Is there Joy Beyond the Joystick?: Immersive Potential of Brain-Computer Interfaces

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by

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Abstract

Immersion, the state of being fully engaged in one's current operation, is a descriptor commonly used to appraise user experience in computer games and software applications. As the use of brain-computer interfaces (BCIs) begins to expand into the consumer sphere, questions arise concerning the ability of BCIs to modulate user immersion. This study employed a computer game to examine the effect of a consumer-grade BCI (the Emotiv EPOC) on immersion. In doing so, this study also explored the relationship between BCI usability and immersion levels. An experiment with twenty-seven participants showed that users were significantly more immersed when controlling the testing game with a BCI in comparison to traditional control methods. The results suggest that increased immersion levels may be caused by the challenging nature of BCI control rather than the BCI's ability to directly translate user intent.

Acknowledgements

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Chapter 1

Introduction

A brain-computer interface (BCI) is a system that enables direct communication between the brain and a computer. To allow for this communication, a user's neural activity must first be monitored. Non-invasive techniques—such as scalp electroencephalograms (EEGs)—monitor neural activity from the scalp using a set of electrodes. Invasive methods such as cortically-implanted electrodes can detect activity more accurately; however, such techniques require surgery. This study uses non-invasive techniques to gather data from participants since a surgical procedure would be an unreasonable requirement for participation. Following the recording of neural activity, a BCI system will pass the recorded data to a computer for processing. Algorithms then classify the gathered signals and translate them into computer action, allowing human control over technology via thought.

Traditionally, BCIs have been used for 'locked in' patients suffering from varying types of paralysis (Gerven et al., 2009). Such patients can use BCIs to regain some level of autonomy—controlling a wheelchair (Kaufmann et al., 2014) or a computer cursor (Wolpaw et al., 1991)—and are thus more willing to tolerate the imperfections these systems pose (Taylor and Schmidt, 2016). Recently, the advent of consumer-grade BCIs has extended the scope of BCI research and applications to include healthy users utilizing BCIs recreationally. These consumer-grade BCIs are more readily available to the public, as they are inexpensive and easy to set up relative to their medical-grade counterparts. Presently, the effect BCIs have on user-experience is understudied, as most recreational BCI research focuses on appraising the accuracy of specific systems (Taylor and Schmidt, 2016; Harrison and Mitrovic, 2013; Maskeliunas et al., 2016). These hardware reviews often note the inaccuracies of BCI detections and thus suggest an integration of BCI controls into existing control schemes, rather than outright replacement (Nijholt et al., 2008). Despite their inaccuracies, BCI technologies continue to be a source of excitement in human-computer interaction (HCI), spawning questions such as: to what extent, and under what conditions, are users willing to accept inaccuracies in HCI? And further, how can a different style of interaction with a task alter our experience with the common or the mundane?

User experience is enigmatic; its criteria are unclear and often associated with personal preference, making it difficult to quantify. Despite this, successful computer games and software applications share the ability to fully engage their users, allowing people to 'lose' themselves in their current operation (Jennett et al., 2008). These applications transport the user into a state where the passage of time may be distorted and perceptions of the 'real-world' may dissolve. This is the experience of 'immersion', a factor of user experience upon which enjoyment is contingent.

The primary purpose of this study is to examine the effect of a BCI control user experience in terms of immersion. The BCI control scheme developed in this experiment consists of a mixture of keyboard inputs, facial expression recognition, and trained mental command classification. A previous study on BCIs and user experience used a medical-grade BCI to make selections in a virtual environment; a significant difference was found in the immersion of their participants across control modes (Hakvoort et al., 2011). In addition to selection, navigation is one of the most common forms of HCI. In order to incorporate these common interactions into a BCI control scheme, this study used a set of trained mental commands to move virtual objects and used blink recognition to simulate a selection process. In doing so the potential of BCIs to replace these central components of HCI is also assessed.

Chapter 2

Background

This chapter aims to provide an overview of the relevant technologies and concepts used in the design and execution of this study. This includes reviewing the conceptual framework of immersion, discussing the use brain-computer interfaces in games, and assessing the brain-computer interface system used in the study.

2.1 User Experience in Computer Games

If one were to ask a gamer's opinion regarding a particular game, one is likely to receive a confident response. Such surety implies clearly defined criteria concerning what a positive user experience of a game entails. This, however, is not the case, as the criteria for user experience are often linked to inconsistent and abstract conditions such as personal preference and a sense of involvement in the game. There are two concepts that are commonly used to further describe involvement: immersion and flow. This section will define these two approaches to engagement to determine which best evaluates the interaction between humans and computer games.

2.1.1 Immersion

There are contrasts between playing PacMan in a crowded arcade in the 1970s, and playing an online multiplayer first-person-shooter—against opponents who are likely located on the other side of the planet—in the present. Yet, in all that time, and after enormous technological advancement, the feeling of getting *sucked into* a game has not varied. This is the essence of immersion, a state both reviewers and gamers agree to be integral to good user experience. In 2004, Brown and Cairns conducted a study aimed at creating a robust division of immersion by asking gamers what immersion meant to them. They initially establish a direct connection between immersion and the degree to which users are *involved* in their current experience. Brown and Cairns further identified 3 stages of immersion that games can achieve, each of which has a set of barriers that need to be overcome to attain a particular immersive stage (Figure 2.1).

The first of these stages is Engagement. According to Brown and Cairns, this is the lowest level of immersion that occurs before any other. To reach this level two barriers must be crossed: Access and Investment. Access refers to the player's preference and game controls. If the user simply doesn't like a specific type of game or if the game controls and feedback are not relevant then this first barrier cannot be crossed and immersion at any level is unlikely. Investment describes the time and effort the user is willing to invest to come to grips with the game and its controls.

The second stage of immersion is Engrossment, whose only barrier is Game Construction. When all the game features combine effectively then the user may feel their emotions change as a direct result of an in-game event. At this stage it is also important for the mode of control to effectively disappear so that the user feels a direct effect on the game. One participant describe this stage as: "A Zen-like state where

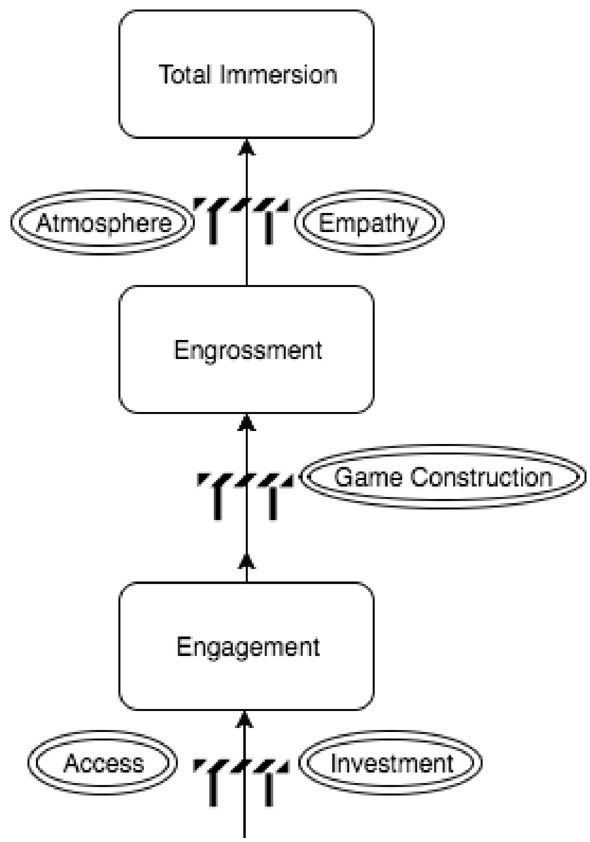

Figure 2.1: Levels and Barriers of Immersion based on (Brown and Cairns, 2004)

your hands just seem to know what to do, and your mind just carries on with the story" (Brown and Cairns, 2004). Such a "zen-like state" facilitates an unawareness of real-world attributes like time and place.

The final stage of immersion is Total Immersion. Presence is the defining characteristic of this stage, described by participants as "When you stop thinking about the fact that you're playing a computer game and you're just in a computer" and "I suppose it's best described as a sense of being cut off from the world you actually inhabit" (Brown and Cairns, 2004). The barriers to this stage are Atmosphere and Empathy. The former is an extension of Game Construction where the game features must be relevant to the actions and location of the avatar. The latter is simply the ability of the user to become emotionally involved with the game, its characters, and its outcome.

Although many of the barriers described are related to personal preference (Game Construction, Investment, and Empathy), the authors note the invariable importance of controls to establishing any immersion. Controls are the way users articulate their intentions into the game world and thus the “invisibility of controls” removes the final separation between the player and the game (Brown and Cairns, 2004).

While the exact construction of Brown and Cairns’ framework may be arbitrary in the scope of this study, their findings suggest that immersion is a shared concept amongst consumers of computer games. Furthermore, their three tier framework emphasizes that there is a scale to immersion and that the barriers limiting access to immersive stages pertain to both the user’s preferences and the game itself. These qualities mark immersion as a consistent aspect of user experience whose effect is perceived similarly by different people. However, the personalized criteria of immersion suggests that differences in immersion holds significance only when comparing experiences within users, rather than across many users. This framework is also later used to construct a likert-scaled questionnaire (Section 2.3.3) which quantifies immersion levels of respondents.

2.1.2 Flow

Flow: The Psychology of Optimal Experience by Mihaly Csikszentmihaly, attempts to produce a criterion for happiness based on the premise that one’s level of happiness can be altered by introducing more Flow. He defines Flow as being the state of optimal experience such that “people are so involved in an activity that nothing else seems to matter; the experience is so enjoyable that people will continue to do it even

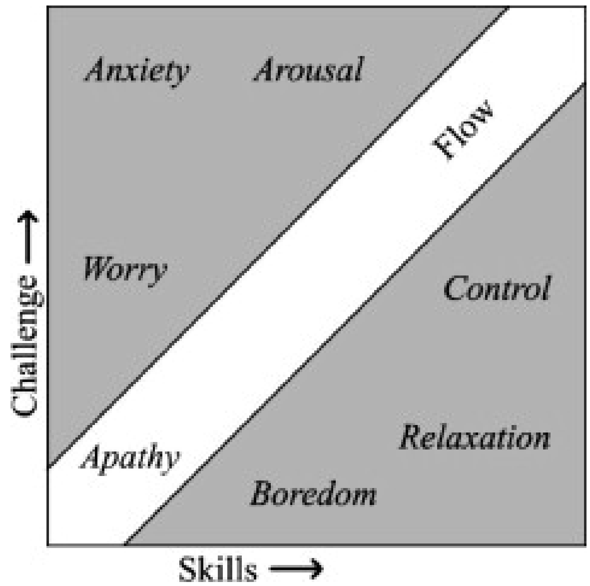

Figure 2.2: Visualization of flow from (Nijholt et al., 2009), based on (Csikszentmihalyi, 1990)

at great cost, for the sheer sake of doing it"(Csikszentmihalyi, 1990) (Figure 2.2). This definition arose out of qualitative interviews targeted at discerning the nature of positive experiences. Csikszentmihaly's findings suggest that Flow consists of eight components, the first three are prerequisites to attaining Flow, while the latter five describe some of its effects:

1. Complete and utter concentration on a task

2. Clear goals with associated rewards

3. A balance between challenge and skill

4. Changing perception of time

5. Perception of control over the task

6. Effortlessness in conducting the task

7. Loss of self-consciousness, where actions and awareness combine

8. A reward intrinsic to the action of the task itself

There are clear similarities between Csikszentmihalyi's Flow and the model of immersion constructed by Brown and Cairns, such as the requirement of concentration and the distortion of time due to involvement in a task. One may even view Flow as being an evolution of immersion in a more specific form, one of optimal experience. The primary difference is that Brown and Cairns define immersion on a scale with multiple stages, whereas Csikszentmihalyi's definition of Flow is binary—you are either inside or outside a state of Flow.

2.1.3 Why Use Immersion as a Metric?

Flow and immersion seem extremely similar when comparing their symptoms at high levels of involvement. They both describe distortion of time, effortlessness or invisibility of controls, and lack of attention to surroundings as being key user attributes in high involvement states. However, as mentioned previously, Flow relates to the evaluation of a game in terms of an optimal experience and is thus intrinsically associated to the outcome of the game. Immersion, on the other hand, is the less extreme evaluation of user experience, one that can either be good, bad, or some combination of the two (Jennett et al., 2008). As the purpose of this study is to ascertain the effect of BCIs on user experience—which may be positive or negative—the grounded model of immersion defined by Brown and Cairns provides a more diverse and comprehensive means of evaluation. Furthermore, the generality of immersion in comparison to Flow may provide further implications of the usefulness of BCIs in human-computer interaction.

2.2 BCIs in Computer Games

Recently, BCIs have been used recreationally by healthy patients, particularly those in the gaming community. Gamers are often early consumers and developers of new technologies as they tend to accept the limitations of such emerging fields more readily than others (Nijholt et al., 2009). Perhaps this is because new technologies often reflect the same challenges computer games pose, such as the need to train for accuracy, and the importance of persistence in advancing to the next level. Currently, BCI technologies are not accurate enough to replace traditional input methods such as gaming controllers and keyboards. Thus, BCI inputs should be used in tandem with existing inputs in order to alter user experience (Nijholt et al., 2008).

Using a BCI to control a game can be viewed as a feedback loop, beginning with the recording of a user's brain signals when they attempt to perform a mental command, or respond to some stimuli. These signals are preprocessed, relevant features are extracted and classified, typically using some machine learning techniques. The output produced is the system's best guess of the user's intentions (Gerven et al., 2009). The game engine receives this output and converts it into a game action as it would do with any other type of human interaction. The cycle is complete when the user perceives the effect the output has on the game environment (Figure 2.3).

There are at least three ways to use BCIs in games design and research. The first treats the BCI system as another input device, directly manipulating aspects of the game through the classification of cognitive commands (Nijholt et al., 2008). To achieve this the BCI must first record the user's neutral state to create a line of reference; then additional cognitive commands can be trained (Taylor and Schmidt, 2016). The second approach logs the cognitive and affective states of the user—obtained by the BCI—as an evaluation method of either the user, or the game, or

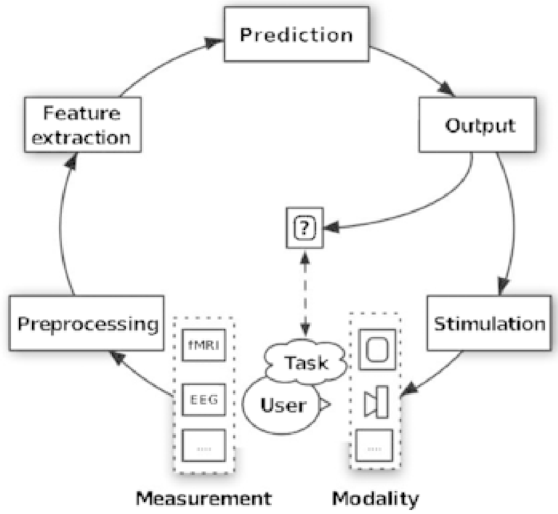

Figure 2.3: BCI cycle as described in (Gerven et al., 2009)

both. Thirdly, BCIs can be used to to create an adaptive virtual environment that automatically readjusts itself depending on the state of the user (Nijholt et al., 2008).

This knowledge spawns questions concerning how—if at all—user experience with a game will change when using a BCI as an input technology. Can that same BCI technology be used to accurately monitor this potential shift in user experience?

2.3 Emotiv Inc.: BCI Systems

Emotiv Inc. is a company based in California, USA that produces EEG technologies. Since their establishment in 2011 they have created two consumer-grade BCI headsets along with EEG analysis software, including a free public software development kit (SDK). Included in their SDK, Emotiv provides 3 different processing capabilities: Affectiv detects the wearer's emotional states (also called Performance Metrics), Expressiv monitors neural activity to determine the user's facial expressions, and Cognitiv cognitive command can detect mental commands after a period of training (Emotiv, 2017).

2.3.1 Emotiv EPOC Headset

The EPOC is one of the headsets available from Emotiv (Figure 2.4). Currently the EPOC is selling for $799, far below the prices of medical-grade EEG devices. It features 16 sensors (14 EEG channels and 2 reference channels) that can wirelessly transfer data to a USB receiver which is then processed by Emotiv's detection software. The relative availability and low cost of the EPOC marks it as a BCI system that may be used outside of the clinical sphere. The EPOC is also highly accessible: the software accompanying the headset allows users with no previous BCI experience to use its detection suites. For these reasons, the Emotiv EPOC was chosen to be the BCI system for this study.

Figure 2.4: Emotiv EPOC on a user

2.3.2 EPOC's Reliability

Mental Commands

As the Emotiv EPOC is used in this study, it is necessary to assess its strengths and shortcomings. In 2016, Taylor and Schmidt conducted a study to evaluate the accuracy of the Emotiv's Cognitiv suite, also using the EPOC headset. They tested the ability of 57 (34 male and 23 female) participants to train and execute twelve of the thirteen possible mental commands. The thirteenth command was excluded because it lacked an opposite pair action. The results were evaluated for false alarms, where the system detected a cognitive command when none was intended, and errors in classification, where the system incorrectly classified an intended command. They found that an average of 45 false alarms occured for every 100 correct detections. Of these correct detections, they found that the EPOC was able to correctly classify mental commands 87.5% of the time, significantly better than chance. This result was uniform over all mental commands studied and the number of false alarms decreased as the participants continued to train the command recognition software.

These results stress the importance of multiple training sessions when using Emotiv's Cognitiv detection algorithms—Taylor and Schmidt's best average error ratio occurred after two training sessions. The results further imply that one must be wary when using the Cognitiv suite as a control scheme in order to not unreasonably diminish user experience. For example, if the game puts the user in a situation where incorrect mental classification results in a 'Game Over', the user may feel frustrated and angry. As this study is measuring the *potential* of BCIs—regardless of their inaccuracies—to augment a user's immersion levels, it is important to minimize these circumstances.

Emotion and Blink Detection

One of the five measures of Performance Metrics offered by Emotiv's Affectiv suite is Engagement, which Emotiv defines as your level of immersion in the moment—a mixture of attention and concentration. Before using Emotiv's built in Engagement score to monitor immersion levels, its accuracy and precision must be appraised.

Maskeliunas et al. (2016) ran an evaluation of the emotion and blinking detection accuracy of two consumer-grade EEG devices: the Emotiv EPOC and the Neurosky MindWave. Ten participants took part in this study, all of whom tested both devices. EEG data was collected while participants were in an *idle* state—where no mental command was required—to determine the accuracy of the relaxation detection. To ascertain the precision of the concentration classification, participants were asked to provide answers to a number of calculus tasks of varying difficulty. To measure the device's ability to notice blinks, the participants were asked to blink at a normal rate for 2 minutes and the number of blinks logged by the BCI was compared to the number counted by an eye tracking device (EyeTribe).

The study found that the Emotiv EPOC was able to accurately classify the user's emotional state 60.5% of the time, while the Neurosky MindWave averaged 22.2%. Both BCIs seemed more capable at classifying attention in comparison to relaxation. Furthermore, the MindWave achieved a mean blink recognition accuracy of 49.6%, while the EPOC achieved an accuracy of 75.6%. Maskeliunas et al. found the EPOC to be more accurate in both detections studied. When considering blinking as a possible control input, the inconsistencies of the EPOC's blink detection presents similar issues as the mental command classification. Namely, if the game presents a situation when incorrect blink recognition results in the termination of the game, the user may feel cheated by the inaccuracies of the control scheme. Moreover, the imprecision of the EPOC's emotional detection indicates that an alternative immersion metric may be required by this study.

The inaccuracies of the EPOC's emotional detection were further verified by Harrison and Mitrovic (2013) who compared participants self-reported emotional states to those classified by the EPOC. Not only did Harrison and Mitrovic find no signifiant relationship between self-reported emotional states and those detected by the EPOC, they also noticed conflicting detections by the EPOC. For example, the Performance

Metrics of Engagement and Excitement were initially found to have a positive relationship; however in a second experiment they were found to have the an opposite relation. In addition to their accuracy evaluation, Maskeliunas et al. discuss the usability of consumer-grade EEG devices. It seem the success of BCIs is wholly dependent on the individual user. They note that in existing systems 20–30% of users display significantly worse detection results, indicating that some users display *BCI Illiteracy*. Maskeliunas et al. note that this is an under researched aspect of this field and the ability to adequately control BCI systems relies heavily upon individual characteristics. These characteristics are not yet clearly defined.

Maskeliunas et al. established the relative superiority of the EPOC over the MindWave; however, neither device is highly reliable at detecting blinks or emotional states. Furthermore, they note the existence of BCI illiterate persons who are unable to create replicable and consistent brain states required for BCI control. It is important to detect illiteracy when participants take part in BCI studies, and deal with their responses their data appropriately. Lastly, the inaccuracies of the EPOC's emotion detection supports the need for an alternate means of measuring immersion, as the Performance Metrics provided by Emotiv cannot be relied upon.

2.3.3 EPOC's Shortcomings Resolved: Immersion Questionnaire

In 2008, Jennett et al. investigated how one can record immersion in a quantitative manner. To do so they conducted three different experiments on forty participants—10 male and 30 female—from London University, with ages from 18 to 36 years old. The first experiment had participants complete a tangram task, then play either a boring game designed to be non-immersive or Half Life, a first-person shooter. During the gameplay, participants were interrupted and asked to fill out a questionnaire designed to measure immersion. Upon completing the game, participants were asked to complete another tangram task. It was discovered that it took longer for participants to complete the second tangram task after the immersive game in comparison to the non-immersive game, indicating that higher immersion in a game leads to increased real-world disassociation. The second experiment explored how the participant's eye movements varied when engaging in an immersive versus non-immersive task. Their results indicated that a user's eye movements decrease in an immersive task due to their attention becoming highly focused on the visual elements of the game. The third experiment assessed how speed of interaction with computer interfaces modulated immersion and affect levels. According to the results, the pace of human-computer interaction has no significant effect on immersion levels.

The first two experiments appraised the accuracy of their questionnaire and found that it could reliably indicate a user's level of immersion. Jennett et al. further identified five factors of immersion using Cattell's scree plot method: cognitive involvement, real world dissociation, challenge, emotional involvement and control. These factors accounted for 49% of the total variance in the questionnaire responses. Their questionnaire was tested on 244 participants and was deemed to be an accurate representation of total immersion as well as its constituent factors: personal factors (cognitive involvement, real world dissociation,and emotional involvement) and game factors (control and challenge).

Jennett et al. created a verifiable way to quantify immersion through a questionnaire, which has been utilized and verified in a number of studies concerning immersion (Cox et al., 2012; Hakvoort et al., 2011; Sanders and Cairns, 2010; Thompson et al., 2012). Such extensive testing indicates the accuracy and robustness of the questionnaire they produced; therefore, due to the aforementioned inaccuracies of the

EPOC's Performance Metrics, it is used by this study to measure immersion levels in users.

2.4 Unity Gaming Engine

Unity is a cross-platform game engine initially released in 2005 by Unity Technologies. It provides developers the ability to produce 2-dimensional and 3-dimensional games with relative ease. By attaching custom C# scripts to the created game objects, developers are able to specify game rules and human interaction. Unity also supports deployment across every popular operating system, games console, and mobile device regardless of the system used when developing the game.

Emotiv Inc. offers an additional Unity wrapper that allow developers integrate the Emotiv into their Unity projects. The relative effortlessness of game development that Unity offers and its ability to integrate the Emotiv EPOC as a means of control are the primary reasons it was chosen as the developmental tool for this study.

2.5 Testing Immersion with a Non-Consumer-Grade BCI

In 2011 Hakvoort et al. conducted a similar study entitled *Measuring Immersion and Affect in a Brain-Computer Interface Game.* They created a simple game, Mind the Sheep!, consisting of a 2D virtual field with grazing sheep, three dogs, and cattle pens. The objective was to use the dogs—which the sheep were programed to run away from—to herd the sheep into the virtual pens. The user would first select which dog they intended to move by holding down the left mouse button. This selection could be completed in two different ways: BCI selection or selection using classic input methods (mouse clicks). During the BCI selection process, the three dogs become circles that flicker at different frequencies. The user must concentrate their attention on the dog they wish to control, release the left mouse button and the game makes a selection using steady-state visually evoked potential (SSVEP). When a user focuses on a particular dog, the flashing frequency of that particular dog is reflected in their brain activity, allowing the computer to make an accurate selection. To select a dog using the non-BCI version of control, the participant holds down the left mouse button, causing each dog to be highlighted in turn and would have to release the button when the desired dog was highlighted. Hakvoort et al. note that they avoided a simple click selection for the non-BCI, preferring instead a method that involves concentration and timing to introduce a similar challenge that the BCI mode presents. After a dog was selected, a simple mouse click would direct the dog to the indicated position, using an A* algorithm to plot the path.

The participant base consisted of 8 men and 6 women aged between 17 and 25 years old. The test was split into three levels. The first, designed to familiarize the user with the game controls, involved selecting dogs to pick up virtual objects on the 2D field by running to their location. The second had users herding five sheep into two pens. The third challenged the user to herd ten sheep into one pen. Each participant played the game using both the BCI and non-BCI selection methods; upon finishing each mode of control they filled out a questionnaire produced by Jannet et al. assessing their levels of immersion and a PATH visual questionnaire to ascertain the user's level of valence, arousal and dominance (Affect). Game statistics were also logged. Hakvoort et al. averaged the results across the participants and found that they were significantly more immersed in the BCI version of the game ($p = 0.031$). Participants also indicated that they preferred playing the game with the BCI selection method. Valence was found to be significantly higher in the non-BCI version ($p = 0.044$), whereas no significant differences were found for the other aspects of Affect (arousal and dominance) over the two modes of control.

This case further informs this study in a number of ways. It is important to have a tutorial stage to familiarize participants with the goals, mechanics, and control model of the game. Misunderstanding elements of the game may have a negative influence on user experience, but introducing a stage that familiarizes the participant with the game may limit this effect so that differences in user experience across control modes can be attributed to controls rather than other variants. Furthermore, Hakvoort et al. only incorporated a BCI into the selection process of their game. By doing so they did not overestimate the ability of a BCI to completely replace previous control schemas. Implementation of BCI control should only be used when applicable in order to enhance user experience. If a game action exists for which there is no translatable BCI command, then omitting BCI control in favor of a classical input method (i.e., a button click) is advantageous.

Although there are clear similarities between Hakvoort et al.'s study and this study, they differ in a number of significant ways. First, this study uses a consumer-grade BCI system which is far more accessible—in terms of price and ease-of-use—than the medical-grade BCI used by Hakvoort et al.. Consumer-grade systems are thus far more likely to be used by healthy patients for recreational purposes. Furthermore, Hakvoort et al. only implemented BCI selection into their control scheme, whereas this study will test if mental commands and blink recognition (simulating navigation and selection, respectively) create similar differences in immersion across control modes. Mental commands and facial expression detection have the potential to integrate BCI control into more aspects of a game and thus it is worth discovering if the same discrepancies in immersion exist between control modes and if it is for the same reason.

Chapter 3

Methods

This study tested the implications of BCIs on user immersion using a simple computer game. Computer games have been used to test immersion (Hakvoort et al., 2011; Cox et al., 2012; Sanders and Cairns, 2010; Thompson et al., 2012) and are the obvious testing choice in this situation due to the developer's ability to keep the testing environment completely static with the exception of the attribute that is being tested. The game's available actions, goals, visual aspects, and auditory features remained constant throughout the tests; only the mode of control varied.

3.1 BrainBlocks: A Multimodal Tetris Game

BrainBlocks is an adaptation of the classic Tetris game first released in 1984. In Tetris, blocks appear at the top of the play-space and systematically move downwards until they hit the bottom or come in contact with another block, at which point the block halts and another block appears at the top. Points are acquired by filling an entire row with different blocks causing the row to disappear. Subsequently, all blocks above the removed row move down one space. Users are able to rotate and move the blocks as they fall in order to gain as many points as possible. A game ends when the play-space fills up to the point where the new block spawns on top of existing ones.

BrainBlocks is very similar to Tetris: it randomly spawns the 7 classic block objects (Figure 3.1); users available actions are the same; and point incrementation and game overs occur in the same situations as in Tetris. This section describes how and why BrainBlocks diverges from classic Tetris and provides an overview of the relevant scripts controlling the game.

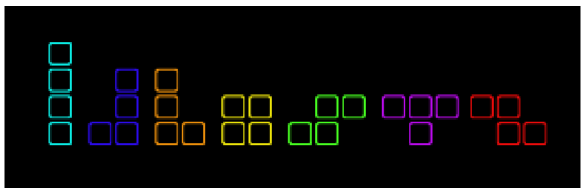

Figure 3.1: BrainBlocks: Block Groups

3.1.1 Game Alterations for BCI Control

The BCI implementation detects blinks to rotate the current block and uses trained mental commands (“Left” and “Right”) to move the current block. In order to maximize the potential for immersion and to minimize user annoyance when using the BCI, BrainBlocks was altered from the typical Tetris implementation in a number of ways. These alterations exist in BrainBlock regardless of the control scheme used.

Static Blocks

The primary deviation from the typical Tetris implementation is that the current block does not systematically move down the play-space. In BrainBlocks the current block spawns above the Snap Line (Figure 3.2). Once the user has rotated and moved the block to the desired position, they can drop the block. A drop action moves the block as far down as it can go before spawning the next block. The primary

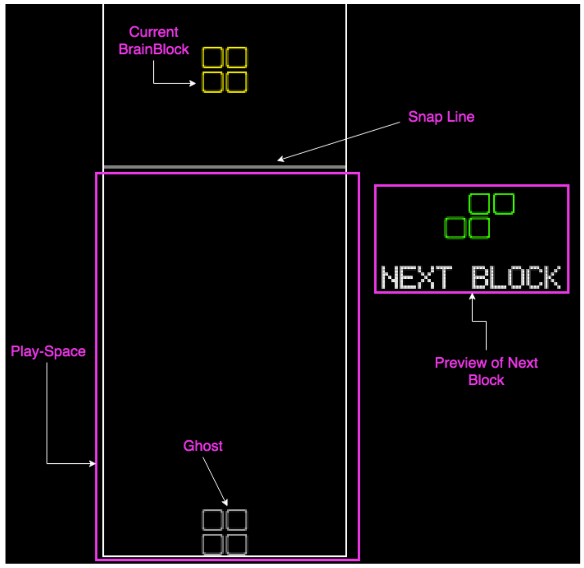

Figure 3.2: BrainBlocks: Labeled Game View

reason for this alteration was to limit the effect of mental command misclassification. This change made such misclassification rectifiable: the user could simply move the block back to the desired position. If the systematic falling was not removed, a misclassification may have occurred right before the block halted and would have been irreversible.

Ghost Blocks

The second alteration aimed at decreasing the amount of noise in the BCI readings. There are two origins of noise that were addressed: movement of the user's head and ocular artifacts. Participants in the experiment used a chin rest to minimize most head movement; however, the need to look around the screen—constantly looking between the current block and its potential final location—may still have caused head movements and ocular artifacts. The solution was to create a *ghost* block that displays the final position of current block if it were dropped immediately (Figure 3.2). The ghost is updated every time the current block rotates or moves. This alteration allowed participants to play the entire game while only looking at the ghost, thereby diminishing the prevalence of the aforementioned problem.

Rotation vs. Navigation Mode

Another issue that arose from the BCI implementation was the frequency of a blink. It would have been unreasonable to ask participants to not blink while attempting to move the current block, and accidental rotations due to unintended blinks would have decreased the usability of the game. The solution was to separate actions into two distinct modes in which only rotation or navigation can occur. BrainBlocks visualizes this in two ways: firstly, when in *Rotation Mode* the current block floats above the Snap Line and, following the switch to *Navigation Mode*, the current block moves down to the Snap Line (Figure 3.2). Secondly, the ghost block changes color to a slightly brighter grey when in navigation mode (Figure 3.3). This second visualization was necessary because the first visualization requires the user to look away from the ghost block to the top of the play-space to notice a change from Rotation Mode to Navigation Mode. The ghost aimed at diminishing the need for such head and eye movement, thus by changing the ghost block's color after switching modes a the solution to decreasing BCI noise addressed in the previous section is maintained.

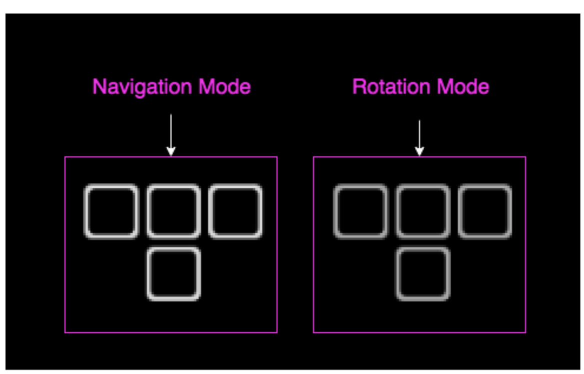

Figure 3.3: BrainBlocks: Ghosts in Rotation and Navigation Mode

3.1.2 Scripts Overview

The scripts controlling the game are relatively simple. The heart of the game's control system is a script named *Grid.cs*. This script holds the 2-D array of Transforms—a component of every active Unity object holding its current position, rotation and scale. This array keeps track of which grid locations are occupied or unoccupied, allowing for the enforcement of the basic rules of Tetris. This script also converts Unity Transform positions to integer grid positions allowing for convenient indexing into the 2-D array of Transforms to check for occupancy.

Attached to each BrainBlock object is a script, *Set.cs*, that manages how user interaction will manipulate the current BrainBlock. Following the detection of an legal input—according to the mode of control—the script will either rotate or move the current BrainBlock. Each time an action is applied to a BrainBlock object, *Set.cs* checks to see if the change is legal (that the block is not out of bounds and that it does not overlap another block). *Grid.cs* is then updated if the input produces a legal action, otherwise the action is reverted. After a block is dropped, *Grid.cs* will check for full rows, deleting them and incrementing the score if necessary.

Throughout all the stages of the game there is a script named *LoggerCSV.cs* that tracks the actions of the user. *LoggerCSV.cs* is a singleton which holds an instance of itself that can be acquired statically, allowing all scripts anywhere in the system to access it and log information. From these logs the progression of each user through the game can be recreated; "Training Right", "Block Created", "Block Rotated", "Block Dropped" are examples of game events that are logged (for a full description of each log event see Appendix H). Each logged event has 2 time stamps. The first time stamp logs the DateTime so that in-game events may be compared to data logged outside of Unity. The second logs the time since the start of the game that the event occurred, allowing for more accurate comparison of in-game events.

There are a multitude of other scripts which control path of the game (through the different experimental stages), the user interface objects, and communication with the Emotiv EPOC. These are not reviewed in this section as they simply enforce the rules of the different experimental stages (described in Section 3.2), and allow for training and acquisition of mental commands and blink detection from the Emotiv EPOC.

3.2 Design of Experiment

The experiment consisted of two sessions of gameplay. In each session, participants used one of the control modes (BCI or non-BCI) to play BrainBlocks. All participants used both modes of control, and all verbal instructions given to the participants were scripted (see Appendix B).

Counter Balancing

Two counterbalancing schemes were constructed to account for the two likely outcomes of the experiment. The first scheme alternated the order in which participants tested the control modes to account for an outcome in which the majority of participants successfully complete both sessions. The second likely outcome concerned majority participant failure due to an inability to train or use mental commands. In order to analyze such failure, 4 counterbalance groups (Table 3.1) were created to counterbalance between which mental command was trained first, and which mental command was tested first following the training of both commands.

Counter Balance Group	Train Left First	Train Right First
1	Yes	Yes
2	Yes	No
3	No	Yes
4	No	Yes

Table 3.1: Counter Balancing Groups for Majority Participant Failure

Set Up

Prior to attempting the tasks of the experiment, participants were asked to read and sign a consent form (Appendix A). This form describes the tasks participants were asked to complete, potential risks and benefits of the experiment, participant rights, and a commitment to the confidentiality of those who participate.

Following the reading and signing of the consent form, participants were given a slip (specifying their participant identification number, their counter balance number, and which control mode they must test first) and a breakdown of the game controls for each control mode (Appendix C). They were then asked to fill out a pre-experiment questionnaire (Appendix E), designed to ascertain their previous experience with BCIs and computer games. The researcher was then responsible for correctly placing the Emotiv EPOC onto the participant's scalp, and establishing a good connection with the computer through the Emotiv Xavier Control Panel (see Figure 3.4). If at this point the tester was unable to establish a good connection between the computer and the Emotiv EPOC, the experiment was terminated and the participant's data was omitted from the final results. If the tester established a good connection, participants were asked to use a sterile table-mounted chin rest to limit movement that may have disrupted the EPOC's signal quality during training periods. At this point the chin rest was adjusted according to participant preference; the researcher ensured that the configuration of the chin rest did not cause the participant to clench their jaw.

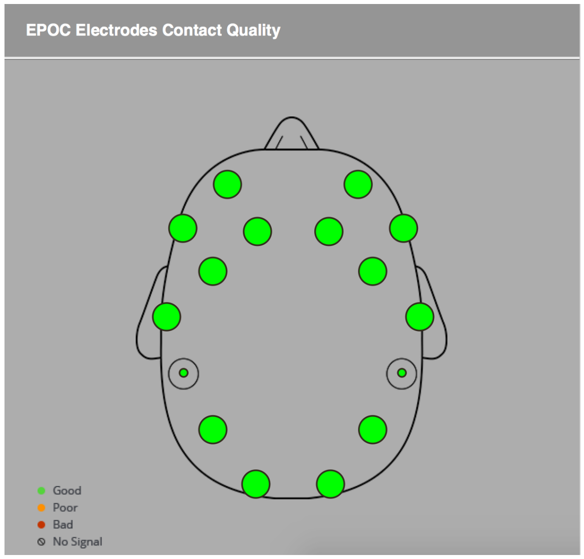

Figure 3.4: Emotiv EPOC: Good Signal Quality, All Electrode Signals are Green

Gameplay Sessions

Each session consisted of two or three stages: a training/familiarization stage, followed by a gameplay stage. When using the BCI control mode, participants first trained the game to recognize a "Neutral" brain state before training their "Left" and "Right" mental commands. Training of these mental commands consists of maintaining a visualization of a right or left action for 8 seconds. Participants were instructed on the basics of mental command training (Appendix B) and were given a printout summarizing these tips (Appendix D) in order to limit typical novice training mistakes such as tensing muscles and excessive blinking. After training the "Neutral" brain state, the game decides which mental command to train first based on the assigned counter balance group. Participants had to train their first action twice before being allowed to attempt a test requiring them to demonstrate their ability to use the first mental command. This test asked users to move the training block over a prompt using their trained mental command (Figure 3.5). Following the completion of this test, participants then underwent the same procedure for the other mental command.

Participants could clear their trained data at any time and restart the training process. The training stage concluded once participants were able to demonstrate an ability to use both trained commands. If after 30 minutes the participant was unable pass the test for both mental commands, the experiment was terminated and the participant's data was omitted from the results concerning immersion. However, this data was used to determine the percentage of participants unable to train the BCI. There was no training stage for the non-BCI control mode.

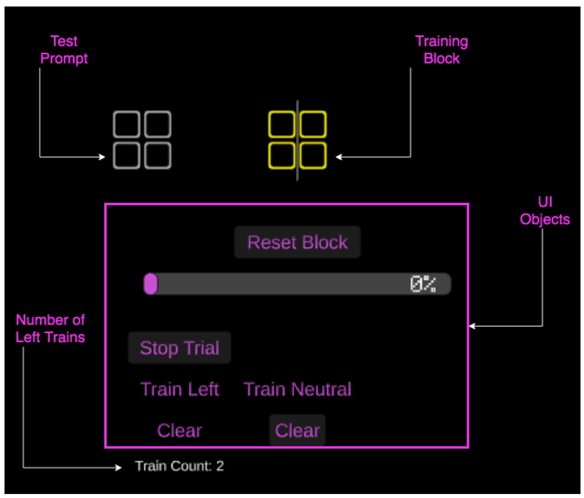

Figure 3.5: BrainBlocks: BCI Training Stage

All participants, regardless of the control mode, then completed the familiarization stage consisting of matching the orientation and position of their BrainBlocks object to one presented by the game (Figure 3.6). Six trials are generated in this stage; half of which spawn prompts randomly on the left half of the play-space, while the other half spawn prompts randomly on the right half. The placement of the first prompt was determined by the counterbalance group, while all following prompts alternate from the first. If the participant was unable to pass a single trial in 5 minutes, the experiment was terminated and the participant's data was omitted from the results concerning immersion. However, this data was used to determine the percentage of

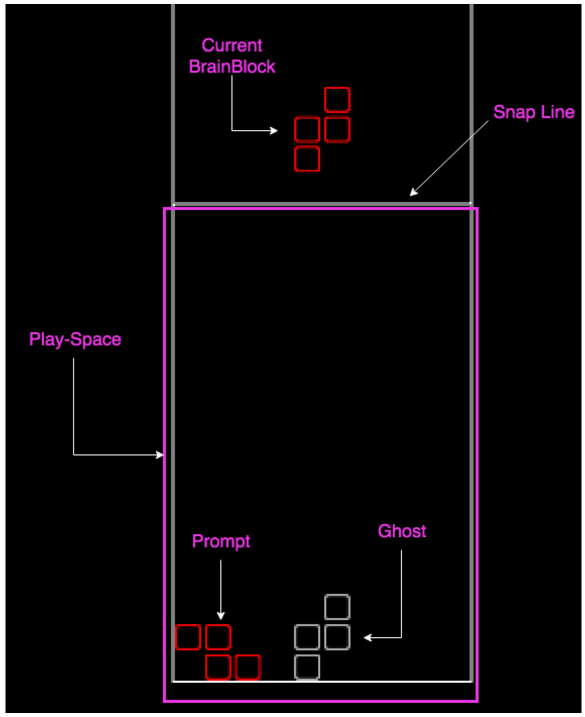

Figure 3.6: BrainBlocks: Familiarization Trial

participants unable to effectively use the BCI.

Following the completion of the familiarization trial, participants were given 8 minutes to play the game. Four minutes into this stage, the game was paused to minimize the fatigue that accompanies prolonged BCI use (Emotiv, 2017). During this break the researcher reapplied saline solution to the EPOCs 16 felt pads if the connection quality had decreased. Following the completion of a session, participants were asked to fill out the immersion questionnaire (Appendix F) and were then given a 5 minute break before beginning the next session. The researcher also used this time to re-apply saline to the felt pads if needed.

After the completion of both sessions participants were debriefed and dismissed. Additional pauses during the experiment may have occurred if the researcher noticed decreasing signal quality due to dry felt pads. Under these circumstances, the researcher briefly paused the process, saturated the felt pads, and reestablished connection between the Emotiv EPOC and the computer. Pauses of any form were logged.

Data Acquired for Results

Throughout the course of each experiment a number of different datasets were gathered. Each participant filled out the pre-experiment questionnaire (Appendix E) which gathered basic demographic information and previous BCI and gaming experience. Participants also completed Jennett et al.'s immersion questionnaire (Appendix F) for each completed session. These likert-scaled scores were aggregated—accounting for negatively worded questions—to produce a total immersion score. The scores for immersion's 5 factors (challenge, control, real world dissociation, emotional involvement, and cognitive involvement) were calculated by summing the likert-scaled scores across specific sets of questions; for a full breakdown of these sets see Appendix G. Lastly, game data such as familiarization trial completion time, block movements, block drops, etc. were logged (refer to Appendix H for a full list of events). All participants that completed the experiment used both control methods, therefore all the data acquired was paired. Due to the data's paired nature and since a normal distribution could not be assumed, a Wilcoxon signed-rank test was utilized to determine statistical significance between the different control modes.

Chapter 4

Results

A total of 27 undergraduate college students were recruited to participate in this experiment. Of these 27 participants, 20 were able to pass all the the experimental trials in the allotted time. 17 of these participants identified as male, 3 identified as female, and only one person had previous experience with BCIs.

4.1 Immersion

From the immersion questionnaire, scores for total immersion and its five factors were calculated (see Section 3.2). The difference between total immersion scores—and its 5 factors—were analyzed for statical significance across the two control methods. Averaged across participants, the BCI control method was rated higher than the non-BCI control method for total immersion and each of its 5 factors (Table 4.1). However, not all of these differences were found to be significant. Significant difference was found for the challenge factor, the real world dissociation factor, the emotional involvement factor, and the total immersion score. No significant difference was found for the control factor, or the cognitive involvement factor.

	BCI	Non-BCI	Z-score	p-value
Challenge ∗∗	16.30(1.78)	12.80(2.48)	−3.80	0.00014
Control	18.50(3.49)	17.05(3.72)	−1.48	0.14
Real World Dissociation ∗	26.35(3.23)	23.90(5.56)	−2.17	0.030
Emotional Involvement ∗∗	23.20(4.42)	17.45(2.47)	−3.49	0.00049
Cognitive Involvement	38.50(4.14)	36.05(5.66)	−1.63	0.10
Total Immersion ∗∗	122.85(13.80)	107.25(15.52)	−3.64	0.00027

Table 4.1: Scores from immersion questionnaire averaged over participants in the form $\mu(\sigma)$, with $*$ indicating significant difference with p$<$ 0.05 and $**$ indicating significant difference with p $<$ 0.001

4.2 Game Data

Correct Commands

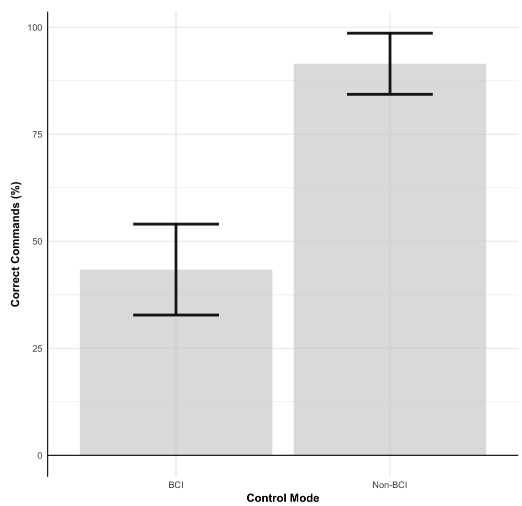

Figure 4.1: Mean Percentage and Standard Deviation of Correct Commands

While participants were completing the familiarization stage, BrainBlocks logged each left or right command along with the resulting position of the block. This data was used to calculate the percentage of commands in the familiarization stage that brought the user's current block closer to prompt (Figure 3.6). These are deemed as "correct commands". On average, participants completed a higher percentage of correct commands when using the non-BCI control (μ = 91.47%, σ = 7.14) mode in comparison to the BCI control mode ($\mu = 43.39\%$, $\sigma = 10.62$) (Figure 4.1). This difference was significant (Z = −3.90, p = 9.6e−5).

Speed

During the familiarization stage, the time taken to complete a given trial was logged. The distribution of all trial completion times within control modes is displayed in Figure 4.2. The mean of the BCI control mode ($\mu = 45.31$ seconds, $\sigma = 50.26$) was found to be larger than the mean of the non-BCI control mode ($\mu = 5.63$ seconds, $\sigma = 3.91$). A significant difference was found when comparing the average completion time for each control mode within participants (Z = −3.90, p = 9.6×10^{-5}).

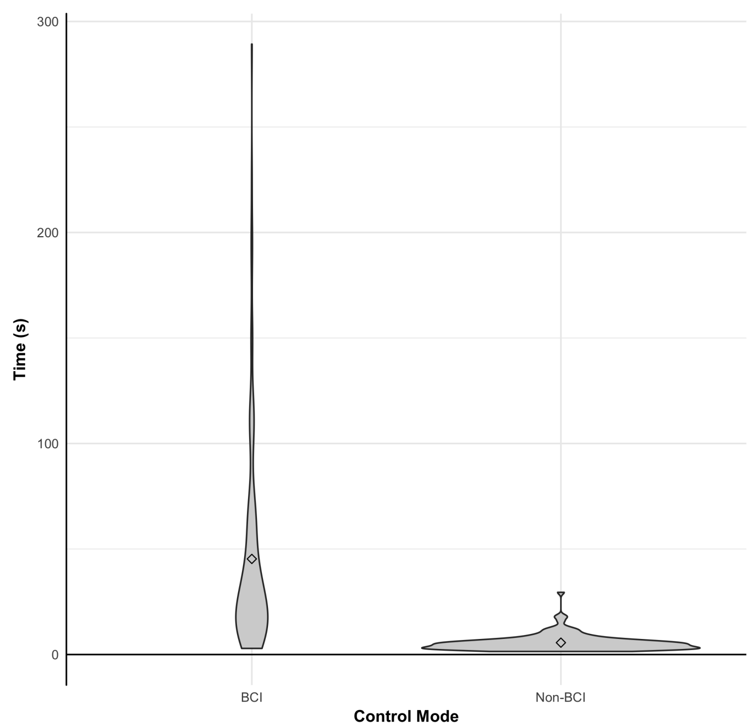

Figure 4.2: Trial Completion Time Distribution. Width of the graph object at any point describes the density of the distribution at that time value, mean values are marked by ⋄.

Score

During the gameplay stage users attained points by filling an entire row in the play-space with dropped blocks. The distribution of the scores for all participants within control modes is displayed in Figure 4.3. The mean score across participants was higher for the non-BCI control mode ($\mu = 25.35, \sigma = 11.54$) in comparison to the BCI control mode ($\mu = 1.85, \sigma = 1.95$). This difference was significant (Z $= -3.90$, p $= 9.5 \times 10^{-5}$).

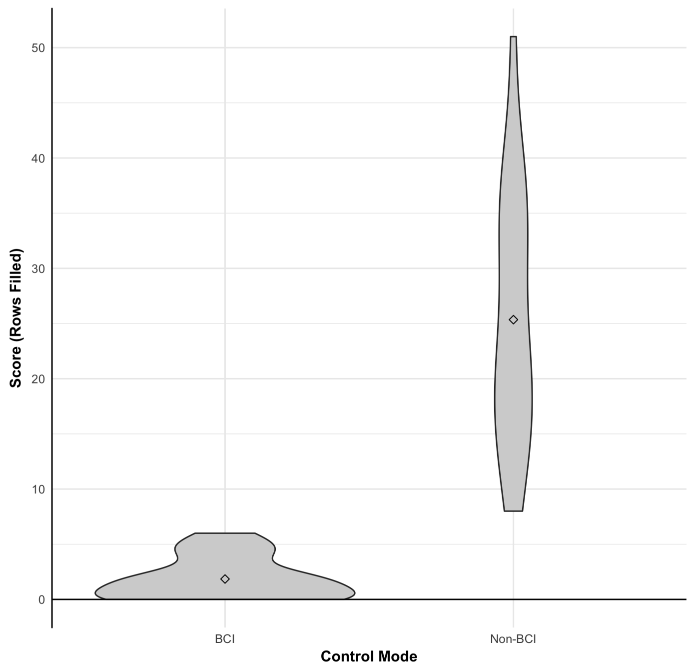

Figure 4.3: Score Distribution. Width of the graph object at any point describes the density of the distribution at that score value, mean values are marked by $\diamond$.

Chapter 5

Discussion

From the immersion questionnaire it was found that participants rated the BCI control mode as significantly more immersive than the non-BCI control mode. An initial analysis of this result may lead one to believe that the BCI commands are a more accurate reflection of the user's intent in comparison to the non-BCI commands. One could argue that when using the non-BCI control mode, users still needed to convert their intent into a physical action (a button press) in order to make the virtual environment react. This disconnect between the user and their virtual environment may not have been present when using the mental commands enabled by the BCI, as the system has the potential to translate intentions directly into virtual actions. Direct translation of intent renders the mode of control invisible, thereby increasing immersion. Such a conclusion would correspond directly with Hakvoort et al.'s analysis concerning the increased levels of immersion they measured when users made in-game selections with a medical-grade BCI (Section 2.5). In both studies BCI control facilitated a more immersive experience; however, a closer review of the 5 factors of immersion complicates the reasons for increased immersion and suggests that the cause of this result differs from Hakvoort et al.'s findings.

The immersion factors of challenge, real word dissociation, and emotional involvement were found to have significantly higher scores for the BCI control method. The significant differences of the challenge factor score between the two control modes is particularly illuminating. The tasks required in the experiment were simple navigation tasks, namely, move a block to a particular position; yet, participants considered this to be far more challenging when using the BCI control mode. In Hakvoort et al.'s study found there was no significant difference between the challenge factor scores according to the control mode. The divergence of these subsets of immersion suggest that the BCI interactions used in this study (mental commands) are more challenging than the BCI selection method used by Hakvoort et al..

The challenging nature of BCI mental commands is verified by much of the game data. Participants were able to complete significantly fewer correct commands (as defined in Section 4.2), indicating that BCI training lead to an overfitting or underfitting of different commands. This in turn lead to unintended commands occurring more frequently than intended commands. These results cannot be directly compared to the EPOC accuracy appraisal by Talyor and Schmidt (Section 2.3.2) as this study did not distinguish between false alarms—commands being detected when none were intended—and incorrect classifications. Taylor and Schmidt found an average of 45 false alarms for every 100 correct detections, and found the EPOC able to correctly classify these correct detections 87.5% of the time. Combining these results produces 57.5 incorrect detections (false alarms and incorrect classifications of correct detections) for every 87.5 correct detections; thus, Taylor and Schmidt found the EPOC able to correctly classify mental commands approximately 60.3% of the time. This study found that on average participants were able to complete correct commands 43.39% of the time. The origin of this discrepency is unclear, potentially due to differing training advice given to participants in each study, or even characteristics of the participants themselves. Regardless, this demonstrates the variability of the Emotiv EPOC's accuracy across studies.

In addition to the frequent occurrence of incorrect commands, participants took significantly longer to complete the familiarization trials, and were able to score significantly fewer points, when using the BCI control mode. This can be explained by the imprecision of the EPOC's detection algorithms; the majority of detected commands were incorrect or unintended and thus it took participants far longer to move their current block to the desired position, leading to longer familiarization completion times and lower scores. The game data combined with the challenge factor scores indicates that the usability of BCI mental commands is low—compared to traditional input methods—and rejects the earlier analysis suggesting that BCI navigation and selection allows for more direct translation of users intents. This is where the results of this study deviate from Hakvoort et al.'s; their BCI selection method allowed participants to make selections by looking at the object they wished to select—an action that participants would have completed regardless of the mode of control. This demonstrates the potential of BCI control to become an invisible piece of hardware, directly translating user intent in real-time. This study was able to implement more BCI control into its control scheme by using trained mental commands and facial expression detection. In doing so the BCI became a conveyer of greater information (selection and navigation) in comparison to what was done by Hakvoort et. al.. However, the results suggest that mental commands do not share invisible quality held by BCI selection. They are not only visible, but become an additional challenge of the virtual task that users need to consciously overcome. Despite the visibility of the consumer-grade BCI control mode, participants considered it to be more immersive than their experience with the non-BCI control mode, indicating that the invisibility of controls is not integral to immersion.

The challenges BCI systems pose when attempting to train and use mental commands may explain the majority of the results concerning immersion. A more taxing control mode, such as the BCI, requires higher amounts of concentration from the user in order to complete basic commands. This concentration may explain the higher real world dissociation and emotional involvement scores. When using the BCI control mode, users needed to remain more concentrated, over a longer period of time, to complete the same commands that required less effort using the non-BCI control mode. When attempting to use a trained mental command, users must focus on their chosen visualization (used to train a particular command), to the exclusion of all else. Thus, due to its challenging nature, the use of trained mental commands dissociates users from the real world. In addition, the difficulty the BCI control mode introduced to the game may have effected user's emotional involvement scores. Challenge can cause a user to feel anxious about failure, particularly if the task is simple. This may prompt the user to expend more energy, attention, and effort into overcoming the challenge, indicating a higher amount of emotional attachment to the game and its outcomes.

Lastly, the presiding researcher noticed a high degree of excitement in participants that were able to complete all the experimental trails. Participants often lingered in the testing room following the termination of the experimental process to reflect on their experience. Many noted that misclassification of mental commands limited their ability to perform their desired movements. Yet, this did not seem to inspire frustration with the BCI's inaccuracies, rather participants seemed excited that they had just controlled a virtual environment with their thoughts and were interested in discussing how to train the BCI more accurately. These reactions suggest a patience with the imprecision of novel technologies. Although not specifically mentioned by Brown and Cairns, user patience relates to the barriers of Access and Investment—

the initial barriers that need to be overcome to reach the first level of immersion, Engagement (Section 2.1.1). According to Brown and Cairns, these barriers are primarily beholden to user preference, however the higher BCI immersion scores across most participants suggest that novelty, and excitement of the same, may supersede aspects user preference in attaining Engagement.

Chapter 6

Conclusion

A consumer-grade BCI—the Emotiv EPOC—was used to assess the immersive potential of BCIs as a means of virtual control. A BCI control scheme was integrated into a testing game, BrainBlocks, with the addition of a training stage, allowing participants to train and use two mental commands (left and right). Twenty, out of twenty-seven total participants were able to successfully complete all the experimental trials (Section 3.2) in the allotted time. All twenty participants completed the experimental procedures with both a non-BCI control mode and the BCI control mode. Following the completion of a control mode participants rated their experience for immersion.

The results suggest a significantly more immersive experience when using the BCI to control BrainBlocks. The game statistics and the five factors of the total immersion score suggest this difference pertains to the challenging nature of using BCI mental commands, rather than the ability of the BCI to translate user intent in a manner that makes the control mode invisible. The challenges BCI systems pose when training and using mental commands require total attention and focus to complete tasks that are relatively effortless with the non-BCI control mode. Furthermore, the presiding researcher reported the excitement the BCI inspired in the participants that were able to complete all the experiment's tasks. Their excitement seemed to outweigh the irritations of the BCI's inaccuracies, demonstrating a degree of patience with novel technologies.

This experiment raises questions concerning the relationship between usability, challenge, and immersion. It would be interesting to conduct a similar experiment with participants who have experience with, and have become adept at using mental commands. Would the BCI control mode still be significantly more immersive if it were easier to use trained mental commands? Would this form of immersion relate more to the invisibility of the control mode? Prior to this, one may attempt to discover the procedures and visualizations that result in the most accurate training and use of mental commands. It would also be interesting to see how novelty plays into immersion. Do people immediately become more immersed in a task when they are using a control mode that is new and novel? How would this change over time? Such an experiment could compare the immersive scores after participants complete the same task with a classic control mode, a BCI control mode, and some other novel control mode (speech, body gestures, or a new tactile control mode).

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Appendix A

Informed Consent Agreement

Study Title: The Ability of BrainComputer Interfaces to Alter Levels of Immersion

Researcher Name: Elias Posen

Advisor Name: Sven Anderson

I am a student at Bard College and I am conducting research for my Senior Project. I am studying how the use of a Brain-Computer Interface (BCI) to control a computer alters the user's experience in comparison to typical input methods.

Your tasks during this study:

Should you agree to participate in this experiment, you will be asked to complete a number of tasks. These include playing BrainBlocks, a Tetris-like game that has been modified for BCI control, and completing a number of questionnaires. During the course of playing BrainBlocks you will be asked to train the BCI system to recognize the mental commands of Left and Right and to then use those commands to control the game. During this experiment I will need to record electrical signals created by your brain. In order to record these signals small electrodes will be placed on your scalp using some saline solution or gel to facilitate better connection. All electrodes will be covered by clean, new, felt pads. There are no risks associated with placing such electrodes on your scalp. This study is expected to last approximately 60 minutes and will not run longer than 90 minutes.

Risks and Benefits:

Potential risks to the participant include minor eye strain caused by lengthy computer use. Minor hand strain may also occur from repeated keyboard action and there is a possibility of minor mental fatigue that accompanies elongated BCI interactions. If you have an undiagnosed neurological condition, risks of adverse responses to the experiment's tasks may occur. There are no direct benefits to the participant, yet you will be allowed to use relatively new form computer interaction which you may not experienced before and will gain experience in the experimental process. As compensation for you time you can be entered into a lottery where two $50 Amazon gift cards are available. Participation in the lottery is optional. Winners will be chosen randomly following the conclusion of all experiments on April 10th. Winning participants will be notified through the emails they provided

Your Rights:

As your inclusion in this experiment is completely voluntary you may choose to discontinue the experiment or skip tasks at any time, without penalty. If you choose to do so you will remain eligible for any aforementioned compensation. Please inform the researcher if you choose to withdraw yourself.

Confidentiality:

All responses to questionnaires and data associated with this study will remain confidential. All data and responses will be solely connected to a randomly generated unique participant ID number. There will be no link, digital or otherwise, connecting your name and email to your participant ID. Any information published from this experiment will not make it possible to identify you as a participant. Prior to the completion of the written report, your questionnaire responses and acquired data will be securely stored on a password protected computer or in a locked cabinet, accessible only by myself and my faculty advisor, Sven Anderson. If you have any questions or wish to have a copy of this consent form, please ask Elias Posen (ep2851@bard.edu) or contact his academic advisor Sven Anderson (sanderso@bard.edu). If you have questions concerning your rights as a participant of this study please contact the Bard College Institutional Review Board (irb@bard.edu).

Participant's Agreement

I understand the purpose of this research. My participation in this test is voluntary. If I wish to stop the test for any reason, I may do so without having to give an explanation. The researcher has reviewed benefits and risks of this project with me. I am aware the information will be used in a Senior Project that will be publicly accessible online through the DigitalCommons and at the Stevenson Library of Bard College in Annandale on Hudson, New York.

The information gathered in this study is confidential with respect to my personal identity. I understand that complete confidentiality cannot be guaranteed, since the researcher may be required to surrender data if served with a court order.

All of my questions have been satisfactorily answered and I have been provided with the relevant contact information should I have any further inquiries.

I have read the consent form and agree to be a participant in this study.

By signing below, I agree to the **participant's agreement** and further confirm that I am 18 years of age or older.

Participant's Printed Name

Date

Participant's Signature

☐ I would like to be entered into the lottery for two separate $50 Amazon gift cards (mark with X)

Researcher's Signature

Appendix B

Researcher's Experiment Script

Prior to Consent Form:

Before we can start experimental procedures, please read the Informed Consent Form. If you have any questions about the consent process or any of the items on the consent form, please feel free to ask me.

After Consent Form:

Thank you for agreeing to be a participant in this experiment, if you would like a photocopy of the consent form please let me know. Here is a listing of your participant id number, your participant group number, and the control mode you will be testing first. You will enter this information at the beginning of each questionnaire and testing session. While the headset is being prepared, please complete the Pre-Experiment Questionnaire open in the internet browser.

After Pre-Experiment Questionnaire:

I will now place the Emotiv on your scalp and establish connection with the computer. While I am doing so please review the BrainBlocks control sheet and let me know if you have any questions.

Bad connection: Unfortunately I was not able to establish the required signal connection for this experiment. This means this is the end of the experiment, your name will still be entered into the lottery if you marked the appropriate box on the consent form. Thank you for your time. **END**

Good Connection: Connection has now been established, please place your chin on this chin rest. Be sure that the rest does not cause you to clench your jaw, you should be holding the weight of your head without much assistance from the rest. Your teeth should not be in contact during this experiment. (*Adjust until participant is comfortable*).

<u>Pre-Session:</u>

Before BCI Control: I would like to take this moment to give you some tips on how best to train and use the Emotiv EPOC. Everything I say is summarized on your mental command training tip sheet. Prior to starting the experimental trials, you will first be asked to train the your unique mental commands of Left, Right, and Neutral. This process will start by training neutral, this will form the baseline to which other mental commands are compared. Each training period takes 8 seconds. When training neutral it is important that you stay mentally and physically calm for the entirety of the training period. Limiting eye movement and blinks is also useful in not polluting the training data. Once neutral is successfully trained you will be prompted to train your first mental command. Key to this stage is to visualize the command to be trained without tensing your muscles, clenching your jaw, or blinking excessively. For example imagine a ball of fluid in a cage hovering in front of your eyes. When training left, imagine that ball squeezing through the left side of the cage, and when training right imagine the ball squeezing through the right side of the cage. Another visualization you may want to try is visualizing clenching your left hand when training left and visualizing clenching your right hand when training right. These are just examples feel free to use your own visualization however it is best to keep them simple like the examples. Successful training requires consistency of the visualization—throughout the entire 8 seconds—and successful use of the trained command requires the ability to recreate the visualization used for training. Once you have trained your first action twice you must pass a trial before being allowed to train your next command. You may clear the training data for your commands if your feel like your mind wandered during the training period, or if you moved (cough, shift in chair), or if you are unable to pass the trial. To restart the training process clear the neutral training data. You will be given 30 min to attempt to pass this stage; you will be notified when you have 10 minutes remaining. The BCI Training Tips summarizes what I have just told you. Do you have any questions about the training or the trials? (*Answer Questions*)

Before Both Control Modes: We are now ready to begin. Please open BrainBlocks, enter your participant ID and group ID and select your first control mode and click start. Be sure not to clench your jaw and to move as little as possible during the session. Please click pause during the stage before you ask any questions or if you feel like taking a break.

<u>During Session:</u>

(*Answer any questions participants have, be sure they are in a pause when this occurs*)

BrainBlocks TimeOut: You have exceeded the allotted time for this stage of the experiment. This means this is the end of the experiment, your name will still be entered into the lottery if you marked the appropriate box on the consent form. Thank you for your time. **END**

<u>Post-Session:</u>

First Session Done: I will now remove the Emotiv to re-saturate the sensors. In the meanwhile please complete the post-session questionnaire in the open internet browser.

First Session Questionnaire Finished, Connection Re-Established: Please open Brain-Blocks, enter your participant ID and group ID, select your second control mode and click start. Be sure not to clench your jaw and to move as little as possible during the session.

Second Session Done: This concludes the gameplay component of the experiment. Please again fill out the post-session questionnaire in the open internet browser.

Section Session Questionnaire finished: This is the end of the experimental procedures. The winners of the raffle will be notified by email on April 19th. Thank you again for your participation in this study. **END**

Appendix C

Brain Blocks Control Sheet

Normal Mode	**BCI Mode**
Orientation Mode *Spacebar*: Rotate Block *Down Arrow*: Switch to Navigation Mode Navigation Mode *Up Arrow*: Switch to Orientation Mode *Left Arrow*: Move Block Left *Right Arrow*: Move Block Right *Down Arrow*: Drop Block	Orientation Mode *Blink*: Rotate Block *Down Arrow*: Switch to Navigation Mode Navigation Mode *Up Arrow*: Switch to Orientation Mode *Left Mental Command*: Move Block Left *Right Mental Command*: Move Block Right *Down Arrow*: Drop Block

Preview Block:

The grey preview block shows you where your block would drop given the current position and orientation. The preview block changes shade when you switch between orientation and navigation mode. It is darker in orientation mode and lighter in navigation mode.

Appendix D

Mental Command Training Tip Sheet

<u>General:</u>

- Each training period takes 8 seconds to complete.
- If you have any questions please pause the game before asking or moving your head off the chin rest.

<u>Rules of Training Stage:</u>

- Neutral must be trained first, this data becomes the baseline to which all mental commands are compared.
- You must train each command (not including neutral) twice before starting the mental command trial.
- Training data for left and right can be cleared. If this is done you must retrain twice before being allowed to attempt the trial again.

- Clear neutral training data to start again. (This will also clear all previously trained data for left and right).
- When to clear:
  - Mind wanders during the training period.
  - Physical movements during training period (e.g. cough, shifting in chair).
  - Inability to pass mental command trial
- After a test is passed, the mental command that was being tested can no longer be trained.
- You are given <u>30 minutes</u> to pass this stage

<u>Training Neutral:</u>

- Remain mentally and physically relaxed throughout the duration of the training.
- Limit blinking or do not blink at all.
- Breath steadily and normally.

<u>Training Left and Right:</u>

- Do *NOT* tense your muscles during training, this will pollute the training data.
- Maintain your chosen mental command thought consistently over the *entire* training period.
- Visualization of the intended command can often help.
  - Example 1: Imagine a ball of fluid in a cage hovering in front of your eyes. When training left, imagine that ball squeezing through the left side of the cage.

  - Example 2: When training left, imagine clenching your left fist. When training right, imagine clenching your right fist.

- Successful training requires *consistency* and *focus*, the ability to replicate these visualization will assist BCI in classifying your mental commands more accurately.

Appendix E

Pre-Experiment Questionnaire

Participant ID: _________

1) Gender: *Female* *Male* *Other:* _________

2) Handedness: *Left* *Right* *Ambidextrous*

3) Age: _________

4) Have you ever used a Brain-Computer Interface (BCI) before?

Yes *No*

5) If yes, how successful were you in controlling a computer through the BCI?

Not Successful *1* *2* *3* *4* *5* *Very Successful*

6) Do you play video games? *Yes* *No*

7) If yes, approximately how many hours a week do you play video games? _________

Appendix F

Jannett et al.'s Immersion Questionnaire

1) To what extent did the game hold your attention?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

2) To what extent did you feel you were focused on the game?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

3) How much effort did you put into playing the game?

Very little	*1*	*2*	*3*	*4*	*5*	*A lot*

4) Did you feel that you were trying your best?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

5) To what extent did you lose track of time?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

6) To what extent did you feel consciously aware of being in the real world whilst playing?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

7) To what extent did you forget about your everyday concerns?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

8) To what extent were you aware of yourself in your surroundings?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very aware*

9) To what extent did you notice events taking place around you?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

10) Did you feel the urge at any point to stop playing and see what was happening around you?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

11) To what extent did you feel that you were interacting with the game environment?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

12) To what extent did you feel as though you were separated from your real-world environment?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

13) To what extent did you feel that the game was something you were experiencing, rather than something you were just doing?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

14) To what extent was your sense of being in the game environment stronger than your sense of being in the real world?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

15) At any point did you find yourself become so involved that you were unaware you were even using controls?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

16) To what extent did you feel as though you were moving through the game according to you own will?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

17) To what extent did you find the game challenging?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very difficult*

18) Were there any times during the game in which you just wanted to give up?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

19) To what extent did you feel motivated while playing?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

20) To what extent did you find the game easy?

Not at all	*1*	*2*	*3*	*4*	*5*	*Very much so*

21) To what extent did you feel like you were making progress towards the end of the game?

Not at all	*1*	*2*	*3*	*4*	*5*	*A lot*

22) How well do you think you performed in the game?
Very poor *1* *2* *3* *4* *5* *Very well*

23) To what extent did you feel emotionally attached to the game?
Not at all *1* *2* *3* *4* *5* *Very much so*

24) To what extent were you interested in seeing how the game's events would progress?
Not at all *1* *2* *3* *4* *5* *A lot*

25) How much did you want to "win" the game?
Not at all *1* *2* *3* *4* *5* *Very much so*

26) Were you in suspense about whether or not you would win or lose the game?
Not at all *1* *2* *3* *4* *5* *Very much so*

27) At any point did you find yourself become so involved that you wanted to speak to the game directly?
Not at all *1* *2* *3* *4* *5* *Very much so*

28) To what extent did you enjoy the graphics and the imagery?
Not at all *1* *2* *3* *4* *5* *A lot*

29) How much would you say you enjoyed playing the game?
Not at all *1* *2* *3* *4* *5* *A lot*

30) When interrupted, were you disappointed that the game was over?
Not at all *1* *2* *3* *4* *5* *Very much so*

31) Would you like to play the game again?
Definitely not *1* *2* *3* *4* *5* *Definitely yes*

Appendix G

Immersion Questionnaire Scoring Sheet

Question	Challenge	Control	Real World Dis.	Emot. Involv.	Cog Involv.	Total Immersion
1					1	1
2					1	1
3					1	1
4					1	1
5			1			1
6			-1			-1
7			1			1
8			-1			-1
9			-1			-1
10		-1				-1
11		1				1
12			1			1
13				1		1
14			1			1
15		1				1
16		1				1
17	1					1
18	-1					-1
19					1	1
20	-1					-1
21					1	1
22					1	1
23				1		1
24				1		1
25					1	1
26	1					1
27				1		1
28		1				1
29					1	1
30				1		1
31				1		1

Appendix H

BrainBlocks Logs

Log	Descrition	AUX Value
Start Normal Mode	Start Button Click for Normal Mode	N/A
End Normal Mode	Normal Mode Stages Finished	N/A
Start BCI Mode	Start Button Click for BCI Mode	N/A
End BCI Mode	BCI Mode Stages Finished	N/A
Start Pause	User Clicked Pause	N/A
End Pause	User Ended Pause	N/A
Start BCI Training Stage	User Entered BCI Training Scene	N/A
End BCI Training Stage	User Exited BCI Training Scene	N/A
Training Neutral	Train Neutral Clicked	N/A
Training Right	Train Right Clicked	N/A
Training Left	Train Left Clicked	N/A
Neutral Cleared	Neutral BCI Training Data Cleared	N/A
Right Cleared	Right BCI Training Data Cleared	N/A
Left Cleared	Left BCI Training Data Cleared	N/A
Right Training Trial Passed	Moved Block Over Right Trial Prompt	N/A
Left Training Trial Passed	Moved Block Over Left Trial Prompt	N/A
Timed Out	30 min Expired: BCI Training Stage	N/A
Start Familiarization	User Entered Familiarization Stage	N/A
Completed Familiarization	User Exited Familiarization Stage	N/A
Trial Prompt Created	Familiarization Trial Prompt Created	x-Position of Prompt
Block xPos at Start Navigation	User Matched Trial Prompt Rotation	x-Position User's Block After Matching Rotation
Familiarization Trial Passed	Familiarization Trial Passed	N/A
Unable to Complete Stage	5 min Expired: Familiarization Trial	N/A
Block Rotated	User Rotated Block	N/A
Block Left	User Moved Block Left	x-Position of User's Block After Movement
Block Right	User Moved Block Right	x-Position of User's Block After Movement
Block Created	Block Spawned in Gameplay Stage	N/A
Block Dropped	Block Dropped in Gameplay Stage	N/A
Score	Row Filled in Gameplay Stage	Current Score
Game Over	Block Exceeds Bounds of Playspace	N/A