Build-A-Castle MI BCI

Effect of High and Low MI BCI Exercise Intensities on Mental Fatigue and Enjoyment

Jacob H. L. Nielsen, Kirstine J. S. Klebæk, and Mads D. W. Pedersen
Department of Architecture, Design and Media Technology
Aalborg University, Denmark

ABSTRACT

Motor Imagery Brain-computer interfaces (MI BCIs) are used in neurorehabilitation of cerebral palsy. An otherwise tedious experience of rehabilitation can be enhanced by applying MI BCI exercises to a game to improve users motivation. Some BCI rehabilitation games integrate non-BCI interactions between the BCI exercise repetitions, however, the impact of users' enjoyment and mental fatigue by adding longer non-BCI breaks, similar to the structure of physical workout routines, remains unexplored. This gap was investigated by testing three different game structures with 12 healthy participants. Two of the game structures were made to have a high or low intensity of MI BCI exercise repetitions, featuring either few but lengthy non-BCI breaks or frequent but brief non-BCI breaks, respectively. While the last game structure gave the participants control of when to take a non-BCI break.

There was no significant difference between the structures in regards to enjoyment and mental fatigue, although participants had a significantly better task performance in the high intensity structure. Despite the qualitative data indicated an average of 8±2 MI BCI exercises before participants wanted a break from performing MI BCI, their actions showed different results when they had control of the intensity in the third game structure. Therefore, the preferred number of MI BCI exercise repetitions before a non-BCI break is required was inconclusive.

0.0.1 KEYWORDS: brain-computer interface, motor imagery, cerebral palsy, video game, game design.

1 INTRODUCTION

Brain-Computer Interface (BCI) is a technology that utilises electroencephalography (EEG) to capture brain activity [1], providing a communication between the brain and an external device. In recent years, a major BCI application is for neurorehabilitation, where motor imagery (MI) BCI is used to induce neural plasticity in people with neuromuscular disorders [1], e.g., cerebral palsy (CP) [2]. MI is the cognitive process of which a subject perform a mental image of a motor movement without actually performing the motor movement.

A known issue with BCI rehabilitation is how patients lose interest and focus, because of the repetitive exercises [3], and as the rehabilitation takes a considerable amount of time to perform, mental fatigue also plays a role in declining performance [4]. A way to negate this is by turning the rehabilitation tasks into a game to promote user engagement and motivation [5, 3].

There have been an increased interest in the effect of using commercial video games in physical rehabilitation [6]. The studies found that video games were at least as efficient as conventional therapy and most of the participants, with a few exceptions of some elderly, preferred them compared to their traditional exercises. The positive results were achieved despite of the video games used, not being designed for clinical purposes [7].

Our research of BCI neurorehabilitation games has been divided into two sub sections, where we first investigate the different uses of the BCI signal and then investigate different game structures.

1.1 BCI Signal

BCI provides the system with a continuous signal; a signal showcasing how confident it is that the user is performing the MI exercise. To be able to detect when the user is successfully performing MI, the continuous signal is often turned into a binary signal using a threshold, when used in rehabilitation applications [**?**]. The binary signal is interpreted as an activation, where a program reacts once whenever the person have performed MI.

BCI games typically have an input window; a set amount of time, where the user attempts to perform the MI exercise, to limit the amount of noise or false positives that may be registered when not performing the exercise [8]. The program would therefore only interpret the signal during the input window. The input window would most often stop the moment it registered a successful performance. The interpreted signal is then typically used to provide some sort of feedback, dependent on if the performance was successful or not [8], e.g. either a mouse will steal your cheese or get scared away by your hand movement [9].

Another important aspect to limit false positives is mirror neurons. Mirror neurons become active during the execution of an action or the observation of an action [10], which makes them important to control for, when performing MI exercises. This is why it is important that the mirror neurons are not triggered while MI BCI is performed, e.g., observing a hand animation that performs the BCI exercise.

Before the input window, the user would have a resting phase, where the user doesn't have to use BCI. When the resting phase is done, the user enters the preparing phase, where they need to mentally prepare for the input window showing up soon after.

Instead of using a threshold on the continuous signal to get a binary signal, the continuous signal can be used directly. BCI games that uses the continuous signal were found to use it to change an important variable of the game, such as the speed of the player avatar [11] or the position in a steering game [12]. This allowed for more skillful action-oriented gameplay that can be considered closer to non rehabilitation games. We were not able to find any literature regarding the continuous signal as input, in the context of MI BCI rehabilitation. This might because the stability of the continuous signal easily can be decreased by things like fatigue, lack of concentration, spasms or tremors [3], which are things that often happen to people with CP [13]. In a MI BCI rehabilitation context, the continuous signal has instead been used as feedback, to make the user more aware of how they are doing.

Kjeldsen et al. used the continuous signal to mimic the hand movements of the player in the game while they performed MI [14]. This was done to have a natural time coupling, meaning that the feedback occurs as soon as an input is made [15], which is important since having a weak natural coupling can discourage users and can reduce their performance [16, 14]. Using the continuous input as feedback this way, they found that it may have improved the perceived feeling of agency in users with bad BCI performance, but ultimately found it had no impact on their MI performance.

1.2 Pacing of Game Structure

A trend can be seen in the game designs for people with CP, which follows an often relaxed and forgiving approach [17]. This rule-set of how CP games should be made, have been experimented with, in terms of making it more action oriented [18]. As long as simplicity was kept in the game, and the input options were restricted in what CP participants could do at any one time, people with CP could play the game just fine.

Jochumsen et al. [19] implemented a BCI fishing game for stroke rehabilitation, where they used keyboard as well as BCI. The game used the up and down arrow on a keyboard to move the fishing hook, and then used BCI to reel the fish in. Here the BCI was used in intervals, alternating between the BCI input and the non-BCI input of keyboard-presses, which would lead to breaks between training. The paper did not look into how long or how frequently breaks should be, and what effects these may have on the game.

This type of structure, in regards to BCI exercises and non-BCI gameplay, has to our knowledge been explored in a limited manner. Kiholm et al. [20] tried to find the best game structure of BCI exercises and non-BCI gameplay. They constructed two different game structures "Interval", where the user would keep switching between doing MI and playing the non-BCI part of the game, and "Battery", where the user had to perform multiple MIs in a row, and then play the non-BCI part of the game for longer. Ultimately their results are non-conclusive due to sources of error, such as the participants having an advantage in "Battery" compared to "Interval", built into the design of their game. While avoiding these sources of error, this study compares different game structures of BCI exercises and non-BCI gameplay, to find out how they influence the mental fatigue and enjoyment of users.

2 BCI DESIGN WORKSHOP

We took part in conducting a workshop, to facilitate BCI game ideas to improve the rehabilitation exercises for people with CP. Anyone were welcome to participate, but the 22 participants who attended were students at Aalborg University studying either Medialogy or Health Science and Technology. Aside from the participants, a CP adolescent, CP expert, and a BCI expert were present at the workshop, to help the participants get more insight in the life of a CP adolescent, or understand the BCI functionalities. At first everyone were introduced to CP by the CP expert, and afterwards the BCI expert explained BCI usage in regards to CP rehabilitation. With this knowledge, the participants were asked to play an Association game that went through ten various questions to create connections between BCI, CP, and other things, e.g., if BCI was an animal, which animal would it be? This question made some participants think about ants or bees, because of their hive mind behaviour, which made them think about a brain and thus a BCI. The newly created connections were then used as a foundation to brainstorm BCI game ideas with the use of the next activity called Post-Up [21]. In the beginning, participants individually wrote down their ideas on post-its to avoid others influence. Then later they shared the ideas within groups to allow further discussions and potentially new ideas would emerge. Afterwards Value Mapping [21] was used to vote within groups to find the preferred BCI game idea. The number of votes each participant had were one third of the total number of BCI game ideas within their group, e.g., if there were six BCI game ideas then each person had two votes. Once every group had decided on an idea, everyone were introduced to how to create paper prototypes. Everyone were shown two examples of paper prototypes, while more were available at the workshop if individuals needed more inspiration. At the end of the workshop each paper prototype was presented between groups and assessed by a jury.

2.1 Workshop Takeaways

While brainstorming BCI games, the CP adolescent brought it to our attention that opening or relaxing ones fist, after grasping it, can be equally, or even more difficult for people struggling with CP. Because of this insight, the mapping was changed for the MI training of the hand to that of opening it, instead of closing the hand. Additionally, both the CP- and BCI expert said that the priority of CP rehabilitation should always be that there was an attempt made at MI BCI, rather than focusing on how well the attempt was.

The BCI game idea 'Aim for the Moon' rewarded the player regardless of their performance by not giving negative feedback to the user, when they failed to perform MI and instead giving them positive feedback, see Figure 1 to the right. They achieved it by making every successful MI BCI input hit the moon, while a failed MI BCI input would miss the moon, but turn the shot into a star. This meant failing in performing the task would not demotivate them as strongly.

The BCI game idea 'Pokemon Snap-like' explored the interactions the player could do while they were supposed to be in the resting phase, in between each MI BCI exercise.They had chosen a metaphor of taking pictures, where taking a picture was done with MI BCI input, and the breaks in between BCI usage was used to adjust the camera frame, by moving to the left or right, see Figure 1 to the left. This would provide the player with something to do, that is important to the game, in their downtime. Being in the resting phase would therefore not feel like wasted time, and by extension, can maybe keep them more motivated to continue.

The 'Phase Shifting' BCI game idea used the same MI BCI input for different sub-tasks, the first subtask being to kill and loot enemies for resources, and the next for spending the resource and building, see Figure 2. The game swaps between these two phases, where the MI BCI input is required to defeat incoming enemies or build the house.

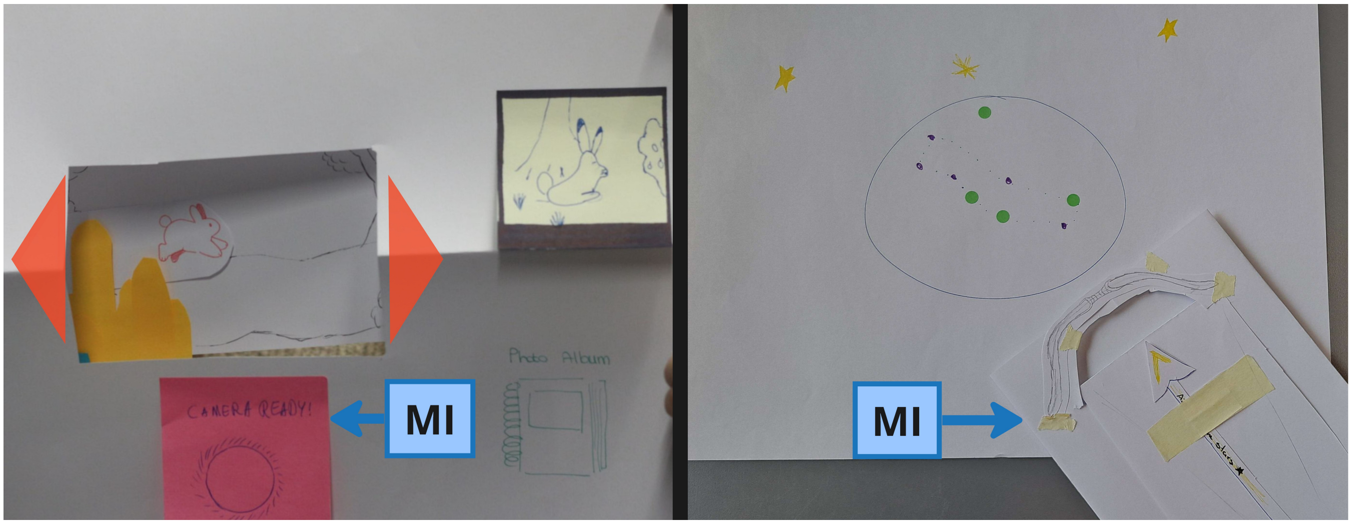

Figure 1: Left figure shows the 'Pokemon Snap-like' game, which have the player move left or right, for then to snap pictures of animals. Right figure shows the game 'Aim for the Moon' where the player shoots stars in a pattern, creating a constellation.

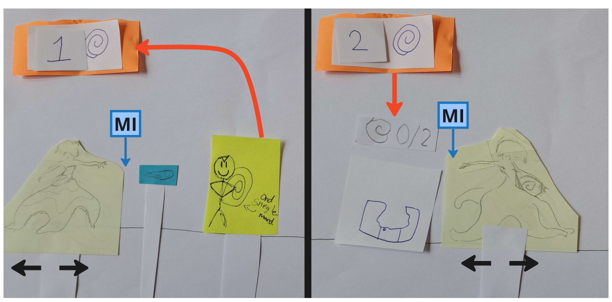

Figure 2: 'Phase Shifting' Prototype. Left Picture shows the first phase, where the player shoots enemies, which gives resources. Right picture shows phase two, where the player spends resources to build houses.

2.2 CP Adolescent Interview

As part of the workshop we had a combined interview with the CP adolescent and CP expert to gain better insight of their personal and professional experiences with CP. We asked them about how it is to stay concentrated throughout a session or if they have any experiences with video games. The interview transcription was analysed, which gave the following insights: a) CP expert mentioned how the ability to stay concentrated varied a lot between CP adolescents, some may only stay concentrated for 5 min. "But then it might be that if you do something that catches [attention], like a computer game, if that's what catches [attention], then you can actually spend more time." (translated to English from Danish). b) The CP expert said the game should be challenging, but in the end you still succeed. "(...) It is what we aim for, that one should make an effort, but succeed. That is awesome. It creates motivation, and then you can stick with it longer. I mean, there is nothing worse than constantly losing." (translated to English from Danish). c) CP adolescents can easily feel overwhelmed by too much stimulation from both visual- and auditory feedback. The CP adolescent mentioned games that has the option of reducing feedback, but due to missing signifiers, or difficulty of discoverability, it is a hidden affordance in most of the games. Therefore there should be minimal visual- and auditory feedback, or an option to lower the amount of feedback. d) The CP adolescent from the interview does not play many video games but do like to play the app game called Candy Crush Saga on their smartphone, which is a turn based grid puzzle, where the player clicks on matching icons, when more than 3 are adjacent, where they will then disappear, giving points, and a rearranging will happen of the icons, to fill in the empty space, before the game repeats. The icons are generally very saturated colours, depicting candy, overlaid on an environment. It does however keep a very simplistic style, which might help to not visually overstimulate. The CP adolescent at the workshop mentioned their difficulty of holding a game controller due to their limited hand function, but were able to play games on their smartphone. Therefore, a touch screen was used as input alongside the BCI due to its accessibility. The BCI expert also recommended reaching a requirement of 80-100 MI BCI exercises in total within 30-60 minutes of playtime, which also corresponds with non-BCI CP rehabilitation exercises [22, 23, 24].

To summarise, it is important to design with a touch screen in mind and not add too many visual or auditory elements that can overstimulate. We should also avoid having gameplay that require the player to display good precision skills, and prioritise motivating them to play, by making them succeed regardless of their game performance. Lastly the game should have the requirement of having 80-100 MI BCI exercises during 30-60 minutes playtime.

3 GAME DESIGN

Similar to the 'Phase Shifting' BCI game idea of switching between phases (see Figure 2), our game switches between two phases of non-BCI and BCI, where the non-BCI phase will work as the break in between the sets of MI BCI repetitions. The reason for separating these, is to provide us with more control over the variables, so we can make all of them static, and as such make sure the output (mana) is identical for each participant. Time is the only variable that may differ between participants. This is influenced by the physical exercise structure and CP physical rehabilitation, where each exercise is done in a number of repetitions per set with breaks in between each set [23].

To make it less punishing for CP players, it was decided to only use BCI input during the second phase, which involved building, as it lacks the time-sensitive nature of action games, and can instead be kept very simple, which follows more in line of some of the CP game guidelines compiled by Hernandez et al. [18].

In the non-BCI phase, the player taps the touch screen to launch an attack on the tapped location, which will kill anything within a large radius, during the sub phase 'Tap to attack' in Figure 3. After successfully killing an enemy, the player gains mana as seen in the sub phase 'Attack cooldown' in Figure 3. Additionally, there is technically a two seconds attack cooldown, where one second is due to the animation of firing the magic projectile from the top of the castle down to the enemies, and the other second being the lingering effect on the ground.

Several things was done to improve the experience of CP players, to motivate them. To make use of the "*unit effect*", the player would get 100 mana when enemies died instead of just one, as it should inflate the perceived worth they experience [25].

The enemies that approach the castle are also automatically killed after on average 20±3 seconds and the player is then rewarded with mana. This ensures players can not fail the game, and to make sure that all participants have the same amount of resources, regardless of their own ability to click and kill the enemies.

The non-BCI phase makes it so we can control the output (mana) of the non-BCI phase, and make sure that it is identical for each participant.

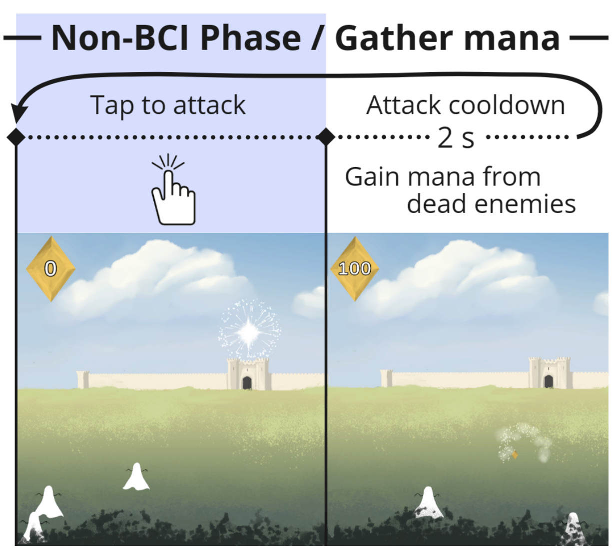

Figure 3: Non-BCI phase where the player gathers mana.

In the beginning of the BCI phase seen at Figure 6, the player is required to choose between various building blocks, and selection is done by tapping the touch screen (in the 'Tap to select block' sub phase in Figure 6). There are nine different building blocks, where three of them are walls, and six are decorations that are layered on a placed wall-piece. Then the player is given three seconds to mentally prepare themselves before they need to perform MI BCI (in the 'Prepare' sub phase in Figure 6). In those three seconds, the in-game character goes from an idle animation, where the character's arms are relaxed, to a prepare-animation where the character has raised their arm holding the wand. Additionally, an animated hand will appear and continuously demonstrate the MI BCI exercise, by going from closed fist to open hand. It will then disappear to avoid triggering any mirror neurons when the program starts recording the actual exercise performance, see 1.1. The sub phase 'Conjure block' then starts (see Figure 6), which is a BCI input window of five seconds. During the input window the player has to perform MI BCI in order to conjure the chosen building block by visualising their hand opening.

Inspired by the 'Phase Shifting Game' and word association game from the workshop, we saw a connection between magic and the MI BCI exercise, as the practice of opening the hand felt close to casting a spell of conjuring something. As such we wanted to establish a strong connection, so the MI exercise felt natural to do, as this could lead to a more intuitive play experience for the user. We attempted to establish a natural time coupling, by adding changes to the effects depending on the performance of the MI BCI input, to better provide the player with feedback. Magical particles therefore appear above the player character as continuous feedback that changes size and colour depending on the confidence level of the continuous signal, to provide the player with a stronger sense of agency (See Section 1.1), where it goes from small red to large green the more confident the MI BCI model is that the player is performing MI BCI (see Figure 4).

Depending on the player's BCI performance during the sub phase of Conjure block, the chosen appearance of the building block change accordingly (see Figure 5). Inspired by 'Aim for the Moon' game idea from the workshop, as well as the PAM called Mitigated Failure [26], the system does not punish the player as harshly for a failed input. Instead of having a failed output, such as the building block not conjuring, and losing the mana. A failed input leads to a more neutral output of conjuring a less appealing building block, e.g. a cracked stone wall (see Figure 5). A successful input gives a successful output of conjuring a building block without cracks. Additionally, another threshold called shiny was made above the successful input, where if the player reaches this threshold, they would conjure a shiny building block that was more opulent than the normal block.

After a building block has been conjured, the player taps the screen to place the building block at the desired location (see sub phase 'Tap to place block' in Figure 6). The placement of building blocks use a snapping grid-base method to limit the need for precise positioning and aiming, of which people with CP have been found to struggle with [18].
For the evaluation, a time limit of nine seconds was implemented for the 'Tap to select block' sub phase, and 10 seconds for the 'Tap to place block' sub phase in Figure 6. This was done to avoid

participants exploiting the game, if they decided to do nothing for a prolonged time period, which in turn extends the duration of the overall test. But for a final version of this game, this time limit should be removed, as people with CP have a harder time when it comes to time constraints [18]. The 'Tap to select block' sub phase is 9 seconds, one second shorter, because it takes the block one second to be placed after the 'Tap to place block' sub phase.

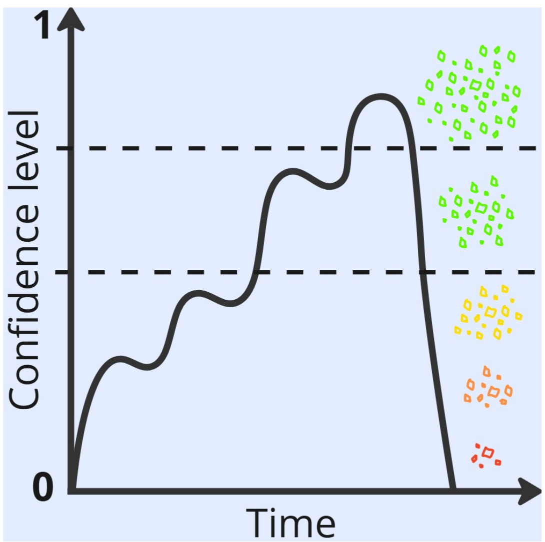

Figure 4: A low confidence level, close to zero, would result in a low, dense quantity of red magical particles while a high confidence, close to one, would result in a large, scattered quantity of green magical particles.

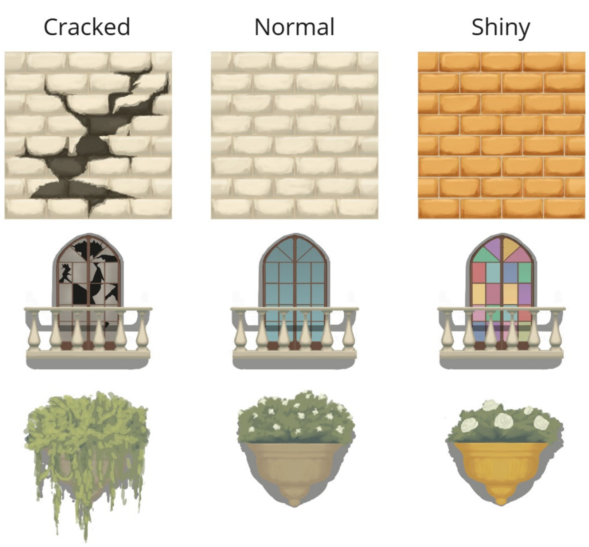

Figure 5: Three building block examples of the three different outcomes: cracked, normal, and shiny.

3.1 Game Structure

We had a game design requirement of reaching 80-100 BCI exercises in total within 30-60 minutes of playtime as it was recommended by the BCI expert. A paper prototype was made of the initial game idea to test how many building blocks could be placed before a break was required. The paper prototype was tested within the group and we concluded 24 MI BCI repetitions per set (reps per set) as a maximum. The minimum MI BCI reps per set was considered to be five, which was derived from a previous study [20]. However, the design of the game went through many iterations since the paper prototype was made, and with the final game design, it was also decided to test the extremities of low and high intensity game structures. To fulfil the game design requirement, we calculated and playtested within the group, different game structures with varying low and high intensity number of MI BCI reps per set, where five and 24 were used as a baseline to work from. Finally, we decided on a low intensity of six MI BCI reps in sets of 15, while the high intensity was set to 30 MI BCI reps in sets of three. Both of these intensities result in a total of 90 MI BCI exercises in an estimate of 60 minutes of playtime. For evaluation purposes, the playtime of each game structure is cut down to 1/3, which means participants will reach 30 MI BCI exercises in total within 20 minutes of playtime for each game structure. Figure 7 shows the low- and high intensity game structures that will be referred to as Low Intensity A and High Intensity B respectively. Additionally, a control game structure called Control C was made (see Figure 7), where the participants could swap freely between the non-BCI phase and BCI phase, but with a limit of 30 MI BCI exercises in total. Thus, when the participant gathered enough mana to perform 30 MI BCI exercises, they would be forced back to the BCI phase, to finish the MI BCI exercises.

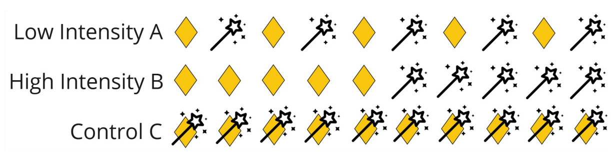

Figure 7: Game structures of Low Intensity A, High Intensity B, and Control C, where the yellow gems are non-BCI phases, the magic wands are BCI phases, and the combined yellow gems with a magic wand indicate the free choice of swapping between phases.

4 EXPERIMENTAL DESIGN

For our study, the dependent variables are enjoyment and mental fatigue, while the independent variable is number of MI BCI reps per set. We created the three conditions called: Low Intensity A, High Intensity B, and Control C. Low Intensity A (see Figure 7) has longer breaks followed by longer exercise sessions where the participant is required to perform 30 MI BCI reps per set. High Intensity B (see Figure 7) has shorter breaks followed by shorter exercise sessions where the participant is required to perform six MI BCI reps per set. The required numbers of MI BCI reps per set used for Low Intensity A and High Intensity B were attained through lo-fi and hi-fi prototype testing within the research group. In Control C,

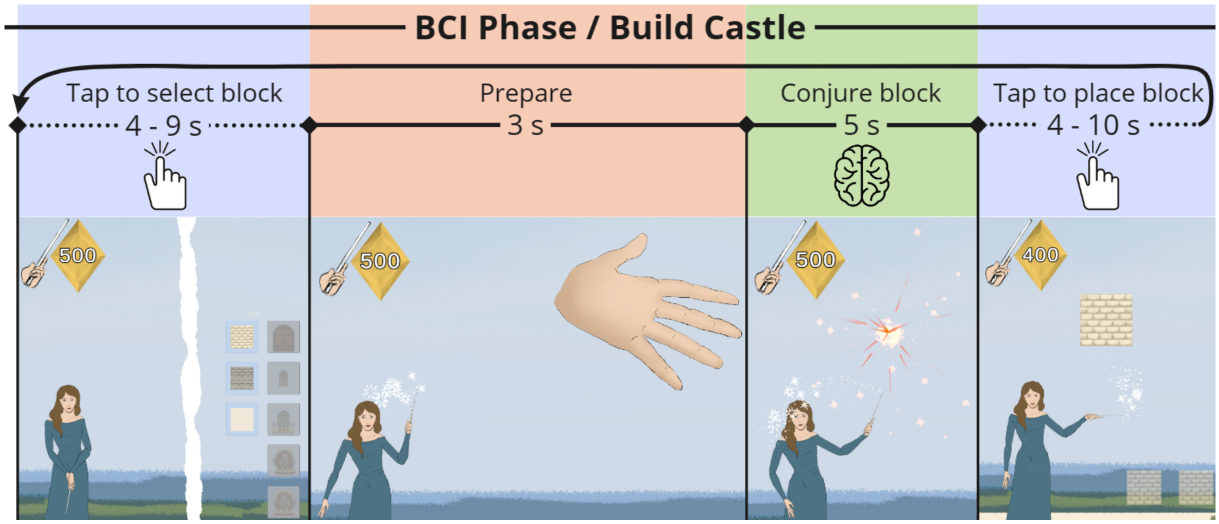

Figure 6: BCI phase where the player builds their castle.

the participant decides when to switch between break and exercise, however, there is a limit to the break duration, which eventually forces the participant to exercise until they reach the evaluation limit of 30 MI BCI exercises in total (see Figure 7).
We will evaluate these conditions using a within-subjects experimental design, incorporating a Latin square method to vary the order of conditions. The following hypotheses were made:
1. Low Intensity A results in a low mental fatigue and high enjoyment.
2. High Intensity B results in a high mental fatigue and low enjoyment.
3. The task performance of Low Intensity A will have a lower failure rate compared to High Intensity B.
4. Control C results in game structures closer to Low Intensity A than High Intensity B, but with more MI BCI exercises per set than six.

Mental fatigue and enjoyment will be quantified through a custom made questionnaire, where the questions are inspired by NASA-TLX[27] and Player Experience Inventory (PXI)[28]. There is at minimum two questions that each inquire about the same, but worded semantically different. There are three categories, the first being in regards to 'Perform BCI'. Here we looked for their sense of mastery at performing MI BCI, their effort, and mental strain, e.g., "It was mentally demanding to perform BCI". Then the second category 'Castle' was in regards to the feedback given through the quality of the building blocks, which we considered our control category so we do not expect any differences between the participants' answers. Lastly was the 'Game structure', here the questions were similar to 'Perfrom BCI' but were directed towards the game structure itself rather than performing BCI, e.g., "It was mentally demanding to play this game structure". Additionally, we had two sub categories: 'Enjoyment' and 'Mental Fatigue', which are both positive and negative loaded questions within the categories of 'Perform BCI' and 'Game structure', e.g., "I thought it was fun to play this game structure". The questionnaire were answered using a 5-point Likert scale going from strongly disagree to strongly agree.

4.1 Participants

Twelve healthy participants took part in the study. One female and 11 male participants between the ages 21-28 years. Six participants had previously tried BCI once or twice in another experiment. All 12 participants described themselves as having a lot of gaming experience.

4.2 BCI System

The BCI used in this study was a project made in OpenVIBE Designer [29] that was given to us by our institution. We used a Cyton Biosensing Board and EEG Electrode Cap Kit with the OpenVIBE project, to get continuous EEG signal. We recorded the EEG signal from F3, F4, C3, CZ, C4, P3 and P4, where the signals were grounded at FZ and referenced to PZ. The signal were sampled with a sampling rate of 250 Hz.

A flowchart showing the process, from calibrating the BCI to using it as a classifier, can be seen in Figure 8. First the calibration of the BCI was done by the participant, where they had to mentally perform 30 movements of the left hand opening. When doing the calibration, the participant would sit and either perform MI or relax. The calibration consists of an input window of 3.75 seconds, where they have to perform MI. Before that an arrow pointing to the left is shown for 1.25 seconds, indicating that they need to perform MI soon. After the input window, the participants have a rest window of 5 seconds, where they need to rest and not focus on doing MI. Between phases, there is a time window of 1.5 seconds, where the participants can do what they want. When the participant has done this 30 times, we now have data of them when they relax and when they perform MI, which can be used to classify.

A 5th order Butterworth Band pass filter, which filtered between 8-30 Hz was applied to the calibration data. Afterwards the signal was filtered with a common spatial filter, where the coefficients were determined by the calibration data.

The features were used in a Linear discriminant analysis classifier, which used a 5-fold cross validation. The linear discriminant analysis was used along with the coefficients of the common spatial filter to finally classify if the participant is doing MI. The final MI Classifier would take continuous online EEG data, and produce a confidence level of how confident the classifier is that the participant is doing MI, ranging from 0 to 1. The OpenVIBE project would provide us with a real-time graph of their confidence level. Before testing, the participant would be asked to perform MI, and from the graph we chose a threshold-value in a Unity project. We also made the shiny threshold to be 0.1 larger than the normal threshold. The continuous output signal of the OpenVIBE project was streamed to the Unity project and used as input for the game.

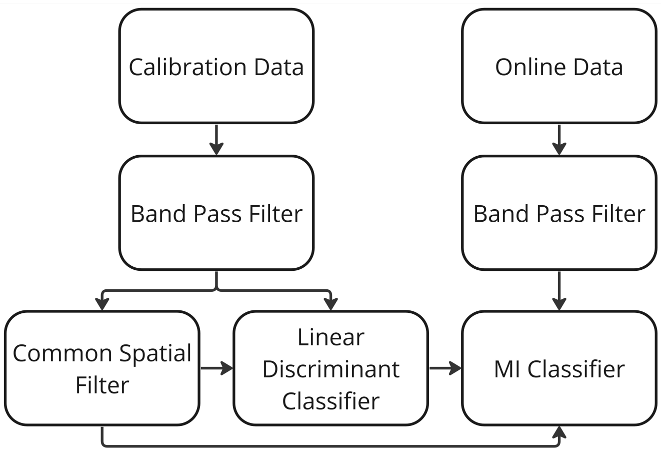

Figure 8: A flowchart showing the different stages of creating the MI Classifier.

4.3 Procedure and Apparatus

The participant was first informed of the intention and process of the experiment, then they were requested to read and sign the consent form. Once the consent form was signed, the participant had to fill out a demographic questionnaire. Afterwards, they were outfitted with a BCI electrode cap, which was hooked up to the BCI board through electrodes. The holes of the BCI electrode cap were then filled with gel to connect the electrodes with the participant's scalp. Before proceeding to the next step, impedance was checked for each electrode, if they were not below 40 (preferably 20), we would have to add more gel to enhance the connection. Next the eye-tracker was calibrated. The participant was then tasked with performing the MI BCI exercises to calibrate the BCI model. Once the calibration was done, and a classifier had been trained, the BCI threshold was set manually by the researchers. Afterwards, the participant would watch an instructional video that showed how the game was played, while an instructor explained what what seen in the instructional video. The instructor would then answer any questions that the participant may have had. When the participant felt they understood the game, they then needed to pick a word from 18 emotions (six positive, neutral and negative) describing their initial mental state. With the test condition and recording software set, the program was then run and logged. After each condition, the participant filled out the questionnaire and then a short structured interview was conducted. The structured interview consisted of the participant picking a word for each question (from the same 18 words) to describe their experience of building, gathering mana, and the game structure itself. Then they were shown a picture of their finished castle and asked to describe it to us. Once all the three conditions were finished, a recording device was activated and a semi-structured interview was conducted. At one point during the semi structured interview, picture of the participant's three castles were displayed, to provide them an overview and not rely on the participant's memory, e.g., when asked which castle they preferred.

5 RESULTS

Post-Condition Questionnaire data and the mean and max BCI confidence levels were tested for normality using Shapiro-Wilk test. All which resulted in a non-normal distribution except for the mean BCI confidence values of Low Intensity A and High Intensity B. Since only two of the conditions have a normal distribution, we went with the safest approach of performing a non-parametric test. A test was considered significant when the p-value is below 0.05.

5.1 Post-Condition Perceived Experience

Prior to the study, the participants state of mind was a tie between the negative and positive words, where the most frequent words were tired and relaxed.

The overall perceived experience of Low Intensity A was mostly positive when looking at Figure 9 and Table 1, where a positive word was picked 18 times out of 36, while neutral and negative words were each picked nine times. Only considering the most frequently picked word(s) (see Figure 9), then the participants would describe their experience in the BCI phase as engaging and frustrating, while the non-BCI phase was exciting, and the game structure itself when swapping many times between BCI and non-BCI was experienced as engaging.

The High Intensity B condition has been overall perceived as neutral when looking at Figure 10 and Table 1, where a neutral word was picked 15 times out of 36, while a positive word was picked 14 times, and a negative word was picked seven times. If only the most frequently picked word(s) were considered (see Figure 10), then the participants would describe their BCI experience to be calming, while the non-BCI experience was uninteresting and indifferent. Lastly, the game structure itself of performing many BCI exercise repetitions after each other was experienced as indifferent and content.

The Control C condition was overall perceived by the participants as both neutral and positive when looking at Figure 11 and Table 1, where a neutral and positive word was picked 13 and 14 times out of 36, respectively, and a negative word was picked nine times. Considering only the most frequently picked words (see Figure 11), then the participants described their BCI experience as frustrating (one participant mentions that this was due to the touchscreen malfunction of not registering their interactions), while the non-BCI experience was engaging, and the game structure itself of

giving the participant control to swap between phases as they wish was considered to be calming.
These observations of each condition shows that the participants had a slightly more positive perceived experience in Low Intensity A, and all of the conditions had a generally, equally, low negative perceived experience. By comparing the perceived experience of the game structures alone from the words clouds (see Figure 9, Figure 10, and Figure 11), Low Intensity A had a more positive perceived experience while High Intensity B and Control C were more neutral. Although, creating a contingency table of Table 1 and performing the Chi-Squared test reveals that there are no significant differences between negative, neutral, and positive words across conditions (*p*=.6).

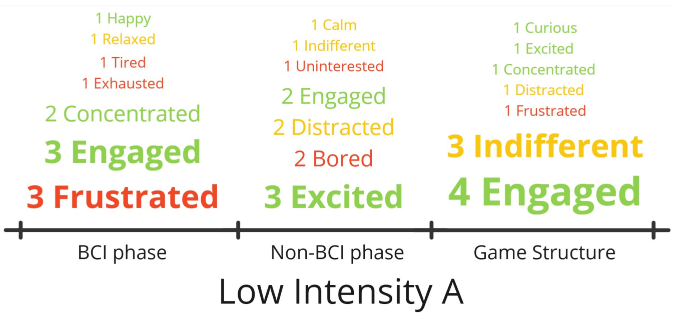

Figure 9: Word cloud of each participants' perceived experience.

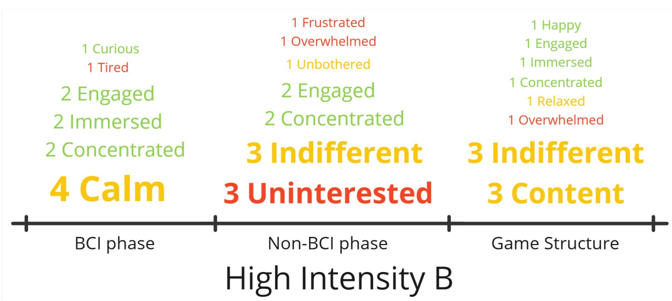

Figure 10: Word cloud of each participants' perceived experience.

Total frequency	Negative	Neutral	Positive
Low Intensity A	9	9	18
High Intensity B	7	15	14
Control C	9	13	14

Table 1: The total frequency of negative, neutral, and positive words across each condition.

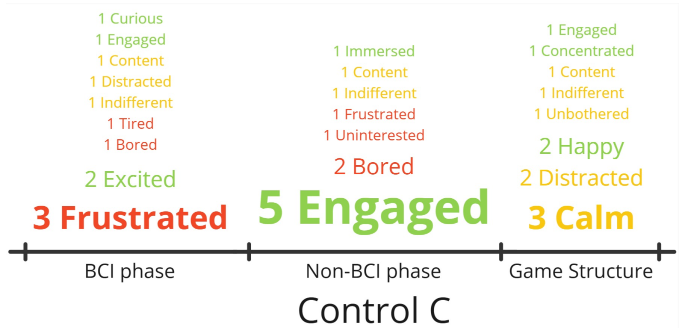

Figure 11: Word cloud of each participants' perceived experience.

5.2 Post-Condition Questionnaire

The results of the post-condition questionnaire are presented in Figure 12 and the scatter plot in Figure 14. Kruskal-Wallis H test was performed to detect any differences in median between the three conditions: Low Intensity A, High Intensity B, and Control C. However, the high overall *p*-value of 0.995 indicates that there is no significant difference, which is also seen by looking at the visualisation on Figure 13, where there are little to no difference between the percentiles of each condition. The Kruskal-Wallis H test was also performed on the categories: 'BCI', 'Castle', 'Game structure' and the sub categories: 'Enjoyment' and 'Mental fatigue' (see Figure 12). Although there were no significant difference found in any of the categories and sub categories.

Figure 14 shows the relationship between mental fatigue and enjoyment for each condition. Low Intensity A and High Intensity B have a very similar trendline that are only offset by 0.5 on the x-axis (enjoyment), while the mental fatigue stays the same. The trendline of Control C is almost parallel with the x-axis, but starts and ends slightly lower on the y-axis. These trendlines indicate that Control C was in general found less exhausting compared to the other two conditions. However, the relationship between mental fatigue and enjoyment across the three conditions are not significantly different enough.

Kruskal-Wallis	P-value	Low Intensity A	High Intensity B	Control C
All	0.995	[2.5, 3.0, 3.625]	[2.875, 3.0, 3.5]	[2.75, 3.0, 3.625]
Perform BCI	0.853	[2.375, 4.0, 4.0]	[3.0, 4.0, 4.0]	[2.5, 3.25, 4.0]
Castle	0.833	[3.0, 3.5, 4.25]	[2.75, 4.0, 4.25]	[3.0, 3.5, 4.0]
Game structure	0.393	[2.0, 3.0, 3.25]	[1.75, 2.5, 3.0]	[2.0, 2.0, 3.0]
Enjoyment	0.583	[2.875, 3.5, 4.0]	[2.875, 4.0, 4,125]	[2.875, 3.5, 4.0]
Mental fatigue	0.996	[3.5, 3.5, 4.0]	[3.0, 3.75, 4.0]	[3.0, 3.75, 4.0]

Figure 12: Result summary of the post-condition questionnaire. The results in the third and fourth columns are presented as percentiles [25, median, and 75].

5.3 Task Performance

In Low Intensity A, High Intensity B, and Control C, participants got an average of 17±8, 20±10, and 19±9 non-cracked building blocks and 13±8, 10±10, and 11±9 cracked building blocks, respectively (see Table 2). This results in a failure rate of 44±28%, 35±34%

Figure 13: Box plot containing the total median of all questionnaire data for each participant.

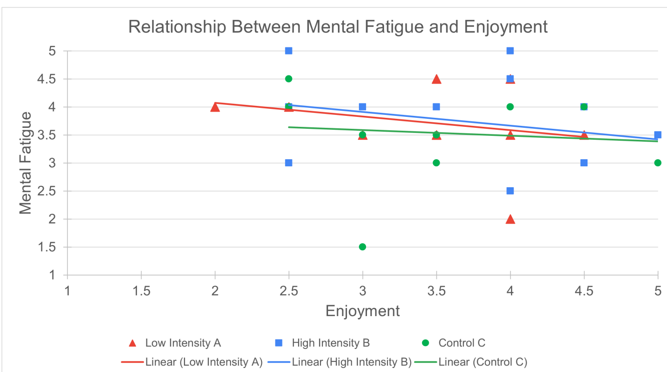

Figure 14: Scatter plot that shows the relationship between mental fatigue and enjoyment for each condition.

and 38±31% for the conditions Low Intensity A, High Intensity B, and Control C, respectively. To check if there is a significant difference between the observed frequency of cracked, normal, and shiny outcomes, we performed a Chi-Squared test (see the table in Figure 15). When looking at all of the outcomes across the conditions there is a significant difference (p<.035). In order to find out where exactly there is a significant difference, the Chi-squared test was performed pairwise between outcomes (see table in Figure 15). Across all conditions there is a significant difference in the observed frequency of outcomes between 'Cracked vs Non-cracked', 'Shiny vs normal', and 'Shiny vs Cracked'. Afterwards, the Chi-squared was performed pairwise between conditions to identify the exact point of significant difference. It was found that there is a significant difference in the observed frequency of shiny and cracked outcomes between Low Intensity A and High Intensity B (p<.016) as well as between Low Intensity A and Control C (p<.022). Additionally, there was a significant difference when considering only cracked and non-cracked outcomes between Low Intensity A and High Intensity B (p<.02). However, there was no significant difference found in any of the pairwise condition comparisons regarding 'Shiny vs Normal', despite the p-value across all conditions saying

Per participant avg.	Non-cracked	Cracked	Failure rate
Low Intensity A	17±8	13±8	44±28 %
High Intensity B	20±10	10±10	35±34 %
Control C	19±9	11±9	38±31 %

Table 2: The cracked and non-cracked columns contain the average and standard deviation of each respective condition while the Failure rate column contain the average and standard deviation in percentage of each respective condition.

Total count	Shiny	Normal	Cracked	Non-cracked
Low Intensity A	102	100	158	202
High Intensity B	124	111	125	235
Control C	132	92	130	224

Table 3: The total count of shiny, normal, and cracked building blocks achieved per condition.

otherwise. The lack of significance in pairwise comparisons suggests that the observed difference are not significant when looking at each condition individually. This could mean that while there may be a general trend across all conditions combined, this trend might not hold when looking at each condition separately. The significant difference between Low Intensity A and High Intensity B in 'Shiny vs Cracked' (see table in Figure 15) confirms that the task performance was better in High Intensity B than Low Intensity A due to the higher total count of shiny and non-cracked (see Table 3). The confidence level of whether or not the participant is resting or performing the MI BCI exercise was collected for each of the 30 MI BCI input windows. The mean and max confidence values were calculated for each input window, to then perform a Kruskal-Wallis H test. No significant difference of either the mean- or max BCI confidence levels across conditions (p=.37) was found, which means that the participants are not better at performing the MI BCI exercise in one condition compared to the other.

Chi-squared P-values	All outcomes	Cracked vs Non-cracked	Shiny vs Normal	Normal vs Cracked	Shiny vs Cracked
Low Intensity A vs High Intensity B vs Control C	0.0348	0.0293	0.0494	0.2201	0.0158
Low Intensity A vs High Intensity B	0.0202	0.0101	0.0533	0.1231	0.0153
High Intensity B vs Control C	0.0875	0.1091	0.0696	0.1185	0.0791
Low Intensity A vs Control C	0.0179	0.0846	0.0819	0.5378	0.0219

Figure 15: Chi-squared p-values across conditions and observed frequency outcomes.

5.4 Post-Experiment Interview

When looking at the participants' perceived experience of each game structure in Figure 9, Figure 10, and Figure 11, they picked a positive word seven times for Low Intensity A, while High Intensity B and Control C had seven and eight neutral words picked, respectively. However, when participants were asked which game structure was their preferred in the post-experiment interview, all three conditions tied by four votes. The four participants, who picked Control C, preferred it due to the ability of swapping between phases when desired. However, one of the four participants did mention that they enjoyed building and would probably overtime, play similar to High Intensity B. The four participants, who picked High Intensity B, preferred it because Low Intensity A felt distracting, due to the frequent swaps between phases. One of the four participants said: "I feel that I get distracted [from the BCI phase], especially in [Low Intensity A], where it took some time because I needed to find my rhythm again [after switching from phase to phase]". The last four participants, who picked Low Intensity A, preferred it because the game structure decided when to swap the phases (compared to Control C), and the frequent swaps made it feel like there was a connection between the two phases. Two of the four participants mention that it was distracting to decide when to swap phases in Control C, where instead the Low Intensity A removed the mental demand required to think about when to swap.

Three out of the four participants, who preferred High Intensity B, showed a disinterest in the non-BCI phase. When they would describe how many MI BCI exercise repetitions they could perform before going to the non-BCI phase, two of them stated 30, and one stated 24. The two participants that said 30, had no issue with mentally performing for that long, and felt it was more frustrating when they were interrupted by the BCI phase and forced to play the non-BCI phase. They also said that they could easily take more than 30 exercise repetitions, but did not specify how many.

When looking at the nine other participants (four Low Intensity A, four Control C, and one High Intensity B) the preferred threshold of MI BCI reps per set is much closer to each other, with an average of 8±2 MI BCI reps per set.

Other than the preferred game structure, the participants were also asked about their preferred castle. Nine of the participants picked their preferred castle based on which looked the prettiest regarding symmetry and/or the amount of golden building blocks (see Figure 16). The last three participants picked based on which one looked the most fun to them, e.g., one built a tall tower, another made a T-pose, whilst a third made a tower looking like the crane machine (see Figure 16).

Additionally, 11 of the participants had correctly perceived their best performing game structure to be the same as their actual best performance, when compared to the numbers shown in Table 2. High Intensity B and Control C had both four participants each, while one participant had the same success rate in both. Three participants performed best in Control C.

Between all three questions regarding preferred game structure, preferred castle, and best performance, only two participants picked the same game structure for all three questions. While four participants had picked the same game structure for preferred game structure and preferred castle, and five participants picked the same game structure for preferred castle and best performance. The last participant had picked a different game structure for each question.

Figure 16: Examples of two participants' preferred castle based on different qualities.

6 DISCUSSION

Contrary to our two first hypotheses that predict Low Intensity A and High Intensity B would result in low mental fatigue with high enjoyment, and high mental fatigue with low enjoyment, respectively, the observed data from the questionnaire revealed no significant differences between conditions. This lack of differentiation suggests that the different game structures did not have a distinct impact on the participants' experience of mental fatigue and enjoyment. Additionally, the scatter plot data (see Figure 14) shows considerable variability within each condition. Some participants experienced high mental fatigue coupled with low enjoyment, while others reported the opposite within the same condition. This wide distribution indicates that individual differences may play a more significant role in influencing mental fatigue and enjoyment than the conditions themselves. Several factors could contribute to this unexpected outcome, such as personal traits like resilience or the participants' mood at the time of the experiment. But an important factor to consider in our study is the potential impact of the order in which participants experienced the three conditions. While all participants were exposed to each condition, the sequence varied, which may have influenced their responses in terms of mental fatigue and enjoyment. Order effects, such as fatigue accumulation, learning effects, or changing attitudes over time, could significantly affect the outcome. For instance, participants who encountered High Intensity B first might have experienced fatigue in subsequent conditions, regardless of their nature. Conversely, participants starting with a more enjoyable condition might have set a higher baseline of enjoyment, influencing their perception of the following conditions. To better understand the potential influence of condition order, it is crucial to analyse the data by considering the sequence in which conditions were presented. This analysis could reveal patterns indicating whether participants' experience were significantly altered by the condition order. But it is then also important to consider the sample size, because we have 12 participants per condition, which will change to a sample size of two per condition order. Another aspect is participants' perceived experiences of each condition, which was revealed to have no significant difference. Although the perceived experience overall and game structure alone was more positive for Low Intensity A. In the end, we currently fail to reject the null hypotheses of the first and second hypotheses.

The third hypothesis predicted that the task performance in Low Intensity A would have a lower failure rate compared to High Intensity B. This prediction was based on the expectation that High Intensity B would induce higher mental fatigue, leading to poorer performance. The data collected from the participants' task performance do not support this hypothesis. There is a significant difference between the outcomes, specifically, the results for the shiny and cracked outcomes. However, it proves that participants were performing significantly better in High Intensity B and not Low Intensity A. A possible explanation of this outcome, could be due to an important insight one participant made that they preferred High Intensity B due to being able to better concentrate during the MI BCI input windows and swapping the phases felt like a distraction, however, we do not know if other participants felt the same. Another important factor that could impact the results is the order of condition as mentioned with the first hypotheses. Although in the end, We currently fail to reject the null hypothesis. The last hypothesis predicted that Control C would result in game structures more similar to Low Intensity A than High Intensity B, but with more MI BCI exercises per set than six. Through the semi structured interview, nine of the 12 participants (three outliers) agreed upon wanting a non-BCI break at 8±2 MI BCI reps per set. A game structure following 8±2 MI BCI reps per set confirms expectations, however, it was not reflected in the Control C data. Contrary to our hypothesis, the game structure that participants played in Control C resembled High Intensity B more closely than Low Intensity A. Several known factors contributed to this unexpected outcome, e.g., the three outliers expressed a lack of enjoyment in the non-BCI phase. The dislike led them to complete the non-BCI phase quickly, resulting in a higher intensity experience similar to High Intensity B. Another known factor was that the order in which Control C was presented influenced participant's behaviours. When Control C was played as the first condition, participants felt uncertain when to swap phases. This uncertainty have also led to a higher intensity experience, resembling High Intensity B. Additionally, one participant reported that they never felt it was a good time to swap phases because of the continuous attacks of the enemies. This perception of continuous threat distracted the participant of the option to swap phases and instead pushed them to stay in the non-BCI phase, inadvertently increasing the intensity of the BCI phase. Lastly, when participants were asked which game structure they preferred, it was a tie between all three conditions. This indicates that participants did not show a clear preference for any single game structure, suggesting that each condition had its own unique appeal. These findings suggests that while participants' stated preferences of 8±2 MI BCI reps per set that align with our hypothesis, their actual behaviour in Control C was influenced by factors such as task enjoyment, the sequence of conditions, and perceived game dynamics. Future studies should consider these influences when designing game structures. The hypothesis can only be accepted through qualitative data so we are inclined to not completely reject the null hypothesis.

6.1 Limitation

Prior to the study for each participant, we manually set the thresholds to obtain the Shiny and Normal building block outcome, based on each participant's MI BCI trained model. These thresholds remained unchanged throughout the experiment. However, opting for manual threshold setting, as opposed to using an algorithm, relies entirely on our judgement and may lead to inconsistent or biased threshold selections.

6.2 Data Validity

The collected eye tracker data was not viable due to the interruptions of the touch screen interactions. The lacking analysis of the analysis data regarding mental fatigue decreases the validity [30].

6.3 Source of Error

During the experiments, a notable issue arose with the touchscreen interface for five out of the 12 participants. They experienced difficulties where the hardware failed to register their touches accurately or, in some instances, registered unintended ghost touches. These technical issues compromised the study process, where occasionally we were forced to pause the experiment in an attempt to clean the touchscreen. Additionally, participants would have trouble performing tasks effectively, which resulted in frustration. This disruption could comprise the accuracy and reliability of the data collected during these periods.

7 CONCLUSION

In this study we presented an MI BCI game, of which we tested the impact of inserting non-BCI breaks in a BCI exercise session, through three game structures with different exercise intensities.

There was found no significant difference between game structures, in regards to the users' perceived enjoyment and mental fatigue.

It was found that participants had a better task performance, when playing a High Intensity B game structure compared to a Low Intensity A game structure.

Through qualitative data, it was found that the participants' on average wanted 8±2 MI BCI exercise repetitions before needing a break. Due to different errors this was not reflected from how they chose to play when given the freedom of choosing when to have breaks in Control C game structure. Therefore, the conclusion of the participants' preferred number of MI BCI exercise repetitions per set is inconclusive due to a mismatch between what participants say they want do and what they actually do.

8 ACKNOWLEDGEMENTS

Thanks to Hamzah Ziadeh for assisting with eye tracking, Mads R. Jochumsen and Dávid Gulyás for assisting with the BCI setup and Bastian I. Hougaard and Hendrik Knoche for supervising the paper. Thanks to the CP adolescent, CP expert, and everyone who decided to participate in the BCI Game Design workshop.

REFERENCES

[1] Jonathan R Wolpaw et al. "Brain–computer interfaces for communication and control". In: *Clinical Neurophysiology* 113.6 (June 2002), pp. 767–791. doi: 10.1016/S1388-2457(02)00057-3.

[2] Zeanna Jadavji et al. "Establishing a Clinical Brain-Computer Interface Program for Children With Severe Neurological Disabilities". In: *Curēus (Palo Alto, CA)* 14.6 (June 2022), pp. 26215–26215. doi: 10.7759/cureus.26215.

[3] Alex Kreilinger et al. "Switching between Manual Control and Brain-Computer Interface Using Long Term and Short Term Quality Measures". In: *Frontiers in Neuroscience* 5 (2012). issn: 1662-453X. doi: 10.3389/fnins.2011.00147. url: https://www.frontiersin.org/journals/neuroscience/articles/10.3389/fnins.2011.00147.

[4] Kaveena Kunasegaran et al. “Understanding mental fatigue and its detection: a comparative analysis of assessments and tools”. In: *PeerJ* 11 (Aug. 2023), pp. 15744–15744. DOI: 10.7717/peerj.15744.
[5] André Antunes et al. “Modeling Serious Games Design towards Engaging Children with Special Needs in Therapy”. In: *CHI PLAY ’21* (Oct. 2021), pp. 192–197. DOI: 10.1145/3450337.3483493.
[6] Loh Yong Joo et al. “A feasibility study using interactive commercial off-the-shelf computer gaming in upper limb rehabilitation in patients after stroke”. In: *Journal of rehabilitation medicine* 42 (5) (May 2010), pp. 437–441. DOI: 10.2340/16501977-0528.
[7] Bruno Bonnechére et al. “The use of commercial video games in rehabilitation: a systematic review”. In: *International Journal of Rehabilitation Research* 39 (Dec. 2016), pp. 277–290. DOI: 10.1097/mrr.0000000000000190.
[8] Bastian Ilsø Hougaard et al. “Who willed it? Decreasing Frustration by Manipulating Perceived Control through Fabricated Input for Stroke Rehabilitation BCI Games”. In: *Proceedings of the ACM on Human-Computer Interaction* 5 (Oct. 2021), pp. 1–19. DOI: 10.1145/3474662.
[9] Martí de Castro-Cros et al. “Effects of Gamification in BCI Functional Rehabilitation”. In: *Frontiers in Neuroscience* 14 (2020). ISSN: 1662-453X. DOI: 10.3389/fnins.2020.00882.
[10] Luca Bonini. “The Extended Mirror Neuron Network: Anatomy, Origin, and Functions Bonini, Luca”. In: *The Neuroscientisest* 23 (1) (Feb. 2017), pp. 56–67. DOI: 10.1177/1073858415626400.
[11] Karina Arrambide et al. “The Development of "Orbit": The Collaborative BCI Game for Children with AD(H)D”. In: *Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play Companion Extended Abstracts*. CHI PLAY ’19 Extended Abstracts. New York, NY, USA: Association for Computing Machinery, 2019, pp. 341–348. ISBN: 9781450368711. DOI: 10.1145/3341215.3356301.
[12] Damien Coyle et al. “EEG-based continuous control of a game using a 3 channel motor imagery BCI: BCI game”. In: *2011 IEEE Symposium on Computational Intelligence, Cognitive Algorithms, Mind, and Brain (CCMB)*. 2011, pp. 1–7. DOI: 10.1109/CCMB.2011.5952128.
[13] Sundhedsstyrelsen. “National klinisk retningslinje for fysioterapi og ergoterapi til børn og unge med nedsat funktionsevne som følge af cerebral parese – 9 udvalgte indsatser”. In: (Mar. 2014). URL: https://www.sst.dk/da/udgivelser/2014/nkr-cerebral-parese.
[14] Thomas K. K. Kjeldsen et al. “Effect of Continuous and Discrete Feedback on Agency and Frustration in a Brain-Computer Interface Virtual Reality Interaction”. In: *2021 IEEE 21st International Conference on Bioinformatics and Bioengineering (BIBE)*. 2021 IEEE 21st International Conference on Bioinformatics and Bioengineering (BIBE). IEEE, 2021-10-25, pp. 1–5. ISBN: 1-66544-262-X. DOI: 10.1109/BIBE52308.2021.9635586.
[15] S. A. G. Wensveen, J. P. Djajadiningrat, and C. J. Overbeeke. “Interaction frogger: a design framework to couple action and function through feedback and feedforward”. In: *Proceedings of the 5th Conference on Designing Interactive Systems: Processes, Practices, Methods, and Techniques*. DIS ’04. Cambridge, MA, USA: Association for Computing Machinery, 2004, pp. 177–184. ISBN: 1581137877. DOI: 10.1145/1013115.1013140.
[16] Robert Leeb et al. “Brain–Computer Communication: Motivation, Aim, and Impact of Exploring a Virtual Apartment”. In: *IEEE Transactions On Neural Systems And Rehabilitation Engineering* 15.4 (Dec. 2007), pp. 473–487. DOI: 10.1109/TNSRE.2007.906956.
[17] Elaine Biddissa et al. “Engaging children with cerebral palsy in interactive computer play-based motortherapies: theoretical perspectives”. In: *Disability and rehabilitation* 43 (1) (Aug. 2018), pp. 133–147. DOI: 10.1080/09638288.2019.1613681.
[18] Hamilton A. Hernandez et al. “Designing Action-based Exergames for Children with Cerebral Palsy”. In: New York, NY, USA: Association for Computing Machinery, 2013, pp. 1261–1270. ISBN: 9781450318990. DOI: 10.1145/2470654.2466164.
[19] Mads Jochumsen et al. “Implementing Performance Accommodation Mechanisms in Online BCI for Stroke Rehabilitation: A Study on Perceived Control and Frustration”. In: *Sensors* 22.23 (2022). ISSN: 1424-8220. DOI: 10.3390/s22239051.
[20] Daniel Dugenio Boiskov Hansen et al. “Comparing How Frequency of Motor Imagery Affects Immersion of BCI Rehabilitation Games for Children with Cerebral Palsy”. In: (2023). DOI: 10.21203/rs.3.rs-2450051/v1.
[21] Dave Gray, Sunni Brown, and James Macanufo. *Gamestorming: A Playbook for Innovators, Rulebreakers, and Changemakers*. 1st. O’Reilly, 2010, pp. 69–70 and 221–222. ISBN: 9780596804176.
[22] Shugeng Chen et al. “Longitudinal Electroencephalography Analysis in Subacute Stroke Patients During Intervention of Brain–Computer Interface With Exoskeleton Feedback”. In: *Frontiers in neuroscience* 14 (Aug. 2020), pp. 809–809. DOI: 10.3389/fnins.2020.00809.
[23] Helle Mätzke Rasmussen. “Implementering af styrketræning i den fysioterapeutiske behandling af børn med cerebral parese”. In: (Aug. 2009), pp. 0–60.
[24] Floriana Pichiorri et al. “Brain-Computer Interface Boosts Motor Imagery Practice during Stroke Recovery”. In: *Annals of neurology* 77.5 (2015), pp. 851–865. DOI: 10.1002/ana.24390.
[25] Mario Pandelaere, Barbara Briers, and Christophe Lembregts. “How to Make a 29% Increase Look Bigger: The Unit Effect in Option Comparisons”. In: *The Journal of consumer research* 38.2 (Aug. 2011), pp. 308–322. DOI: 10.1086/659000.
[26] Ingeborg Goll Rossau et al. “How can we help? Towards a design framework for performance-accommodation mechanisms for users struggling with input”. In: *CHI PLAY 2021* (Oct. 2021), pp. 10–16. DOI: 10.1145/3450337.3483497. URL: https://doi.org/10.1145/3450337.3483497.
[27] Sandra G. Hart and Lowell E. Staveland. “NASA Task Load Index”. In: 1st. Moffett Field, California: NASA Ames Research Center, 1986, pp. 1–19. URL: https://ntrs.nasa.gov/api/citations/20000021488/downloads/20000021488.pdf.
[28] Vero Vanden Abeele et al. “Development and validation of the player experience inventory: A scale to measure player experiences at the level of functional and psychosocial consequences”. In: *International Journal of Human-Computer Studies* 135 (Mar. 2020), p. 102370. DOI: 10.1016/j.ijhcs.2019.102370.
[29] Yann Renard et al. “OpenViBE: An Open-Source Software Platform to Design, Test and Use Brain-Computer Interfaces in Real and Virtual Environments”. In: *Presence : teleoperators and virtual environment* 19 (1) (Feb. 2010), pp. 35–53. DOI: 10.1162/pres.19.1.35.
[30] Luca Longo et al. “Human Mental Workload: A Survey and a Novel Inclusive Definition”. In: *Frontiers in Psychology* (July 2022). DOI: 10.3389/fpsyg.2022.969140.