Enhancing In-game Immersion Using BCI-controlled Mechanics

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ABSTRACT

Due to multimodal approach, the virtual reality experiences become increasingly more immersive and entertaining. New control modalities, such as brain-computer interfaces (BCIs), enable the players to engage in the game with both their bodies and minds. In our work, we investigate the influence of employing BCI-driven mechanics on player's in-game immersion. We designed and implemented an escape room-themed game which employed player's mental states of focus and relaxation as input for selected game mechanisms. Through a between-subject user study, we found that controlling the game with mental states enhances the in-game immersion and attracts the player's engagement. At the same time, using BCIs did not impose additional cognitive workload. Our work contributes qualitative insights on psychocognitive effects of using BCIs in gaming and describing immersive gaming experiences.

CCS CONCEPTS

• **Human-centered computing** → **Virtual reality**.

KEYWORDS

virtual reality games, brain-computer interface

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1 INTRODUCTION

Modern gaming reaches beyond the established control modes, inviting players to use the entirety of their body and senses to interact with the gameplay. Multimodal game experiences are strongly related to virtual reality systems, which offer unique capabilities to build immersion and sensory engagement into virtual worlds. Numerous multimodal technologies enabled the VR gamers to interact through touch [56], smell [11], temperature [5], taste [31], motion [28] (which is central to certain game genres [39]), tactile sense [59], player's emotions [4] or external stimuli [23], in addition to visual and audio interfaces. These new endeavours for engaging control modes made games more compelling and highly enhanced the immersive experiences of play [10]. Recent studies reached beyond the physical interaction, employing brain activity as one of the input modalities, therefore making the players engage both their bodies and minds into the gameplay [36, 37].

Inspired by past research on traditional gaming [19], we investigate how introducing game mechanics driven by players' mental state affects the in-game immersion. We describe an experimental inquiry conducted with the use of a custom-made escape room-themed game, which employed players' focus and relaxation states to control certain game features. Differently from past studies on BCI-controlled gaming [53], our inquiry is focused on highlighting the immersion-building capabilities of this modality and qualitative analysis of the experiential aspects of BCI-driven games. Our work contributes an analysis of in-game immersion and cognitive load, and provides insights on player experiences within the game narratives employing their mental states as a control modality.

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2 RELATED WORK

In this section, we first navigate the definition of in-game immersion and discuss the methods of its assessment. Then, we explore the lessons learnt from previous HCI efforts on employing brain-computer interfaces in games.

2.1 In-game immersion assessment

The immersion has been one of the key factors contributing to engaging and pleasurable game experiences, reaching well beyond the modern video games [26]. Brown and Cairns [12] describe the immersion as gradual involvement in a game – consecutively reaching engagement, engrossment and full immersion states. The final state of full immersion is reached once the player starts ignoring his real surroundings, having his mind, body and emotions devoted and stimulated by the game events. The associated characteristics of those consecutive stages enabled the development of immersion assessment methods [46]. Ermi and Mäyrä [15] expanded this concept through distinguishing the sensory, challenge-based and imaginative immersion. Within those categories, the VR systems are particularly successful in triggering sensory immersion through intense visual and audio stimuli [50], as well as their ability to provide tangible and directly manipulated controls [51].

Past works described endeavours to assess in-game immersion using objective methods such as analysis of EEG potentials [17], EMG activity and facial expressions [29]. However, self-reported methods have been used most widely, covering the player's emotional response regardless of individual physiological characteristics [6, 46]. Jennett et al. [27] created and validated an Immersive Experience Questionnaire (IEQ), which proved successful in multiple past works [14, 21, 22, 45]. Jennett's approach has also been applied in contexts, where the solutions assessed involved BCI-driven interactions [33, 43]. The immersive aspects were also analysed in Game Experience Questionnaire, being treated as an ingredient of broadly analysed experience [25].

2.2 BCI in games

Brain-Computer interfaces are a recurring topic in game research, while still reaching limited popularity within commercial-grade solutions. The variety of mechanics that employ player's brain activity offer the players various levels of agency - Kerous et al. [30] categorizes these interventions as explicit (when BCI is used as a controller) and implicit (where the game interprets player's mental state and adapts to it) BCI usage. In our work, we focus on EEG regarded as an input modality.

Along with the development of consumer-grade EEG devices, using BCI as control modality became more and more popular in the area of computer games. Vasiljevic and de Miranda suggest that along the last twelve years, this field transitioned from being focused on simplified research prototypes (e.g. as reviewed by Marshall et al. [38]) towards more complete entertainment experiences [53], such as proposed by Wang et al. [55]. However, embedding BCI-driven mechanics into already well-established game genres remained a design challenge. Bram et al. [52] showed that such enhancement may provide similarly pleasurable experience, despite the loss in precision and player's involvement. These results are echoed by Ok-Hue et al. [13] who observed high immersion for FPS-style game, which passively adapted its conditions to player's level of focus. In BrainBasher [9], participants reported that BCI-controlled game was perceived as more challenging and stimulating. Controlling the games with regard to mental states has also proven successful for classic logic games [18, 35] and relaxation-oriented virtual experiences [1, 44]. Our work focuses on games where the BCI-related mechanics play an important role within the narrative of the game, contributing to more personal aspects of immersion [2] and building the feeling of presence [16].

3 EXPERIMENTAL INQUIRY

Inspired by past work [38, 53], we investigated treating the user's mental states as a control modality, so to enhance player's presence and in-game immersion. To explore this theme, we constructed a prototype virtual reality game, which included mechanics driven by the user's focus and relaxation. Based on our considerations, we decided to explore how using BCI-driven mechanics which reflect the narrative would affect the player's immersion and in-game experience. We investigated these questions through a between-subject experiment, where players completed an escape room-themed game using one of the proposed control schemes. The players used either a standard control setup for the VR headset (Baseline condition), or an extended setup with an EEG headset (EEG condition). The mental states of focus and relaxation are used for controlling respective mechanics within the game.

3.1 Research Prototype

In order to compare the different control schemes, we developed a custom-made virtual reality game, inspired by an escape-room paradigm, where the player's task is focused on solving consecutive puzzles. This leitmotif has been widely adapted in game design in the past [57], and is widely employed in highly-immersive real-world entertainment [40]. The game's storyline, set in a fantasy world, provides a rationale for using mind-related game mechanics. The player uses telekinesis and alternative vision skills to solve consecutive puzzles. Both of the skills are controlled either with buttons on the controllers (Baseline condition) or the player's levels of focus or relaxation (EEG condition). To ensure narrative validity, we associated the increased focus with the telekinesis, and the relaxation with the enhanced vision. Brown and Cairns argument that a logical connection between the actions performed and their representation within the game world is necessary to create an immersive game experience [12]. The gameplay consists of 4 puzzles, where the first two act as tutorials in operating the special abilities. The remaining two require the player to use both abilities more than once. The game takes ca. 30 minutes to complete, and is preceded by the calibration process (for EEG condition) lasting ca. 5 minutes.

3.2 EEG Processing

In order to provide an adaptive experience of EEG-driven control, we derived the activation thresholds for respective actions, using a semi-supervised approach. We followed the signal analysis and calibration protocol by Khong et al. [32], who detected user's relaxation and focus based on ratios of selected brain wave bands. In particular, ratios of RMS values of theta ($3.5 - 7.5Hz$), alpha ($7.5 - 12Hz$) and beta ($12-30Hz$) bands were considered (determined using AF3, AF4, T7, T8 and Pz channels). — $\frac{\alpha}{\theta}$ was used to determine the relaxation state, while $\frac{\beta}{\alpha}$ identified the focus state. A calibration procedure was necessary prior to the gameplay, in order to determine the activation thresholds appropriate for individual participants. We applied the protocol of Khong et al. — the participants were asked to relax and inhale deeply for 1 minute, then watched a video clip,

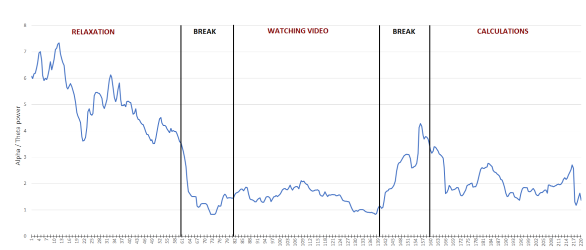

Figure 1: $\frac{\alpha}{\theta}$ signal ratios analysed during the calibration procedure, used to recognise relaxation.

after which they were asked to complete an iterative mathematical calculation. Figure 1 shows example records of $\frac{\alpha}{\theta}$ and $\frac{\beta}{\alpha}$ signals, obtained during the calibration procedure. Given a low number of channels available, we decided not to implement additional signal filtering, on top of the in-built solutions of Emotiv Insight. The algorithm was validated in a pilot session with N=6 participants. We have observed that player's ability to reach the pre-calibrated thresholds changed along with the playing time. Therefore, we introduced a semi-supervised procedure of adapting threshold values. The experimenter observed the $\frac{\alpha}{\theta}$ and $\frac{\beta}{\alpha}$ ratios in real-time. Once the participant futilely tried to activate an ability twice (determined by the experimenter's observation), the experimenter would adjust the threshold value, so that it matched an average of the peak values of these two trials. Therefore, the consecutive trial was likely to activate the ability. This procedure allowed us to avoid irritation among participants, which could harm their ability to relax. During the pilot sessions, we observed that after 3 failed trials, most players questioned system's operation, which echoes previous findings on error-induced negativity [54]. The abilities were also pre-selected using an in-game GUI, which limited accidental triggering.

3.3 Experimental design

3.3.1 Conditions and Measures. We conducted an experiment to measure how BCI use affected players' immersion. The use of the BCI was the independent variable, with two conditions: game played with the BCI as control modality (EEG) and using only the standard controllers (Baseline) We measured the cognitive workload using NASA TLX [20] scale. The in-game immersion was measured using Immersive Experience Questionnaire (IEQ) [27]. Additionally, we conducted semi-structured interviews to add qualitative data corpus to our observations.

3.3.2 Participants. We recruited N = 28 (19 male and 9 female) participants, aged 18-49 (M = 23.43 SD = 6, 11), using university mailing list and snowball sampling. 14 participants were randomly assigned to each of the experimental conditions. 21 participants reported having previous occasional experience with VR. A total of 7 participants reported to have experienced motion sickness.

3.3.3 Apparatus and Procedure. A HTC Vive Pro was used in an $5m \times 5m$ arena. The headset was connected to a VR-dedicated PC. We used an Emotiv Insight 5-channel headset (www.emotiv.com/insight/) for gathering the EEG data. The interview setup with an audio recorder was deployed in a separate room. We welcomed the participants, reiterating on the goals of the study, obtaining a written consent and inquiring about previous VR experiences and motion sickness. Then, we assisted the participants with gearing up the VR and EEG headsets (if applicable), and explained the game's themes and mechanics. Further, a calibration procedure was conducted (EEG condition). The participant solved the training puzzles with hints from the experimenter. Once completed, the player proceeded with the remaining puzzles, with no unsolicited advice. Having completed the gameplay, participants filled NASA TLX and IEQ questionnaires, and participated in a semi-structured interview. The procedure was pre-registered and the participants compensated according to Lodz University of Technology institutional scheme.

4 RESULTS

In this section, we present the results of our experimental inquiry. First, we report the quantitative results of the self-reported measures. We then analyse the qualitative data corpus from the post-hoc interviews.

4.1 Quantitative results

4.1.1 Immersion. We used an independent samples t-test to compare the IEQ scores for experimental conditions. We analysed the total score, as well as the individual axes. We conducted Shapiro-Wilk and Levine tests to verify test assumptions. Levine's test showed that the variance assumption is violated for the Enjoyment subscale. Therefore, we used a Welch-corrected test for this dimension. Given the low sample size (yet significantly higher than in similar past inquires e.g. [18, 35]), and the IEQ calculation method, we decided not to correct the p levels, as our analysis distinguishes parts of the data, avoiding multiple comparison effect.

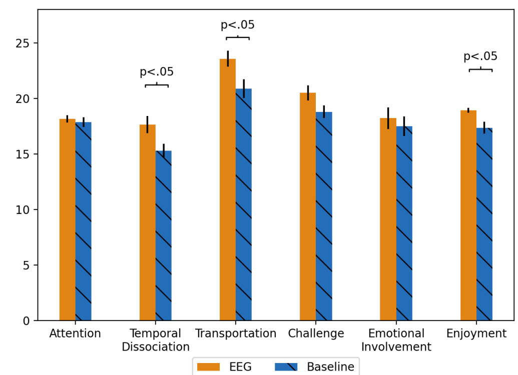

Figure 2: Mean IEQ scores for experimental conditions for individual subscales. Error bars show standard error.

We found a significant effect on the total IEQ score ($t(26)$ = 2.931, p = .006), as well as for Temporal Dissociation (TD) ($t(26)$ = 2.357, p = .0391 and Transportation (T) ($t(26)$ = 2.430, p = .0312). The Welch adjusted t-test for Enjoyment (E) showed a significant effect $t(17.243)$ = 2.689, p = 0.043. For all significant results, we calculated the Hedges' g [49] to assess the effect size. We found that BCI had large effect on the scores (Hedges' g = 1.075 for total IEQ score, g = 0.865 for TD, g = 0.892 for T, and g = 0.987 for E. We observe that the immersion scores are increased for EEG condition in all four of these dimensions.

4.1.2 Cognitive workload. We conducted an independent samples t-test to investigate the effect of using the BCI on the total NASA TLX score. We found no significant effect, $t(26)$ = 0.014, p = 0.989. We then analysed the individual dimensions of the NASA TLX with the independent t-tests and found that there were no significant differences for the respective subscales.

4.2 Qualitative analysis

All debriefing interviews were recorded (total duration $3h$ $14min$) and transcribed verbatim. We used the pragmatic approach to thematic analysis as described by Blandford et al. [8]. Two researchers coded a representative 20% of the material. We then developed an initial coding tree based on iterative discussion. The rest of the interviews were then evenly split between the two coders. In the final discussion, we further refined the coding tree and looked for higher-level themes. Our analysis resulted in two main themes: *BCI as in-game control modality* and *Immersion-breaking constraints.*

4.2.1 BCI as in-game control modality. Participants reported that using the BCI as input modality encouraged them to empathize with their in-game character. One participant commented that it helped him impersonate the protagonist in the game:

> *Using my brain to activate abilities made me feel more like the wizard I played as.*

The BCI-driven mechanics were intuitive and made the experience more cinematic. Players declared controlling objects with their minds contributed to immersion, both on a plot-related level, and in relation to game mechanics and movement.

> *Every time I wanted to use a special ability, I had to get into character. There was a moment when I moved a cube and I did it nicely and naturally. At that point, I had a feeling that immersion was great.*

Other participants mentioned that using the BCI was a refreshing and entertaining experience. The relaxation-based mechanic has been warmly received.

> *Using the BCI allowed me to empathize with the character and focus more on the game. [...] But it made the game more relaxing, and there were moments to relax and wind down.*

Participants mentioned that having to re-focus or relax helped them re-immerse into the game world once they became distracted. Users speculated that such games might attract new players. Four users compared BCI feature to motion controllers, suggesting it would be most appealing to the so-called "casual players".

4.2.2 Immersion-breaking constraints. Interviewed participants reported multiple factors impairing in-game immersion. Users expressed that wearing both headsets at the same time was uncomfortable and sometimes even painful. The control scheme was also reported to cause confusion, especially to players that had no previous experience with VR. Although the majority of participants perceived the BCI as an interesting control modality, some reported problems with its implementation. One of the issues noted by users was that the response time of the system was too slow. Further, players noticed that it became increasingly more difficult to reach relaxation and focus as the study was carried on. This remark is confirmed by our observations and use of the threshold-adjustment protocol. We believe this effect occurred due to players' emotional involvement in the game, as suggested by Kosiński et al. [34].

> *... however, I had this feeling that I was relaxed, and the system didn't react. In the beginning, I activated the perks easily, but then it took more time to make it work.*

Participants emphasized that inconsistency of actions and their feedback within the game was the factor most likely to break the immersive experience. Even minor issues (like a missing sound effect or insufficiently tactile experience of switching a lever) prompted players to inquire about the game working properly.

5 DISCUSSION

Here, we summarize the findings and reflect on the lessons learnt from using BCI interface for increased in-game immersion.

5.0.1 Using BCI as input modality encourages the players to empathize with their characters. IEQ scores showed that using BCI-driven mechanics resulted in increased immersion, which is echoed in the interviews. The mechanics implemented forced the participants to devote their thoughts to the game in order to progress within it. Participants emphasized the ease to build a connection with the protagonist and showed appreciation for the relaxing elements of the game. These aspects were likely to contribute to enhanced perceived transportation and temporal dissociation. We suspect that controlling the thought-related mechanics through a BCI does benefit from more direct manipulation [24], therefore making the game more tangible and easier to relate to [3].

5.0.2 Reflecting the in-game narrative builds the player engagement. Our observations show that bridging the gap between the player and its character contributed to making the experience more cinematic and helps users deeply engage in the game world. Our participants noted that controlling the supernatural abilities with their minds felt natural and intuitive. These observations echo the theoretical considerations of Brown and Cairns [12], who emphasized the role of accurate representation. Game designers shall closely consider matching different control modalities, so they enhance their narratives and complement the virtual worlds.

5.0.3 Pragmatic and technological issues impair in-game immersion. Qualitative results show that BCI as game interface is useful for building an in-game immersion, while this state is fragile towards possible disturbances. Pragmatic issues, such as software performance, cabled devices and spatial limitations of the arena, may disrupt the immersive experience. However, once achieved, the immersion state can be easily retrieved, as mentioned in the interviews. Fostering reaching certain mental states through the game mechanics makes this comeback easier to perform. Therefore, we suggest designing games considering both technological and environmental factors, so they support player's involvement in the game world.

5.0.4 Limitations and future work. While we endeavoured to design and study our BCI-supported VR game with utmost care, our approach is prone to limitations. As an artefact-driven study, the results are affected by our design process and implementation drawbacks of the game, as mentioned in section 5.0.3, as well as the limited duration of the game session. Future studies could explore more sophisticated signal processing for increased accuracy of EEG processing. Furthermore, our analysis concerns self-reported measures, which while valid for game evaluation [6, 7], are by nature prone to subjective bias. Our approach is also constrained with using a custom-made game instead of a commercial one, unlike some past studies [52, 55]. Future inquiries may explore the potential of BCI for AR technology in industrial applications where mediating focus and relaxation could aid analytic experts and on-site technicians working in training [41, 58] and everyday work with data [42, 47, 48].

6 CONCLUSION

In this paper, we investigated how using brain-computer interfaces as controllers influences the immersion in video games. We designed and implemented an escape room-themed game which employed player's mental state of focus and relaxation as input for selected game mechanisms. We compared the traditional control scheme with a BCI-extended one in a between-subject user study. Our work shows that in-game immersion can be successfully enhanced through employing mind-related mechanics that reflect the in-game narrative.

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