Interacting in 3D Virtual Worlds with Brain Computer Interfaces

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ABSTRACT

Interaction with 3D virtual worlds found in first-person action games is mainly based on keyboard input or pointing devices. Console games add new input devices like motion capturing or voice control. Though immersion is a key issue, most games do not rely on player's emotions. To take this important communication factor into account, we propose a method capturing the player’s emotions of anxiety and shock in a game and use this data to control player's and non-player-character's actions. We present a game setup that is specifically designed to evaluate the use of emotional interaction based on a small user study. A simple EEG based Brain Computer Interface (BCI) is used to translate amplitudes of alpha (stress) and beta (shock) rhythms to corresponding commands in the game engine. The game is set in a horror scenario in which the player needs to control his emotions as they may adversely influence the difficulty of the gaming tasks. The game concept implements an immersive atmosphere to bind the player emotionally and evoke signals captured by the BCI. The game engine passes these emotional inputs to actions of game entities (visuals and opponent’s reactions). Finally, the impact of emotional interaction is evaluated by a small group of test players projecting the needs for future approaches and enhancements.

Keywords

Brain Computer Interfaces, BCI, EEG, game design, emotions, immersion, multimodality, evaluation

1. INTRODUCTION

With the release of Nintendos Wii and its gesture recognition technique to control movements, a lot of new input modalities have been developed. No one would doubt that these new modalities took a major role in the success of these systems. Most of these modalities, however, focus on gesture or voice recognition. Very little attention is put to using the player’s emotion as additional gameplay element.

A well designed, immersive, game can evoke emotions for the user. This communication between the game and the player, however, is limited to one direction since the game does not have the means to capture emotional reactions to the situations it creates.

Bidirectional communication, however, would enhance not only the gaming experience, but also alleviate human-computer-interaction. In human-to-human interaction the emotional level plays a very important role to decipher the meaning of the information conveyed. An emotional input modality would close this gap in human-computer communication. For interactive games this would possibly result in a higher immersion, since the communication with the game would feel more natural and the additional modality would draw the players focus even more to the virtual world.

To approach the issue of emotional feedback, we have created an immersive computer game, located in the horror genre, based on an EEG based Brain-Computer-Interface (BCI) to capture the emotions of shock and anxiety/stress and translate them to actions and events in the game.

Usually the emotions have a negative effect for the player, hindering his process, so he needs to monitor his emotions constantly and thereby is focused on his emotional reactions to the events in the game.

Since a game can only evoke emotions if the player is immersed in it, we analyzed and implemented several factors creating immersion and supporting the emotional binding of the player in the game.

Contributions

Our brain-computer-based game development and its evaluation is directed at the following goals

- we propose multiple interaction patterns where the user's emotions directly influence his perception and the action of his opponents
- a game concept using these patterns and their key implementation issues are provided
- based on a small user study, we assess the possibilities and limitations of brain-computer interaction in games

Though our work is highly experimental and our user study is far from being representative, we are able to provide a proof of concept showing the full benefit of emotional sensing, anticipating its future advances in game development.

Overview

The remainder of our work contains an overview of EEG-based Human-Computer Interaction (HCI) in section 2. Section 3 introduces our game design and shows how the emotional user input can be processed to enhance immersion. Sections 4 and 5 contain implementation issues and the results we obtain from our experimental user study, respectively.

2. BACKGROUND

Human-Computer Interaction

A Brain-Computer-Interface is a communication system that allows the user to communicate to a machine or the surroundings, without relying on signals from peripheral nerves or muscles [Nic12a].

Since the beginnings of BCI development in the 1970s for military purposes, the focus of research increasingly concentrated on medical and, more recently, on entertainment uses.

Today, there is a rising interest in BCI research, mainly due to more powerful and affordable hardware, but also because of a rising public interest and acceptance of BCI use to aid disabled people and successful studies in this field. The number of active research groups on BCI related topics went up from six to eight 10 years ago to currently over a hundred [Nic12a].

Many gamers are early adopters and open to new technologies. They are also used to invest time to learn and master a game. Competition is also a big part of gaming and new communication or movement modalities could be a benefit. That makes games interesting for BCI research and even researchers for medical applications have looked at games to find training solutions for patients. [Nij09a]

Brain-Computer-Interfaces are usually divided in two classes: Dependent and independent [Wol02a]. While an independent BCI completely ignores common output pathways of the brain and offers new communication channels to the user, a dependent BCI still relies on them to some extent (e.g. a BCI may depend on electrical potential differences generated by visual evoked potentials).

Electroencephalography (EEG)

Most modern Brain-Computer-Interfaces depend on EEG for signal acquisition. EEG based BCIs offer a relatively easy to set up and risk free way of recording brain activity.

Signals are acquired by placing electrodes on the users scalp that measure electrical activity generated by ionic currents flowing within and across neurons, see figure 1. Although the latency is quite small the signal quality is often poor and the system is easily distorted by background noises either in the brain itself or from external sources [Nic12a].

Due to the difficulties with EEG-based BCIs, users need to invest time to learn how to make the desired inputs. However, during a study executed in 2004 at the Fraunhofer Institute they managed to minimize the training time through the use of neural networks. Parts of the learning process were now transferred to the computer and successful results were possible in about 30 minutes of training. [Car06a].

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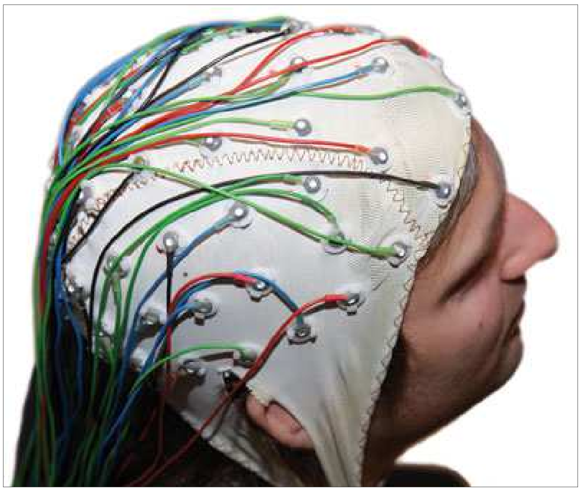

Figure 1: EEG-based sensing, http://www.emg.tu-bs.de/bilder/forschung/eegekg/eeg_w.jpg

Nonetheless, certain signal patterns recorded by EEG seem to be connected to specific mental activities. Basically the acquired signals can be divided in two classes, evoked or event related potentials and EEG rhythms. Evoked potentials are potential differences recorded on a limited area of the brain. They reflect physical (evoked potentials) or mental (event related potentials) stimuli.

If the mental activity of a BCI user is recorded on a large scale with EEG, certain rhythmic patterns emerge that can be classified into different EEG rhythms. These rhythms can be linked to certain brain functions, since they desynchronize with specific mental tasks or activities carried out. This behavior is called event-related desynchronization (ERD) and can help to interpret signals recorded in the EEG [Pfu99a].

Name	Frequency	Description
Alpha (α)	8-13 Hz	Mental or visual effort
Beta (β)	13-30 Hz	Motor activity

Table 1: Frequency range of alpha and beta signals.

For the emotion aware game that has been developed, two of these rhythms, listed in table 1, were particularly interesting. One of them is the alpha rhythm. The alpha rhythm is continuously developing over the first ten years of a human. At the age of ten the mean alpha frequency of adulthood is reached. It attenuates or suppresses at a degree of higher alertness [Nie99a] and can be linked to mental or visual effort and is used in the game to keep track of the players stress level. When the player is at a calm, relaxed state the alpha rhythm does not desychronize, while at a stressful situation this changes with increasing mental activity or rapid eye movement.

The second rhythm used is the beta rhythm which can be linked to motor activity or tactile stimulation of the BCI user, even if it is just mentally imagined motor activity [Nie99a]. This is used to catch the shock emotion of the player. If the player is shocked he will most probably shudder or wince thereby using his muscles which then serves as an indicator for the system to trigger related actions in the game.

EEG-based BCI devices have been used for games before. Besides the NIA Game Controller, described in Section 4, there are devices like the “Mindset” (NeuroSky Inc. 2009) and the “Epoc” (Emotiv Inc. 2009) that control a variety of applications. “NeuroBoy” for example is a game in which the player has to focus or relax to achieve certain goals while in “Stonehenge” motor movements are used to reassemble fallen pieces of the Stonehenge [Tan10a].

Engagement	**Engrossment**	**Total Immersion**
- Become focused - Lose track of time	- Emotions are directly affected - Wants to keep playing - Game becomes most important part of attention - Less aware of surrounding / less self aware	- Cut off from reality / Game is all that matters - Feels attached to a main character or team
Access: Player's preferences, game controls **Investment:** Time, effort, attention	**Game construction:** Combination of Game features	**Empathy:** Growth of attachment **Atmosphere:** Development of game construction

Effect on player	**Barriers**

Table2: Levels of Immersion [Bro04a]

Immersion in Computer Games

For a game processing shock emotions, it is important to create a virtual world in which the players can immerse. When players are immersed, their emotions are directly affected by the game [Bro04a] and emotional reactions happen more frequently. Brown and Cairns divided Immersion into three levels and described which barriers must be lowered to get to them, see table 2.

One part of the game construction is storytelling. Mateas [Mat00a] integrated the concept of agency in Aristotle's theory of drama. Agency is a feeling of control and empowerment that players can get when their actions in the game world relate to their intentions. The players will experience agency when the material for action is balanced with the affordances of the game world. For example, if the game suggests that the player can pick up an object but it's not possible to do so, the sense of player agency will decrease.

Roth et al. [Rot09a]. described experiential dimensions that can motivate players:

- Curiosity (“What will happen next?”),
- suspense (“Will they survive?”),
- aesthetic pleasantness (“Beautiful!”),
- self-enhancement (“We are great!”) and
- optimal task engagement (“Don’t disturb me!”)

3. GAMING CONCEPT

Goal

The goal of our work is to create a game implementing a Brain Computer Interface as an additional modality to identify and process emotions of the players. The game is set in the horror genre because it is suitable for creating mental stress and shock moments which can then be captured by EEG. To create such situations, methods facilitating immersion had to be adopted.

Preparation

Before implementing the game the required components had to be analyzed and evaluated. This includes a Brain-Computer Interface that is capable of analyzing the relevant parameters and carrying out corresponding configurable actions.

On the other hand, a game engine is needed that is able to interpret the actions coming from the BCI. Also, this engine needs to be technically able to create an immersive feature-rich atmosphere.

For fulfilling these requirements we decided to use the NIA Brain Computer Interface by OCZ Technologies and the Unreal Development Kit for the Unreal Engine 3 by Epic Games Inc.

To test the functionality of the BCI with sensing emotions in horror games some tests were carried out with a test subject playing a horror game (Amnesia: The Dark Descent by Frictional Games). The test included three different camera views: The game itself, the parameters of the NIA BCI and the face of the subject.

By doing this, a correlation between the muscular face movements and the beta rhythms of the EEG could be observed. Also the anxiety seemed to strongly correlate to the stress the subject was experiencing.

To evaluate the possibility to connect the NIA output to the game engine the NIA user interface was found to be able to output key presses as actions when certain amplitude thresholds were met. So the UDK only had to take these inputs and translate them to corresponding actions.

Game Concept

To create an atmosphere evoking mental stress and exposing the user to shock moments, the game takes place in a dark forest inhabited by strange creatures, plants and objects. The players have to walk across this forest after they crash with a hang glider in the mountains. The players have no weapons thereby the only option during most of the enemy confrontations is to flee. The BCI captures mental stress and shock reactions of the players. The game gets more difficult when they are stressed or shocked. For example, enemy tendrils in the forest grow and spikes shoot through the ground when the players can't keep calm.

Creating Immersion

To create an immersive game world the barriers had to be lowered so the players can get to the level of total immersion.

To lower the access barrier the game's controls are similar to the controls of a first-person shooter. This assures that everyone who played an first-person shooter before is familiar with the control scheme.

To lower the investment barrier the players have to invest time effort and attention. To give them a motivation to do so the game starts with an introduction in which they learn something about the initial situation of the story. This is to make the players curious and motivate them to find out what's going on.

The most complex barrier that has to be lowered is the game construction because it consists of many game features like visuals, sound, plot and challenges.

The research showed that most of the games players felt immersed in were played in first-person perspective. This also reduces the risk that a player cannot identify with a predetermined character.

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Figure 2: Gate is blocked by tendrils

Figure 3: Dark atmosphere

The game's story is told by the game world and its creatures and objects. To keep players motivated the creatures and objects are introduced one after another following an arc of suspense that lead to a climax which is a boss battle. Constructions and altars suggest the presence of an ancient, friendly civilization and the tendrils and enemies stand for an evil infestation of the forest, as illustrated in figures 2 and 3.

To create the feeling of agency the game tries to avoid situations in which the player's actions have no meaning for the plot. The number of possibilities for interaction is always at a manageable level and every object for interaction must be used to proceed with the game. For example, there is a situation in which a gate is blocked by tendrils. Beneath the gate is an altar with small, gray mushrooms on it. Nearby this gate players can find a blue mushroom which is the only object to interact with. When the mushroom is put on the altar, a cutscene shows how the mushroom is growing and the tendrils are moving back and unblock the gate. This scene teaches the players that the mushrooms and altars are helpful while the tendrils hinder them to move forward. We hereby also address the experiential dimensions described by Roth et al:

- Curiosity: “What are these tendrils?”
- Aesthetic Pleasantness: “The way the mushroom grows and the tendrils move back looks very nice.”
- Self-Enhancement: “My idea with the mushroom worked right away. I am clever!”

Music and sound effects have a big impact on the atmosphere of a game. To create music that fits a mysterious and eerie forest, the soundtrack uses minor chords and deep bassy sounds.

Furthermore, the speed of the track has to collaborate with the situation in the game. Therefore the game has slow ambient music with emphasis on bass when the players explore the forest and hectic music with a fast drum beat when they get chased by enemies.

Atmospheric sounds describe the surroundings and actions of the players. For example, in the forest they can hear the rustle of the wind in the trees, animal calls and the sounds of their own footsteps. Some sounds are related to certain objects like altars and enemies. There are also special hint sounds playing when events occur in the presence of the player.

Obviously, the visuals have a great influence on the game. To create an atmosphere that supports mental stress and allows shock moments the forest consists of closely spaced trees from which the players often can't see more than the silhouettes. Because of a dark twilight and dense fog the surroundings are uncovered little by little and the paths are bordered by tendrils that are moving slowly. This is to give the players the feeling that something lurks around in the forest that can savage them at any time.

Sometimes the dark atmosphere is intercepted by peaceful places which are brighter and more colorful to avoid that the players get used to the dark and thereby lose their anxiety. This is also a way to arouse their curiosity. Furthermore the changes of mood are important to make the effect of the BCI appreciable.

To lower the barrier atmosphere, the objects in the game (see figure 4) need to be relevant for the player. To ensure this, all the objects have a meaning. Plants with red berries help to navigate through the forest, blue mushrooms work as a source of energy, and altars give hints. Tendrils (figure 5) block the way to places were the players are not supposed to go or hurt them. The different tendrils have a similar appearance and at the end the boss can be identified as their origin.

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Figure 4: Objects in Mori: Altar, Plant with red berries, mushroom

Figure 5: Different tendrils

Enhancement of the game experience due to player's emotions

To enhance the player experience through the use of his emotions meaningful, the game implements multiple components that react to them. The plants in the game are introduced early to the player as emotionally sensitive. They hinder his process the more he shows fear and shock. Is the player close to a tendril it begins to glow red, grow and becomes more aggressive thus making it harder for the player to pass. Also thorns can appear almost everywhere in the game world, which hurt the player on contact.

Of course, the player is dragged deliberately in stressful and terrifying situations, especially when near an area of tendrils. There is, for example, a situation where he is being followed by enemies, who want to attack the player. He then has to run through a passage covered in tendrils to escape these enemies.

Also, the final enemy, who is presented as the root of all tendrils, is aware to the shocked state of the player and starts his attacks when he senses this emotion. To shock the player, there are thorns constantly emerging from the ground if he is near them.

The second analyzed emotion is the stress level of the player. A higher stress level results in a manipulated view for the player. The field of view broadens and a material is overlayed resulting in a tunnel view that makes it more difficult more the player to navigate through the world. When he stays calm for some moments, the view returns to normal so he has to try to stay calm especially in stressful situations to be able to pass through them more easily.

After the player gets used to the emotional interaction, she actively has to control this interaction method in both directions: there is also a situation where the player has to deliberately fake his emotions to proceed. It consists of a trap where a tendril attacks an area on top of a bride as soon as it senses shock. The player needs to cross that bridge two times. While the first time he has to stay calm to prevent himself from being hurt, the second time there is an enemy on the bridge, blocking the path. To get rid of this enemy, the player needs to fake his shock emotion so that the enemy gets attacked by the tendril.

This experience makes it possible for the player to get an insight of the way the Brain-Computer-Interface works so that he is able to estimate the reactions of game objects to his emotions. By this he is able, for example, to fake his emotions in the fight against the final enemy, timing the attacks of the enemy so that he can get pass it safely.

4. IMPLEMENTATION

NIA Game Controller

The NIA (Neural Impulse Actuator, figure 6) is an EEG-based BCI capable to capture alpha and beta rhythms. It comes with an easy-to-use user interface for configuring input triggering behavior when certain thresholds in the amplitudes are reached.

Figure 6: The NIA BCI

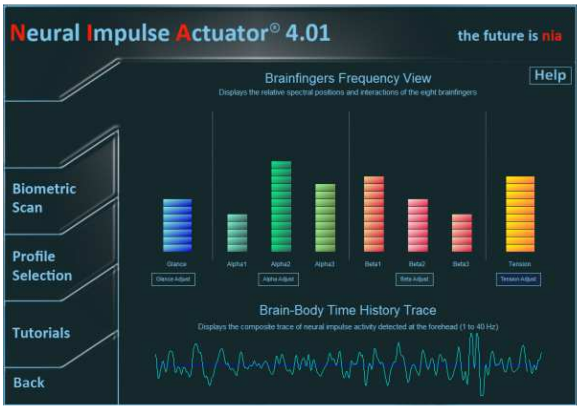

Figure 7: Brainfingers, the software to visualize the BCI parameters

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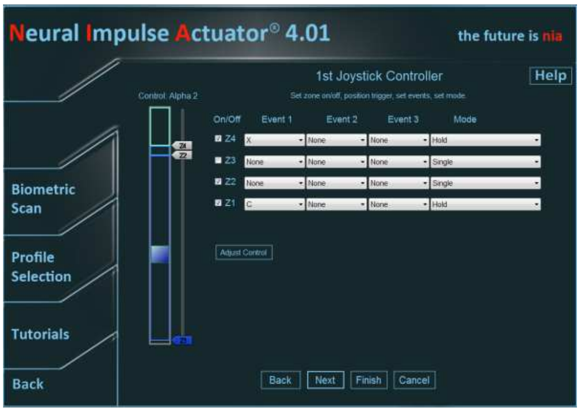

Figure 8: Configuration of parameter thresholds

When the amplitude reaches a defined threshold defined in the NIA software interface (figures 7 and 8), external input controls are addressed, e.g. holding down or pushing a button on the keyboard. This can be used to forward EEG input to other applications, like the game created.

Using the NIA Game Controller to capture the shock and stress/anxiety emotion

To capture the shock or stress emotion, certain thresholds for the corresponding EEG rhythms must be defined in the NIA interface.

When the player is in a completely relaxed state, alpha and beta amplitudes are quite low and should not trigger any actions.

As the stress emotion can be linked to the alpha rhythm, as described formerly, there are two triggers defined: One covering the upper section of the effective range and one at the very lowest. So the alpha amplitude strength rises if the mental state of the player is active and/or a lot of visual processing is taking place (for example by rapid eye movement). When the alpha amplitude reaches high levels, a trigger is activated that presses (and holds down) a predefined key later used in the game to notify the game engine that the stress level is rising.

The same is done with the stress lowering trigger and the shock emotion for the beta rhythm (except this only triggers a single key, since the shock emotion is a one-at-a-time event).

The game engine on the other hand takes this key input and translates it to certain actions that manipulate game objects or the user view. A tendril, or thorns, that suddenly appear may shock the player, so he will shudder or wince, which will consequently make the beta amplitude rise and activate the corresponding actions. Alpha and beta signals for different states are depicted in figure 9.

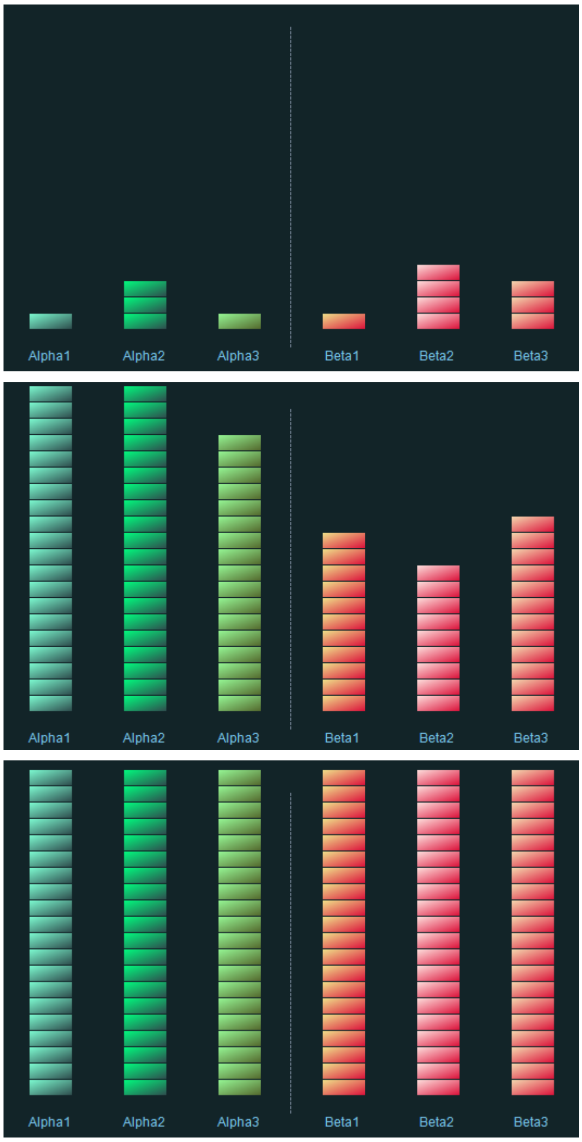

Figure 9 Player Alpha/Beta amplitudes in relaxed state(top), in anxious state (middle) , and in shocked state (bottom)

The stress emotion alters a material overlay for the players HUD (Heads Up Display), which results in a tunnel view and a blurred sight according to the level of stress the player currently experiences, as illustrated in figure 10.

The shock emotion triggers various effects in the game. One of them are the tendrils that become more aggressive, glow red and grow in size, thus hindering the players passage through them. The final opponent's attacks are also linked to this emotion, since they are only carried out when the player is shocked. There also exists a trap in the game, which the player has to trigger deliberately to get rid of an enemy standing on top of the trap.

Figure 10: Visual effect for anxiety parameter

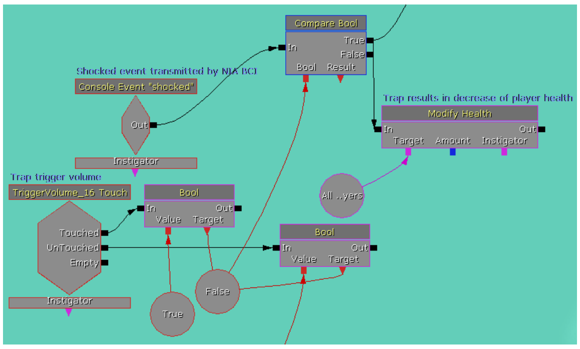

Figure 11: Kismet, UDK's graphical script editor

Unreal Development Kit (UDK)

The Unreal Development Kit (UDK) is a C++ based game development suite for Epic Games' Unreal Engine 3. Since the release of the first Unreal game it has continually been enhanced to meet the current technical state of the art. It offers the developer several tools and editor for almost every aspect of a game (see figure 11) while also implementing its own programming language named UnrealScript. The full version of the UDK is free to use for non commercial projects.

With the scripting framework and the graphical script editor Kismet it was possible for us to create own entities in the game that react to the inputs given from the NIA BCI.

5. RESULTS

Evaluation of the game

To evaluate our concepts and their implementations in the game we created a test scenario and let eight participants play through the entire game. We observed them while they were playing and asked them questions after they finished the game.

To support the immersion the participants had to play in a dark room with a 27 inch monitor in front of them. To have an adequate presentation of bass and other sounds we used a sound system with a sub woofer. The sensors of the NIA headband on the foreheads of the participants had direct contact with the skin. In front of them they had a keyboard and a mouse. To ground the NIA, they had to lay their arm on the NIA device. Before the game was started we adjusted the amplitudes of the brainfingers in the NIA Software to a balanced level so they were on a low level when the participants were relaxed and reached maximum values when the participants did strong movements or were shocked. To test this we scared them all of a sudden from behind.

All the participants stated that they like to play computer games and that they are familiar with games played in first-person perspective. Five participants had heard of BCIs before and two of them had tried them but none of them believed that it's possible to make controlled inputs via BCI.

All of the participants got scared during the game through audio visual effects (only this combination works significantly). This happened in a situations were a skull appears (figure 12) with a loud sound and when spikes come out of the ground and where a tree that works as a bridge over a canyon falls down. All of these situations are happening all of a sudden and address more than one stimulus modality of the player.

Figure 12: Shock sequence

All of the participants got immersed in the game. That was observable during shock moments and exclamations like “Ouch!” when they were attacked, “This is beautiful.” during exploration, “I think I need a counterbalance here.” while solving a puzzle and “Ha!” after an enemy was defeated. The participants stated that they were immersed the most when they were challenged to get through tendrils, to solve puzzles, to get used to a new situation and when the world reacted to their actions.

There also were situations which decreased the immersion. That is when something in the game world seems implausible. For example, the strange appearance of the enemy creatures and the partial exaggerated tunnel vision effect that reminded one participant more of icicles than a visual

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representation of mental stress. Other situations were when the participants didn't know what to do next, when they had to think about a puzzle for too long and when they died.

The participants described the atmosphere as dark, eerie, mystic, mysterious, disturbing, thrilling, surreal and dense. As reasons for that they identified the dark presentation, field of view and blur effects, music and sound. They also mentioned the interplay between places and moods and the tendrils that reacted to the BCI.

The participants liked the fact that there are no weapons in the game and that artifacts like altars and gates stir their imagination. Their motivation to play through the game was their curiosity and the will to find a way back to civilization. Although the game never explains what it is all about, most of the participants drew the conclusion that they were knocked out after the crash with the hang glider and that it was all a dream.

Asked about the effects of the BCI, the participants answers were skeptical. Five participants stated that it worked partial while three participants couldn't tell that the BCI had any effect on the game. Maybe the reasons for that are that the NIA Game Controller doesn't work precisely and we weren't able to calibrate it exactly to fit with every participant. The NIA can't recognize which emotion or action caused a change of alpha or beta rhythms so the game reacts not only to mental stress or a shock moment but also to laughter, a cough and other things. Furthermore the players aren't able to associate every action that the BCI triggers with a brain activity that they are unconscious of. For example, one participant thought that the tunnel vision is a scripted event that always triggers with a shock sequence although it wouldn't be triggered at all without the BCI.

Concluding Remarks

Despite of the technical limitations of low-cost input devices, we were able to provide a proof of concept for emotion-based human computer interaction patterns and their use in a tailored game environment.

Emotional inputs may be evoked on demand, but it is by far more difficult to suppress them. Since the users in our experiments were aware of their emotional tracking, most of them recognized the impacts of their emotional input on the game progress, particularly regarding the opponents' actions. It should be noted that not being aware of these impacts does not necessarily indicate that these do not exist, as in real life also many cues are missed.

All in all, we conclude that emotional sensing has great potential for future game design, since it provides the players' challenge of using and reflecting about their emotions in a systematic way.

Outlook

Since the appearance of cheap BCIs for the mass market, scientific studies and development costs for new applications and approaches for brain controlled systems have greatly dropped. This results in a raising interest of the industry, especially the game industry, since here new innovations are adapted very early to stand out from the huge count of competitors on this market.

Our evaluation concluded that all participants viewed the BCI as an improvement to the game experience and immersion of the players. This hints that further development should be considered, especially by enhancing the methods to correctly decipher player emotions.

One approach of enhancing these methods are the use of machine learning and neural systems. Murugappan et al. already conducted a promising study on these methods [Mur10a] that would make the process of correctly interpret user emotions much more precise.

Since the precision of control with a Brain-Computer-Interface as the only method is still very low, the use of a BCI as the only input modality would probably not cope (at least in the near future) with the complex control mechanisms of a modern computer game. Future BCI controlled games would probably implement a BCI as an additional modality.

Apart from the use as a game input method, emotion aware applications for Brain-Computer-Interfaces could theoretically fill one of the most important gaps in human-computer communication: The emotional level of communication. Emotions are a natural factor in human-to-human communication and make up a big part of the information transferred to the other. In communication between humans through a computer this problem is usually countered with the use of emoticoncs or smileys to give the other a help on how to interpret a message. A working emotion aware system could possibly solve this issue better and more precise. In a pure human to computer interaction the computer would have the means to understand the users intentions better and act accordingly.

6. ACKNOWLEDGMENTS

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