A Study on New Gameplay Based on Brain-Computer Interface

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ABSTRACT
Brain-Computer Interface (BCI) is a way to control computers by using human brain waves. As the technology has improved, BCI devices have become smaller and cheaper, making it possible for more individuals to buy them. This allows BCI to be applied to new fields outside of pure research, including entertainment. We examine whether BCI devices can be used as a new gaming device, approaching it from a game design perspective. We propose game play elements that can effectively utilize BCI devices and present a game prototype that demonstrates several of these game play elements. Next, we use statistical data analysis to show that using a BCI device as well as keyboard and mouse interfaces makes the game's control clearer and more efficient than using the traditional input devices. The results offer guidelines for effective game design methodology for making BCI based games.

Author Keywords
BCI, Game Design, Intuitive, Gameplay

INTRODUCTION
A Brain-Computer Interface (BCI) is any hardware which enables humans to interact with a computer using their brainwaves. Currently, BCI is utilized for the healthcare and education based on neuro-feedback technology. Neuro-feedback is a kind of bio-feedbacks using brainwaves. Usually, bio-feedback is a medical treatment controlling the reactions in the autonomic nervous system with blood pressure, body temperature and pulse frequency. Specifically, neuro-feedback is used for testing and improving brain capacity or brain characteristic [3, 5].

Figure 1: "NeuroComp System(manufactured by Neurocybernatics Inc.)

Because early BCI devices were quite large and expensive, they were used primarily by medical institutions doing research on brain-related subjects like analysis of brainwaves for helping medical treatment. Figure 1 shows a medical treatment brainwave system manufactured by Neurocybernatics Inc. [9]. Now that BCI devices are becoming smaller and less expensive, it's possible to create programs for individual users and to target broader experiences such as gaming and multimedia.

A great deal of research has been conducted on methodologies for utilizing BCI. Researcher Matthew Middendorf has introduced the hands-free control system with electroencephalography (EEG) which is performed by The Air Force Research Laboratory. He has also shown that users can, with practice, learn to control their brainwave signals [8]. In his experiment, he EEG is acquired using gold-cup electrodes located over occipital sites O1 and O2 (left mastoid as ground). The differential signal between O1 and O2 is amplified, filtered, and then processed by a lock-in amplifier system (LAS) that provides a measure of the SSVER amplitude. The roll position of a simple flight simulator was controlled with variances of SSVE amplitudes over time.

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Jaime A. Pineda, etc has also shown that users can, with practice, learn to control their brainwave signals [12]. In his experiment the game character's movement was based on two particular brainwaves, one from the left side of the user's brain and one from the right side of brain. If the two signals were approximately equal the character would move to the left and if the levels were different, the character moved to the right. The experiment carried out twice a week for 5 weeks, twice a week for 45 minutes. Over the course of the experiment users became increasingly skilled at controlling their character.

Figure 2: A screen of Mind Balance. There are two checker boards of differentf frequencies on the bottom.

Based on these results several researchers, including E. Lalor, decided to look at whether it would be possible to use BCI based on Steady-state Visual Evoked Potential (SSVEP) in a game framework in real time [6]. SSVEP is a group of signals created by the brain in response to a certain frequency of visual stimulus. Different frequencies for each visual stimulus will generate different SSVEPs. In the first step of the experiment, the researchers showed users a checkerboard with squares that alternated between white and black at stated intervals. Researchers measured the resulting signals generated according to the intervals. After that, the user was asked to play a game designed for the experiment. The game contained checkerboards that changed at the same intervals as the checkerboard on the first step as seen on the Figure 2. Based on SSVEP, it was possible to determine which checkerboard the user was looking at simply by analyzing their brainwave signals. The game character would then tilt the selected checkerboard in real time. The experiment showed that BCI technologies based on SSVEP could be used to measure user responses in real-time and control a game environment.

Bredan Z. Allison, etc evaluates the hypothesis that overlapping stimuli can evoke changes in SSVEP activity sufficient to control a BCI [1]. According to their results, there was no significant correlation between EEG measures and gender, age, substance use. Also, they explored that subjects who have a background playing video games or performing similar activities might be better suited to certain types of BCIs and subjects could be trained to perform better on tasks of visual attention. They also conclude that training with other tasks requiring selective attention, such as playing certain types of computer games, may also improve performance with SSVEP.

Although a great deal of research has currently been conducted on methodologies for utilizing BCI, most of these are focused on methods for applying BCI to applications or low-level technology. Research on BCI from a game design perspective to suggest optimal game play for BCI devices is still quite rare.

In the paper, we examine whether BCI devices can be used as a new gaming device, approaching it from a game design perspective. We first propose game play elements that can effectively utilize BCI devices and then present a game prototype that demonstrates several of such game play elements. Finally, we use statistical data analysis to show that using a BCI device as well as keyboard and mouse interfaces makes the game's control clearer and more efficient than using the traditional input devices. The results offer guidelines for effective game design methodology for making BCI based games.

GAME PLAY ELEMENTS UTILIZING BCI

In order to illustrate game play elements that take advantage of BCI, we'll need to first look at effective traditional game play elements and define what kind of information can be transferred from the user to the computer via BCI.

Definition of brainwave information transferred by BCI

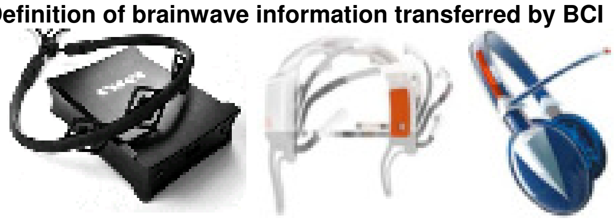

Figure 3: (To the left) NIA, Emotive EPOC, Mind Set

Comparing their prices and sizes, three portable BCI devices are currently available or will be available soon for applying gaming industry, NIA, Emotive EPOC, and Mind Set. Figure 3 shows the images of the three portable BCD devices.

These three emotions were chosen because they're detectable by most of the small-sized, inexpensive BCI devices that are currently available or will be available soon. The information perceived by typical BCI devices is summarized in Table 1 [4, 10, 11]. Two emotions, attention (or immersion) and meditation (relaxation) are common human emotions and EPOC and Mind Set can also response both of these emotions. In the paper, we will consider how these two emotions, attention and meditation are applied for designing a game in the following sections.

Table 1: Data perceived by three portable BCI devices

BCI Device	Data Perceived by Device
NIA	-Expressions : wink, frown, laughing
EPOC	-Emotions : immersion, relaxation, tense, boredom, excitement, frustration -Expressions : Blink, Wink, Look, Eyebrow, Furrow, Smile, Clench, Smirk
Mind Set	-Emotions : attention, meditation, anxiety, drowse

Analysis of traditional game play elements

To utilize BCI devices as new input devices, it is necessary to explore game play elements in existing games. Though games employing new input devices often contain new game play that replace traditional game play elements, new game play elements are frequently based on older ones. For example, the ‘Nintendo Wii’ which adopted a remote controller mounted with a gyro sensor replaced traditional button inputs with swinging the controller. Also, it enabled various body motions to be applied to game play. This was a new experience for users who hasn’t experienced that kind of game plays before. However, it is based on a traditional game play element that moves game characters according to the information transferred via an input device.

One of the most frequently encountered definitions of what constitutes a game is game designer Sid Meir’s “a series of interesting choices.”[14] This shows that input devices play a central role in game play because they’re the only means players have for selected choices. These choices could include, for example, changing a variable in the game or influencing the game’s environment in ways that are advantageous for the player.

Games in the racing genre provide a clear example of variables that are changed by player choices. The speed of the player’s car changes directly according to the player’s choice. On the other hand, in adventure games players are asked to solve a quiz or a puzzle using hints that are hidden in the environment. To make the game play more exciting or create new game play methods, designers deliberately tweak the game’s environment to make it more challenging for players to find the hints.

Suggestion of game play elements adopting BCI

In this chapter, game play elements adopting BCI as a means for player’s to express choices will be dealt with based on the examples of game play elements discussed in the previous chapter.

Firstly, for the game play where some variables change, the degree to which the player concentrates on the game among all brainwave information can be used as a tool for player’s choice. For example, in a racing game concentration could influence the speed of the player’s car, so the speed would go up as the player concentrated more on the game. In fact, this has already been adopted by a gaming toolset called ‘Smart Brain Games,’ seen in Figure 4. The toolset is quite basic. It simply replaces a few buttons on a traditional game controller when the player plays existing games [16].

Figure 4: Toolset of Smart Brain System

For first-person shooter (FPS) games like ‘Sniper Elite’ [17] serious or ‘Call of Duty’ [2] series, the degree of concentration affects the aiming or accuracy of the player’s weapon. For example, as seen in Figure 5 if the player has to use a sniper rifle, the crosshairs might be made to jitter less as player concentration was increased, improving the rifle’s accuracy.

Figure 5: Game play image of 'Sniper Elite' [17]

In Role Playing Games (RPGs) and action games, some particular emotions like concentration or meditation could be used to influence the success rate of the game character’s skill or the recovery speed of a player who had been cursed.

Secondly, for games that focus on changes to the game’s environment, like adventure games, brainwaves could be used as a method for selecting a choice, creating interesting new game play. For example, in a crime scene hidden clues might appear when a player’s concentration level gets high enough. Alternately, if the player was relaxed or meditated enough, he or she could receive an important hint for solving a puzzle or escaping from a dangerous situation.

For espionage adventure games like ‘Metal Gear Solid’ [7] series and for survival horror games like ‘Silent Hill’ [15] series or 'Resident Evil' [13] series, the player's tension level would be a natural means of affecting game play. For example, the player's tension could influence the behavior of non-player characters. Or the enemy could be designed to recognize the player and begin moving towards them if the player's tension level rises or they become nervous. Non-player characters could also be designed to help the player instead when he or she is getting nervous. The most challenging issue to consider when designing this kind of game play is composing all the game's elements, including the game story, visuals and game mechanics, so that the player naturally feels the emotion that the designer intended for the player to feel at a certain point in order to use the tension caused by horror or fear.

DEVELOPMENT OF ACTUAL PC GAME USING BCI

Figure 6: Title image of the game

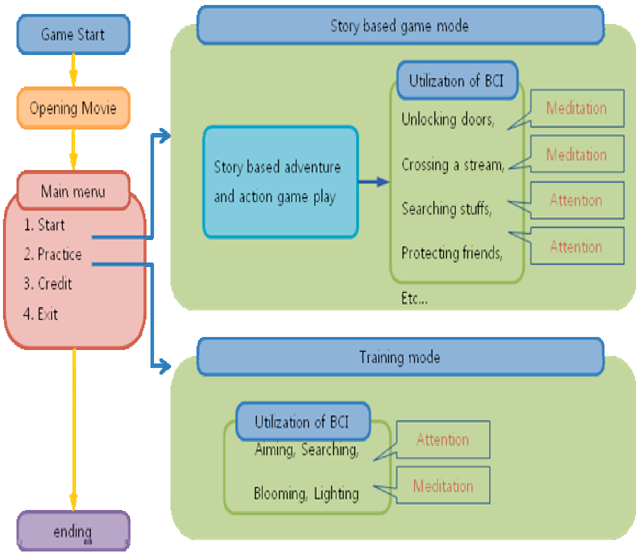

Figure 7: Game flow

In order to test the hypothesis of this research a PC game utilizing BCI was developed. Figure 6 shows the title image of the game. The game is composed of two game modes. The first one is the training mode which teaches a player how to control attention and meditation while the player wears a BCI headset through playing four kinds of mini games. The second one is the story mode based on a simple scenario: while a pretty girl is taking a nap in a park, she falls into a strange world with her cat and an adventure begins. The player has to find the portal to take her to home controlling her cat and animals in the world with emotional signals from BCI device as well as traditional input data from keyboard and mouse to defeat monsters and solve puzzles in the world. While the player plays the game, her brain status is reflected into the game progress continuously. At certain spots during the game play, the player can do the actions mentioned above: aiming and searching. Figure 7 shows the game flow.

Figure 8: Game play images

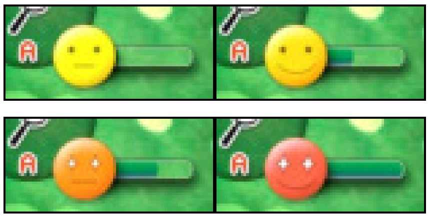

Figure 9: Visualization of attention in the game (To the left, 0 ~ 25%, 26% ~ 50%, 51% ~ 75%, 76% ~ 100%)

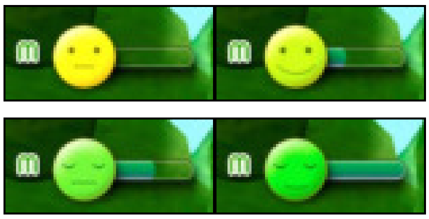

Figure 10: Visualization of meditation in the game (To the left, 0 ~ 25%, 26% ~ 50%, 51% ~ 75%, 76% ~ 100%)

Figure 8 shows game play screenshots. We placed icons and a gauge bar at the upper left corner of the screen to show that the player either concentrates or meditates while playing the game. As the value of player's meditation increases, the gauge is gradually filled. We quantized the value into four and displayed icons showing four levels of the value with ease control. Figure 9 and figure 10 show the icons and the bar used for displaying player's attention and meditation while the player plays the game, respectively.

Figure 11: Game play images of the bulb lighting mini game utilizing the player's meditation value (To the left, 0 ~ 25%, 26% ~ 50%, 51% ~ 75%, 76% ~ 100%)

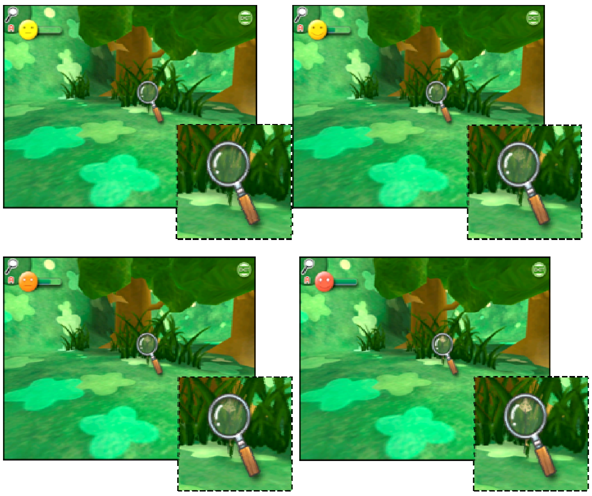

Figure 12: Game play images of the hidden object searching mini game utilizing the player's attention value (To the left, 0 ~ 25%, 26% ~ 50%, 51% ~ 75%, 76% ~ 100%)

In the training mode, the player can learn how to control her concentration and meditation level nicely by playing four simple mini games. In the bulb lightening mini game, the player tries to light the electric bulb by relaxing her mind. The more the player relaxes in the game, the bulb turns on faster with some special effects. Figure 11 shows game play images of the mini game. In the hidden object searching mini game, player's concentration level affects difficulty of finding the hidden object. Figure 12 shows the image of the game.

In the story mode, the player plays a side-scrolling action adventure game having a simple storyline that a main character escorts a girl to the end of the game stage. While playing the story mode, the player resolves puzzles and defeats monsters by controlling her cat and a mouse with the BCI device as well as keyboard and mouse. The game focused on using BCI to control three elements of game play: aiming, searching and resting. In the game, when a player concentrates more on the game, it becomes easier for them to shoot enemies. Sometimes, when they are concentrating or relaxed, they can find some hidden items or hints. Also, when players are relaxed they can take a rest in the game and recover from any damage they've sustained. When the player aims at something, the crosshair jitters to an extent based on how much the player is concentrating. If the player is concentrating a great deal on the game, the jittering will be very minor, making it easy for them to shoot enemies. When the player searches for a hidden object or hint on the game stage, the player's level of concentration or meditation affects how easy it is to find things. For resting, the speed of the player character's recovery varies according to the degree of the player's meditation. In some areas of the game, a very relaxed player will even be able to make flowers bloom. Figure 13, figure 14 and figure 15 show game play images of utilizing BCI data to solve puzzles in the story mode.

Figure 13: Game play images of aiming. The degree of jittering of the crosshair varies according to the player's attention value

Figure 14: Game play images of searching a hole to enter. The hidden hole appears if the player's meditation value exceeds a certain threshold

Figure 15: Game play images of defeating monsters. The damage to the monster increases according to the player's attention value

EVALUATION OF BCI ELEMENTS USED IN THE GAME

This research is intended to suggest a number of game play elements adopting BCI and to verify if players can actually experience more intuitive and exciting game play when they play a game in which some of the game play elements are controllable using a BCI device.

In order to evaluate the game play elements using BCI we developed a version of the game in which all BCI related elements were removed. The two versions of the game are the exactly same except that in the first version players control the game using a BCI device as well as traditional interface devices including mouse and keyboard, while for the second version players use only traditional interface devices.

Subjects

15 undergraduate and graduate students (average age: 24.5) and 5 non-students (average age: 28), for a total of 20 participants, were tested. They were divided into two groups of 10 people each.

Conditions of the research

As described above, two different versions of the game were used. The versions were exactly same except that one included support for a BCI device. Both versions were developed using XNA 2.0 and .Net Framework 2.0/2.0 SP1 and were played on PC. For the BCI device we used NeuroSky's Mind Set. We used brainwave information that is commonly detectable by most small-sized BCI devices that are currently available.

Research procedure

The research was carried out dividing the subjects into 2 groups of 5 people each. One group was asked to play the version of the game using BCI and the other group to play the version that did not use BCI. Neither group had any information about what the other group played.

All subjects played Single Game from the beginning to the middle of the second stage. After that, they played two Mini Games adopting different game elements: aiming and searching. The total play time was approximately 20 minutes. Afterwards they were asked to fill in a questionnaire.

The questionnaire asked about the degree of convenience, fun and intuitiveness in both the overall game play and the game play using the BCI device (or not). Each category had two or four questions. Each question had 5 choices numerically ranged from 1 to 5: 5 (Highly), 4 (Q.Highly), 3 (Average), 2 (Q.Low), 1 (Low).

The questionnaire given to both groups was exactly the same.

Results of the research

Based on questionnaire responses, scores by category about game elements differentiated by using BCI or not are seen in Table 2.

Table 2: Scores of each category

Group	Total	Average	Standard Deviation	Degree of Freedom
With BCI	149	14.9	2.645	9
Without BCI	102	10.2	4.18	9

We performed statistical t-test with the results above and it was induced that the game version adopting BCI is significantly better than the version without BCI in terms of convenience, fun and intuitiveness (α=0.05, $t_{.05}(18) \fallingdotseq 2.101$, $t \fallingdotseq 5.605$).

CONCLUSION AND DISCUSSION

This research was intended to study and suggest game play elements that can be developed around BCI and a player's emotions from the perspective of game design.

In order to verify if the suggested game play elements can provide the user with an intuitive and exciting experience, an experimental game using several proposed game play elements was developed and tested by users. Feedback was collected via a questionnaire.

The results of this feedback showed that the suggested BCI-based game play elements provide users with a more intuitive and interesting experience than traditional non-BCI-based game play elements. Also, it was possible to induce that simply adding BCI to a general PC gaming environment can make the game play more intuitive and immersive. The result and assets of this research are expected to be an effective guideline for developing BCI-based games.

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