Impact of BCI-Informed Visual Effect Adaptation in a Walking Simulator

by

Max Chen

A Thesis

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Master of Science

in

Interactive Media and Game Development

by

December 2022

APPROVED:

Professor Gillian Smith, Thesis Advisor

Professor Erin Solovey, Committee Member

Abstract

In this paper, we explore the use of brain-computer interface (BCI)-adapted visual effects to support atmosphere in a walking simulator, and investigate its impact on player-reported immersive experience. While players were using a keyboard or joystick controller to control the basic movement of a character, their mental state was accessed by a non-invasive BCI technique called functional near-infrared spectroscopy (fNIRS) to implicitly adjust the visual effects. Specifically, when less brain activity is detected, the players' in-game vision becomes blurry and distorted, recreating the impression of losing focus. fNIRS measures blood oxygenation levels, are related to brain activation. When a particular area of the brain is activated, it receives an increase in blood flow. With this biological indication, we designed a BCI-controlled game, in which the vision becomes blurry and distorted when less brain activity is detected, recreating the impression of losing focus.To analyze the player's experience, we conducted a within-subjects study where participants played both a BCI-controlled and non-BCI-controlled game and completed a questionnaire after each session. We then conducted a semi-structured interview to investigate player perceptions of the impact the BCI had on their experiences. The results showed that players had slightly improved immersion in the BCI-adaptive game, with the temporal dissociation score significantly different. Players also reported the BCI-adaptive visual effects are realistic and natural, and they enjoyed using BCI as a supplemental control.

Keywords: BCI, Personalized Experience, Immersive Experience, Visual Effect, fNIRS, Walking Simulator

Acknowledgements

I would like to acknowledge my advisor, Professor Gillian Smith, and my committee professor Erin Solovey, for their encouragement, patience, and support throughout this research. I am deeply grateful for the support of the Crafting Computational Creativity research group and WPI HCI Lab. I sincerely thank the participants for their participation in the study. Lastly I would like to give thanks to my loving partner, Shano Liang, for celebrating every accomplishment along the way with me.

Contents

1 Introduction

Visual effects are critical elements of game design that, while not contributing to system functionality, support information already delivered by other means [1]. Visual techniques are applied in video games for rendering either realistic or stylistic images and creating dramatic effects, with the goal to help the player become immersed in the game world. A realistic game world is not sufficient to generate a sense of immersion in players, but it can help facilitate the transition from mundane life to game [2]. Visual effects also support the players' emotional response to a game; for example, Seif El-Nasr et al. found that player interest in a game increased when the lighting was dynamically adapted in parallel with tension [3]. Traditionally, visual rendering effects are designed by the game development team and triggered by the player's in-game activities. In this paper, we propose an instance of creating dynamic and personalized visual effects via player modeling based upon physiological data gathered from an fNIRS brain sensor.

Our study uses fNIRS as a novel interface to let the player's subconscious mind interact with the digital space. We chose to work with a walking simulator game because it focuses on gradual exploration and discovery through observation [4], highlighting the aesthetic aspects of the game. Walking simulators do not have points, goals, or tasks [5], so that the players can focus on ambient experience. To emphasize that the importance of a dynamic, ambient environment in such games, Zimmermann and Huberts proposed the term "ambience action game" as an umbrella term that highlights the atmosphere and environment in the game [6]. While the system-controlled environment and player actions are distinct, bridging the player's subconscious mind to video game can create a novel experience.

Brain-computer interfaces (BCIs) extract meaningful information from brain activity and communicate with the computer, and have potential as a novel modality for collecting objective player data. With BCI, the game system can collect players' physiological signals and adapt the experience for them. However, most existing BCI studies have been designed for training purposes or to test a BCI paradigm, and did not emphasize gameplay mechanics and game design [7]. There is a research gap in constructing a bridge between BCI and game design.

We chose to use functional near-infrared spectroscopy (fNIRS) because it is resistant to movement in normal computing environments, such as mouse-clicking, typing, eye movement, and eye blinks [8]. As most game players are capable and familiar with using standard game inputs, we use fNIRS as a passive BCI input to minimize the learning barrier while providing an additional and unique stream of emotional state. Being resistant to common movements enables fNIRS to better detect player emotional states compared to other BCI technology, but there is limited work exploring the use of fNIRS as secondary passive input in video games.

Inspired by previous research on games and new interfaces [1, 9, 10], in this paper we investigate how introducing visual effects driven by players' mental activity affects experiences. Specifically, our study focused on fNIRS, which is a less studied interface compared to EEG. We developed a game that is instrumented for fNIRS, which employed players' brain activity states to control visual effects; in order to do this, we developed an open-source library for connecting industry-standard real-time BCI data to the Unity game engine. Our work contributes a novel fNIRS-based video game, and the results of a user study that provide insight into possibilities and limitations in designing implicit BCI games.

2 Related work

2.1 Dynamic visual effects in video games

Visual effects have strong effects on the player's perception of the game world. Misztal et al. studied how visual effects in virtual reality (VR) games impact players' perception of stress [11]. In video games and films, dynamic visual effects are used to enhance realism and engagement. Hillaire et al. proposed a method to introduce a combination of depth of field blur and a peripheral blur in a virtual reality game [12]. Mauderer et al. investigated a gaze-contingent depth of field using the eye tracker method to produce realistic 3D images and found increased subjectively perceived realism [13]. There is also work in dynamic visual effects from player modding communities; the *Skyrim* mod community created Dynavision to adjust the auto-focus effect of a camera so that when you are close to an object and looking right at it, the object stays in focus while the background blurs [14]. The same mod is also available and popular in *Grand Theft Auto V*, *Fallout 4*, and *The Witcher 3: Wild Hunt* player community. We build on this prior work in dynamic visual effects through exploring the use of BCI as an implicit controller.

2.2 Personalized content generation

Personalized game design is a player-centered iterative process that adjusts the game based on the player's model [15]. Player models can be built by the player's reported preferences, data collected from alternative modalities, or the player's reaction to the game [16, 17]. Physiological data that is collected during the game is also a promising approach for modeling the player's experience. Tijs et al. created an emotionally adaptive game using biofeedback, such as blood volume pulse, respiration, skin conductance, facial electromyography, and keyboard pressure [18]. Blom et al. use facial expression recognition to reveal the human player's affective state and tailor the game experience to individual players [19]. In our work, we use fNIRS brain data as physiological data, providing a model for a player's focus level.

Common domains for personalized game adaptation are dynamic difficulty adjustment and procedural level generation, which aim to adapt the environments and mechanics. Lopes et al. suggest that all game components can become adaptive and dynamic, such as game worlds and their objects; game mechanics; non-player characters; game narratives; and game quests. Up to now, little work has been done in dynamic visual effects that contribute to personalized gameplay experience. Our work explores the space of personalized visual effects based on physiological signals.

2.3 BCI and its application in games

BCI can be used as primary, direct control input in video games. This approach has been applied to classic games such as *Tetris* [20] as well as custom-designed games such as *MindBalance* [21]. Limited by the performance of real-time classifiers, these games often have simplified gameplay mechanics. Hampered by the low transfer rate, these games are adapted to be turn-based and have slow gameplay [22].

BCI can also be used for indirect control, which shows promise with games that have more complex mechanics because players still use conventional game input such as keyboard and controller, while BCI detects mental activity as additional input. For example, *Alphawow* runs on a modified version of the popular game *World of Warcraft*, in which the player has full control of a character via keyboard and mouse while the character's form can be altered by their parietal alpha activity [9] reflecting player attention and relaxation.

Such usage of attention and relaxation is common in BCI-based game adaptation. Cho et. al. proposed a responsive environment system in a first-person shooter (FPS) game in which the fog and lighting change according to attention and meditation levels [10]. *Skyrim* VR mod *Real Virtual Magic* changes the magic power based on attention level detected by commercial-grade EEG, which means if the player is unfocused, they are not able to do damage [23]. Wozniak et. al. developed and implemented an escape room VR game that employed players' focus and relaxation states as input for switching the telekinesis and alternative vision skills and proved enhanced immersive gaming experience [1]. These systems use EEG input, while our work explores the possibility of using fNIRS as a supplemental controller.

fNIRS as a Supplemental Controller

fNIRS uses a fundamentally different approach to detecting brain activity from EEG. While EEG detects electrical impulses from neurons firing, fNIRS reflects the hemodynamic response of oxygen traveling to the brain due to that increased brain activation. The neuronal response is reflected within milliseconds in the EEG signal, while the hemodynamic response occurs over a period of 3–7 seconds [24]. This difference in the time course is crucial to game designers as it leads to different affordances and constraints on the design. In addition, there are differences in the spatial resolution, with the fNIRS signal being more localized, enabling headsets to be designed that target a particular area of interest. The EEG signal has lower spatial resolution meaning that there is less direct connection to the area of activation. Another consideration that is important to designers is the susceptibility to noise. EEG typically requires more controlled settings, while fNIRS is resistant to artifacts introduced by motion, eye movements, and other electrical noise [25, 8]. There is growing interest in further mitigating these effects and increasing work in the field of mobile EEG and fNIRS recording.

Given all of these considerations, fNIRS is most suitable as a secondary input for gaming alongside the primary input from a more traditional controller. Utilizing BCI in games as supplementary input also has the benefit of maintaining a familiar primary input, lowering the barrier of entry for players to learn and play with novel mechanics. Studies show that as the natural mapping degree of the game controller increases, expressions of "intuitive", "fun to use, and easy to learn" appear more frequently in user studies [26]. Thus, we explore the use of fNIRS as a secondary input, with a traditional game controller serving as the primary input.

Other work has taken this approach with fNIRS outside of the gaming context. For example, Boyer et al. investigated mental workload changes in a long-duration monitoring task, finding a diminished hemodynamic response when engagement and attention degraded [27]. When applied to interactive systems, Afergan et al. used mental workload obtained by fNIRS to dynamically adjust the number of unmanned aerial vehicles to optimize mental workload in real-time [28]. Solovey et al. describe the *Brainput* system where human-robot interaction is enhanced by a continuous supplemental fNIRS input stream [29]. These projects are encouraging examples of how fNIRS can serve as a supplemental input in complex environments.

3 BCI Game Prototype

Inspired by previous work, we use the player's mental workload as a secondary input modality to adapt visual effects in video games. We developed two versions of a 3D walking simulator game with player-adapted visual effects. In the BCI-controlled version, the player's mental workload is associated with the visual effects, while in the non-BCI-controlled version, the player's in-game actions are used to adapt visual effects.

3.1 Brain Sensing Equipment and Tools

We used NIRSport2, a portable device for collecting the raw fNIRS signals. Data is captured in the NIRx Aurora software, and then transferred to Turbo Satori for analysis (Figure 1). Turbo Satori is an industry-standard software designed for a non-BCI experts to perform real-time analysis on fNIRS data [30]. Turbo Satori uses the Lab Streaming Layer (LSL) protocol to import raw data from data acquisition software such as Aurora. It has a customizable analysis pipeline, and allows third-party applications to access the processed data and statistics in real time. An example of this was shown by Benitez-Andonegui et al. who established a proof-of-concept for an fNIRS-based augmented reality interface [31] that used Turbo Satori for processing brain signals, Matlab for real-time classification, and Unity for creating AR displays. In our work, the brain signals are processed and converted to oxygenated and deoxygenated hemoglobin in Turbo

Satori, and then sent to the game application through a direct TCP connection for in-game adaptation. Unlike that prior work, we did not use MATLAB in the pipeline since Turbo Satori provides the statistical analysis capabilities necessary for processing brain data. We describe the mapping of the fNIRS signal to the game mechanics in Section 3.3. We plan to release the software that directly connects Turbo Satori and Unity as open-source, in hopes of future research exploring the use of fNIRs in both games and other Unity-based projects.

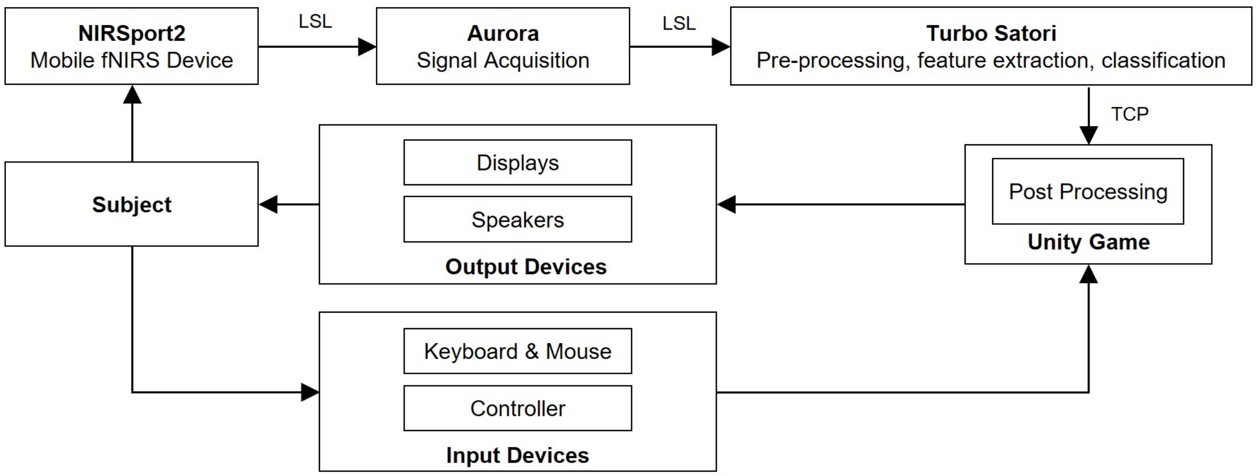

Figure 1: Data flow in the fNIRS-adaptive game. NIRSport2 was connected to the Aurora software via LSL, and to Turbo Satori via LSL. Turbo Satori was connected to Unity3D software via TCP/IP to control the visual effects.

A diagram for describing the fNIRS data flow

3.2 Game Design

To explore the use of visual effects based on BCI signsls, we developed a custom-made walking simulator game using Unity Engine, in which the player focuses on exploring an urban environment. We chose the walking simulator genre because it highlights aesthetics and has limited mechanic complexity; this allows the player to pay attention to the graphic details because they don't need to concentrate on strategy and can just focus on the experience. This is a helpful feature for our initial study on BCI-controlled visual effects, as we do not need to account for additional mental workload such as that incurred by solving puzzles or reading complex text when interpreting the BCI data.

In this study, we focused on three specific effects in the Unity built-in render pipeline: depth of field, color grading, and chromatic aberration. With these effects combined, we simulated the feeling of distortion and loss of focus in the first-person view. All three effect filters are adapted based on one continuous value from the BCI. The adaptation of visual effects is based on the player's experience modeling with a focus on the attention level of the game. When the player's attention is degraded, their view becomes blurry and distorted, indicating that the character is mind wandering; when the player is paying attention and they are engaged in the game, the view is clear and colorful, meaning that the character is actively receiving messages from the world.

Using Fantastic City Generator and UniStorm packages, the walking simulator game includes a modern urban city with a complete traffic system, dynamic weather, ambient sound, and day/night cycle. The virtual world is set to be 2 minutes in daylight, and 1 minute at night. Weather conditions change every 50 seconds from a list of weather presets.

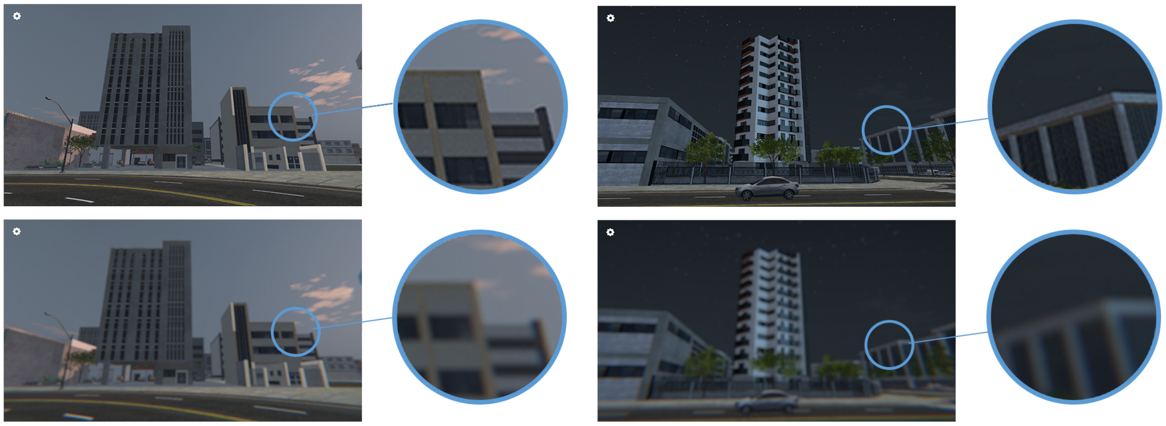

Figure 2: Comparison between visual effects under high and low levels of attention. Left upper and bottom: comparison in the daylight condition; Right upper and button: comparison in the night condition
A set of screenshots of the walking simulator game with different levels of blurriness and distortion

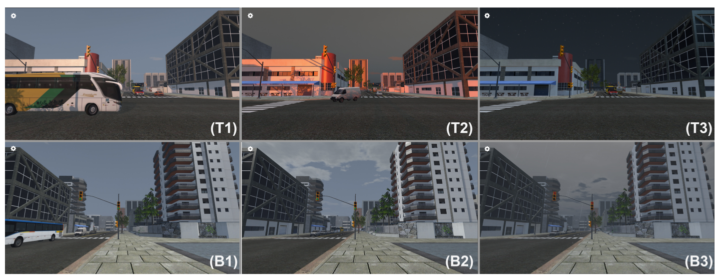

Figure 3: Screenshots of our prototype in different conditions. Set T: different times of the day, (T1) morning, (T2) sunset, (T3) night; Set B: different weather conditions, (B1) clear, (B2) cloudy, (B3) rain.
A set of screenshots of the walking simulator game at different times of the day

3.3 Visual Effects

To study the player's perception with and without BCI integrated, we made two variants for how visual effects are controlled dynamically. The first uses BCI mechanics to adjust the visual effects; the second uses the player's in-game actions to control the effects which serves as a control.

In the BCI version, we map the intensity of visual effects to the player's brain activation, based on the hemodynamic response given by the HR%, defined below. The hemodynamic response range reference is defined by the maximum and minimum values in the 30 seconds before the event. The percentage of hemodynamic response change from the reference is used to reflect brain activity at the moment. We calculate hemodynamic response % change ($HR(\%)$) as follows, where HbO_{t_1} and HbO_{t_1} refer to HbO and HbR at the current timestamp, respectively; $(HbO_t - HbR_t)_{max}$ and $(HbO_t - HbR_t)_{min}$ refer to the maximum and minimum difference between HbO and HbR in the past 30 seconds:

$$HR(\%) = \frac{(HbO_{t_1} - HbR_{t_1}) - (HbO_t - HbR_t)_{min}}{(HbO_t - HbR_t)_{max} - (HbO_t - HbR_t)_{min}}$$

When the hemodynamic response level decreases, the in-game character loses focus and enters a mind-wandering state and the visual effects adapt accordingly. When $HR(\%)$ is high and approaching 1, the player's vision becomes clear and bright; when the $HR(\%)$ is low and approaching 0, the vision becomes blurry and distorted.

The range of each effect intensity could be defined by the game designer, to meet the specific aesthetic goals. The relationship between the input data and filter parameters in our game is as follows, where $Effect$ refers to focus distance in depth of field, hue shift and saturation in color grading, and intensity in chromatic aberration:

$$Effect = HR^{0.8} * Effect_{max} - Effect_{min}$$

In the non-BCI version, in-game character movement is mapped to the effects. When the character remains at the same location or moves at the same speed, the vision gradually becomes blurry and distorted. Only when the action differs from the norm, the screen becomes clear.

In both versions, the visual effects are linked with the day/night cycle such that when the player is fully focused at night, their vision is less clear than when they are fully focused during daylight time.

4 Experiment

We conducted an experiment to measure how BCI affects players' immersive experience. We had the following hypothesis: perceived immersion is higher in the BCI version of the game compared to the non-BCI version. We counterbalanced the conditions (BCI and non-BCI version of game), with each version played for five minutes in random order. The participants wore the fNIRS headset for both sessions to avoid awareness of which game version was which.

We recruited 24 participants; 15 self-identified as male, 9 as female and 0 as non-binary. Their ages ranged from 19–57. Three participants reported having participated in BCI research before, while the rest were new to BCI.

The walking simulator game was operated in a laboratory setting. We used a NIRx 54-channel research-grade NIRSport2 headset for gathering the fNIRS data. The interview was set in a separate room with an audio recorder. When each participant arrived for the study, we explained the goal and procedure of the study, obtained their written informed consent to participate, introduced the game mechanics, and asked about previous fNIRS experience and gaming experience. Then, we helped the participants with setting up the fNIRS headset and conducted a calibration to optimize signal levels. Next, we assisted the participants in setting up the game controller.

After playing each version of the game, the player was asked to complete a modified Immersive Experience Questionnaire (IEQ) [32]. The original questionnaire reported by Jennett consists of six sections, with the first three sections concerned with varying degrees of attention to the task: basic attention, temporal dissociation, and transportation; and the next three sections concerned with factors that could influence a person's motivation during the task: challenge, emotional involvement, and enjoyment. Since the walking simulation game doesn't have any win/lose conditions, we removed questions related to challenge and win/lose conditions. To calculate the immersive experience score for each category, we calculated a combined average of all participants in each category under two conditions. For each question, 1 represents strongly disagree and 5 for strongly agree.

Additionally, we conducted semi-structured interviews to gain insights into individual experiences and thoughts about the game. The input modality and the visual effect design were not revealed before the interview. During the interview, the participants used "the first session" and "the second session" to refer to the games. We asked questions as a cue to let the participants talk about their gameplay experience in general, perceptions of the visual effects, and immersion-breaking moments. All interviews were recorded (total duration 162 min) and transcribed verbatim. We conducted thematic analysis on the

Table 1: Average IEQ score in BCI and non-BCI condition (* for p ¡ 0.05, N = 24)

Condition/Category	non-BCI	BCI
Emotional Involvement	3.609	3.652
Enjoyment	4.043	4.109
Transportation	2.826	3.174
Temporal Dissociation	3.319*	3.609*
Total	3.449	3.636

interview transcripts, to identify common themes in ways participants describe their experience in the BCI and non-BCI conditions. The interview was voluntary and not required for every participant.

5 Results

As shown in Table 1, the difference in level of immersion (3.636) reported via the IEQ after playing the BCI version and the level of immersion (3.449) in the non-BCI version is not statistically significant. We found significant differences in perceived immersion between BCI and the non-BCI version in the sub-category temporal dissociation, and no significant differences in emotional involvement, enjoyment, or transportation.

With our participant interviews, we identified three core themes in the interview responses: descriptions of general gameplay experience, perceptions of BCI-adaptive effects, and immersion-breaking moments.

General Gameplay Experience In general, participants liked the dynamic urban city setup, especially the ambient sound, weather system, day-night cycle, and city view. These elements helped to build a dynamic environment.

> "Both the audio and the video did their best to pull me in into the whole city experience. . . I think the portion where I stopped a little bit and just like looked around listening to the sound of the wind when it was snowing that was the most memorable. That's still fresh in my memory." (P2)

Participants enjoyed the aesthetic experience in the walking simulator, but some described it as boring comparing to action game.

> "I liked the setup. I liked the environment, the city and I also liked that I don't have to fight any monster just walk around and explore. . . it reminds me of some place I'm very familiar with, plus the lighting it's even better." (P6)

> "It felt slow to me because I'm more oriented to action game. It just felt chill. Maybe a little boring for what I'm used to." (P3)

Perceptions of BCI-adaptive visual effects. Participants reported that in the BCI version, having the brain-controlled blurry effect gives them a realistic feeling, as if they are experiencing a "zone out" in real life.

> "It felt as if the game was going out of focus, but I was not thinking about it. And then I was focusing, see everything back coming back into focus. I think that's something that we do in real world as well. But we do not notice things around us when we are not actively focusing on it or when we are not thinking of something else at the time. So that was a nice experience to see." (P2)

"It is probably like, you are kind of like in the zone or zoned out and not like aware of your surroundings around you in the real world." (P4)

"The thing that I found most interesting the second game [BCI] was when I was like walking, I was thinking it felt as if the game was coming into focus a little bit; but when I was just idly walking around, things were just blurred and out of focus" (P7)

The current BCI model can also handle the player's active control. Participants expressed they have tried to actively control the visual effects and successfully manipulated them:

"When I started to stop moving and look at one object, I felt like that's when the blurry went away." (P7)

"I did on the first one [non-BCI]. I was like, trying to look then I'm trying to look up other like on the other parts of the same but it doesn't, like change the blurriness on what I did like what I thought or what I did on the game, so I think it was random. But in the second one [BCI], I became focused and after a while, it became clear. So I think, I think the second one is brain controlled" (P2)

"I definitely noticed that it'll get blurred and I'd be like, Oh, wait, and then I'd look at it for a second. Stop moving and then it would kind of come back. So maybe that was just me like refocusing" (P1)

The emotional response to the dynamics of visual effects varied for different participants, mostly depending on whether they can sense the control of the visual effect. One participant described it as satisfying:

"It felt satisfying to see like, things come back into view." (P2)

One participant complained that the visual effect is disturbing, thus preventing them to focus:

"It was too blurry for me. I could still see colors, but it stopped letting me see the edges of objects, you know, it will stop me from focusing on each particular object" (P6)

Immersion-breaking moments. Similar to other BCI game studies [9, 1], some participants emphasized the inconsistency of actions and their feedback in the game has caused the immersion-breaking experience. Two participants expressed confusion when cannot actively control the in-game visual:

"I was paying attention to see whether my mental focus have anything to do with how the blurry would go, but I only noted one time where that actually did. And I do not know whether it's just by chance or it's or if it's just you know, actually working." (P6)

"I don't know what my brain was controlling. It would get fuzzy so mad. I was like, did my brain do that to me?" (P8)

One participant expressed that they noticed a significant time delay in the system, but they managed a way to manipulate the visual effect:

"There were some significant lags, though, but I felt like I was in control of it... like if there was no lag, it would definitely bump up the immersion of the game" (P7)

6 Discussion

Our design process and user study findings point to challenges and design tensions in applying BCI techniques in game design, as well as reflection upon how players react to BCI and relate to immersion. We also identify areas of potential future work in the field of BCI and game adaptivity.

Using fNIRS to adapt visual effects has potential to enhance immersive experience. IEQ scores showed that using BCI-driven control resulted in slightly increased immersion ratings, with a significant difference in temporal dissociation. Temporal dissociation refers to an individual having less awareness of time while engaged in interaction [33]. One potential reason is when player noticed that the visual effects were adapted based on their mental workload, the players were learning and experimenting with how to channel their inner strength to successfully manipulate the visuals. Further, since the BCI is a supplemental input directly tied to time-based senses such as attention and focus, players may feel more temporally immersed in the BCI condition.

Player learned and enjoyed asserting active control, despite a design intent of implicit control. Players had experimented with how to control the visual effects and enjoyed it when they learned how to assert explicit control. These observations echo the theoretical considerations of Csikszentmihalyi in the sense of control and intrinsic rewarding are elements to create a flow experience [34]. Due to the biological process, fNIRS has a systematical delay that is noticeable to users when they attempt to manipulate it. We designed the game to use the fNIRS input as an implicit control, where the player needs not to be aware of it. Although the game was designed to be experience-oriented, the players exerted active control and enjoyed controlling the system based on their own will. This finding informs us that the players are eager to learn how the implicit BCI work, and how to manipulate that BCI game mechanics. This shows promise and challenges in how to design games to support explicit control well given that time delay factor. Further work also needs to be done in instructing players how to exert BCI control in the game.

Better tool is needed for creating a dynamic and personalized gaming experience. Implicit BCI can enhance the interactive system by providing mental status in real time. However, there is little support for developers to integrate BCI in concrete game production. There is a need for off-the-shelf fNIRS classification models that are pre-trained with large datasets, so that game developers can focus on building concrete games.

Nature of effects shows potential generalizability on interpreting immersion. The qualitative study suggested that the players found the BCI-adaptive visual effects realistic and natural, which contributes to an enhanced immersive experience. Screens and displays are the portals that connect players to game spaces. Player-adapted post-processing visual effect maps the player's feelings into the character's viewport, letting the player merge their real-life status onto the in-game representation. The same effect can be generalized to all first-person games, on all screen-based platforms including VR and AR. Third-person games are not the perfect match for these visual effects, because the cameras are not directly representing the character's view.

Choosing what to connect the BCI input to matters. The dynamic blurry and distortion effects helped bridge the player's feelings to the in-game character. The in-game blurry effect recreates the real-life experience of being disconnected to surroundings. As we discussed earlier, the same control can be applied to other game genres, if the game uses first-person camera. However, at the current stage, BCI is not perfect and can be misclassified. The qualitative study found that participants noticed an inconsistency of actions and their feelings occasionally. This echoes with findings in previous studies [1, 9]. Connecting BCI input to a non-gameplay mechanics mitigates the influence of such inconsistency to player's experience.

Subjective preference in adaptation is necessary. Taking personal taste into account, the expressive range of the visual effect should also be adjusted based on the player's preference. The qualitative study showed that while some participants found this effect intuitive. However, one participant found it disturbing because the visual effects were too intense, so they were not able to see anything.

7 Limitations and future work

To date, fNIRS systems are not commercially available, limiting the fNIRS-based BCI game to the laboratory. The cost and difficulty in setup prevent large-scale user studies or cloud-based user experience evaluation. The duration of each play session was limited, especially for the BCI version, where the player may need more time to practice the control modality. Beyond access to equipment, there is also a need for making interpretation of data from fNIRS more accessible to non-BCI experts. Trained fNIRS models that classify precise mental status, such as emotions and rules learning, are needed for creating more accurate player models in the interactive system. Pre-trained models have the potential to lower the barrier for non-BCI experts and game developers to implement the system into new games, and thus popularize BCI in the game community.

Future work can be done in examining the classification models on affective status and build an adaptive game based on player's emotional status. There are possibilities to go beyond visual mechanics and work on connecting other aspects of the walking simulator, such as audio, level design, and narrative. Further work with understanding individual preferences could also help identify specific techniques in adjusting visual effects for a better immersive experience. More studies need to be done in addressing the importance of tutorial and instruction on teaching players how to use the novel control. For example, instead of giving oral instructions or click-through tutorials, it is better to incorporate the control mechanics as the first section of the game.

In conclusion, we presented an fNIRS-based BCI game that links visual effects to the player's mental status, creating an adaptive gaming experience. We demonstrate how we can integrate fNIRS into a video game to support dynamic visual effects adaptation could support a higher level of immersive experience, and provide open-source software connecting industry-standard fNIRS software to the Unity game engine. This work builds a foundation for further exploration of fNIRS-based visual effect adaptation in games.

References

[1] Mikołaj P Woźniak et al. "Enhancing In-game Immersion Using BCI-controlled Mechanics". In: *Proceedings of the 27th ACM Symposium on Virtual Reality Software and Technology*. 2021, pp. 1–6. DOI: https://doi.org/10.1145/3489849.3489862.

[2] Sarah Lynne Bowman. "Immersion and shared imagination in role-playing games". In: *Role-Playing Game Studies*. Routledge, 2018, pp. 379–394. ISBN: 1315637537.

[3] Magy Seif El-Nasr et al. "Dynamic Lighting for Tension in Games". In: *Game Studies Journal* 7.1 (2006). URL: www.gameinnovation.org.

[4] Daniel Muriel and Garry Crawford. "Video games as culture: Considering the role and importance of video games in contemporary society". In: *Video Games as Culture: Considering the Role and Importance of Video Games in Contemporary Society* (Jan. 2018), pp. 1–194. DOI: 10.4324/9781315622743/VIDEO-GAMES-CULTURE-GARRY-CRAWFORD-DANIEL-MURIEL. URL: https://www.taylorfrancis.com/books/mono/10.4324/9781315622743/video-games-culture-daniel-muriel-garry-crawford.

[5] Melissa Kagen. "Wandering Games". In: *Wandering Games* (Oct. 2022). DOI: 10.7551/MITPRESS/13856.001.0001. URL: https://mitpress.mit.edu/9780262544245/wandering-games/.

[6] Felix Zimmermann, Christian Huberts, and Zimmermann Huberts. "From Walking Simulator to Ambience Action Game". In: *Press Start* 5.2 (Aug. 2019), pp. 29–50. ISSN: 2055-8198. URL: http://press-start.gla.ac.uk/index.php/press-start/article/view/126.

[7] D Marshall et al. "Games, Gameplay, and BCI: The State of the Art". In: *IEEE Transactions on Computational Intelligence and AI in Games* 5.2 (2013), pp. 82–99. ISSN: 1943-068X 1943-0698. DOI: 10.1109/tciaig.2013.2263555.

[8] Erin Treacy Solovey et al. "Using fNIRS brain sensing in realistic HCI settings: experiments and guidelines". In: *Proceedings of the 22nd annual ACM symposium on User interface software and technology*. 2009, pp. 157–166.

[9] Bram van de Laar et al. "Experiencing BCI Control in a Popular Computer Game". In: *IEEE Transactions on Computational Intelligence and AI in Games* 5.2 (2013), pp. 176–184. ISSN: 1943-068X 1943-0698. DOI: 10.1109/tciaig.2013.2253778.

[10] Ok-Hue Cho and Won-Hyung Lee. "BCI Sensor Based Environment Changing System for Immersion of 3D Game". In: *International Journal of Distributed Sensor Networks* 10.5 (2014). ISSN: 1550-1477 1550-1477. DOI: 10.1155/2014/620391.

[11] Sebastian Misztal et al. "Intensifying Stress Perception Using Visual Effects in VR Games". In: *ACM International Conference Proceeding Series* (Sept. 2020). DOI: 10.1145/3402942.3409781. URL: https://doi.org/10.1145/3402942.3409781.

[12] Sébastien Hillaire et al. "Depth-of-field blur effects for first-person navigation in virtual environments". In: *IEEE Computer Graphics and Applications* 28.6 (2008), pp. 47–55. ISSN: 02721716. DOI: 10.1109/MCG.2008.113.

[13] Wei Jiang et al. "A study of color-emotion image set construction and feature analysis". In: *Proceedings - 18th IEEE/ACIS International Conference on Computer and Information Science, ICIS 2019* (June 2019), pp. 99–104. DOI: 10.1109/ICIS46139.2019.8940231.

[14] Michael Mauderer et al. "Depth perception with gaze-contingent depth of field". In: *Conference on Human Factors in Computing Systems - Proceedings* (2014), pp. 217–226. DOI: 10.1145/2556288.2557089. URL: http://dx.doi.org/10.1145/2556288.2557089.

[15] Darryl Charles et al. "Player-centred game design: Player modelling and adaptive digital games". In: (2005).

[16] Georgios N. Yannakakis and Julian Togelius. "Experience-driven procedural content generation". In: *IEEE Transactions on Affective Computing* 2.3 (July 2011), pp. 147–161. ISSN: 19493045. DOI: 10.1109/T-AFFC.2011.6.

[17] Adam M. Smith et al. "An inclusive view of player modeling". In: *Proceedings of the 6th International Conference on the Foundations of Digital Games, FDG 2011* (2011), pp. 301–303. DOI: 10.1145/2159365.2159419. URL: https://dl.acm.org/doi/10.1145/2159365.2159419.

[18] Tim Tijs, Dirk Brokken, and Wijnand IJsselsteijn. "Creating an emotionally adaptive game". In: *International Conference on Entertainment Computing*. Springer, 2008, pp. 122–133.

[19] Paris Mavromoustakos Blom et al. "Towards Personalised Gaming via Facial Expression Recognition". In: *Aiide*. 2014.

[20] Gabriel Pires et al. "Playing Tetris with non-invasive BCI". In: *2011 IEEE 1st International Conference on Serious Games and Applications for Health, SeGAH 2011* (2011). DOI: 10.1109/SEGAH.2011.6165454.

[21] E. C. Lalor et al. "Steady-state VEP-based brain-computer interface control in an immersive 3D gaming environment". In: *Eurasip Journal on Applied Signal Processing* 2005.19 (Nov. 2005), pp. 3156–3164. ISSN: 11108657. DOI: 10.1155/ASP.2005.3156/METRICS. URL: https://asp-eurasipjournals.springeropen.com/articles/10.1155/ASP.2005.3156.

[22] Grégoire Cattan. "The Use of Brain–Computer Interfaces in Games Is Not Ready for the General Public". In: *Frontiers in Computer Science* 3 (Mar. 2021), p. 20.

[23] Cangar. *Real Virtual Magic*. 2021. URL: https://www.nexusmods.com/skyrimspecialedition/mods/58489.

[24] Felix Putze et al. "Understanding HCI Practices and Challenges of Experiment Reporting with Brain Signals: Towards Reproducibility and Reuse". In: *ACM Transactions on Computer-Human Interaction* 29.4 (Aug. 2022), pp. 1–43. ISSN: 1073-0516. DOI: 10.1145/3490554.

[25] Evan M Peck et al. "Using fNIRS to Measure Mental Workload in the Real World". In: *Advances in Physiological Computing*. Ed. by Stephen H Fairclough and Kiel Gilleade. London: Springer London, 2014, pp. 117–139. ISBN: 978-1-4471-6392-3. DOI: 10.1007/978-1-4471-6392-3{_}6. URL: https://doi.org/10.1007/978-1-4471-6392-3_6.

[26] Serefraz Akyaman and Ekrem Cem Alppay. "A Critical Review of Video Game Controller Designs". In: *Springer Series in Design and Innovation* 13 (2021), pp. 311–323. ISSN: 26618192. DOI: 10.1007/978-3-030-65060-5{_}25/FIGURES/2. URL: https://link.springer.com/chapter/10.1007/978-3-030-65060-5_25.

[27] Mark Boyer et al. "Investigating Mental Workload Changes in a Long Duration Supervisory Control Task". In: *Interacting with Computers* 27.5 (Sept. 2015), pp. 512–520. ISSN: 0953-5438. DOI: 10.1093/IWC/IWV012. URL: https://academic.oup.com/iwc/article/27/5/512/710915.

[28] Daniel Afergan et al. "Dynamic difficulty using brain metrics of workload". In: *Conference on Human Factors in Computing Systems - Proceedings* (2014), pp. 3797–3806. DOI: 10.1145/2556288.2557230. URL: http://dx.doi.org/10.1145/2556288.2557230.

[29] Erin Treacy Solovey et al. "Brainput: Enhancing interactive systems with streaming fNIRS brain input". In: *Conference on Human Factors in Computing Systems - Proceedings* (2012), pp. 2193–2202. DOI: 10.1145/2207676.2208372.

[30] M Luhrs and R Goebel. "Turbo-Satori: a neurofeedback and brain-computer interface toolbox for real-time functional near-infrared spectroscopy". In: *Neurophotonics* 4.4 (2017), p. 41504. ISSN: 2329-423X (Print) 2329-423X (Linking). DOI: 10.1117/1.NPh.4.4.041504. URL: https://www.ncbi.nlm.nih.gov/pubmed/29021985.

[31] A Benitez-Andonegui et al. "An Augmented-Reality fNIRS-Based Brain-Computer Interface: A Proof-of-Concept Study". In: *Front Neurosci* 14 (2020), p. 346. ISSN: 1662-4548 (Print) 1662-453X (Linking). DOI: 10.3389/fnins.2020.00346. URL: https://www.ncbi.nlm.nih.gov/pubmed/32410938.

[32] Charlene Jennett et al. "Measuring and defining the experience of immersion in games". In: *International Journal of Human-Computer Studies* 66.9 (2008), pp. 641–661. ISSN: 10715819. DOI: 10.1016/j.ijhcs.2008.04.004.

[33] Wee Kheng Tan, Po Wei Lee, and Che Wei Hsu. "Investigation of temporal dissociation and focused immersion as moderators of satisfaction–continuance intention relationship: Smartphone as an example". In: *Telematics and Informatics* 32.4 (Nov. 2015), pp. 745–754. ISSN: 0736-5853. DOI: 10.1016/J.TELE.2015.03.007.

[34] Mihaly Csikszentmihalyi. *Flow: The psychology of optimal experience*. Vol. 1990. Harper & Row New York, 1990.