players with respect to the game and others was an important consideration for controlling concentration and relaxation. Deliberate adjustments in body posture were performed to relax and achieve focus. Consider a sequence from a participant in Group 4 (Figure 2).

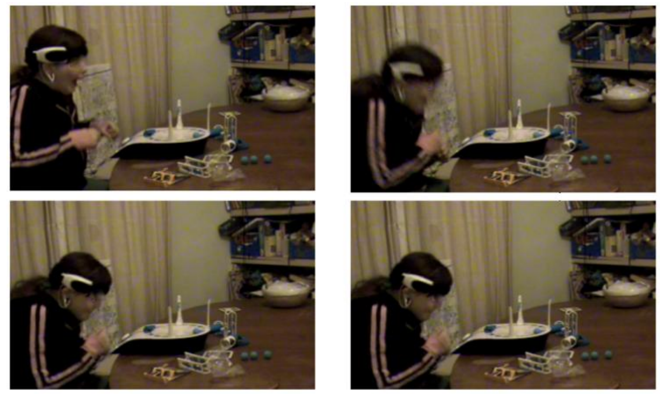

Figure 2. Holding breath and clenching for concentration

The younger daughter, staring at the ball, lifts her whole body up as she takes a deep breath and holds it. While holding her breath, she lowers her body downwards and towards the device. She clenches her hand and tenses up her whole body as if this will squeeze out some imaginary energy to raise the ball. This posturing has little to do directly with facilitating the wireless transmission of signals between headset and game. Rather, it is a strategy to achieve focus and concentration.

Such spatial arrangements were not simply static but rather were dynamically organised in response to the behaviour of the game and player performance. For example, players would lean in and increase the intensity of their visible gaze when the ball was not responding as they intended. What is of significance in these behaviours is the way gestures are closely choreographed with the behaviour of the game. We can see this illustrated in the following sequence (see Figure 3). In the beginning, the player (Group 1) looks at the ball with her hand on the control knob, trying to keep the ball raised through concentration. However, the ball begins to lower. As the ball lowers, she removes her hand from the control knob and begins to clench and unclench her hand. Closely choreographed with this is a scrunching up of her face. The intensity of the squeezing and grimace increase as the ball becomes precariously low but the gestures gradually relax as she manages to raise the ball. Only then does her hand return to the control knob. What we see here is the use of gesture in attempt to get back into a state of concentration. In using her hands in this way, she is temporarily unable to control the other mode of input, namely the control knob. Only once she has achieved a more stable state of focus does she return to the multimodal input control.

Figure 3. Gesture and Posture choreographed with game

Proxemic arrangement and gaze orientation were also used as means to try and reduce concentration on the ball in order to lower it. Most typically, this involved averting the gaze away from the game. Consider the following sequence in which a player from Group 2 was struggling to reduce the height of the ball (see Figure 4).

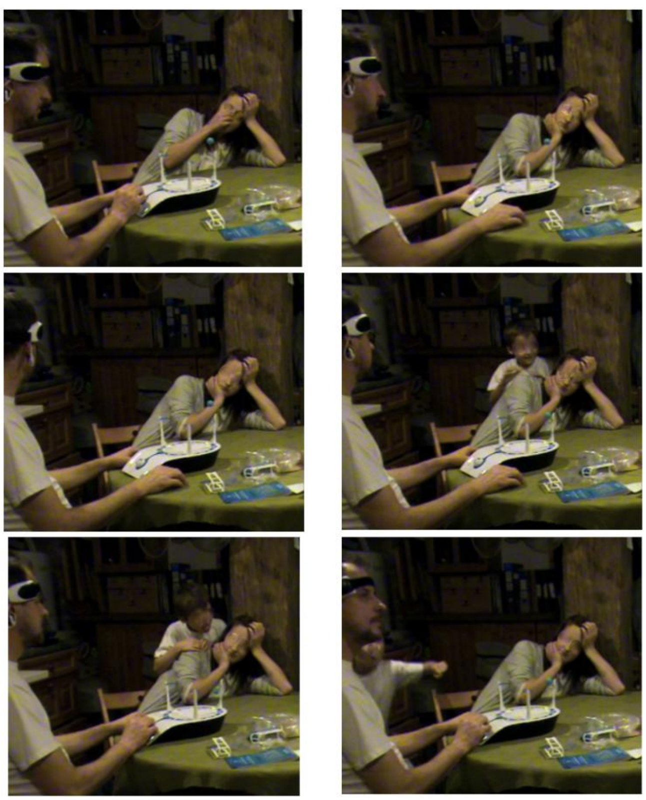

Figure 4. Averting gaze to reduce concentration

The sequence begins with the player staring at the ball, with his hand on the control knob ready to move the ball around the game board when it lowers. As he is unable to reduce his concentration and thereby lower the ball, he removes his hand from the control knob and looks away to his left. As he is looking to the left, the ball lowers in height as his concentration is reduced. Importantly as the ball lowers, the pitch of the fan reduces indicating that it is falling. When it gets to a low enough pitch, he then briefly brings his gaze back to the ball to quickly monitor its height before returning his gaze again to the left. The ball and the pitch of the fan drop lower allowing him to feel confident that he is in a state of relaxation. With that, he turns again to face the ball and brings his right hand back onto the control knob to begin to steer it. As he does this, his concentration increases and the ball begins to rise. To his frustration, he removes his hands from the knob and turns his gaze to the right and up into the air. Important here is the turn away from the visible as a means to guide the player interaction with the device. This potentially raises interaction difficulties because of a lack of visual monitoring of the system. However, the audio feedback provided by the noise of the fan allows the player to continue monitoring the system behaviour.

Mental Imagery and Narrative

During game play, gestures were performed as part of an additional narrative fantasy layer acted out over and above the basic elements of the game play. In the following vignette (Group 2), a father is playing with his younger son, and the father is offering guidance and instructions for how to get the ball to rise. In offering these instructions, the father adds an additional layer of narrative to the game that goes beyond what is necessary if we consider the interaction purely in terms of the control mechanisms. He suggests: *"Relax your face and put everything through your hands and into the ball flying"*. The instructions here, then, make reference to an imaginary energy that flows from the brain through the body and hands to the system. In response to this, the son moves his hands over the system and hovers them next to the ball to facilitate the channelling of this "energy" (see Figure 5).

Figure 5. Magician fantasy gestures

This additional narrative fantasy adds an extra source of mysticism and engagement for the son playing (and the father watching). With his father watching, the son plays it out through his bodily actions, waving his fingers about the ball, simulating the movements of a magician. He cups his hands underneath the ball without touching it and raises them, moving the "energy flow" in an attempt to move the ball upwards. These additional layers of narrative interpretation and mental imagery were evident in other strategies used by players in their attempts to more explicitly control the interaction in the game too. Such strategies involved thinking directly about moving the ball up or thinking about related concepts of height or flying objects. Another example is from the daughter in Group 2 :

> *"Birds , Plane takes off into the air. Up very high. Sky diver from very high up." She is saying this as she is looking into the air "Up up up up up!"*
>
> *"At the end of the day it helps to think about moving up – I don't know why. Think about stuff that moves up." Son 2, Gp 2*

Of significance here is how these kinds of strategies contribute to engagement with the device, adding a layer of intentionality to the way interaction is achieved, and a narrative in which players can engage. With this particular BCI mechanism, control is achieved through any non-specific concentration level. That is, it is not necessary to think of the ball moving up. However, by virtue of thinking about the ball moving up, they are in consequence increasing their concentration. So while it is simply this increased concentration that is causing the ball to rise, the association it makes with their intentional thoughts gives the impression that the intentional thought is responsible. Ironically, adopting this approach can also lead to a lack of control. For example, in other cases, players were seen to think explicitly about lowering the ball in order to get it to fall. This turns out to be counter-productive since these kinds of thoughts lead to increased concentration levels. We can see this in another episode where the father (Group 2) is interacting with his young son who is playing the game. The father says to his son *"Lower it in your mind"*. In response to this comment the son begins to stare intently at the ball, trying to control it rather than relax. The concentration levels that accompany this lead to the ball remaining in the air. Within the narrative of control, this is the appropriate opposite but is mismatched with the actual underlying control mechanics.

This has implications for thinking about the design of games and other applications utilising these relatively simplistic non-specific BCI mechanisms. That is, it suggests how design of the game experience might focus on the construction of appropriate narratives within the game to encourage stronger engagement with the game at the same time as teaching players how to achieve better control.

Intentionality and Invisibility

Watching and interpreting the game (whether for coordination purposes or enjoyment of the spectacle), was not always straightforward and unambiguous. Other players and spectators were not always able to understand the intentions and actions of others in relation to the game, particularly when there was no bodily manifestation of their intention. Key here is that focus and concentration are often at odds with communicating with others. Consider an example of this interpretive difficulty.

Participant J, the young son from Group 2 is playing the obstacle course version of the game while his father watches from the other side of the table. The father has been instructing his son in terms of how to control the ball and also the rules of the obstacle course such as correct direction for the ball to pass through the hoop. As J approaches the upcoming hoop obstacle with the ball floating below the hoop, the father says "*Top down that one"* as he points to the hoop in question. Because J is concentrating on trying to raise the ball higher and rotating it around in line with the hoop, he is unable to acknowledge his father's instruction either verbally or through gesture. The father is therefore reliant on the behaviour of the ball to confirm that his son has understood. However, because of the difficulty J is having controlling the ball, it is lower than the height of the loop giving the impression that he is approaching the hoop from the bottom up. The father takes this to mean that J has ignored his instructions so repeats them: *"Top down"*, to which J replies *"I know. I'm thinking, I'm thinking."* In verbally acknowledging his father, J is distracted and the ball drops to the game surface.

The example demonstrates how interaction *manipulations* [27] in this BCI are difficult to discern by those watching the game. Because these manipulations are not visible, those co-present might normally infer intentionality of a player from the interaction *effects* – namely the system's output. However, one difficulty with this approach in the context of this game arises from the relative lack of precision over the control of the system and a lack of strong mapping between the intentionality of the player and the game. This means that intentionality is not always represented in the interaction *effects* with this kind of interface. These factors lead to the misinterpretation of the player's intentions by the father. To exacerbate the problem, having to correct this misinterpretation also interferes with the player's attempt to concentrate, further undermining his ability to control the ball.

The imprecision of mapping between intentionality and interaction effects was also dealt with by players volunteering explanations of their behaviour through visible utterance or gesture. Consider the following episode. The father (Group 2) is playing the obstacle course version of the game while his children watch. He has his hand on the control knob, but keeps it still, ready to move the ball around once it is at the correct height. The ball is floating in the air and oscillating gently at a certain height. The father is staring at it and then looking away. The children are motionless watching him. This continues in silence for several seconds. At this point, the father glances across at them, chuckles and says: *"I can't get it to go down."* Because the ball has been up in the air for so long and not making any progress visible to the observing audience, he feels a need to explain what is going on to those watching.

Gestures too were used to make intentions visible to the audience when they were not being revealed through the state of the system. We can see an example of this in the following sequence by the daughter in Group 3 (Figure 6).

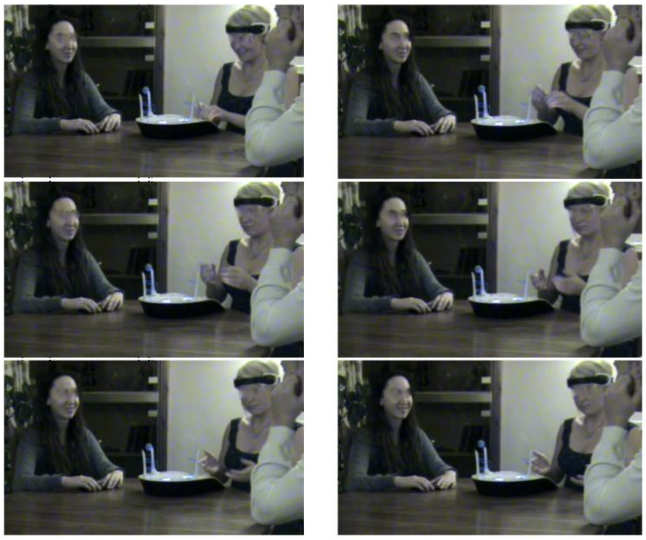

Figure 6. Using gesture to reveal intentionality

The daughter in this sequence is playing the obstacle course. She has raised the ball and prepares to move it around to the next obstacle. Once the ball is positioned above the obstacle, she needs to lower it through the hoop. As this does not happen immediately, she signals her intent through gesture. She looks at the ball and brings both hands off the console. As she raises them up, she turns them over and then gently lowers them in a downward gesture. While moving her hands down, she closes her eyes and gently nods her head to signal that the action should be initiated. She repeats this gesture phrase again, but with a stronger nod of the head to emphasise her intent.

Play as performance

Beyond simply trying to account for, or explain one's actions to others, we also observed that bodily movements and verbalizations while interacting with the device were sometimes about creating a performance for those watching. At times, gestures were deliberately exaggerated not only to help make visible the intentions of the player to the audience, but also to make it more engaging to watch. This is illustrated well in the following segment (Figure 7). Here, we see the daughter from Group 2 playing the obstacle course with her father sitting on the opposite side of the table, and her younger brother also in the room (but out of sight of the camcorder). She is trying to get the ball to rise higher so that she can get it through one of the hoops. She is initially intently focussed on the ball. After a while she glances up and then flicks her head upwards as if to usher the ball upwards. Immediately after this gesture she leans back and then begins to raise both hands from their resting place on the table. With her palms facing downwards she raises both arms together into the air high above her head. Her whole body moves upwards as she performs this gesture. She then gently lowers her arms before repeating a more forceful upward gesture. This gesture is then repeated two more times with a wave like flow to the movements. This is then followed by a couple quicker and jerkier arm lifts, palms raised up in the air like she is willing it to rise. A short while later, the ball falls lower than she wants it to drop. This creates panic and excitement on her part. In her excitement she screams "at the top of her voice. She moves in closer to get it to rise and then shouts *"Nooooo - birds birds birds - birds"*. As she shouts she smiles, and her father laughs.

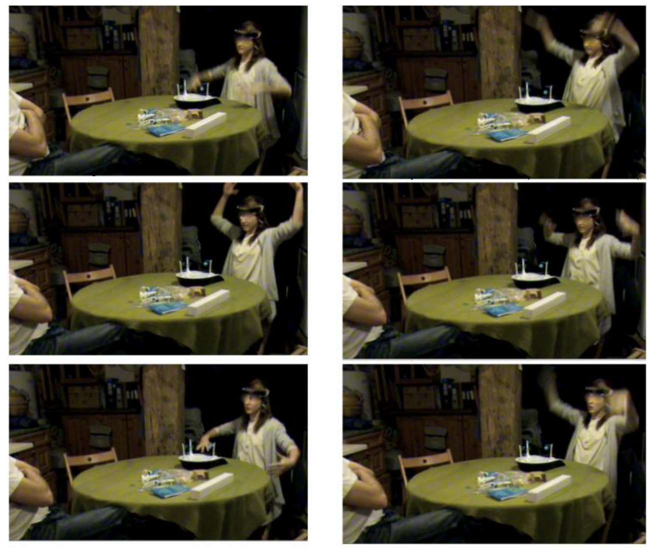

Figure 7. Gesture as performance

Spectatorship verbalisations and play

Much of what we have discussed so far has been how actions and intentions are visibly manifest by players within this social context. These manifestations help make the game understandable for those watching as well as making it more entertaining as a spectator experience. Even the minutiae of facial expressions when trying to concentrate were at times engaging to observers as well as the more deliberately performative aspects undertaken by the players:

> *"Is that your concentration face with your weirdy wizard eyes?" V (Gp 1)*

Spectatorship is not simply about passively watching but is more a two-way relationship between players and observers who are actively participating. This participation can be seen, for example, in active attempts to influence the thought patterns and behaviours of the players, providing a source of encouragement, distraction and humour. Of note too, is the sensitivity to particular familial relationships and a means through which these particular relationships are played out. Consider the following example. The mother from Group 4 is playing the game with a time limit. She is being watched by her son and daughter sitting with her at the table and her partner, sitting on the sofa. The game indicates she has 10 seconds left to go. She is looking up at the ceiling in an attempt to lower the ball. The machine then begins a 5 second countdown at which point she realises she needs to raise the ball again quickly. The son, conscious of the urgency, shouts *"Mum, Hugh Jackman, Hugh Jackman, Hugh Jackman's naked!"* as he points to the other side of the room. They all burst out laughing.

What we see here is the use of the game characteristics to create humour. The family are fondly aware of the mother's penchant for Hugh Jackman and offer it as subject matter to get her to concentrate. While used to encourage her concentration, its primary motivation is the opportunity for an affectionate expression of humour. This example also confirms that this audience understands the generic nature of the BCI in being based on general notions of concentration levels. This general, as opposed to a more specific BCI control mechanism, means it is open to interpretation. It is this that allows it to be appropriated in this personal way for humorous purposes.

In a similar vein, it is the close timing between system response to such verbalisations that becomes a source of humour. In this respect, the system is taken as a reflection of the thought processes and brain activity of the player. This can be seen in the following example, again from Group 4 but this time with the father playing. The father is staring at the ball attempting to concentrate and raise it but having no success. After a few seconds of not raising the ball, the son says *"Dad, remember when City lost 6-0 to Cardiff? Do you remember that?'* The father looks at his son and replies *"Yeah."* The ball is still not moving. The daughter then says *"Explain the whole match. Think about the match and remember it"*. He says *"Nah."* but it is at this moment that the ball rises. The daughter, son and mother burst out laughing. The father is a strong City fan and was not happy about the huge 6-0 defeat by local rivals Cardiff. They are trying to tease him through this suggestion and, while he tries not to think about it, the system response and its timing are used humorously by his family to suggest that he *must* be thinking about it. Again, it is the non-specific notion of concentration levels BCI that enable this appropriation. Ambiguity and interpretability are important here in allowing these behaviours.

Related to these issues were the more general inferences made about cognitive ability and activity in relation to the particular state of the machine. For example, inactivity of the ball for an extended period of time led to expressions of embarrassment on the part of the players. This would also prompt acts of self-deprecation as seen in Group 1:

"Its very worrying man. Look its not moving at all." V – laughs

"I think it's you're not thinking." – M smiles

"At all." - V laughs again

Similar behaviour can be observed in the following episode from Group 3. The father in Group 3 manages to lift the ball up momentarily only for it to fall back down again. This prompts laughter from the watching family members. He smiles, with mild embarrassment and says "*It's stopped*." – then adds laughing "*My brain has stopped*." A little while later he causes the ball to roll off the board. His wife comments: *"You made it fall off – that's very clever"*. After replacing the ball, it falls off again - she laughs and says: *"Yours is obviously not very ordinary thinking, is it darling?"*

With this audience interaction in mind, a pertinent concern is the sensitivity of the BCI to these kinds of external factors and impact on performance. Indeed, robustness under real world conditions is a motivating factor for this kind of study. Play too, evokes its own particular type of audience engagement relative to other domains of usage. That is, in our observations, there were attempts both to encourage *and* distract people using the BCI. This choice of encouragement or distraction is done with particular social meaning and bound up in particular relationships between players and audiences and performed with particular social sensitivity. The point we are trying to make here is that while these interaction mechanisms are delicate and susceptible to distraction within such a social context, this is not something that is inherently problematic as a feature of the mechanism itself. Rather, the ways people orient towards this delicacy become an important part of the game, and a key part of what makes it engaging and fun. So, for example, in Group 2, the older brother and sister would actively tease and distract each other during BCI play (through staring, leaning in, and distracting utterances) because they were closer in age. By contrast, when their younger brother was playing, they were more encouraging and respectful in their utterances and proxemic arrangements. To further illustrate, the children in Group 2 were trying to distract their father while he was playing, making noise and offering amusing suggestions about what to think. The father tolerated this for a while but then said.

"Ok can you both be quiet please… This is supposed to be a game of concentration." S

"No no but we're helping." M responds.

"No no shut up." S says again.

"At the end of the day it helps to think about moving up – I don't know why. Think about stuff that moves up." Sm

"Will you just shut up." S

M tries again to distract S by waving her hands magically over the ball. He pushes her away because it is distracting. After this they watch more quietly.

DISCUSSION

In this paper, we have begun to examine Brain-Computer interaction within the context of a real world setting [17] - namely within the context of social game play in the home. In doing this, we have been able to offer an alternative and complementary perspective on this kind of interaction. Our concerns with this perspective are not only about the efficiency and effectiveness of the BCI as a games controller, but rather lie with how the interaction mechanism affects the social construction of behaviour and meaning-making around the device and how social context affects interaction with the device. In addressing these concerns, we draw on notions of embodied interaction [e.g. 6, 28], which highlight the importance of people's participation and action in the world. This is, in part, about their physical action but also social action and how people to create and communicate meaning with the system and other social actors.

While it may at first seem curious to reinstate notions of bodily action in systems designed to bypass the body, what we hope to have shown in the findings is the importance of such a perspective. What is significant here is that a BCI interface puts the player in the unusual position of treating their own thoughts--their own brain--as a physical effector much like they would their arms or hands. Rather than using physical actions to engage with the elements of the game or interface, the player must use their levels of concentration in this way. This has several implications. First, whereas we have no need to think explicitly about how to move a game piece with our hands on a chessboard, players in this game need to explicitly think about how to use their own thoughts to achieve a desired effect. This means that what is usually taken for granted in game play (how to effect simple moves in a game) becomes instead central to the game. This also has the further complication that thinking about one's thoughts changes the nature of those thoughts, and, as a result, changes the way in which thoughts effect action. As we have seen, this recursive relationship is then used as a source of humour and a resource for interference in the game by others. Further, any lack of visible embodiment is often compensated for by the player, providing additional cues to their audience to account for and explain their actions. All of these findings point to the importance of embodiment both for players to work out how to use their minds *as body*, and for bodily action to be used as a resource for social engagement.

These findings point also to ways in which we might extend the design space for these kinds of games. For example, we have seen ways in which players used bodily action (postures, gestures, orientation and stillness) as a set of strategies to control brain state and interaction with the system. This suggests that players might be encouraged to explore various physical strategies to impact their interaction in the game. More interestingly, there might be ways in which BCI might be used in combination in interesting and novel ways with new physical interaction paradigms such as the whole-body interaction. An important consideration here is to understand when the physical demands of other interaction modalities might *facilitate* BCI versus when they *interfere*. Facilitation may be a focus for efficient interaction, whereas interference might be a focus for game-like challenging interaction.

We have seen too the importance of bodily action arising from the lack of visibility, with this technology, of interaction *manipulations* [27] (namely brain state) and the loose coupling between intentionality and interaction *effects* [27] (namely the ball rising). While this can lead to difficulties in interpretation by other social actors present, efforts are made through physical gestures and verbalisations to make these intentions visible to and interpretable by others. This has implications for thinking about how such technologies can be enjoyed in social contexts as an understandable spectacle. But there are pointers here too for thinking about how these interaction mechanisms might work within more explicit collaborative contexts where coordination and collaboration are the desired design goals. Further, within competitive contexts, this particular relationship between invisible interaction *manipulations* and visible *effects* could be exploited in design to interesting effect by enabling things such as surprise and deception for example.

The BCI game too had further consequences in the context of social game play. For example, bodily actions were used to performative effect to make the game more visibly interesting to watch. These kinds of actions in relation to the game can play an important role in the success of these games in a social context and therefore in their successful adoption. What was also revealed was the delicacy of these interaction mechanisms in terms of how the audience evaluated them, sometimes leading to deliberate attempts at distraction. While this points to some pragmatic concerns for BCI as a control mechanism, what is important in the context of game play is that such interventions are socially mediated and are an important channel through which particular social relationships are played out – both through affectionate teasing or moral support. The playing out of social relationships between player and audience was enabled too through because of the generalised control mechanism of concentration/relaxation. This lends a sense of ambiguity to the game that makes player and system performance open to interpretation [9]. This possibility for interpretation is an important resource that can be used by player and audience alike to create social meaning and to playfully nurture social relationships. These important sources of engagement may not be so possible with more explicit BCI commands that are less open to interpretation.

CONCLUSION

In conducting our real world study of BCI gaming in a social context, we have explored a complementary set of issues to those being addressed in existing BCI research. In particular, when we consider BCI in such social contexts, we hope to have shown the importance of reinstating the social organisation of bodily and mindful behaviour in our understanding and analysis of these technologies. Given the potential for bodily movement to both facilitate and inhibit BCI control [21, 24], understanding the circumstances of this action has consequences for thinking about the application of BCI design in these contexts. As Nijholt et al [24] argue, shortcomings and idiosyncratic characteristics of BCI can be incorporated into game challenges by design. But our concerns are not simply with the direct impacts on BCI control. Rather, we have also highlighted the work done to make internal brain states and any intentionality visible and interpretable by others present, through actions, gestures, expressions and utterances. This is important for how social meaning is created and how social relationships are played out for both players and audiences.

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