BrainGames: Using Your Head For A Better Experience?

A study into the effect of noisetag BCI usage on immersion

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1. Abstract

This paper presents a study into the possibilities of expanding BCI use beyond clinical settings. In order to do so, effects of BCI use on immersion are investigated. The accompanying research question is 'Does the use of a noisetag-based BCI controlled with selective attention positively influence the experienced level of immersion of the player compared to controls with a mouse?'. Seventeen participants played two different games with either a sabotaged mouse or a BCI. Both games and both controllers were used once per subject. The two independent variables were SelG1, and SelG2, indicating the controller used for the first and second game, respectively. Comparisons were made between the two methods of selection to see whether there was a difference between them. This was done with two different dependent variables. The first was an indirect objective measure of immersion, task-completion time (TCT), measured through a puzzle task. The second was subjective immersion (ImSc), measured through questionnaires filled in by the participants. A one-way ANOVA showed that using the BCI did not differ significantly from using the mouse, both in terms of TCT and ImSc. This was the case in both games.

Keywords: Brain-Computer Interface, Games, Immersion, SSVEP, EEG, Selective Attention, Noisetag, VR

2. Introduction

Brain-computer interfaces (BCIs) enable people to control various machinery with their brains. While multiple types exist, all of them share in the fact that they pick up brain signals, and subsequently translate those to commands for the computer the device is connected to. The main intent of use is to restore various senses and physical functions of people with disabilities, including hearing, sight, and movement.

MindAffect is a company that is developing a noisetag BCI, additionally being the venture from which this study was carried out. Their main focus lies on enabling ALS patients to regain communicative options. Despite that, this paper focused on whether using a noisetag BCI within a game has any positive effects on the immersion of the user. Immersion can be seen as game involvement, and will be explained later. Since games have had a multitude of various modalities of control. The BCI could be the next big step for the industry. Games could benefit from this as well; BCIs could provide games with a very different input modality, thereby opening up new ways of gaming.

2.1. BCIs in games

Whereas the fields of BCIs, immersion, and games have been researched separately for years now, the combination of these disciplines is a rather novel endeavour. As of such, not much research exists in this area yet. In an attempt to explore the possibilities of this particular combination, this study shall focus on whether noisetag BCI usage in a game has any effects on the immersion of the user. Within such a game-like environment, immersion usually indicates a certain degree of involvement of the player with the game.

Investigating whether BCIs would be appreciated outside clinical settings could shed more light on the possibilities to expand to a wider audience. This would bring along more attention for BCIs, which in turn would improve possibilities for the original goals for BCI usage.

2.2. Premises of the study

This paper considered whether using a noisetag BCI has any positive effects on the immersion of the user. As the concept of immersion can have different interpretations, the assumed definition in this case is the amount of involvement someone has within a game. Indeed, as was shown by

Jennett et al. [19] and Nacke & Lindley [25], there exists a direct correlation between the level of immersion and the gaming experience, which is why this study focused on measuring immersion. Based on the above, the main research question is as follows:

R_0: "Does the use of a noisetag-based BCI controlled with selective attention positively influence the experienced level of immersion of the player compared to controls with a mouse?"

2.3. Related work

After the first BCI game was created by Vidal [33], there was not much progress into BCI games. The application he created more so 'happened' to be a game, and was an attempt at evaluating the possibilities of using brain signals in a human-computer conversation [32].

In 2005, Lalor et al. [21] were the first ones to evaluate the applicability of using a SSVEP-based BCI for binary control in a 3D game. Their results found the BCI performance to be quite robust to distracting visual stimulations, and relatively consistent across their subjects. From here on out, various other researchers started making attempts to combine BCIs and games.

Initially, the stimuli used to evoke brain activity consisted of stationary ones. Legény, Abad, & Lécuyer [23] integrated the visual stimuli with animated and moving objects found in the virtual environment. By doing so, the presented stimuli were animated and moving around the environment in a dynamic manner. According to their results, despite a reduction in performance in terms of speed, users tended to feel more immersed and preferred the controller integrated within the virtual scene. This trend of decreased performance versus increased preference is visible in other studies [6, 18]. However, Van de Laar, Gürkök, Bos, Poel, & Nijholt [20] found that players generally tended to view the BCI as a hindrance to their gaming experience, due to its slower performance.

There are various performance issues BCIs suffer from: low detection accuracy, reliability, information transfer rate, user acceptability [3], performance variability both within and between different subjects [17], in addition to BCI illiteracy [27]. Apart from that, there exists another important issue. As explained by Ahn, Lee, Choi, & Jun [2] in their work, the BCI community primarily aims at integrating a BCI into a game. This leads to reliable but not necessarily enjoyable games due to the focus on system performance or showing the feasibility of the BCI. The game community develops BCI games with the reverse priorities, placing entertainment above reliability. Therefore, BCI games may not yet have realized the full potential that they could have.

2.4. Structure

This paper is organized as follows: The concepts of immersion, measurement systems, and BCIs will be explored in Section 3. After having done so, Section 4 provides the methodological information of the empirical experiment. Section 5 presents the results from this experiment. In Section 6, conclusions regarding the hypotheses and research question will be drawn from the results. These are further discussed in Section 7.

3. Immersion & BCIs: a theoretic framework

Presence and immersion are common terms to indicate how much someone is drawn into a medium, especially when talking about games. However, both the exact definition of these terms as well as the rough interpretation of how they are understood are not very clear [7]. The concept of presence can be divided in multiple parts, all of which in some way include the perception of a (part of a) medium as belonging to reality [24]. While this usually concerns situations in virtual environments, presence is not limited to this. It also concerns topics surrounding agency and body ownership, as is the case with self-presence [28]. Immersion, on the other hand, is defined as an experience within a timeframe that is related to the experience with a medium [6, 19]. Usually, this medium is a game [19]. Furthermore, it tends to include multiple aspects, such as a heightened state of concentration (flow) and the sense of being part of the game, which is a part of 'presence'. An important distinction is that immersion includes the suspension of disbelief, indicating the willingness to let oneself be enveloped in the experience despite of its artificiality.

3.1. The aspects of immersion

Brown & Cairns [6] use the term immersion as a way to describe the degree of involvement a user has with a game. This degree changes with time and is controlled by barriers that can be lifted by either the game or the player. A different model was proposed by Ermi & Mäyrä [15], called the SCI-model, which includes the following three components: sensory, challenge-based, and imaginative immersion. Each of these components indicated a different kind of immersion, all of which could be present simultaneously.

Generally speaking, there are three concepts that are related to immersion: presence [24], flow [10], and cognitive absorption [1]. Although similar, differences do exist between these concepts.

The definition ‘the perceptual illusion of nonmediation’ of presence was formulated by Lombard & Ditton [24]. This referred to a situation where one’s senses fail to recognize or acknowledge the presence of a medium in his/her communication environment. In this case, ‘nonmediated’ was defined as a situation experienced without human-made technology. They furthermore defined six different conceptualizations of presence, namely ‘presence’ as social richness, realism, transportation, immersion, social actor within a medium, and as a medium being a social actor. The various kinds of presence do not stop there, however. A much-debated concept is self-presence. Generally seen, it considers how a user experiences him/herself within a virtual environment [4, 5, 28]. Lastly, there is also the extent to which presence influences the experienced emotions of the user of a medium. Called ‘presence as affect’, it indicates a relationship between presence and emotions [29].

Flow is a term first defined by Csikszentmihalyi & Csikszentmihalyi [10] as “the holistic sensation that people feel when they act with total involvement”. Flow arises once there is a balance in the perceived challenge and perceived level of skill for the player, which induces a hyper focus-like state of mind. This is, however, a rough interpretation, and the specifics of the concept are still much debated.

Cognitive absorption is a term coined by Agarwal & Karahana [1], which refers to a state of deep involvement with software. This definition can be specified further into more specific cases. The research of Agarwal & Karahana [1] suggests the existence of two beliefs that influence people’s regard of information technology, namely perceived usefulness and perceived ease of use [19].

As can be seen, there exists a variety of various kinds of ‘immersion’, especially when considering relatable concepts. However, ‘immersion’ as a concept tends to be related more to involvement in games than the others do. More specifically, it will be considered as the extent to which a user is involved with a game.

3.2. Measuring immersion

In order to provide information on what is causing changes in immersion, multiple studies have come up with ways to measure the experienced level of immersion within a player. Some of those use various questionnaires [18, 19, 25], whereas empirical measures are also employed. Nacke & Lindley [25] employed a combination of electromyography and galvanic skin response. From these measurements they derived a participant’s state of emotional valence and arousal, respectively. In theory, an indirect objective measure of immersion could be derived from these two values by combining them.

While it is not a direct measure of immersion, this method does pose an indirect way of measuring it. Not only that, Ehrsson et al. [14] showed that participants experiencing more ‘presence’ had stronger emotional responses. In this case, however, they considered presence instead of immersion. While similar, the two concepts are not identical.

Jennett et al. [19] carried out experiments which, among others, included switching from immersive to non-immersive tasks. While their research showed that the task-completion time on this task increased with a higher level of immersion, it remains an indirect measure of immersion instead of a direct one, therefore limiting reliability.

3.3. BCI effects on immersion

Much research has been done on the feasibility of various BCI applications. Less so, however, for any effects BCIs could have on immersion. When talking about BCIs, it is good to know what sort of paradigm is discussed, as there are multiple kinds with their own mechanics. Among others, there are: P300, based on the P300 peak in brain activity that occurs in response to a rare and awaited stimulus [13]; SSVEP, relies on responses that occur when a person focuses on a stimulus that flickers at a constant frequency. When looking at such a stimulus, an identical pattern can be seen in the user's EEG signals [12]; Motor imagination, which has participants think of specific motor actions in order to perform tasks, and is frequently used in navigational tasks [22, 26].

More specifically, this study will limit itself to a noisetagging-based BCI, which is further explained below.

3.3.1. Immersion through BCIs

Among the most-used paradigms is EEG, a typically non-invasive method. EEG stands for electroencephalography, which concerns the recording of electrical activity in the brain. One of the applications of EEG is the investigation of ERPs, event-related potentials. These consist of fluctuations in brain activity that can be linked to events, such as the press of a button. One of the ways in which these ERPs can be detected is through a VEP-based BCI. A VEP, visual evoked potential, is an electric potential in the brain that is caused by the subject being shown visual stimuli. What's more, depending on where the user looks, neural activity varies for different sites of the primary visual cortex [33].

A more specific kind of VEP-based BCI is one that uses the SSVEP paradigm. SSVEP stands for steady-state visually evoked potential, and is elicited when a presented visual stimulus is blinking at a certain frequency. There is a direct connection between elicited brain activity and stimuli blinking at different frequencies. This allows the BCI to detect what stimulus is being looked at by the user. As of such, it is considered to be an attention detection mechanism.

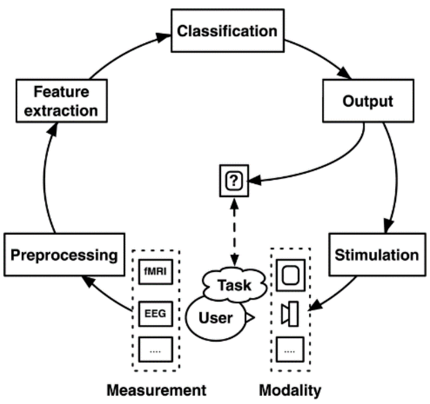

Figure 1. The general framework of BCIs [30]

Both the hardware and software of the BCI used for this study were developed at MindAffect. Additionally, the BCI was developed to use a method called noisetagging. Similar to SSVEP-based BCIs, noisetagging employs stimuli that flicker in various patterns to allow comparisons to be made with brain signals in order to determine what stimulus the user is focussing on. The difference between SSVEP-based BCIs and noisetag-based BCIs is that in the latter the blinking patterns of the stimuli are pseudorandom binary sequences, while in the first they are repetitive periodic oscillations. This random generation is done by using 'gold codes' in the code generation. Gold codes ensure that the stimulus patterns are both uncorrelated with themselves over time, and also uncorrelated with each other. Since the elicited brain activity is directly correlated to presented stimuli, this ensures the brain activity is uncorrelated as well, which improves its detectability [12]. By spreading the signal in a wider range of frequencies this way, it provides additional robustness, as losing one particular part of the signal spectrum has a lessened effect [16]. Furthermore, this minimizes interference with other noisetags, enabling multiple tags to be used simultaneously.

In short, by using a noisetag-based BCI, the performance should both be more robust and fast [16]. This is because various brain activities are uncorrelated and stand out more from one another, allowing for easier detection.

3.3.2. How immersion arises

In order to see how a BCI may affect immersion, it is important to know how immersion is elicited. There are various ways in which immersion, and similar concepts, arise, but no consensus on the specifics exists as of yet. According to Brown & Cairns [7], it is mainly determined by the amount of time and effort spent playing a game. They distinguish between three levels of immersion that are gradually progressed through. The first level, engagement, considers the ease with which a game is picked up, as well as someone's general game preferences. BCIs in their current state are not very easy to pick up; various cables and mechanisms need to be plugged in, connected, and prepared before it can work. The second level, engrossment, is reached when the features of a game combine in such a way that emotions are directly affected by the game. Unless the BCI is implemented in a way to directly affect this process, it is unlikely to have an effect here.

Lastly, total immersion requires a need for atmosphere, among others. Atmosphere concerns the development of game construction; the relevance of the game features to the actions and locations of the characters within the game. This is where a BCI may have an impact, but before that is possible, it would need to be incorporated fully into the game. In multiple ways, even, aside from 'just' being a controller, but also to make sense within the game itself.

Ermi & Mäyrä [15] consider other sources of immersion. These can all coexist simultaneously and interact with both game and player dynamically, as well as with each other. Sensory immersion is related to the audio-visual components of a game, and should therefore be unaffected by a BCI. Challenge-based immersion could be influenced by using a BCI. Care should be taken to ensure a believable and likable challenge, instead of one arbitrarily imposed by technical limitations, however. When a player becomes absorbed by the game's story, characters, or the game world in general, this is called imaginative immersion. The author's expectation is that, similar to Brown & Cairns, this is where a BCI seems most likely to have an effect, if it is incorporated within the contents of the game.

3.3.3. Sub-conclusion

As can be summarized from the two prior sections, there are various ways in which a BCI may influence the sense of immersion. If one considers immersion can arise from how a game is structured and the fantasy it provides, incorporating a BCI in such a natural and believable way may increase said immersion. However, this has not yet been proven. On the other hand, using BCIs may limit immersion in multiple ways due to its drawbacks. Among others, this could be due to the drop in speed and accuracy.

4. Method

This paper considers whether using a noisetag-based BCI has a positive effect on the immersion of a participant while playing a game. The goal of the experiments was to measure the level of immersion within the subjects, in order to establish what effect use of the BCI had on immersion.

Initially the intention was to use a combination of electromyography and galvanic skin response as used by Nacke & Lindley [25] in combination with a questionnaire, to measure immersion. The first measurement however appeared not to be accessible.

In order to design the method to measure immersion, based on literature two hypothesis have been formulated

H_0: "TCT is significantly higher when using the noisetag BCI, than when using the mouse as controller."

H_1: "ImSc is significantly higher when using the noisetag BCI, than when using the mouse as controller."

The study had eighteen participants play two different games (Appendix, images 3 and 4) which were to be controlled either with a mouse or the BCI, chosen in a random order. In each game, the subject was told to select objects in a way appropriate for combination of controller and game.

After each task, the user would complete a tangram puzzle. For this task, the task-completion time in seconds was measured in order to provide an indirect objective measure of immersion. This is derived from the assumption that more time is needed for individuals when switching from an immersive to non-immersive task [19]. Lastly, the immersion questionnaire would be filled in after each game as well, from which a subjective measure of immersion was derived.

Initially, a description will be presented considering the taken procedure and the accompanying implementation. Followed by this, the used measures to gather data will be explained, along with what materials were used in the acquisition. After this, information will be given on the participants. Lastly, the expectations regarding the study will be provided considering all the discussed parts of the paper up till then.

4.1. Procedure

All experiments were executed in the same room. Participants were not left alone while carrying out their tasks due to regulations, but there was no communication during the experiments, with the exception of task explanations.

Before the experiment would start, the participant was asked to fill out the consent forms, and was provided an explanation about the experiment. After this, the tangram task was given for familiarization.

After filling in the forms and completing the tangram task, the BCI would be fitted onto the subject’s head. The training would then commence after an explanation. Two games were played after the training, either with the mouse or BCI. Each method of selection was used once.

Both games were played for roughly five minutes by all participants, with about 30 seconds of difference in playing times. After playing each game, the participants were asked to perform the tangram task, and to provide their subjective experiences by filling in the immersion questionnaire. After finishing, the BCI headset was removed, the participants were thanked for their participation and escorted out of the lab after being debriefed and having their questions about the research answered.

The experiment consisted of three separate parts, with the experiment as a whole taking about 40 to 60 minutes.

4.1.1. Tangram task

An initial screen was presented for the participant when doing the tangram task. It consisted of an initially black screen which provided explanatory text of the task. When pressing the return key, participants would start the task, and be presented with the fox figure they had to recreate with the blocks in the physical world. Participants were made clear that there was no time limit, and that they could take the time necessary to complete the puzzle, although it did have to be completed.

A timer was shown to visualize their task-completion time. After pressing the return key once again, they would be shown their final task-completion time. Despite the possible presence of a learning effect, it was opted to use the same figure to provide everyone with an identical challenge. Using different figures would induce a variety in difficulty, which would make it harder to attribute changes in TCT to either the game that was played or the used method of control.

4.1.2. Training session

The training session was necessary to calibrate the BCI, as well as for the subject to become familiar with the workings of the BCI.

The training presented the participant with a door on which eight differently-coloured symbols appear in four rows and two columns (Appendix, image 3). Twenty trials were done, in which each time a symbol got highlighted which the participant would have to focus its attention on. A black screen would be shown after the trials, stating that training was over.

After calibrating the gathered data, two games were played in a predetermined order that was identical for everyone.

4.1.3. Games

The first game was a memory game, which used the same virtual environment presented in the training scene (Appendix, image 3). In this game, the participant was presented with a series of symbols, ranging from three to five in length, which would be highlighted in a specific order. The user had to select these symbols in the same order as shown with the given method of selection. This was done by clicking the corresponding symbols (mouse), or focusing their gaze on them (BCI). When finished, a new pattern would be presented.

The second game took the form of an exploration through a cave environment (Appendix, image 4). It was played with the method of selection not used in the first game. In this second game, participants were guided through a cave system in which various objects were located. The player was asked to select as many of these objects as possible while coursing through the environment, which provoked different reactions depending on the object selected. Similar to the first game, this was either done by clicking on the objects (mouse), or by focusing their gaze on them (BCI). To make the objects in both games selectable with the BCI, noisetags were applied to them in various manners, as is further explained in 4.4. (Visualization).

In both games, the user would initially be presented with a black screen containing explanatory text. Apart from that, another black screen would be shown after each game, informing the player that the game had ended, as well as their performance. In the first game, the performance was illustrated by the number of trials in total, and the number of mistakes that were made. The second game provided information about the total number of selections made.

It is important to note that the mouse was sabotaged for the duration of the experiment. As BCIs as of yet do not have performance similar to a mouse, it was chosen to make the mouse less reliable instead. Otherwise an accurate method would be compared to a less accurate method, which would possibly cause the player to prefer the accurate method [20]. What this meant in practice, is that users would have to click multiple times and keep the mouse cursor aimed at the target they wanted to select. One mouse click had a 60% chance of being registered, and the cursor would have to be aimed for roughly two seconds at the target.

It had been decided deliberately to play these games in a fixed order rather than randomizing them. Due to the limited number of participants, a randomized game sequence would not allow to conclude for any significant difference.

4.2. Measurements

4.2.1. ImSc & TCT

Two measurements were taken in order to investigate whether BCI-usage has an effect on the experienced level of immersion. One of these was the immersion questionnaire developed by Jennett et al. [19]. A slight adaptation was made to this questionnaire to include how long the participant thought to have played the game. This questionnaire has been used on multiple occasions by other researchers (such as Cox, Cairns, Shah, Carroll [9]; Denisova, & Cairns [11]) and is focused on measuring immersion within a game. For measurement purposes, the responses on the questionnaire were given on a scale of 1 to 5. The responses on the questions were added together to calculate the immersion score (ImSc). For questions 7, 9, 10, 11, and 19, a reverse scoring was applied, as a lower response in these questions indicated a higher level of immersion.

The second measurement was task-completion time (TCT), measured as the total number of seconds it took the participant to complete the puzzle

In order to measure this, the participant had to perform a tangram task. For this experiment, the shape of a fox will have to be created (Appendix, image 2), as was done by Jennett et al. [19]. The participant performed this task one time prior to the experiment as practice and to get to know the task, and once after playing each of the two games.

Five different dependent variables were calculated: three for the task-completion times, called TCT0, TCT1, and TCT2 respectively for each time the tangram task was performed. The remaining two were for the immersion score, called ImSc1 and ImSc2 for the questionnaire that were filled in after game 1 and 2 respectively.

Counterbalancing was used to create equally-sized groups of participants. These were based on what method of control was used in each game. Per game, comparisons were made between the group that used the BCI and the group using the mouse. This was done with a One-way ANOVA.

4.2.2. Material

The BCI that was used consisted of a custom-made headband developed by MindAffect, which used seven electrodes to measure EEG. The headband used water-soaked sponges on the electrodes to enable measurements of brain activity to be taken. The ground electrode was a wet wristband made by TMSi, which was put on the wrist of the participant. The TMSi Porti was used as amplifier for the BCI.

A duo of separate computers were used. A laptop (Dell Inc. Latitude 5480, Intel® core™ i7 – 6600U CPC @2.60GHz, 8GB RAM, Intel® HD Graphics 520) was used to run the software for the BCI. A desktop pc (Dell Inc. Precision Tower 5810, Intel® Xeon® CPU E5-1620v4 @3.5GHz, 8GB RAM, NVIDIA GeForce GTX 1050T) provided the stimulus presentation. An optosensor was used to synchronise the BCI and stimuli through sync pulses, shown on the top-left on the stimulus presentation screen. The software used for stimulus presentation, which includes the training scene, the puzzle scene in which the tangram task is done, and two test scenes, were all made in Unity 2017.3 (Appendix, image 1).

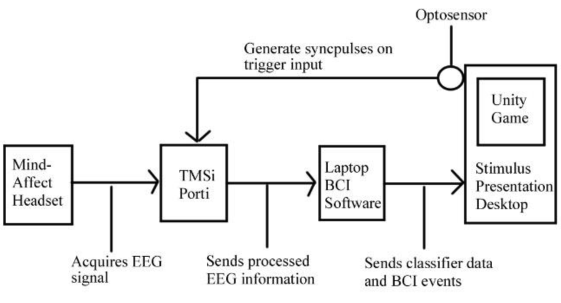

Figure 2. The general mechanisms of the used setup for the study.

4.3. Participants

Eighteen people were asked to participate in the study, both from MindAffect, as well as the author's social network. Due to technical complications, the data of the first participant was not used in the study. This left the remainder of participants to consist of five women and twelve men, aged from 21 to 83 (M = 36.24, SD = 18.498). Five people have had previous experience with BCIs. Eight of them were gamers, of which one had previous BCI experience. In this case, being a gamer indicated that one consistently had gaming sessions lasting at least one hour for at least twice a week. None of the participants were given any compensation for their participation with the exception of travel costs where it was applicable.

4.4. Visualization

In the first game, all of the eight symbols alternated between two states according to their assigned noisetag. The off-state presented a black square, whereas the on-state showed the object, a uniquely-coloured square with a mark in its centre. When an object was selected, all but the chosen object would be set to their off-state. After the selected object was briefly shown in its on-state, all objects would resume blinking to indicate further selections could be made.

In the second game, objects that were present and selectable in the cave were bats, crystals, mushrooms, and clouds of fireflies (Appendix, image 5). Both the bats and fireflies moved about in a random fashion, whereas the crystals and mushrooms were motionless. Selecting the objects, provoked different reactions. A bat would fall out of the sky and disappear for a while, whereas fireflies would scatter and vanish. Mushrooms would cause a burst of spores to explode, and crystals would emit an increasingly bright light before returning to their normal state. (Appendix, images 6 and 7).

There were various ways in which the noisetags were applied to the game objects in the second game. The entire object of both the bat and crystal objects would blink between two contrasting colours. The mushroom and fireflies used a particle system that showed similar blinking behaviour.

Bloom post-processing was used for the camera in Unity to create a halo-effect around the objects in the second game. This caused the effects of blinking to spread out in an area instead of being solely centred on the objects themselves, thereby increasing the likelihood for the BCI to detect the noisetags.

4.5. Expectations

Based on what has been said in the previous sections, a perspective can be formed on the expectations of the study. Various studies seemed to indicate an increase in immersion when using a BCI [6, 18, 23]. There were various reasons why this study could provide different results. The BCI was incorporated in the games in a rather arbitrary manner, purely as a method of operation. Since this was the main point where a BCI could add value to immersion despite its drawbacks, it was not expected for a BCI to improve the immersion within a player. Therefore, H_1 is not expected to hold.

Furthermore, using a BCI increases fatigue faster than a mouse [18], which may have increased the amount of time someone needs to complete the tangram puzzle. On the other hand, this may also have 'forced' subjects to make an effort in order to progress, which may have induced immersion through investment [7]. On the other hand, subjects may have disliked this sense of being forced.

It should be noted that a large gap in personal skill exists among people when considering making puzzles. As of such, TCT may not have been the best indication for immersion, as the differences between participants would be much larger than the intended ones: differences in immersion. The resulting large standard deviation would require a large number of participants in order to draw statistically sound conclusions. Derived from this, it was not expected for H_0 to hold, since any effect from immersion would be hidden by the effect of skill levels.

The games themselves may also have impacted immersion. Since the second game took place in a much more elaborate and dynamic environment, it was expected to elicit more immersion within the player. On the other hand, the first game had a clearer sense of performance, as participants were shown their errors and successes, which could have induced a sense of challenge.

5. Results

The descriptive statistics for the five core dependent variables are shown below in Table 1.

Table 1. Means and standard deviations of the five base variables. TCT was measured as time in seconds.

	M	*SD*
TCT0	262.263	253.221
TCT1	134.169	141.297
TCT2	68.747	74.758
ImSc1	101.35	15.648
ImSc2	105.06	20.783

A number of various effects have been investigated in both games. The effect of the method of selection on both ImSc and TCT is the main investigation. Apart from that, other possible effects were investigated. These are as follows: the effect of the games on ImSc and TCT; the correlation between ImSc and TCT, and whether prior BCI experience had an effect on player performance.

The effect of the method of selection was split in two parts, one for each game, and was computed through the use of a One-way ANOVA. This was done to provide a more detailed answer, since usage of a BCI may be differently regarded depending on the type of game being played. The eight participants who played the first game with the mouse had an average TCT of 109.025 (*SD* = 122.205), and an average ImSC of 96.63 (*SD* = 17.976). The nine participants who used the BCI had an average TCT of 156.519 (*SD* = 160.213), and an average ImSc of 105.56 (*SD* = 12.837). These proved not to be significant effects for both TCT, $F(1,15) = 0.462$, $p = 0.507$ and ImSc, $F(1,15) = 1.415$, $p = 0.253$.

Table 2. Means and standard deviations for TCT and ImSc in game 1, for both mouse and BCI conditions.

Game 1	Mouse	BCI
M, TCT1	109.025	156.512
SD, TCT1	122.205	160.214
M, ImSc1	96.63	105.56
SD, ImSc1	17.976	12.837

In the second game, the eight participants who used the BCI had an average TCT of 74.223 (*SD* = 94.767) and an average ImSc of 103.63 (*SD* = 27.203). The nine participants who used the mouse had an average TCT of 63.879 (*SD* = 57.119), and an average ImSc of 106.33 (*SD* = 14.577). The method of selection did not appear to have any significant effect on both TCT, $F(1,15) = 0.076$, $p = 0.786$, as well as ImSc, $F(1,15) = 0.068$, $p = 0.798$. As opposed to the first game, participants who used the BCI in the second game rated this game as being less immersive than the first one.

Tabel 3. Means and standard deviations for TCT and ImSc in game 2, for both mouse and BCI conditions.

Game 2	Mouse	BCI
M, TCT2	63.879	74.223
SD, TCT2	57.119	94.767
M, ImSc2	106.33	103.63
SD, ImSc2	14.577	27.203

Since the order in which the two games were played was not randomized, any effect the games could have had on the TCT was confounded with any learning effect. Investigating to what extent each game had an impact on the ImSc was done through a paired samples t-test. Results indicated no significant difference between ImSc1 (*M* = 101.35, *SD* = 15.648), and ImSc2 (*M* = 105.06, *SD* = 20.783), $t(16) = -0.743$, $p = 0.468$. Another paired samples t-test between TCT1 (*M* = 134.169, *SD* = 141.297), and TCT2 (*M* = 68.747, *SD* = 74.758) did prove to be significant, $t(16) = 2.244$, $p = 0.039$.

As stated before, when someone is immersed, this should translate to an increased difficulty in performing tasks that are unrelated to the environment in which the person is immersed. In order to test this theory, the correlation was computed between the TCT and ImSc pairs for both games. In the first game, there was a slight correlation between TCT and ImSc. However, it was rather weak, $r(15) = 0.357$. There did not seem to be a correlation between TCT and ImSc at all in the second game, $r(15) = 0.047$, $p = 0.857$.

Due to some of the participants having had prior BCI experience, it was investigated whether this had any effect on performance. This was done through a One-way ANOVA. The dependent variable in this case is the number of faults made during the first game. Out of the eight participants who played the first game with the BCI, there were two (*M* = 1.5, *SD* = 2.121) who had prior experience with BCIs. The remaining six (*M* = 0.5, *SD* = 0.837) did not have prior experience. This did not prove to be a significant effect, $F(1,6) = 1.125$, $p = 0.33$. In the second game, performance was measured according to the number of selected objects while playing the game. Out of the nine subjects who played the second game with the BCI, there three with prior experience (*M* = 15.67, *SD* = 4.163), and six without (*M* = 11, *SD* = 4.05). This effect was not significant either, $F(1,7) = 2.613$, $p = 0.15$. However, the amount of people with prior BCI experience was small, which lessens the validity of statistical results.

6. Conclusions

Reiterating, the research question of this paper and the accompanying hypotheses were as follows:
R_0: "Does the use of a noisetag-based BCI controlled with selective attention positively influence the experienced level of immersion of the player compared to controls with a mouse?"
H_0: "TCT is significantly higher when using the noisetag BCI, than when using the mouse as controller."
H_1: "ImSc is significantly higher when using the noisetag BCI, than when using the mouse as controller."

The goal of this research was to investigate whether the use of actions controlled by noisetag-based BCI detection of selective attention positively influences the experienced level of immersion within the player. In the first game, the nine participants who used the BCI reported to experience more immersion than those who used the mouse, and took longer to complete the tangram task. Neither effect was significant in both cases. The eight participants who used the BCI in the second game had a higher average TCT than those who used the mouse, but not significantly so. As opposed to the first game, those who used the BCI in the second game reported less immersion than the mouse-users, although not significantly so either. Furthermore, the differences between both measures were smaller than in the first game.

Based on this, both H_0 and H_1 are rejected, as no effect was significant. According to these results an answer can be provided to R_0; namely that it could not be proven that usage of a noisetag BCI had a positive influence on the experienced level of immersion, or any effect altogether. It is important to note, though, that the study had a variety of limitations, which will be discussed in the next section.

7. Discussion

In this research, the effect of BCI-usage on the level of experienced immersion has been investigated. Despite the effect on TCT not being significant, the data showed a trend in the expected direction, as subjects who used the BCI generally took longer to complete the tangram puzzle in both games. Similar results were found for the reported immersion in the first game, where it was higher for BCI users, but not for the second one. Not only were these results not significant, but the differences between the scores were rather small. According to this, it can be said that some level of indifference exists between the two methods of selection. As is in line with previous research [6, 8, 18, 23], subjects found using the BCI to be an interesting experience. Some, however also commented on the unreliability of the BCI, similar to what van de Laar et al. [20] reported.

As was previously stated, a BCI would be most likely to increase immersion when it's well-incorporated within a game due to possibly enhancing the fantasy of a game, thereby increasing the corresponding immersion [7, 15]. Since the played games lacked this property, any opinions regarding BCI could have been altered due to the various drawbacks of using the BCI [3, 17, 27], or the required effort to utilize it [7]. Another explanation is that the games as well as the BCI utilization were unable to be used in a satisfactory way [2] because the study focused on determining whether BCI usage increased immersion, instead of how to provide the best of both worlds.

Closely related to this is how meaningful the interaction of the BCI with the game was. In both games the only activity was the, rather superficial, selection of objects within an environment. Providing in-game context as to why the BCI is used, and finding a more appropriate usage for it, may have had increased the effect the BCI had on immersion due to enhancing the fantasy of being in the game [7, 15].

Both of games were played in a non-randomised order that was identical for every subject. Whereas this did limit the conclusions that could be drawn from any effect a game could have had on TCT or ImSc, it should not have limited any effect of the selection methods on the variables. What's more, if game order was randomised, there would have been four different groups of participants, which would have decreased the statistic reliability because of the lower number of participants per group.

Another point worth noting, is that most of the participants had never used a BCI before. Rudimentary usage may be possible without prior experience. However, knowing how to make the best use of the BCI may influence performance on tasks. Even though in this study it was shown not to have any significant effect, this does not mean it goes for all studies. At MindAffect, it was observed that people without prior BCI experience could use the BCI decently enough to use a speller to type a word. It should be taken into account that this information considers visual SSVEP and noisetag-based BCIs, and therefore may not pertain to other types of BCIs, such as those using motor imagination.

7.1. Limitations

A major issue resides within the number of participants. Personal differences in skill caused a large standard deviation in TCT. A larger number of subjects would have alleviated this effect, allowing for any effect of immersion to be discovered.

The participants were recruited from the company at which this research was done, MindAffect, as well as from the author's own social circle. This may have induced multiple biases in the data, as both groups either were personally connected to the author or may have wanted the research to succeed for MindAffect.

The camera was programmed to temporarily focus on an object after making a selection. However, all objects were visible to the camera at all times, and every now and then the camera selected an object that should have been invisible to it because of a faulty classification by the BCI software. During the testing it did not seem to be a large problem, and a lot of time would be needed to solve the issue, so it was kept in. After processing the data, the reported immersion for the second game appeared to be less than that of the first game. It is possible that this was caused by the camera. While an attempt had been made to implement a camera that would slightly look about in different directions to simulate a person taking a walk and looking at the scenery, a better choice might have been to leave it out.

Furthermore, as opposed to the first game, some of the objects in the cave, most notably the crystals and mushrooms, didn't seem to be selected very often. Before performing the experiments there were some doubts about there being a sufficiently high level of contrast for these objects. Even though attempts were made to remedy this before commencing the experiments, it could still have had an influence on the ease with which these objects were selected.

It should also be noted that the training phase was conducted with objects identical to those used in the first game. Therefore, BCI performance within the first game could have gained an increase in performance. This is because the objects used in the second game had different shapes than those used in the first game, were animated, and some of them were moving around dynamically within the environment. Initially, before the experiments, a second training phase would be used to train the BCI on these objects. However, this turned out to have a very bad training performance, usually resulting in about 30% accuracy. As of such, it was decided to leave it out of the experiments. During testing, however, the second game did seem to be playable, as objects could be selected with decent accuracy.

Lastly, while the author has been shown how to fit the BCI headset on someone's head, it was a first-time experience. The headset was fitted according to the instructions, and measured from the right areas. However, it may have been fitted slightly incorrectly on a participant's head in some cases. Subsequently, this may have led to a lesser performance and accuracy of the BCI for those participants.

7.2. Future directions

Aside from implementing improvements to rectify any shortcomings in the research, there are various ways in which the research could be expanded upon. In order to better shift the research to its intended direction, it would be wise to create a game that more closely resembles contemporary games that are played for fun. While it is true that some of these newer games include gameplay in which very high accuracy and speed are required, there is a plethora of different genres to explore where a BCI may be more fitting to be used. Aside from that, it should be easier to measure immersion if it is present in the first place, which starts with an immersing game. Additionally, incorporating more reason and meaning for the usage of a BCI within the context of the game, could be beneficial as well [7, 15]. Determining when a BCI would add value to a game compared to conventional controls may be an investigation all on its own, however.

This paper made a comparison of either BCI or a conventional mouse controller. On the other hand, it may be worthwhile to see whether there exists any difference between using conventional controls and conventional controls with the addition of a BCI. While van de Laar [20] studied this previously, more research may be worthwhile as there does not exist much other research into this yet.

Using TCT as indirect measure of immersion may have worked with large amount of subjects. On the other hand, it would be beneficial to look for more reliable solutions. By measuring electromyography and galvanic skin response while playing a game in different conditions, this might be achieved. These measurements could have a lower standard deviation compared to TCT. However, prior investigation would be necessary in how to derive a measure of immersion from these two separate measurements.

8. References

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9. Appendix

Image 5. Hardware setup, consisting of the TMSi Porti, MindAffect BCI, laptop and computer, and the optosensor.

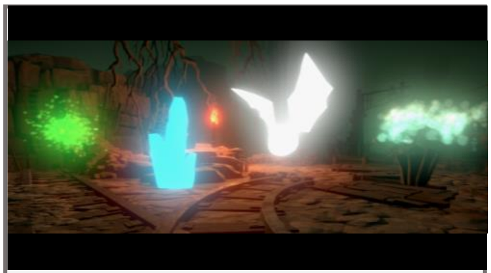

Image 3. The various objects used within the second game.

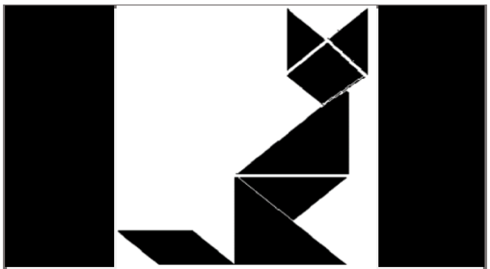

Image 2. The shape used for the tangram task. During the task itself, the white outlines weren't there.

Image 4. Selecting a mushroom would cause it to release a burst of spores in the air

Image 7. The training scene, as well as the scene for the first game.

Image 6. A crystal would start to illuminate its environment upon selection.

Image 1. A shot of the environment used for the second game.