BRAIN INVADERS

FINDING THE PARADOX OF CONTROL IN A P300-GAME THROUGH THE USE OF DISTRACTIONS

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“Let my playing be my learning, and my learning be my playing”

– Johan Huizinga

Preface

It has been approximately one year since I left The Netherlands for Grenoble, France, to start the research that would ultimately lead to the master thesis now in front of you. The first half of that year consisted of finding myself in a strange city in a strange country, while I hardly managed to speak any French at all. I spend my days there designing, developing and testing a game, and of course of making many new friends. The second half was spend trying to write this thesis, perhaps requiring a bit longer than I had anticipated.

One of my greatest passions has been a leading thread throughout my studies: gaming. Not just in playing them, mind you, although I did my fair share of that as well. I have also spend time analysing them as a reviewer and learned about them through a study tour to the United States I partook in and by designing them as a student in Human Media Interaction. The pinnacle of those many experiences in the field of gaming is perhaps this thesis, as it too focuses on gaming.

To me the medium of games is one that might very well define the coming decennia. For games are more than just forms of entertainment. They are an active medium and, as such, encourage players to think out their actions logically, emotionally, or even morally. Through gamifications tasks can be learned, and through interactive stories art can be created that was deemed impossible before. We are, however, not quite at full potential of the medium just yet.

Game designers should be the primary source for unlocking the full potential of games, but, nevertheless, scientific research can prove of high value. The research on new input methods, such as done in this research, will pave the way for new forms of gaming and, therefore, new ways in which we consume our media. Yet, as I have seen frequently, there is little regard for actual game design theories. I have argued for their usefulness before and shall continue to do so throughout this thesis. For we have to ask ourselves how valid research can be if we do not fully understand the scope of such research.

If I can achieve one thing with this thesis I hope it is encouraging a stronger inclusion of game design theories in new input research. Because through understanding we might just get closer to gaming with a Brain-Computer Interface.

- Gijs van Veen

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Abstract

Research on Brain-Computer Interaction is slowly moving away from purely medical topics and into fields that allow for broader uses. Among these groups gaming is becoming a popular focus. While BCI-research in general requires precision, speed, and accuracy, gaming has its own separate requirements for controlling inputs, most importantly the presence of a Paradox of Control. That is to say; a game must give the player the feeling of being in control while also giving the feeling that control can be lost, causing failure.

This research aims to find a form of the paradox of control within a specific paradigm of Brain-Computer Interaction, the P300-response. While the paradigm is usually used to select a single element out of a group of elements, we are interested in the consequences of trying to disturb this selection process. For this, we have developed the P300-controlled game Brain Invaders, a game based on the classic Space Invaders that tasks players to focus on specific targets while the game tries to distract them. This will give insights into the balance between control precision and challenge.

Results of the experiment indicate that distractors as implemented in this thesis do not sufficiently influence difficulty. Although some flaws in the experimental set up might have skewed these results, the general tendency of the experiment indicates that colours and movement do no influence difficulty. Nevertheless, they do seem to influence player enjoyment.

Contents

Chapters

Appendices

CHAPTER 1

Introduction

When Johan Huizinga posed his hypothesis of the Playing Man in his revolutionary work *Homo Ludens* [1] little could he have expected that less than a century later, humanity would have embraced its playing roots with such passion. Although the act of playing is older than humanity itself and, therefore, not necessarily a solely human property – let alone a modern one – the 21th century man has embraced his desire to play like never before. From sports to gambling and from simple card games to complex video games, the availability of ways in which one can play has never been broader nor has playing a game ever been more widely accepted. While playing was once the domain of children, nowadays our entire culture seems to revolve around it.

Like many elements of our modern society, the act of playing has seen a big influence by the rise of computer technology. The 1961 MIT experimental game *Spacewar!* was but the start of a new medium that evolved into a billion dollar industry, recently even surpassing music and video in terms of revenue [2]. Humanity seems obsessed with playing, with beating yet another high score. Since – as Huizinga noted – playing functions as a method for learning, it seems that people that are playing games are willing to try something new. New input mechanisms, such as motion- (Nintendo Wii and Microsoft Kinect), voice- (Kinect), and touch control (smartphones, Nintendo DS); all seem to have found their entrance into the modern household (partially) due to gaming.

1.1 Brain Gaming

It is thus no wonder that other – more experimental – input mechanisms are considering video games a holy grail of mass market penetration. One of the more promising fields is perhaps that of the Brain-Computer Interfaces (BCI). A BCI consists of the communication between the brain and some external device, usually through Electroencephalography (EEG). Already, BCIs are an starting to become an established technology in the medical field, where they have applications such as prosthesis control or biofeedback [3]. Furthermore, in order to get the BCI technology used more widely, focus has recently started to shift towards other fields. Due to the apparent willingness of gamers to adapt new input mechanisms, gaming is one of the fields that has seen an increased interest in research applications [4].

Current BCI games range from very simple concept games such as BrainBall [5] to the implementation of additional control input in games such as World of Warcraft [4]. In fact, the company NeuroSky has already released a very simple commercial EEG device that supports some games [6].

Most of these games task the player with achieving a certain user state in their brainwaves, such as concentration or relaxation. There are more BCI paradigms that can be used for gaming purposes however. Plass-Oude Bos et al. describes three groups of these paradigms, the neurofeedback, the stimulus response, and the motor-imagery paradigms [7].

The neurofeedback paradigms are found in the games mentioned previously. Through the measurements of the characteristic broadband frequencies of the brain, such as the alpha, beta, and gamma waves, the paradigm assigns a mental state to the player. This state is then displayed to the player, who is usually required to adjust or maintain the state. Games using a neurofeedback paradigm often task players to relax, concentrate, or focus.

The second group of paradigms – the stimulus-response paradigms – is based on involuntary actions by the user of the BCI. The wearer of the BCI device will be given some stimulus, usually an audio-visual one, to which the brain will react. By detecting this reaction it becomes possible for users to do a selection on a screen simply by focussing on the desired selectable. This paradigm group has multiple variations, such as the P300 response and the Steady State Visually Evoked Response (SSVEP). The P300 response is an event related potential that takes place roughly 300 milliseconds after a stimulus is presented to the user. The SSVEP uses stimuli at specific frequencies that the brain synchronises to. In essence, the P300 response is based on stimuli only occurring after a random interval whereas the SSVEP requires an almost constant presence of stimuli. Both are often used for selection, such as on a virtual keyboard, and are perhaps the closest to the pressing of buttons often seen in video games. Games made using these paradigms include The Mindgame [8] (P300 based) and MindBalance [9] (SSVEP-based).

The last of the major paradigm groups are the motor-imagery paradigms. Here the BCI detects imagined motion by the wearer of the EEG device. Motion can range from simple left or right movement to the imagined movement of entire limbs. In theory imagined motion has the highest potential for game design, as it has the potential to give the highest degree of freedom. However, detection is also among the most complex of BCI paradigms, limiting the actual range of the input. Nevertheless, there have been some games based on motor imagery, such as the game Brain Basher [10] and a BCI controlled variation on Pacman [11].

1.2 Staying in control

Despite the numerous BCI-based games described in research, there is often a discrepancy between the goals of experiments executed and the inclusion of game design in those experiments. Games created for brain computing research seem to either take existing games and replace some of their input mechanisms by BCI paradigms or are newly designed games with very little regard for gameplay itself. This is problematic not only because wrongly designed games could result in incorrect research conclusions but also because failing to research the new requirements of an input mechanism vastly different from a normal game controller might result in bad games and, therefore, limit the potential of BCI devices as game controllers. As Gürkök notes, the scientific community designs BCI games to test some psychological hypotheses without properly testing elements such as user experience. This results in games that may be functional but often hardly enjoyable. At the same time, BCI games developed by game designers may focus on enjoyment but show little regard for technical aspects related to BCI. This results in games that are lacking in sense of control [12].

Therefore, all research related to games should consider game design theories, while research on BCI as a control mechanism should consider BCI literature. A properly designed game will most likely lead to better and more accurate research, results in research that may assist in the development of future games, and may even lead to finding unexpected optimisations in the related research field. In the case of BCI-controlled games, this includes more successful games and potentially insights into the improvements on signal processing that can be made.

While there are many different game design theories – which we will look into a bit deeper in Chapter 2 – BCI-related research should consider the theories based on control the most important, since BCI games tend partially replace traditional controls with a BCI paradigm at the very least. The exception here is the usage of *passive* BCI control, wherein a subconscious user response is used for control. Passive BCI can only be an additional control mechanism as conscious control over a game is usually assumed. The scope of this thesis is therefore limited to active BCI paradigms. Interactive media games are highly dependent on controls being not only accurate, clear, and fast – a focus of broader BCI research as well – but also on controls that are engaging to the player.

This is shown by what Salen and Zimmerman call the *paradox of control*, described by them as:

> *"In an optimal experience, the participant is able to exercise control without completely being in control of the situation. If there is no chance of failure, the activity is not difficult enough. "Only when a doubtful outcome is at stake, and one is able to influence that outcome, can a person really know whether she is in control." As game players struggle against the system of artificial conflict, they attempt to assert control by taking actions. Yet the outcome of a game is always uncertain." [13].*

The paradox of control, which is strongly based on Csikszentmihalyi's theory of *Flow* [14], assumes that a game will be at its most engaging if a player feels in control of the events that occur in a game, while at the same time feeling the possibility of losing control due to his own failure. There are limits to this loss of control however, as it is essential that any failure is only to blame on the players themselves. Losing a game due to imprecise controls breaks immersion and leads to a less enjoyable game. If we consider a regular video-game controller, this means that when a player presses the jump button, the onscreen character should jump immediately but should never jumps when the button is not pressed. Therefore, when a player falls into a pit, he can only blame himself for failing to jump correctly but never the game itself.

Therefore, it seems that finding ways to create an implementation of the paradox of control is essential for proper BCI-controlled games. Since brain signals are hardly similar to the pressing of buttons, techniques need to be found to create such a paradox of control. There are multiple problems that immediately come to mind. First of all, we already distinguished three different groups of BCI paradigms. All these paradigms work in a different fashion in terms of signal processing and may, therefore, have a different form in which a paradox of control can be achieved. Secondly, there is the occurrence of the problem called BCI illiteracy, which essentially means some players will not be able to use a specific BCI paradigm [15]. Furthermore, there is the issue of conscious interaction. Some BCI paradigms will feel more natural to a user than others. Therefore, it is wise to consider a specific BCI paradigm – ideally the one best suited for gaming – when trying to create the paradox of control.

On the other side there is the illusion of control, which shows that users will feel some form of control even if they have none at all [16]. This is a useful trait as it means that users can be tricked into feeling some sense of control. This illusion allows for the paradox of control to exist, despite the fact that BCI paradigms tend not to achieve a 100% accuracy rate. Low accuracy can be attributed to signal contamination such as by player movement, blinking, and the special mixing of brain signals in different parts of the brain, which causes signals that are of high interest to become more difficult to detect [17].

1.3 Selecting a paradigm

Still, some paradigms might prove more useful for BCI gaming than others. Paradigms may be more accurate, have a higher sense of control, or simply offer higher speed or more dimensions of control. Furthermore, all paradigms will have their own potential as well as limitations with respect to the paradox of control. This leaves us with the task of selecting the best paradigm for achieving an occurrence of the paradox of control.

The neurofeedback paradigms have several limitations. First and foremost, there is the difficulty to achieve a proper sense of control. Players will most likely find the task to alter some of their brainwaves a highly abstract concept. It is difficult for people to tell whether they are relaxed, especially when a BCI device is determining the mental state. While this can be trained, such training can be time intensive. Secondly, due to the time required to assign a mental state, neurofeedback paradigm games should be played at a slow pace. Thirdly, while mental states can be assigned over a continuous scale, most games usually implement a binary scale (e.g. relaxed/not relaxed), as a gradual scale is non-trivial [12], limiting the degrees of freedom. Finally there is the so called Midas Touch problem, the accidental selection of an unintentional action. For instance, a player can trigger the game to think he is relaxed even when such interaction is not intended. Such interaction is limiting to the sense of control [18].

Much of the same limitations can be found in the motor imagery paradigms. While in theory many different forms of motion could be detected, the paradigm works best when used to detect a single motion, such as the movement of a finger [19]. The Midas Touch problem can also occur. However, the motor imagery paradigms are more similar to a normal human interaction and, as such, will feel more natural to most players. While the paradigms require some time for training, it is easier for the player to imagine the movement of a finger than for them to judge their own relaxation level. The detection of imagined motion is fast as well, allowing for fast performance games [12]. However, the paradigm is severely limited by BCI illiteracy, the inability to use a use the paradigm. Simply not being able to control a game is directly breaking the paradox of control and should thus be limited as much as possible. Research by Guger et al. showed that after a few minutes of training only 19% of the people trying to use motor imagery got an accuracy of 80% or higher [20].

Both of the previous paradigm groups have been self driven paradigms, using interaction that is triggered by the player on any desired moment in the game. The stimulus response paradigms differ in that respect, as they are an interaction form that can only occur at a moment the game allows it (e.g. provides the stimuli). This brings along two potential issues for the use in gaming. First of all, players can perceive the fixed moments of interaction as limiting, which might break their sense of control. While this can be circumvented by proper interaction design, the limiting nature of the stimuli paradigms needs to be considered. Secondly, having the player concentrate on stimuli constantly can become very tiresome and uncomfortable to the player [19]. This is particularly true for the SSVEP paradigm, as it features a constant flickering [21]. While the stimulus response paradigms are also relatively slow in their detection, they allow for many more dimensions of interaction, as the player is essentially tasked with selecting an option out of as many selectable options that fit on screen. They have relatively low illiteracy rates – 89% of the users are able to get an 80% accuracy or higher after only a short training [20] – and can be used without requiring long training sessions.

So which of these paradigms are most suitable to be used for a game? While all have their strengths and weaknesses, we have decided to focus on the P300 paradigm. Due to the unnatural form of interaction the neurofeedback paradigms are estimated to have a low sense of control and are, therefore, less suitable to achieve a proper form of the paradox of control. Similarly, motor imagery has a big loss in proper sense of control due to its high illiteracy rate. From the sense of control perspective, we consider the stimulus response paradigms to be the most suitable. While these paradigms also have their limitations, we believe these to be easier to circumvent through game design than the problems of the other two paradigm groups. Since the P300 paradigm shows high accuracy with little training required and has a smaller likelihood of tiring the player, this paradigm was selected for this thesis.

1.4 Research Question

A stimulus-response paradigm seems the most ideal for the first part of the paradox of control. That is, a stimulus response – more specifically the P300 response as tested by Guger – provides a relatively high sense of being in control of the situation. But the latter part of the paradox – the sense of failing control – is still nowhere to be found. Consider a standard P300 speller, which lets users select elements from a group of flashing rows and columns by focusing on the desired element. The question arises how users can be given the sense of failing at selecting the desired element without them blaming the BCI signal. More broadly speaking, we ask:

> What are the best ways to make selections through a P300 paradigm more difficult without giving the sense of lost control (i.e. create a paradox of control)?

The remainder of this thesis aims to set some first steps in creating this paradox of control.

1.5 Overview

The structure of this thesis is as follows:

Chapter 2 delves deeper into the underlying literature. In other words, the chapter will explore theories on games, game design, the P300 paradigm, and research where these elements meet each other. This chapter will eventually lead to our hypotheses.

Chapter 3 explains how this thesis aims to prove the hypotheses and eventually answer the research question.

Chapter 4 walks through the design process of the software required for the experiments.

Chapter 5 explains the set up and process of the experimentation itself.

Chapter 6 reviews and analyses the results of the experiment.

Chapter 7 uses the experimentation results to review the hypotheses and answer the research question.

CHAPTER 2

Related Work

This chapter delves further into the literature related to game design, the P300 effect, and BCI games. The chapter serves to expand upon the definition of terms given in the previous chapters and include additional terms where fit.

Furthermore, it should be noted that the research question posed in Chapter 1 is still very broad. Undoubtedly there are many ways in which one can achieve the paradox of control for a P300 game. Therefore, this chapter will also serve as a literature study in order to find potential ways in which the paradox of control can be accomplished. This will eventually lead to the hypotheses for this thesis, posed at the end of this chapter.

2.1 What is a Game?

A term which we have mostly ignored so far – yet standing at the centre of this thesis – is the actual game. Naively we have assumed to know exactly what a game entails, a mistake that is in fact found in many studies on BCI-games. Perhaps this is because, as Huizinga noted, gaming is present in the core of our nature [1]. We know something is a game when we see it.

Nevertheless, it is wise for us to formalise the meaning of games instead of counting on our intuition. This does not just clarify the scope of our research; it also prevents conflicts between different definitions of a game. Since Huizinga – who already tried defining games – there have been many definitions of games. Instead of his original definition, however, we will take the refinements and critique given by Caillois as the first basis of our definition [22].

Caillois defines a game as an *activity* that is:

- **Free**, where play is never forced.
- **Separate** from the real world, meaning it has limits in space and time set in advance.

- **Uncertain,** so that the outcome cannot be determined beforehand.
- **Unproductive,** as it creates no goods or wealth, although exchange of property can occur (for example in a bet)
- **Governed by Rules**, which determine how the game is played.
- **Make-believe**, as games require all players to accept the new reality in which the game takes place.

However, this early definition seems to lack some elements we might intuitively expect. For instance, Caillois' definition lacks the mention of a goal the player has when playing a game. Yet, a goal is to be expected within the concept of a game. When playing football, the goal of the game is to make the most points. And when playing Super Mario, one tries to reach the end of the level without dying. At the same time, Caillois' definition might be seen as too broad – as this definition could, for example, also include an improvised play, which we would not necessarily count as a game.

A definition limiting the scope while also including the goal of a game is given by Clark C. Abt. Abt defines games as an activity wherein two or more decision makers are trying to achieve their goals while in some limiting context (e.g. rules). In more simple terms, a game is "*a context with rules among adversaries trying to win objectives*" [23]. While this definition clearly describes a game, again it is – as Abt himself also noted – both too broad and too narrow. Too broad, because it may include forms of play we do not really consider games. Too narrow, because, for example, cooperative games where there is no clear goal for an adversary are not included.

Another definition too narrow – but interesting due to its focus on games themselves rather than the process of playing a game – is the definition given by Avedon and Sutton-Smith. According to them "*games are an exercise of voluntary control systems, in which there is a contest between powers, confined by rules in order to produce a disequilibrial outcome*" [24]. This definition works well because it includes rules, a goal, and some form of influence on the system by the players. Once again, this definition lacks the inclusion of a cooperative game. However, a disequilibrial outcome does ensure that a player versus the environment type of game – which is highly common in modern video games – is included in the definition.

The previous definitions seem to indicate that defining a game properly may result in definitions either too broad, too narrow or even both. Rather than giving yet another incomplete definition, Chris Crawford – one of the few actual game designers trying to capture the essence of a game – lists four primary qualities that a game should have: representation, interaction, conflict, and safety [25]. Crawford describes these as the following:

> *"Representation: A game is a closed formal system that subjectively represents a subset of reality. By "closed" I mean that the game is complete and self-sufficient as a structure. The model world created by the game is internally complete; no reference need be made to agents outside of the game. By formal I mean only that the game has explicit rules. A game's a collection of parts which interact with each other, often in complex ways. It is a system. A game creates a subjective and deliberately simplified representation of emotional reality.*
>
> *Interaction: The most fascinating thing about reality is not that it is or even that it changes but how it changes the intricate webwork of cause and effect by which all things are tied together. The only way to properly represent this webwork is to allow the audience to explore its nooks and crannies, to let them generate causes and observe effects. Games provide this interactive element, and it is a crucial factor in their appeal.*
>
> *Conflict: A third element appearing in all games is conflict. Conflict arises naturally from the interaction in a game. The player is actively pursuing some goal. Obstacles prevent him from easily achieving this goal. Conflict is an intrinsic element of all games. It can be direct or indirect, violent or nonviolent, but it is always present in every game.*
>
> *Safety: Conflict implies danger; danger means risk of harm; harm is undesirable. Therefore, a game is an artifice for providing the psychological experiences of conflict and danger while excluding their physical realizations. In short, a game is a safe way to experience reality. More accurately, the results of a game are always less harsh than the situations the game models."* [25].

Because these qualities are very open, the definition by Crawford is relatively broad. Nevertheless, Crawford seems to mention most of what we expect a game to have. Rules, a goal, and the fact that games take place somewhere out of the real world have all been accounted for. Furthermore, because Crawford is the first actual game designer posing a definition, some elements we might expect in a video-game definition are mentioned for the first time. For instance, interactivity is explicitly mentioned and of essence in a single-player video game. But while these qualities are essential to a game, they hardly define the concept itself.

All these elements and definitions seem to have some sort of overlap, from rules to the artificial reality created around games. To capture a more final definition, Salen and Zimmerman merged them all into one of their own. While not necessarily better in scope than the definitions given above this one seems to capture their essence while also taking into account the emergent requirements for video games. Salen and Zimmerman define a game as:

> *"A* game *is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome."* [13].

In this definition we again see rules, a goal (in this case called a quantifiable outcome), and the removal of the game from the real world (in this definition through an artificial conflict). We should also note that this definition does not rule out a single player or a cooperative game, as the conflict is not defined as being between the players. Furthermore, by defining a game as a system rather than as an activity, some additional features can be extracted.

Salen and Zimmerman use the definition of a system as given by Littlejohn, where four elements constitute a system: objects, attributes, relationships, and an environment [26]. Rather than just approaching a game as a system from a mathematical (formal) perspective, where a game is simply a set of logic and rules, they should also be framed from an experiential and cultural perspective. In this framing the experientially framed system contains the interaction and psychological experience of the game while the culturally framed system holds the broader impact on society and the comments the system gives on this society.

To illustrate, consider a game of Chess. In the formal framing of a system a game of chess consists of pieces (objects), the movement of those pieces (attributes), their positions and resulting effects (relationships), and finally the act of playing of the game itself (environment). But when seen as an experiential system, the players of the games become the objects of the system themselves. The relations then include tactics but also communication between players and psychological influence they have on each other. Finally, as a cultural system chess might reflect the (social) status of the player, it can be seen as commentary on monarchy, or simply influence culture by being referenced in other formats, such as movies or books. Understanding that a game is a system in all of these frames is essential to the definition by Salen and Zimmerman, as it defines games less as a simple set of rules and more as a system that has a broader impact on society.

For the remainder of this thesis, we shall use the definition as given by Salen and Zimmerman. Since we are focussing on video games in particular, the four traits that according to Salen and Zimmerman embody digital games more robustly than general games cannot be left unmentioned.

- **Immediate but Narrow Interaction** Due to the fast processing power of computers there is an almost immediate response to interaction, but the types of interaction a player can have is relatively limited.
- **Information Manipulation** The vast amount of memory in a computer enables computer games to have more detailed information on the game. This includes audio-visual representations as well as the fact that a player does not have to learn all the rules in order to play.
- **Automated Complex Systems** Because computing performance is very fast, video games can consist of a much more complicated rules system than if they would have had if only humans would enforce the rules.
- **Networked Communication** Through networking many computer games can allow for communications between players.

Note that video games do not necessarily have all of these traits. For example, single-player games can easily function without networked communication. Furthermore, these traits do not necessarily result in a game, as software that is not a video game may also incorporate them – albeit to a lesser extent.

2.2 Good Game Design

Although we now have some concept of what exactly games *are* we still hardly have an idea of what makes them engaging to the player. Creating a game is only one part of the problem and possibly the easiest one at that. The more important question to ask ourselves is what makes a game '*good'*.

The necessity of game design arises when this question is asked. Like any type of design, there are both good and bad game designs. Over the years some theories have been posed, trying to explain why games are entertaining and compelling. By extension these theories describe the groundwork of 'good' game design. In Chapter 1 we already briefly explored two of these theories: The Paradox of Control and Flow-theory. However, before zooming in on those aspects we ought to focus on what Salen and Zimmerman describe as *meaningful play* [13].

Meaningful play is the meaning derived from playing a game. For example: when playing a fighting game, the actions engaged by the player are simply the repeated pressing of several buttons on a controller. Only within the context of a game this action derives meaning – such as giving a virtual opponent a punch. In much the same way, going to jail in a game of *Monopoly* only means something besides placing a pawn on a square on the board within the context of the game. Therefore, we can derive the meaning of a game from the relationship between the action the player performs in the game and the outcome of the game. According to Salen and Zimmerman, the goal of any game design should be to achieve meaningful play [13].

While this answers why games are compelling, we still lack insights on how to achieve meaning. In a broad sense, the meaning of a game emerges through the relation between the actions of the player and the outcome of the system. This descriptive meaning occurs in every game. More precisely, the *evaluative* meaning of a game occurs when this relation is both *discernible* and *integrated*. In other words, the player should perceive the result of any action immediately, and this outcome should influence the game system as a whole. To illustrate using the previous example of a fighting game: when the player hits button for punching, he should observe whether the enemy was hit (discernibility), and the game system should be changed, such as by lowering the health of the enemy (integration).

Creating meaning can be done through three core concepts: Design, System, and Interaction. We have already discussed the System concept but will also give a brief introduction into the other two.

When considering game design, it seems obvious that design is an integral part of the process. While there are many definitions of design, the core concept is the design of a context wherein the player derives meaning from the game. An important field related to this definition of design is the field of *semiotics*, the study of meaning. Semiotics relies heavily on the usage of signs – elements that represent something other than themselves. When interpreted by a user, meaning is derived from signs. To illustrate, the rook in a game of chess would be nothing but a piece of wood if it was not designed to represent the tower of a castle. To create meaningful play, game designers should, therefore, include signs that give context to in-game events in their design.

Since we have already discussed the definition of a system, we shall mostly skip this core concept here. It should be noted, however, that games can be given a meaning, especially when framed as experiential and cultural systems. For example, by creating a sense of rivalry between players.

The last concept is perhaps the most of interest to us with regards to BCI gaming. Through interaction between a player and the system meaning is derived. This interactivity can take on many forms. The psychological and emotional participation of the player, the act of pressing buttons, or even building a fan website for a game, all these forms can be seen as interaction between the player and the game. The most obvious form of interaction, however, is *explicit* interaction, wherein the player follows the rules of the game and influences the game itself.

With respect to explicit interaction, meaning is derived from the inclusion of choice. In a game, choices are made by the player – either from moment-to-moment or as a long term process. The consequences of choices made by the player cause the interaction to become meaningful. Much like meaningful play in general, choices have to be both discernible and integrated, as they serve as a direct link between player and game.

Beside meaningful choices, there is another leading theory in game design. As suggested by Chen [27] and Sweetster and Wyeth [28], the Flow-theory of Csikszentmihalyi is a perfect fit for gaming. Flow – a concept taken from positive psychology – can be very useful to understand immersive gameplay, for it represents the mental state of someone fully invested in an action. This state results in a high sense of enjoyment and fulfilment [14]. Hence, Flow can be compared to the immersion players often experience when playing a game.

As Csikszentmihalyi [14] noted, Flow can be split up into eight different components, though not all of them are required to achieve Flow:

- A challenging activity that requires skill
- Clear goals

- Direct, immediate feedback
- Sense of control
- A Merging of action and awareness
- Concentration on the task at hand
- A loss of self-consciousness
- An altered sense of time.

The first four of these components can be seen as the requirements of Flow, while the final four may be interpreted as the result of being in a state of Flow.

Sweetser and Wyeth define a model consisting of eight core elements in a game – concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction – that can be related to the components of Flow. This shows that game design and the Flow theory can easily be linked to each other. Implementing Flow can thus serve to make a game as engaging as possible [28].

The first of these criteria requires the creation of a satisfying difficulty level. This can prove challenging, for the difficulty of a game may differ strongly from player to player. The Flow Zone (see Figure 2.1), a balance between challenge and abilities, allows for some elbow room, but may not be sufficient. As Chen states, when the audience of a game gets broader, it becomes harder to create a game that allows for a good Flow Zone. The average player will have different requirements than a "hardcore" gamer or someone who never picked up a game before [27].

The solution for this, much like stated in Salen and Zimmerman's meaningful play theory, is the implementation of choice. Chen argues for the implementation of adaptive choices to be made during the game. Too many choices may overwhelm the player and result in the loss of Flow, so a game design should offer choice where it is the most effective. Therefore, choices should be embedded into the core activities of the game. This allows a broad range of players to adjust the game to their own skill level. For example, a player can opt to simply beat a game or try to gain the high score while doing so.

In short, to achieve Flow within a game the following methodology should be followed [27]:

- Mix and match the components of Flow
- Keep the user experience within the users Flow Zone

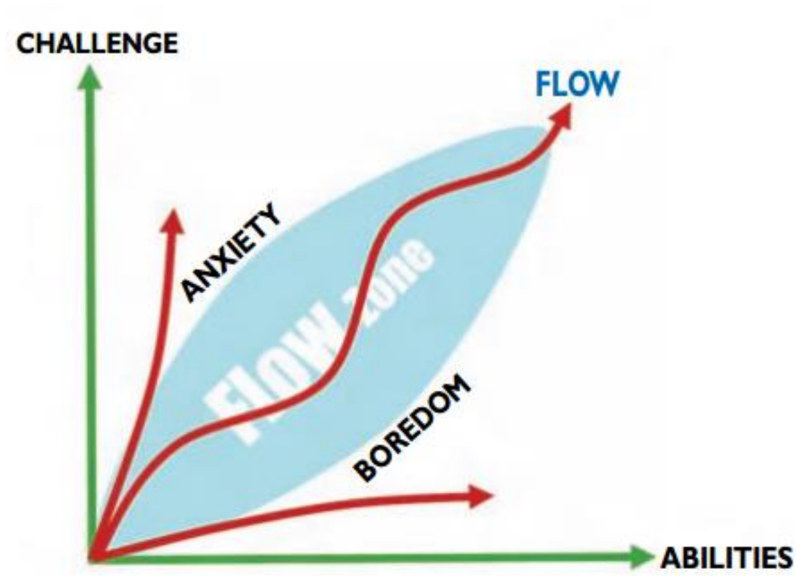

Figure 2.1: The Flow Zone [27].

- Offer adaptive choices
- Embed the choices into the core concepts of the game.

The second and third components for achieving Flow – the inclusion of clear goals and direct feedback – have already been covered by the definition of games themselves and the meaningful play theory respectively. This leaves us with the sense of control. It is essential that players feel in control of the game. Input should not only be discernible and integrated but also direct and consequent. In the case of digital games, which as we have seen may only have limited interaction possibilities, there may also be the challenge of keeping control effective.

In order to achieve Flow the player, therefore, has to feel both in control and challenged. This may prove difficult to balance, for difficulty relies on the player's abilities and failures. The problem can be solved by the inclusion of choices (e.g. the player makes the wrong choice and fails as a result) but that would rule out certain forms of player skill. For example, a game of Tetris relies not only on the player to decide the placement of the next block but also to do so on time. In much the same way a fighting game requires the player not just to decide upon the next attack but also to press the button(s) quickly and in the right order.

Hence, there is a balance between feeling in control and feeling challenged. This is the paradox of control, which we previously mentioned in Chapter 1. Like any form of difficulty, the paradox of control may differ from player to player, as speed or precision of input is not a player independent factor. Determining the balance of control for the average player may require many iterations of fine-tuning. Difficulty can be influenced by the required reaction speed or the complexity of the input required.

While the majority of the game design theories described can most likely be applied for any type of input, there are two elements that may differ greatly for a new type of input: the inclusion of choice and the paradox of control. Choice may be independent of the input type, such as in simple yes or no choices. However, as we noted previously, digital input may have limited degrees of freedom, and, as such, choice can be limited by the control modality (e.g. only a select few options or time required to make the choice). Similarly, each type of control will most likely have some factor that influences the perceived sense of being in control. In the next section we will look more closely at the P300 paradigm to identify these factors.

Before finishing up on Flow theory, it should be noted that it is not exclusive to games – nor does it necessarily describe a game itself. Rather, Flow-theory describes the mental state of the player and how to achieve this. Games are simply a means to an end.

Finally, we should also mention the occurrence of effectance. According to Kimmt et al. effectance is the *“perception of receiving immediate, direct feedback on one’s actions and of influencing the game world*”. Effectance is considered one of the contributing factors to making games enjoyable [29]. Note that effectance is already very similar to some of the game design theories described previously. Immediate and direct effect of influencing the world is, in essence, similar to discernible and integrated control and builds upon the artificial world described in many game definitions. A game is more enjoyable if the player perceives the effect of his or her actions within the game.

2.3 P300

In order to identify factors that can influence the P300 paradigm, we should first examine the paradigm itself. The P300 – or Oddball – paradigm is an evoked response that was first used by Squires et al. They describe two auditory evoked potentials detected on the scalp. The first – called the P3a – occurs approximately 240 milliseconds after an infrequent and unpredictable shift in the frequency or intensity of a tone, regardless of whether the subject is focussing on the sound or not. A second potential – the P3b –

occurs after roughly 350 milliseconds and does require the subject to focus on the audio. Both of these responses have been referred to as the P3 or P300 response [30].

However, the most frequently used form of the P300 paradigm is visual rather than auditory. The classic P300 speller as first described by Farwell and Donchin in 1989 is a primary focus point in research on the paradigm. In the classic speller subjects see a matrix of 36 elements (usually the 26 letters of the alphabet plus 1 to 10 additional characters for functionality). By repeatedly flashing rows and columns of elements in this matrix the computer is able to choose the element the subject is focusing on. In the first version of the speller approximately 2.3 characters could be selected per minute [31].

Since the first implementation of the speller, there has been a lot of research on optimizing the selection speed as well as understanding the conditions to optimise the P300 response. Despite the lack of speed, both the P300 test by Squires et al. and Farwell and Donchin show that unexpected events – here either a sound or a flash – can be detected through the P300 response.

By 2000 Donchin repeated the P300 speller experiment. Much like in the first attempt, a six by six matrix with letters was used, and subjects were asked to focus on a specific letter while the rows and columns of the matrix flashed. Compared to the first experiment the effectiveness of the system improved greatly. By now, an average of 7.8 characters per minute could be typed at an accuracy of 80%. When the accuracy was scaled up to 90%, 4.8 characters could be typed per minute. Although the experiment was enhanced over a broad range of factors (higher resolution screens, better BCI-devices, improved algorithms etc.), Donchin theorised that the main reason for this improvement was the algorithm for calculating the item to select. Rather than taking the averages of each row and column individually, the item was selected using an average of the combination of row and column responses [32].

Over the recent years there have been many improvements to the P300 speller. For instance Serby used a matched filter to achieve a speed of 5.45 words per minute at an accuracy of 92.1% [33]. Support Vector Machines [34, 35], wavelets [36], and Stepwise Linear Discriminant Analysis [37] have also been used in research. A comparison between these classification techniques has been made by Krusienski et al. [38].

Besides classification techniques, there have been some tests on influencing the speller. One of these is the occurrence of *adjacency-distraction* phenomenon, which causes users to be distracted by elements flashing next to the target. When the user gets distracted by these flashes, a P300 response may occur, which results in selecting the wrong target. Though this phenomenon cannot be completely prevented, placing elements into random groups for flashing – instead of just flashing them as rows and columns – may reduce the effect [39, 40].

Although the peripheral view thus seems to influence the accuracy of a P300 speller in some way, Brunner et al. have shown that the P300 effect depends on eye gaze. While it was once believed that the effect did not require visual focus, the research has shown that the accuracy decreases significantly when users are asked to focus on the centre of the screen rather than on the desired element [41].

Another optimisation is the usage of randomized flash times. Usually P300 spellers use a fixed flash time and time between flashes. Since the P300 response depends on a surprise effect, randomization of these times can result in better accuracy. Through the usage of an exponential distribution these times can be randomized while still averaging a certain time. Congedo et al. describe and successfully implemented this distribution for P300 spellers [42].

Research by Gibert et al. has shown that magnifying the flashing symbols in a P300 speller may also increase the P300 amplitude and classification accuracy [43].

In summary, a stronger surprise effect such as by randomized flashes and size increases during flashing (and possibly other transformations that may be applied to the flashing object), seems to strengthen the P300 effect. Conversely, events happening in the peripheral vision may reduce the accuracy of the effect, although focus on the desired element still increases this accuracy.

2.4 Previous Games

Now that we have a proper insight on what constitutes a game and how the P300 paradigm is to be used we can turn our attention to combining the two. By analysing previous games that tried implementing the P300 paradigm we might learn methods for achieving the paradox of control.

The functionality of the P300 speller brings along some limitations to what can be achieved by a game. Kaplan et al. define six aspects that potentially limit P300 games as compared to other paradigms, despite noting that the paradigm itself is very suitable for games due to its high accuracy. These six aspects are [44]:

- **The separation between stimuli and action**: the location where the stimuli that the player should focus on occur and the place where the action in the game takes place may differ.
- **Simple, static and stereotyped stimuli:** The user must keep focussed on fixed stimuli to stay in control, whereas concentration may be relocated in regular games.
- **Goal selection instead of process control:** The P300 limits the user to select between a set of actions, while other BCI paradigms may allow for more gradual selection methods.
- **Repeated mental actions are required to trigger a single action in the game:** P300 selection often requires multiple repeats of the same stimulus to allow for the selection of a single action.
- **The need to use mental actions unnaturally mapped to virtual-world actions:** Since users have to count for a P300 selection to be optimally accurate, users may not feel a link between the mental action they have to perform and the result of that action in the virtual world.
- **The P300 BCI as a “synchronous” BCI:** Users need to perform an action at the moment the game requires them to as opposed to at the moment they feel inclined to perform the action.

While these issues may limit a P300 game, they can at least partially be circumvented, as we shall see when reviewing previously developed P300 games.

Although not really a game as per the definition, we can consider the virtual environment described by Bayliss a virtual game-like experience. In the experiment users see a virtual apartment wherein objects can be manipulated by focussing on them. The research shows that P300 can work for more complex environments than the basic P300 spellers but lacks any form of rules or goal state. As such, it becomes difficult to learn to influence the controls. It should also be noted that in the research users did not link their performance to the appreciation they had for the game. Though conflicting with the theories of Flow this was most likely explained by the novelty of the experiment [45].

A P300 game that seems a lot more like a game is The MindGame, wherein a chess-like board is shown with several virtual trees in it. The trees function as elements in a P300 speller set up. The game tasks the player with the goal of progressing along the Z-Axis by focussing on the next tree. It has a clear goal state, but much like the virtual apartment there are no indications of a (form of the) paradox of control [8].

Another game based on the P300 speller is Brain Invaders. This game, which is based on the classic Space Invaders, tasks the player with focussing on a single alien that is placed within a group of aliens. After a single round of flashes the alien that the game estimates to be the selected one is shot (removed from the field). If the target alien is not hit the cycle continues. Brain Invaders includes clear rules (you shoot the element you focus on) and final goal (hit the marked alien) [42]. However, meaningful interaction is somewhat lacking in the game. The player can choose whether to focus on the target or not, but the game does not generate a paradox of control as the sense of control and difficulty are uninfluenced over the course of the game. If the player succeeds with shooting the target the game simply restarts without increasing challenge.

Additionally some games might use additional input methods. For instance, the game Mind the Sheep!, wherein the player is tasked with herding a group of sheep by directing sheepdogs with mouse input. The player has to select the dogs in the game through Steady State Visually Evoked Potential (SSVEP) or alternatively through P300 selection. The user can indicate a dog should be selected, after which all dogs are shortly flashed and a dog is selected according to the paradigm. Using mouse movements the players could increase or decrease the time required for selection, which allows for the choice between doing a quick but possibly imprecise selection and doing a more accurate selection while losing time. Since a regular mouse does the rest of the controls, the game is not a dedicated BCI game (e.g. a game solely controlled by the BCI). While Mind the Sheep! has some clear rules and goals, these are mostly dependent on the traditional controls rather than the BCI input. As such, the game cannot be fully compared to games detailed previously. It should be noted that the BCI selection procedure was implemented to increase the difficulty of selection. Because the game allows the players to choose between a quick, imprecise selection and a longer but more accurate selection, the game manages to incorporate a paradox of control. The user can get the sense of losing the controls due to personal mistakes. However, the paradox requires additional control modalities such as a mouse to function [46].

Another multi-modal-input game is Bacteria Hunt, which implements the SSVEP, P300 and relative alpha power paradigms. Bacteria Hunter tasks the player with moving an amoeba towards bacteria and eating them. Movement is primarily done by keys on the keyboard. Eating a bacterium is successful if the player is close to it, resulting in a positive score, whereas being too far from any bacteria results in negative points. The game is further complicated by a randomisation in player movement, so the player never knows exactly where the amoeba will be. While initially the game is only played using the keyboard, later levels implement some form of BCI paradigms. In the second level the randomisation in the movement of the amoeba is directly influenced by the alpha power of the player. The two levels afterwards add a SSVEP and a P300 selection paradigm respectively. In the SSVEP level the bacteria starts flashing when the player is close, who will eat the bacterium when a SSVEP is detected. In the P300 level all bacteria will start flashing, and the player is tasked with selecting the right bacterium [47].

While the game still implements some keyboard movements, Bacteria Hunter shows a clear regard for game design requirements. For instance, the gameplay is clear and structured, but the BCI controls are also integrated in the design. Since one of the requirements of the game itself was to properly communicate the BCI detection, such interaction is also discernible. The paradox of control is mostly related to the alpha power modality however [47].

So how do these games compare to game design theories and to what extend do they manage to circumvent the six limiting aspects by Kaspan et al? With the exception of the virtual environment by Bayliss, all games described include rules and a goal state. Interaction is usually discernible (by showing an explosion or by moving the player forward for instance) and integrated (by resulting in selection of dogs or killing bacteria). Some games, such as Mind the Sheep!, are less dependent on the used input methodology. For other games, such as Brain Invaders, achieving accurate control can be considered the goal of the game. Therefore, most games satisfy the basic requirements given by the definition of a game.

All games succeed somewhat in circumventing Kaspan's limiting aspects. By having the player focus on the dogs to select or the alien to shoot, Mind the

Sheep! and Brain Invaders both manage to prevent user focus on anything other than the element that will perform the action (aspect 1). By changing the environment such as by killing bacteria or aliens, the games also manage to include some variation during gameplay (aspect 2). And while users often have to repeat actions, games such as Brain Invaders and Mind the Sheep! manage to vary the length of stimulations to reduce the issues of aspect four.

However, some issues have not been fully resolved. There is no form of gradual input in the games discussed (aspect 3). Since this is not often seen in regular video games, the problems imposed by this limitation seem negligible. There is however no clear solution for the distinction between mental and virtual actions (aspect 5) nor is there for the synchronisation problem imposed by the P300 paradigm (aspect 6). Solving these issues is out of the scope of this research, however, and for now they shall be accepted as a necessary evil.

The small amount of P300-based games and the little focus they have on game design shows that there is a lot of room for improvement. None of the P300 games discussed satisfy our research question, and, therefore, the paradox of control has to be found in some other way.

2.5 Distractions

Rather than basing ourselves on previous games, we shall, therefore, consider general P300 literature and try to think of our own ways in which we may achieve the paradox of control.

Since the P300 response is so dependent on focus, it seems wise to attempt to break the player’s focus, as this can be controlled and mastered by a player. With regards to the Flow theory focus can be considered a skill. In order to achieve Flow what remains is to challenge this skill, i.e. make focussing more difficult.

As we have seen previously, the P300 response may be influenced by the peripheral vision of the player. Events happening around the area of focus of the player seem to be distracting enough to influence the selection of elements. Simply stated, we assume focus can be broken by distracting the player with something that is happening during the game. This thesis, therefore, revolves around what we call *distractors*, elements that modify the selectable objects so that they may lead player focus away from the intended target.

There has been a lot of research to determine whether specific factors positively influence the P300 effect, to create a higher probability of generating a P300 response. Effects examined include brightness enhancement, scaling, rotation, colour inversion, and masking the element with a grid. With the exception of the grid and a combination of the effects, all of these show a somewhat similar response [19].

However, research to decrease the selection probability of the intended target (without losing the sense of control) has been relatively rare. Since we are dealing with the peripheral view rather than the element the player is focussing on, we cannot assume that these effects show a similar result when used for distractions. As such, we have randomly chosen two effects to study. Further research may explore additional distractor effects.

The effects considered for this thesis are differently coloured elements and movement. The effect of colour on target elements has been previously researched. Takano et al. have shown that a difference in both luminance and chromatics improves the P300 response significantly [48]. We hypothesise that differently coloured elements are more noticeable in the peripheral view and, as such, show a higher selection change.

Additionally we also consider movement as a potential distractor. Shishkin et al. have shown that gradual movement has little effect on the P300 response if such movement is horizontal and at a relatively slow pace. Nevertheless, we hypothesise that step wise movement rather than gradual movement – as well as more complex movement patterns – can break the focus of the player. Stepwise movement will create an additional stimulus, while complex movement (e.g. movement that changes direction) should be harder to follow and, therefore, increase the difficulty of staying focussed on the element.

2.6 Hypotheses

This leads to our first hypothesis:

> Using colour and movement to modify non-targets in a P300-selection game will result in a higher level of difficulty without making the player feel out of control, thereby creating a paradox of control. **(Hypothesis 1)**

Provided Hypothesis 1 proves true, it follows from the theories of Flow and the paradox of control that player enjoyment will increase. Therefore, we pose a second hypothesis:

> Using colour and movement to modify targets in a P300-selection game will increase player enjoyment of the game. **(Hypothesis 2)**

This thesis aims to prove these hypotheses.

Chapter 3

Methodology

This chapter will detail the methodology with which we aim to test the concepts of distractors in a P300 game. Because there are many ways in which we could set up research to try to validate the hypotheses, this chapter will also give insights into the higher level decisions made when a strategy for the research was developed.

3.1 Requirements

As we have seen by the end of Chapter 2 there are no previously developed games that fully satisfy our needs out of the box. Yet in order to test the effects of distractors within the proper context, a game that supports distractor functionality will be a necessity. Simply implementing distractors in a P300 speller will not suffice either, as ignoring game design theories might lead to weakened player enjoyment. This could cause us to falsely reject Hypothesis 2.

One of the primary requirements of this research is, therefore, to have a game that properly supports distractors. Due to the lack of such a game we will be designing one ourselves. To ensure a proper testing base, this game will be required to support the game design requirements as given in Chapter 2. In other words, a game has to support interaction, a goal, and rules among other things and ensure these elements are discernible and integrated.

Not only should we be taking game design into account. We should also consider optimizing the P300 response as much as possible. As the paradox of control depends on the player feeling in control, it is essential that we attempt to make selection as accurate as possible. This ensures that there is a higher chance that selection of the wrong element is caused by the player's (lack of) focus. Therefore, we implement random group flashing, exponentially distributed Inter Stimulus Interval (ISI) time, and transformation of the size of flashing target elements.

The game to be developed has to meet the following requirements:

1. The game features a clear goal.
2. The game features clear rules.
3. The game has discernible interaction.
4. The game has integrated interaction.
5. The game is controlled solely by the P300 paradigm (e.g. no keyboard or mouse modalities as they might skew the results).
6. The game features both coloured and moving distractors.
7. The game features selection optimisations such as randomised group flashing, exponentially distributed ISI, and size transformations.

Only when such a game is completed, we can set up the experiment itself. We will require an experiment that supplies both objective and subjective data, since player enjoyment is almost by definition a subjective. However, the accuracy of control can be measured in an objective manner. Therefore we require a set up to supply both types of data.

The next two sections will further explore the methodologies used for the development of the desired game and the design of the experiment used to test our hypotheses respectively.

3.2 Designing a Game

Although we lack a game to satisfy the goals of this research, we can expand and partially redesign existing games. Since these games already have P300 functionality at a basic level, redesigning them to include distractors, while using game design theories to improve them, could potentially reduce the workload for this research tremendously.

We have, therefore, chosen to utilise a P300-controlled game that was developed previously. In Chapter 2 we already briefly introduced the game Brain Invaders developed by Congedo et al. [42] which will serve as a basis for the game developed in this thesis. The advantages of using Brain Invaders stem mostly from the functioning P300 framework. Already there is a clear communication structure in place that allows for easily setting up the BCI devices. This liberates us from having to implement these elements ourselves and allows for a larger focus on the game design itself – the inclusion of distractors in particular.

As we have seen in the previous discussion of Brain Invaders, the game already satisfies some requirements that follow from game design theories.

There is a goal state, there are rules – if you do not succeed in hitting the target in a given amount of attempts game is lost – and the game already carries some meaning and a clear visual language that represents something due to the inspiration taken from Space Invaders. With respect to game design we can, therefore, primarily focus on the implementation of distractors and on optimizing the game where necessary.

However, it seems unwise to simply implement game by following a checklist. As in every design process, it is sensible to first consider the steps we ought to take with respect to designing the game itself. To prevent the pitfalls of the game design process we shall follow the recommendations on game design as given by Rouse III [49].

Besides recommending focussed game design (e.g. basing the game design on what the game is trying to accomplish), Rouse III calls for the inclusion of a *Game Design Document*. This document should specify how the game should work and play, so that the designer has a clear view of what should be designed. Elements that should have a detailed description in the Game Design Document include:

- Game Mechanics
- Artificial Intelligence
- Game Elements
- Story Overview
- Game Progression
- System Menu

Most of these sections should be self explanatory. However, we shall specify the difference between Game Mechanics, Game Elements, and Game Progression. The mechanics describe the inner workings of the game such as how interaction is handled, the rules of the game, and the goal of the player. Essentially the mechanics detail the game from the same level that we used to define games in Chapter 2. The Game Elements section contains the elements featured in the game, such as items, objects, and characters. These differ from the mechanics: elements are signs that carry some meaning whereas the mechanics do not. Finally, the Progression describes a typical game session – such as the different interaction models – and even details distinct levels [49].

The design of a game does not end at the Game Design Document, however, as the document only summarises gameplay. To explore the inner functionality of the game we turn our attention to regular Software Engineering. Much like any software project, a game can be approached from a software engineering perspective. This means that the game should be designed with requirements, use cases, class diagrams, and interaction diagrams all in mind. Although we will not explore their implications here, Lethbridge and Langière discuss these software engineering paradigms in detail [50].

In terms of the requirements of the game, we shall consider the requirements as they have been described in this chapter and in Chapter 2. In other words, the game should be based on Brain Invaders, build upon requirements given from game design theories, utilize optimisations of the P300 speller as found in literature, and finally include colour and movement distractors.

A final requirement we have not detailed yet follows not only from the Flow theory, where challenge should be increased as skill progresses, but also from a necessity of properly comparing the effects of distractors versus non distractors. To allow for comparisons of player performance the game should allow for multiple levels that can steadily increase the amount of distractors and thus the complexity of the game. This brings us to some additional requirements:

8. The game is based on Brain Invaders.
9. The game features multiple levels.
10. The game is developed using a game design document.

3.3 Building an Experiment

The second phase of the research consists of testing the hypotheses posed in Chapter 2 by playing the developed game. Since difficulty has both an objective and a subjective component, we have to design the experiment to test both these factors.

In terms of objective data the experiment will result in numerous logs and data files that are to be used to compare the challenge in different levels of the game. In order to generate such data we will ask multiple players to play Brain Invaders. A play session consists of multiple levels, each with a different amount of distractors implemented. To ensure no bias in the research is created by the sequence of the levels (e.g. players learn from playing) some players will play the levels in reverse order. Furthermore, in order to collect enough data the same player will play all levels multiple times. This ought to ensure that the average performance of a player is measured more accurately, as playing the game for the first time will most likely show a weaker performance than playing the game for the tenth time.

During the play sessions we will record all the EEG signals of the players. Furthermore, we will obtain logs generated by the game, so that we can see the behaviour of the game afterwards. As the EEG signal will also contain markers for in-game flashes, this allows for matching game data and EEG data. In order to test the first hypothesis, we will consider the average attempts required to finish the levels as well as the strength of EEG signals during distractor flashes.

Difficulty of the game can be measured by comparing the average amount of attempts required by players to finish different levels. If the signal processing algorithm is the same and flashes occur similarly across levels, any difference between the required attempts to finish different levels is caused by the only differentiating factor: the design of the levels. Since the level designs are only influenced by the distractor elements, this will then prove the effect of distractors. To find such an effect, participants to the experiment will, therefore, play levels without distractor elements (the null case) and levels with increasing amounts of distractors. A difficulty increase should show an increase in average attempts required to finish the level by a single player, and, as such, the results between levels can be statistically compared. Rather than basing ourselves upon the amount of attempts required to finish a level, we will assign a score to the level performance of each player. This allows for a distinction between good, average, and bad performance of a level. If difficulty is higher in levels with distractors implemented one would expect the average amount of attempts required to hit the target and, therefore, the score would be higher than in non-distractor levels. Since each player will play each level multiple times, enough data should be supplied to calculate these scores and their differences.

The underlying P300 response to specific elements can also be compared, however. If distractor elements do indeed disturb the player's focus, the P300 response to them should be higher than it is for regular elements. Therefore, we will compare P300 response strength between element types. If a paradox of control exists such a comparison should prove a difference between distractor and non-distractor elements. Through the use of a Student's T-Tests we can compare the response to distractors to both the actual target of the level as well as the non-distractor–non-target elements of the level. The comparison of these values will show a difference between distractors and non-distractors if the former indeed influences the target selection in a significant way and, therefore, alters the difficulty level.

We will also consider the experience as perceived by the players themselves (e.g. subjective data). Already, we consider that difficulty is a relative term, as we compare the performance between levels for individual players. However, we also take into account that difficulty is in the eye of the beholder. When Hypothesis 2 – which focuses on player enjoyment – is included, the subjective experience of a game becomes even more prominent. We, therefore, not only look at raw player data collected through play tests but also pay equal attention to the player's opinion of the game.

After play sessions, we will ask the player to answer a short questionnaire that examines the perceived difficulty. Through the use of seven-point Likert-scale questions the questionnaire should give insight into the general experience of the game and lets players identify the more challenging elements. This allows for clear comparisons between players, which might prove difficult if only the raw BCI signals are considered. Perceived enjoyment and challenge is as important as factual difficulty, since Flow is a psychological state that can best be judged by the one experiencing the state. From a game design perspective subjective data is, therefore, of similar importance as the objective data.

CHAPTER 4

Software Design

As we have seen in Chapter 3, we require a game that supports distractors in order to test the hypotheses. As such a game does not exist we have to design it ourselves. This chapter deals with the design process of the game.

The updated version of Brain Invaders – as compared to the version described by Congedo et al. [42] – not only supports distractors. We have also redesigned it to allow for greater flexibility with respect to extending the game. While the original version of the game used a fixed amount of aliens moving across a fixed path, the version described in this chapter supports complex movement and different amounts of aliens on screen.

This chapter is split up into multiple sections, each focussing on a different design cycle. The first of these is the design process of the game. This section will describe the gameplay, the game elements and -mechanics, and, finally, the progress of a typical game session. In a broader sense, it will also detail the interaction between player and system through interaction diagrams.

The second section of the chapter will describe the software design of the game and discusses Class diagrams and Class functionality. It also provides sequence diagrams from a slightly more technical perspective.

However, describing the design process of the game – from both a game and software design perspective – will not suffice, as the acquisition and signal processing of the EEG signal is not to be ignored. For the development and design of these elements we used the middleware engine OpenViBE, which we will detail this in the third section of this chapter.

Finally, we will describe the communication process between the game and the OpenViBE platform. Communication is essential, as without proper synchronisation between the EEG signal and the visuals on screen the P300 effect cannot be measured accurately. Therefore, we will detail the protocols for communication and synchronisation in the final section of this chapter.

4.1 Game Design Document

The game design document details the entire game in terms of elements, mechanics, and progress. The full design document can be found in Appendix A, while this section will serve to summarize the document to the reader.

Brain Invaders tasks the player with shooting an alien by focussing on it. Through a P300 speller the game will determine – after a single round of flashes – which alien the player was focussing on. This alien will subsequently disappear from the field – referred to within the game as 'shot'. If the player manages to shoot the target alien within a given number of shots, the level is won. If the player fails to do so the level will reload.

As the levels progress distractors are introduced. Distractors are aliens that have a different colour than the regular aliens. Some distractors have the same colour as the target alien, others have a different colour. They are often placed near the target so that they will appear in the peripheral view of the player. Furthermore, all aliens will follow a predetermined path, making them move as the game progresses.

The gameplay is split up in two phases. The first phase is the training session, which serves as a way to calibrate the BCI. During the training no aliens are shot. Instead, the target is flashed multiple times (to increase precision) before a new target is selected. Once the player finishes the training, the game as described previously will commence. In the version of the game used for this thesis three levels are present: A level without any coloured distractors, one with a few, and a level with a lot of distractors as well as complicated movement patterns. We designed the game so one can easily extend it with additional levels.

Figures 4.1 through 4.3 show flowcharts of the progression of the game. In these flow charts, both player choice and in-game checks are represented by choice blocks at states. The flowchart in figure 4.1 shows the control of the game's menu, where the states *Play Game* and *Training* represent the gameplay phases described above. Figures 4.2 and 4.3 show these two gameplay phases with more detail.

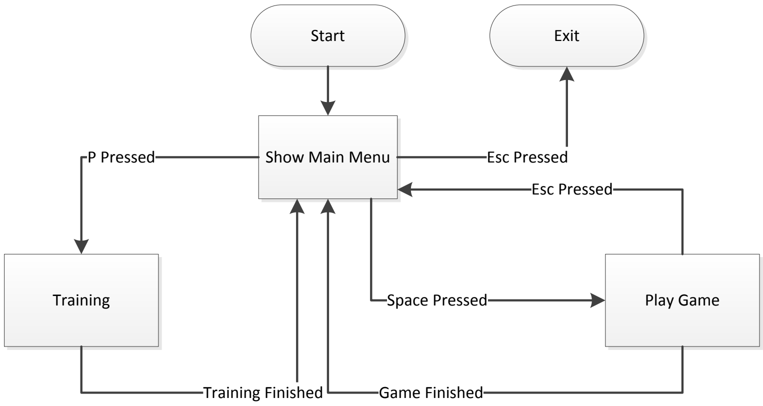

Figure 4.1: Progression of the game in general.

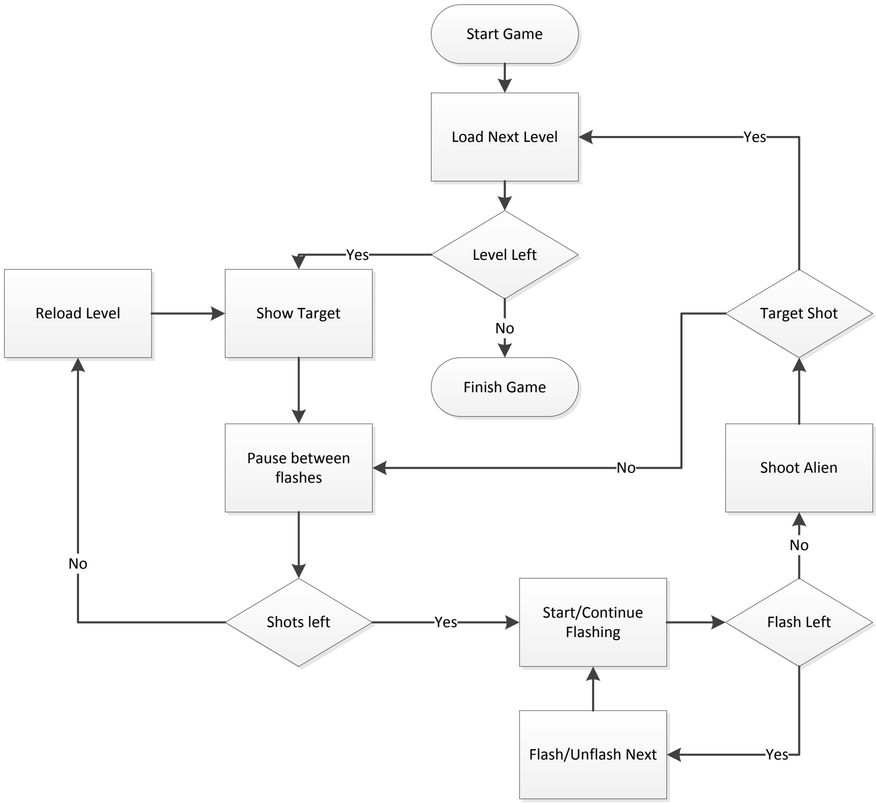

Figure 4.2: Progression of the Main Game.

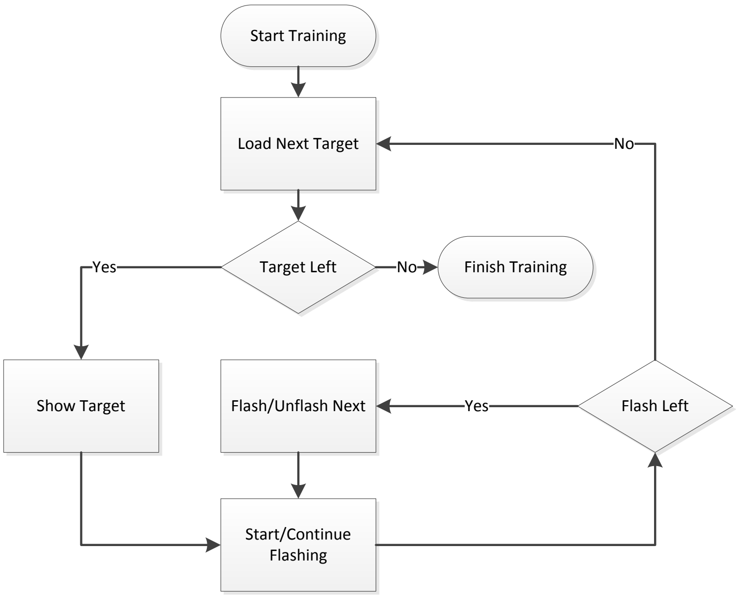

Figure 4.3: Progression of the Training

Since the game extends upon the original Brain Invaders, already some of the requirements posed in Chapter 3 have been met. The game supports rules, a goal, and a meaningful representation inherited from Space Invaders. Through the extension as proposed here, we introduce distractors to the game.

The introduction of a score creates integrated interaction, while the explosions of aliens that are shot and the bar displaying the amount of shots the player has left allow for interaction to be discernible. Additionally, we implemented some optimisations to the target to increase the P300 response. Since the entire game is controlled with the P300 paradigm, Brain Invaders can be considered a dedicated BCI game. We used a game design document for the design of the game, satisfying the design process requirements.

4.2 Brain Invaders Design

This section describes the design of the game from an Object Oriented software engineering perspective. Rather than providing the entire class diagram and class descriptions, this section will only serve to explain the most important elements.

We designed the game on top of the VR demo of OpenViBE (see next section) and the Ogre 3D framework [51]. This means the game itself is an extension of the class COgreVRApplication that can be found in the source code for OpenViBE, which in turn utilises Ogre 3D. The class was originally designed for 3D applications that use some form of BCI control through OpenViBE. Although Brain Invaders is primarily a 2D program, the original version of the game as described by Congedo et al. [42] made use of the same class structure. Although we have rewritten the majority of the original code for this version of Brain Invaders, the project was initially designed around the same base as the original game. As such, the main class CSpaceInvadersBCI, which serves as the screen manager of the game, is an extension of the original COgreVRApplication class.

The screen manager controls multiple screens in the game and offers the functionality to switch between them. Screens are distinct parts of the game that are visually represented to the player. In Brain Invaders the available screens are a main menu screen, a loading screen, and the in-game screen. The screens handle their own mechanics, operating independently of each other.

The most important screen to the game is the GameScreen as this class contains all the internal mechanics of the gameplay itself. The mechanics of this class consist of roughly three parts: The level construction, the flashing sequence, and, finally, the target selection.

For the level construction, the GameScreen loads a XML file containing level information. From the XML file, the GameScreen will construct a set of Alien elements, which will be put in AlienBlock groups if the level specification requires them to. Furthermore, the Alien elements will be saved internally in the flash matrix. This matrix helps the game distinguish between rows and columns of alien elements so that each element can be flashed exactly twice in a cycle. If randomised flashing is set this flash matrix can be shuffled during the initialisation of the level so that the Alien elements are no longer stored in the order in which they appear on screen.

The game will activate the flashing sequence phase after the level has loaded. The phase consists of several internal states (which can also be seen in Figure 4.2) which the game will cycle through. During this phase, the player is required to strongly focus on the screen as the stimuli that evoke the P300 response are presented. Directly after a level has loaded, the GameScreen will switch to a target display state, in which the target is temporarily marked by a red circle. After the target display the flashing and target selection phases will loop until the player has either succeeded in selecting the target or he has surpassed the maximum amount of attempts allowed in the level. In the flashing state, the `GameScreen` will select a row or column to be flashed according to its flash list. All the `Alien` elements that are stored in the corresponding location of the flash matrix are then flashed. After the flash time has passed, the elements will all be reset to an unflashed state. The game screen will then pause for a time determined by the exponentially distributed ISI time or – if all rows and columns have been flashed – proceed to the target selection.

In order to do the target selection the `GameScreen` requests the status of the BCI (for more detail see section Communication), which contains the strength of the response to each row and column. By adding these two values together the game determines an individual score for each `Alien` element. The `GameScreen` stores all these values and selects the element with the strongest response to shoot. If this is the target, the level is won. Else, the flash sequence is repeated. When a new flashing sequence is finished, the results for this sequence will be added to the values of the previous cycles. In this way the game eventually selects the element with the highest average P300 response.

Besides the flashing sequence, the `GameScreen` also frequently tells its `AlienBlock` instances to move. Blocks follow a predefined path as per the XML specification and can move in one of four directions (up, down, left, and right). A block moves stepwise along the path and stops moving in this direction if at least one `Alien` is on the same height as the goal. This means that if the block is moving from the right top corner to the left top corner, the movement stops if at least one `Alien` has reached the left most part of the field. We do this to ensure that if the top left alien is shot, the block will not move out of bounds.

Figure 4.4 shows a simplified version of the operation sequence of the game during a regular gameplay session. To allow for a clear overview, the sequence diagram omits some internal functions as well as some classes, such as the `ProgressBar` and `WinLooseScreen`, which the game would interact with as well. Furthermore, the diagram assumes only one level exists, which contains only a single `Alien` that is shot immediately. Finally, most of the communication has been omitted as this will be explored in more detail later in this chapter.

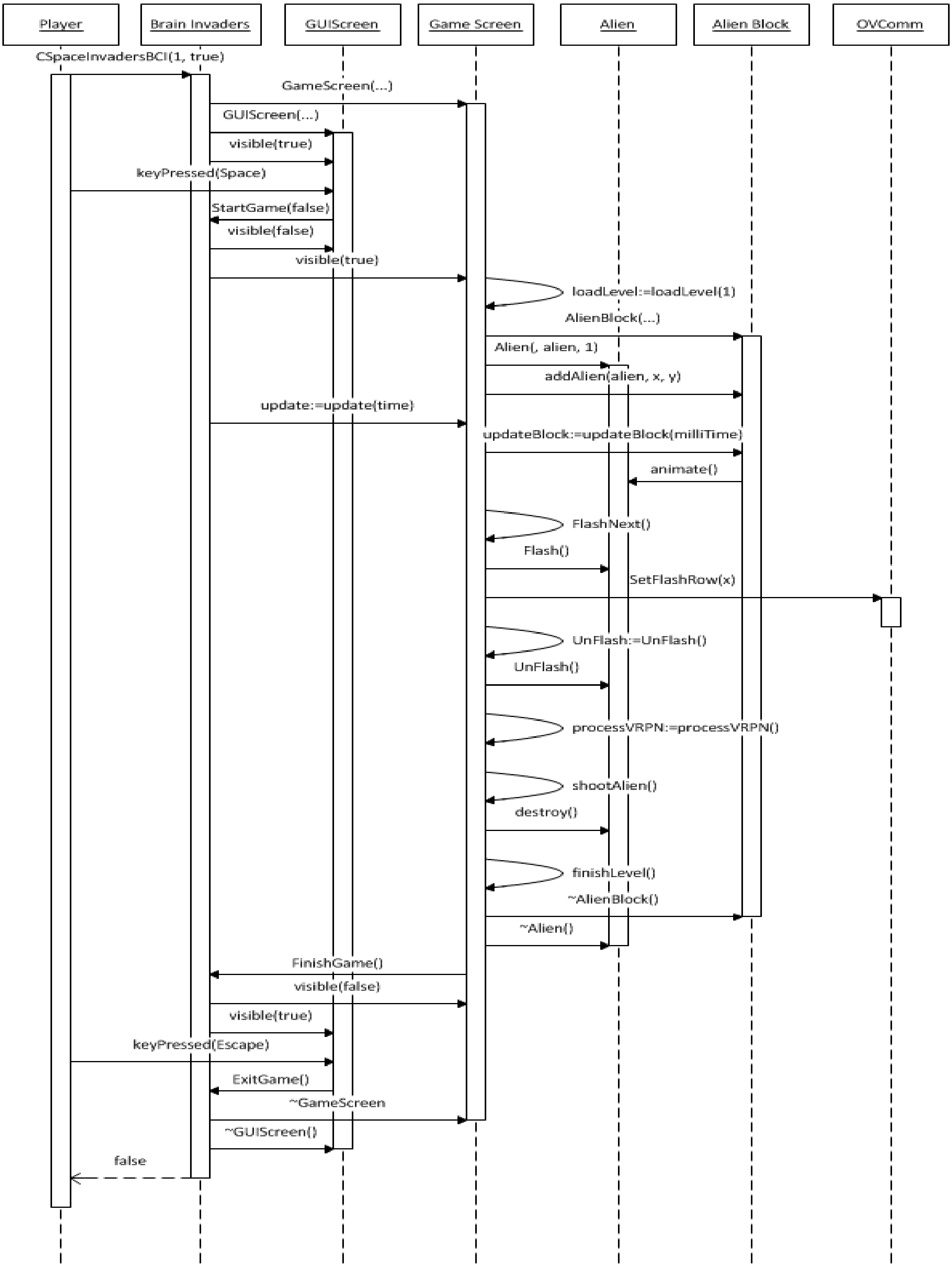

Figure 4.4: Simplified Sequence Diagram of a game session.

4.3 OpenViBE

Just the game design will not suffice. As can be seen in the descriptions of the software design, we have so far omitted the signal processing of the EEG signal. We have to process the raw signal supplied by the EEG device in order to select the target to be shot in the game. To simplify this Brain Invaders utilises a middleware engine specialised in BCI signal processing: OpenViBE [52].

OpenViBE is a software platform that aims to simplify the design, testing, and use of BCI-based software. The design of BCI systems requires expertise not only in software engineering but also in neurophysiology, signal processing, and often even graphics programming. Because expertise in such a broad spectrum is rare the simplification of some aspects of BCI development proves useful. For instance, the Brain Invaders project was approached from a game- and software design perspective but with limited knowledge of the signal processing required for BCI control. Through pre-programmed modules OpenViBE allows the developer to easily implement the signal processing of a P300 speller. Since the platform supports external software, OpenViBE proved ideal for Brain Invaders.

With respect to the signal processing OpenViBE follows the three steps by Wolpaw et al. [53]. In the first step the data to train OpenViBE has to be recorded. Training the software is essential, as learning the exact pattern of a P300 response while the element the player is focussing on is known allows for the recognition of that pattern. Consequently, OpenViBE can estimate the element a player is focussing on in the real game based on the acquired pattern. To ensure the training data is equivalent to the data generated while playing the game, this step is a collaboration between the game and OpenViBE (online). This also explains why Brain Invaders has a training mode.

The second step is done entirely by OpenViBE (offline) and trains the platform to properly detect P300 responses when playing the game. The platform goes through the data collected in the first step and uses this to determine the best calibration parameters (such as optimal features and relevant channels) to distinguish a P300 response. These values differ from player to player, and, therefore, the training (step one and two) has to be redone each time a new player starts Brain Invaders, or even whenever a previous player puts on the EEG device for a second time.

The final phase is the actual play session of the game and, therefore, can be considered the most important. The online use of the BCI is a continuous cycle of six steps: brain activity measurement, pre-processing, feature extraction, classification, translation into command, and, finally, feedback. Steps one through three take the raw EEG signal and extract the features that were determined important by the training phase. Based on these features, OpenViBE builds a classification, essentially estimating the probability that the player was looking at a specific row or column. The translation into a command is primarily the responsibility of the game itself as it shoots an alien in Brain Invaders. However, one might consider sending the data from OpenViBE to the game a form of command generation as well. Finally, the feedback step serves to let the user see the effect of the BCI. This is done in-game and already covered in the chapter on game design.

The three steps and details on the third step can be seen in Figure 4.5.

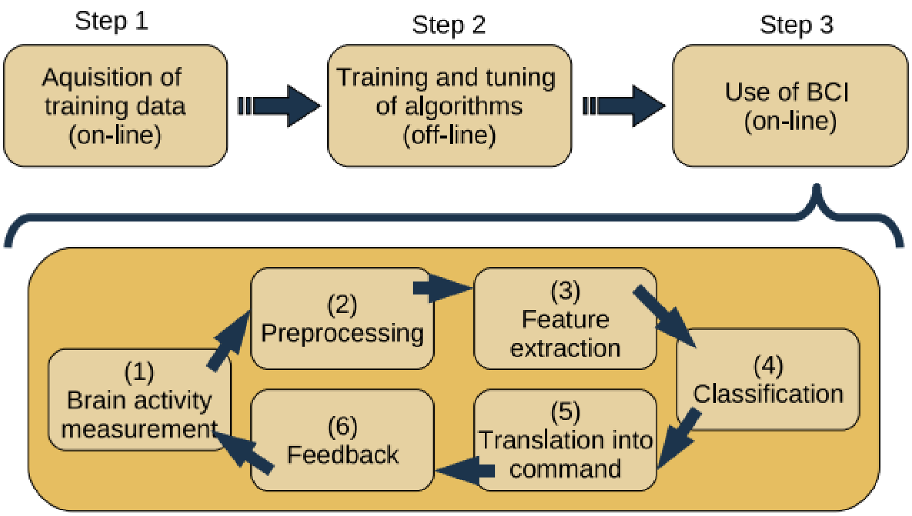

Figure 4.5: Three steps of signal processing [52].

4.4 Communication

It has already been established that Brain Invaders and OpenViBE share some form of communication with one another. Brain Invaders is not just responsible for the game mechanics but the visual aspect of the game as well, while OpenViBE handles the EEG device and the signals it produces. These two platforms have to communicate and synchronise. This becomes clear when considering the flashing sequence as the game handles the visual flashing while OpenViBE measures the user response. In order to properly determine to which flash the player responded OpenViBE needs to know the exact moment on which the flash occurred and synchronise this to the brain signal generated on and shortly after the flash. This synchronisation needs to take place in real time as delays by latency may result in erroneous classification and, therefore, target selection, eventually breaking the paradox of control by removing the sense of control.

To do the synchronising the class `OVComm` has been included in the Brain Invaders software design. This class can use multiple protocols to inform OpenViBE that a flash occurred, allowing synchronisation. The game calls for this class immediately after a flash, so that any delays that may occur are caused by the used protocol rather than the game. The original version of Brain Invaders did the communication through a parallel port protocol, which added an additional channel to the EEG signal detailing whether a flash occurred. The parallel port implementation offers two versions based on the size of the messages. The 4 bit message protocol tells OpenViBE when a flash occurs, but the number of the row or column that flashed has to be told beforehand. The second – 8 bit – version can contain the row or column flashing.

However, due to frequent signal loss experienced the protocol we selected a software tagging protocol for Brain Invaders. In this protocol we assigned specific tags that can be read by OpenViBE to flashes. This means OpenViBE can extract a flash from the tags received rather than from an additional channel in the EEG signal. The disadvantage of this software tagging protocol is a strong drift over time, resulting in tags eventually arriving in OpenViBE with a delay. Since we only held short play sessions for the experiment, this was deemed a minor problem for the research presented in this thesis.

As we have seen in the previous section, the game needs to make decisions based on EEG data gathered by OpenViBE. This means that Brain Invaders does not just send information to OpenViBE but receives it as well. Rather than through the `OVComm` class this communication is done through the Virtual-Reality Peripheral Network (VRPN), which buffers the P300 response values for all rows and columns. The game can read out this buffer and use its data when it needs to select an `Alien` to shoot.

The communication cycle can be seen in Figure 4.6.

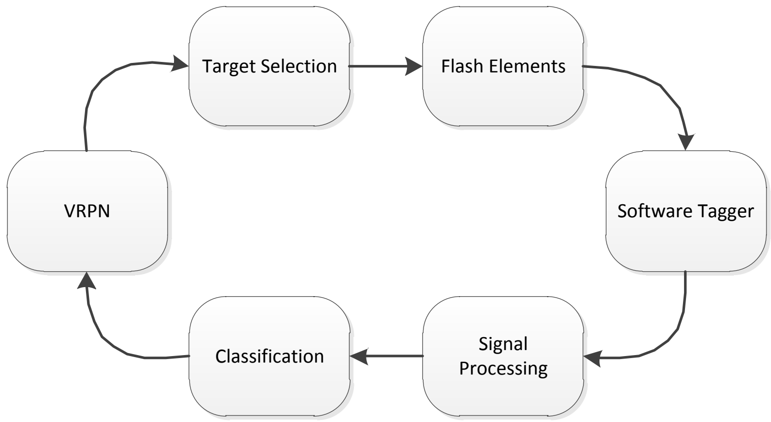

Figure 4.6: Communication cycle for Brain Invaders.

CHAPTER 5

Experimental Set Up

Now that we have developed a game that features distractors, it has become possible for us to test the hypotheses from Chapter 2. This is done by play testing the game. In this play test experiment we asked several students to play three levels of the game. During these play tests we observe participants, acquire data from the EEG device, and generate logs of in-game events. Afterwards, we ask participants to fill in a questionnaire.

The experiment serves for acquiring two types of data. First, there is the objective data, which is gained through data acquisition of both EEG and game data. We can process this data into results that compare players to each other and to make comparisons between performance in different levels and, therefore, the effects of distractors. We can consider this data as a mean to assess the *factual* difficulty of the levels. The second form of data we derive from the questionnaire, which covers the player experience with regards to difficulty and distractors. From this we can obtain the *perceived* difficulty.

This chapter does not describe the actual data processing, which can be found in Chapter 6 instead. Rather, it describes the process leading up to the acquisition of the data. In this chapter we will detail the set up of the experiment, explain the procedure during the play tests, and elaborate upon the conditions in which we require the participants to play the game.

5.1 Goal

We designed the experiment with a clear goal in mind: We aim to check whether the distractors as implemented in Brain Invaders are a viable method for achieving the paradox of control in a game controlled using the P300 paradigm. To do so, it is required that we design an experiment that tests whether the game functions as desired. Since the goal of the distractors is to increase difficulty by creating a distracting effect, the experiment tests whether there is a difficulty increase when the game contains distractor elements. The paradox of control assumes that an increase in the challenge of the game also increases the player enjoyment, as long as there is no lost sense of control. As evaluating the sense of control can prove difficult, we measure player enjoyment, because an increase in both difficulty and player enjoyment suggests the paradox of control occurs in the game.

Therefore, we designed the experiment to evaluate both the difficulty and enjoyability of the game as a whole and the effect of distractors on these factors, in particular. If distractors indeed result in the paradox of control they should cause the game to become more difficult while also increasing the enjoyment of the player. Since difficulty and enjoyability are two different factors to measure, we adjusted the experimental set up to collect multiple forms of data. While difficulty can be measured both objectively (by comparing player performance) and subjectively (by the player rating of difficulty), enjoyment is mostly a subjective rating.

We gather the data for all measurements through play sessions of Brain Invaders. Without playing the game participants will not be capable of properly judging the difficulty of the game or the enjoyment gained from playing it. The play sessions consist of multiple levels with a different amount of distractors in place, including a level without any distractors, in order to see the effects of including distractors. To rule out any influence of the order in which the levels are played, we set up the play sessions to allow for different orders of levels. Besides playing multiple levels, the player plays each level a multiple amount of times as well, as a learning curve might skew the performance in the first attempt. A game session, therefore, consists of multiple levels that the player all plays for a few times in repetition.

We measure the difficulty of the game through the use of data generated during a play session as well as based on the feedback of the participants. We accomplish the former both by observation and by signal processing. Through observation we compare difficulty based on the attempts a player requires to finish a level, as we assume that a level that is less difficult requires fewer attempts than a more difficult level. If distractors cause an increase in difficulty, the player should require more attempts to finish levels featuring them than in levels without distractors.

Signal processing may also provide insights on the difficulty of the game. Therefore, we use the EEG signals that are recorded and processed for the target selection in the game to measure difficulty as well. Since the signal processing measures the P300 response to all elements rather than just the response to the target, we can calculate the selection probability for each element. If distractor elements do indeed increase difficulty they should show a higher likelihood of being selected. Therefore, we process the recorded signal to compare the P300 response strength of the target, distractor, and non-distractor elements to each other. These calculations are useful for the coloured distractors as they can be selected in the game, as opposed to the movement distraction effect which is unselectable and, therefore, not easily identified.

Additionally, we collect subjective data. If the players perceive distractors as increasing difficulty, we estimate them to indicate as such. Therefore, we ask users to rate the change in difficulty when distractor elements (e.g. colour and movement) are present. Furthermore, we ask the participants to indicate which level they find the most difficult. If distractors increase difficulty, we expect most users to indicate that the level featuring the most distractors is also the most difficult.

Since enjoyment is most easily measured by user response, we ask the participants about their perception of the game as well. If distractors create a paradox of control, players should rate both their difficulty and their enjoyability positively.

5.2 Set up

Because the game is dependent on the ability of participants to fully concentrate, we try to create a relaxing environment to the player. In other words, the player has to have as little external distractions as possible and has to feel comfortable when playing the game. To achieve this, we set up the experiment in a quiet, darkened room to allow for full focus on the game. We placed a screen displaying the game on top of a table in the room so that the participants, sitting on an office chair, are able to face the screen without having to tilt their heads. An observer, who starts the game, is placed in another room and can see a duplicate of the screen in order to observe the user interaction.

Comfort is an important factor in the set up of the experiment but so is accuracy. As has already been established, the input from a BCI needs to be as precise as possible due to the sense of control. The EEG device we used in the experiments is the NeXus-32 cap [54], as this sensor proved very accurate during software testing. The NeXus-32 is a wet sensor, so gel has to be applied to the cap. This is of some discomfort to the player and causes the experiment to take slightly longer than it would take with a dry sensor. Unfortunately, we could not implement dry sensors in time due to software errors.

Seventeen electrodes plus a ground electrode are connected to the EEG device. In Figure 5.1 the sequence of the channels and their location on the head can be observed.

Channels
1 - F7
2 - F3
3 - Fz
4 - F4
5 - F8
6 - T7
7 - C3
8 - Cz
9 - C4
10 - T8
11 - P7
12 - P3
13 - Pz
14 - P4
15 - P8
16 - O1
17 - O2

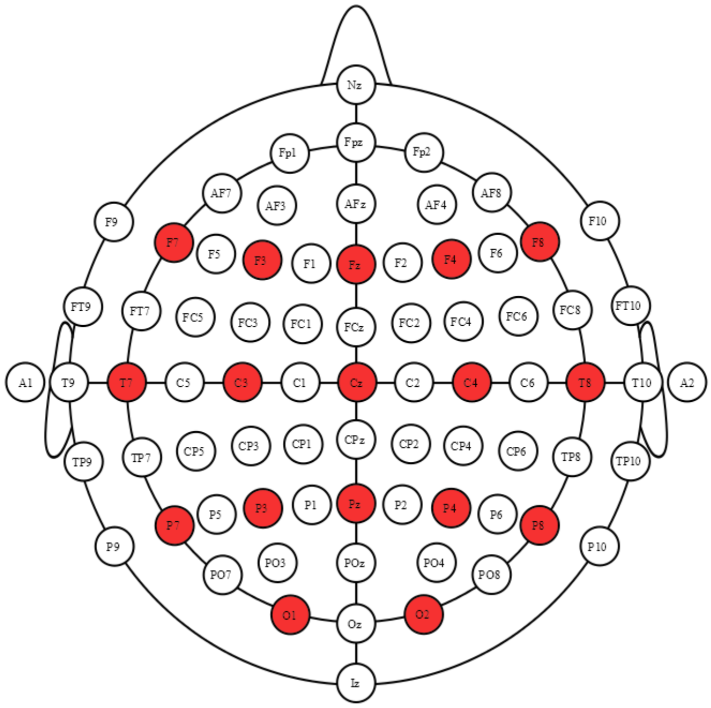

Figure 5.1: Chart of the BCI channels used.

5.3 Procedure

Before the experiment commences we set up the BCI-cap and check whether the signal is properly recorded. Once we properly place the cap on the head of the participant and connect it to the PC, we start the training of the game. Afterwards we use the data collected during this session to train the P300 classifier.

Once the set up and training is done, the player plays the game. The goal of the experiment is not communicated to the player, although the goal of the game is explained. We also give the player tips for using with the BCI, such as the advice to limit blinking and to count the number of flashes seen. In order to collect enough data and prevent possible effects of latency, we changed the procedure of the game somewhat from regular gameplay. The player plays all of the levels as described in the Game Progression section of Appendix A separately, with a small pause in between to reset the BCI signal and to allow for distinct signal recordings. In order to have enough data and to prevent any lucky shots or bad rounds, the player plays all levels for a minimum of three and a half minutes. To be more precise, rather than loading the next level when the target has been hit, the level is repeated until the minimum time has passed. After this three and a half minute mark the level will no longer reload when the target is hit. We choose this timeframe because it will result in a minimum of four rounds in a worst case scenario. We opt to use a timeframe in favour of a fixed number of rounds due to latency problems that pop up after approximately five minutes of gameplay. Furthermore, in order to ensure that a learning curve does not skew the results with respect to difficulty, half of the players play the levels in reverse order (so they play the level estimated most difficult first and the one deemed easier at the end of the experiment, instead of vice versa).

In the end, a total of twenty-six participants – nineteen male, seven female – partook in the experiment. Their age averaged on 24.4 years (standard deviation: 2.76, youngest 21, oldest 31) and half of them played games occasionally, estimating their average playtime per week around four and a half hours.

5.4 Signal Processing

The signal processing of a single session consists of three phases. First, we acquire the training data. Using OpenViBE, we the process this data to train the BCI classifier. Finally, we use this trained classifier during a game session to process the EEG waves for gameplay purposes. We store all the recorded EEG signals for future reference.

During training phase of the experiment, the recorded signal includes the 17 EEG channels as detailed in section 5.2 and the additional software tags that indicate when elements are flashing. The training data is stored so we can reuse it during data analysis.

We then use this recorded training data to generate an xDAWN spatial filter as defined by Rivet et al. [55]. Using the same data acquired during the training session and the generated spatial filter we then train the P300 classifier through a Linear Discriminant Analysis [38] set to 20 partitions.

During play sessions the game uses the trained classifier in order to determine the shot to be taken. After each flash repetition OpenViBE sends the classified data back to the game. The game then processes the data to select the element to be shot. The in-game signal processing resets every time the level is reloaded. During a single play of a level, the game adds up the values per element, and after each repetition it selects the non-shot element with the strongest response. We also record the signal acquired during the play session for processing at a later time, such as when we want to calculate the response strength to each element type. The recorded signals contain the data generated during the entire play of a single level, including all repetitions. At the end of a play session the data recorded, therefore, includes separate files for training data and level one, two, and three.

5.5 Questionnaire

The Questionnaire can be found in Appendix B. We ask all participants to fill in the questionnaire after they finish the game. The questionnaire focuses on the experience of playing the game, primarily with regards to difficulty and distractors as perceived by the players. Furthermore, we inquire players about their gaming habits and possible colour-blindness (due to the importance of colours of distractors this might prove significant). Finally, we ask players to indicate which level was their favourite, as through the paradox of control we can be assume that the more difficult level will also correlate to the favourite level.

Due to time constraints we constructed the questionnaire shortly before the experiment began, and a critical non-participant only briefly tested it. After three subjects had partaken in the experiment, we added two additional questions that we had forgotten but deemed of importance for the remainder of the subjects to answer. Participants filled in the questionnaire through a website dedicated to construct and collect surveys, although they filled in the questionnaire on a laptop placed nearby immediately after the experiment.

5.6 Discussion of Set up

While we remain confident that the experiment set up as described above provides a basis for judging the effectiveness of distractor elements, we should apply further reflection on the experimental design. Due to an unexpectedly long time required to bug fix the software and a strict deadline, we had to formally design the experiment in just a few days. This resulted in a largely unreviewed experimental procedure, which in retrospect contains some strong flaws. Since additional experiments would cause a substantial delay for this thesis, we opted to analyse the weaknesses of the experiment instead. Therefore, this section details the flaws that can be identified in the experiment, proposes solutions for preventing those flaws in future research, and argues for the validity of the experiment.

The most important flaw of the experiment stems from the levels we selected for use in the research. These were not properly designed with the null hypothesis fully in mind and, as such, are quite limited in their scientific validity. The short time between functional testing and the execution of the experiment resulted in us using levels that had been used for testing purposes, while other levels might have been better for more accurate results. Most notable is the fact we lack a full null hypothesis for movement, as both level one and two move in a similar (horizontal) fashion, while the third level adds additional movement directions. Although Shishkin et al. already proved that horizontal movement has no significant influence on the P300, their research was limited to gradual movement rather than the step-wise movement that we implemented in Brain Invaders [56]. As such, we cannot compare between no-movement and movement but rather make a comparison between horizontal movement and more complicated movement patterns.

The same can be roughly said for colouring, although this restriction applies primarily to colour placement. While there is a null case and a similar level with a few colours implemented, this second level is highly dependent on the placement location of the colour distractors. In the level, these distractors are set up at a fixed position relative to the target element, and, therefore, any effect they might have on selection may also be related to their position. As such, we should have compared between a level with no distractor elements and a level with only distractor elements. The third level, while more complicated, differs on both colour placement and movement and, therefore, serves as a less solid basis for comparisons to a null case, because we manipulated too many factors (e.g. distractor placements, movement patterns, and number of distractors present in the level). While the third level may serve as a basis for player perception of the effects of distractors, it may, therefore, not necessarily serve as a statistically valid basis.

Secondly, one might argue that playing the game in either normal or reverse order is leading the player's expectations of the experiment. Players may conclude by themselves what the game is trying to achieve with regards to difficulty. This could potentially skew the results of the questionnaire, as players may experience more or less of a difficulty increase if they focus on this aspect of the game. With three different levels there were six different orders in which the levels could have played, but instead we only tested two of these. Randomising the test to include the full range of level orders might have resulted in somewhat more reliable results, although we cannot be certain that the implementation of the level order in the experiment resulted in a significant negative effect. The possibility of such an effect taking place has to be taken into account, however.

Besides the playing order of the levels, results of the questionnaire may also be somewhat influenced by the moment in which the players answered the questions. Rather than asking users about each individual level directly after they played the level, we let them fill in the questionnaire after the entire experiment. This was done due to the fact that players were hooked up to an EEG device, which limited their movement. Furthermore, the questionnaire was filled in on a computer. Since the computer on which Brain Invaders was played did not offer privacy (due to a monitor duplication to allow for easy observation), using an additional PC would have resulted in a more complex procedure of the experiment. Such a procedure was only considered in retrospect.

Having participants answer the entire questionnaire after playing the game has two risks with regards to the results. First of all, the same risks that follow from the playing order are present here. By answering the questions after the entire experiment has taken place, users may post-rationalise their responses. In other words, users may have considered that the intended effect of the research is to increase difficulty through distractors and subconsciously try to confirm that hypothesis in their responses. Secondly, there is the risk that players forget their performance in the first level played. With at least two variables being compared in the questionnaire and three levels played, there is a chance that users can not accurately remember and, therefore, rate their performance. Combined with post-rationalisation, the player may judge the effects of the first or last level played differently than he would have in a separate questionnaire after each level.

In retrospect, we should, therefore, have designed the experiment differently. Most importantly, we should have based the level structure more around isolating the distractors and testing these against some null case. A better set of levels would have been a null case level with no coloured distractor elements and no movement, a level with no movement but all distractor elements, and a level with movement but no coloured non-targets. This would have allowed for comparison between the null case and both the implementation of coloured distractors (regardless of their position from the target) and movement. The players should have played these three levels in a randomised order to ensure he was not guided towards a conclusion. Additionally, we should have asked the player to rate the level played on difficulty, immersion, enjoyment, etcetera after each level was finished.

Nevertheless, we still believe there is some validity in the performed experiment. While the results will not prove conclusive, they most likely still indicate which results can be expected if the experiment is executed as suggested above. If this experiment shows no evidence for distractors working it is likely to be the case in another experiment as well. While the null case may be flawed in this experiment, there is still a clear difference in distractor implementation. We expect including more distractors gradually increases difficulty, rather than the difficulty being raised to a fixed point if any distractor is present. Therefore, we can expect to see a difference in difficulty in the experiment as it was executed as well. However, due to the lack of a proper null case or the clear differentiation between levels, such an increase does not prove the cause of any difficulty change. In short, if the experiment shows no increase in difficulty we expect the same to happen when executed properly, but if a difference can be shown, we cannot conclude which distractor element (if any) is the cause of such an increase. Hence, if a difference is found, we should redo the experiment to confirm the cause of the difficulty increase.

CHAPTER 6

Result Analysis

The experiment as described in Chapter 5 provides us with data in the form of observations, raw brainwave signals and response to the questionnaire. In this chapter these experimental results will be summarised. As we have noted before, the results from the experiment may be skewed due to flaws in the experimental design. We remain confident, however, that data analysis will at the very least give us insights into whether player performance differs between levels.

While 26 students participated in the experiment, we will omit some data from analysis due to technical problems encountered during the experiment. Most notably we have removed the entire data from sessions of two participants due to a drift that occurred in the BCI signal acquisition. This caused a high imprecision in the selection procedure of the game; as such, we have determined that this data does not accurately reflect the results of a normal play session of the game. Furthermore, the short timeframe in which we set up the experiment caused some of the data acquisition to be implemented only after the experiment had commenced. This means we did not properly log the gameplay for the first two participants. We also added questions regarding concentration after the first three participants had already filled in the questionnaire. Therefore, we have omitted these participants from the analysis of the results of the corresponding data type. In short, we will exclude two participants from the attempts analysis and the entire questionnaire, four participants from the signal processing analysis, and five participants from the questions regarding concentration. For clarity we shall not N where necessary.

As noted previously, we set up the experiment to gather two forms of data: objective and subjective data on the difficulty of the game. We can split up the objective data in two, however, as we can process data from both observation and recorded signals to analyse the difficulty of the game. As such, this chapter contains three separate sections of results.

6.1 Attempts

We do a first analysis of the data by observing the average amount of attempts required to finish a level. This proves useful, as logically a level in which it is more difficult to hit the target requires the player to fire more shots than an easier level. If distractors are increasing the difficulty, then the levels assumed to be more difficult should, therefore, show a higher amount of attempts.

To determine this we noted down all the shots players required during play sessions (N = 24). Analysis proves slightly difficult however, as simply averaging the total amount of attempts results in data skewed by the time limit we imposed on a play session. A well skilled player averaging only one or two shots per level can play a level more times in the time span than a player averaging at four shots. Therefore, we will adjust the results by assigning a player score, wherein a higher score reflects better performance in the game. Such a score allows us to rate the performance of an entire session rather than the average performance during play.

The calculation for the score is based on the total average attempts players required to hit the target in any level, s we can estimate aveage performance. At 2.3 attempts to hit the target (with a standard deviation of 1.4) the game performs on par with the original Brain Invaders [42]. We will also use this average to base the calculations of the score on. If the player performs much better than the average and only requires a single repetition we will assign four points. Since the average is closer to two repetitions than three, we will assign two points if the player required the former amount of attempts but only one point in case of the latter. No points are assigned if the player required more than three attempts. This scoring calculation mechanism ensures that a player performing on par with the average performance approximately gains half the maximum score. Table 6.1 shows the score for each attempt per level repetition.

Attempts	Score
1	4
2	2
3	1
>3	0

Table 6.1: Overview of the score per level repetition.

Table 6.2 shows both the average of attempts and the average score for the sessions overall as well as each distinct level.

	All	Level 1	Level 2	Level 3
Total Sessions				
Average (Std Dev)	2.3 (1.4)	2.3 (1.3)	2.2 (1.3)	2.4 (1.6)
Score (Std Dev)	13.7 (7.9)	13.7 (7.3)	14.6 (8.9)	12.8 (7.7)

Table 6.2: Average attempts and score during play sessions

Upon first sight there seems to be little difference between the levels with and without distractors. All levels require approximately the same amount of attempts and see a similar score. Considering the relatively large standard deviations, first evidence suggests distractors as implemented in Brain Invaders may have little effect.

Averages only tell a small part of the story however and as such some additional statistical tests should be applied to the results. Before we do such tests we should evaluate whether the score calculation results in a normal distribution, for this allows for comparisons between performances through a Student’s T-Test. Figures 6.1 through 6.3 show the histograms for the score distribution for each individual level, while Table 6.3 shows the results of both the Kolmogorov-Smirnov and Shapiro-Wilk normality tests.

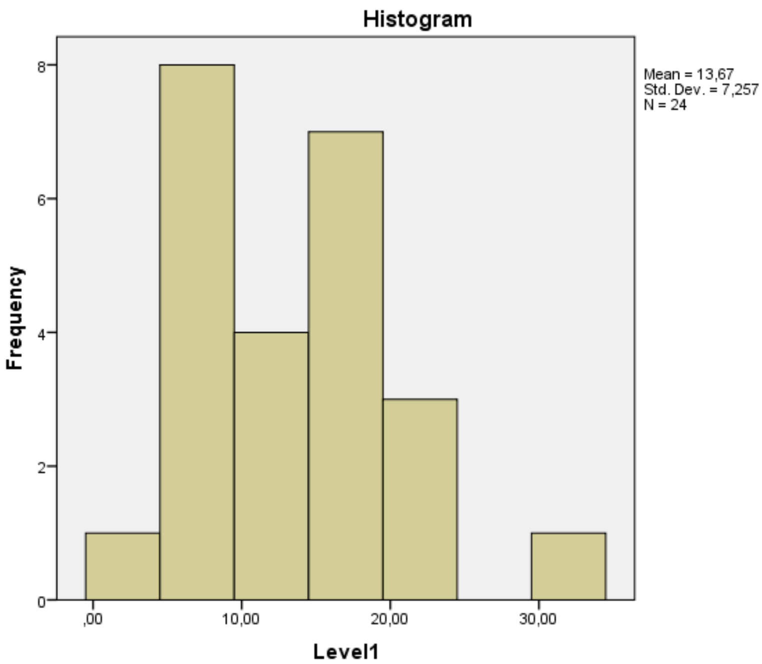

Figure 6.1: Histogram for scores in Level 1

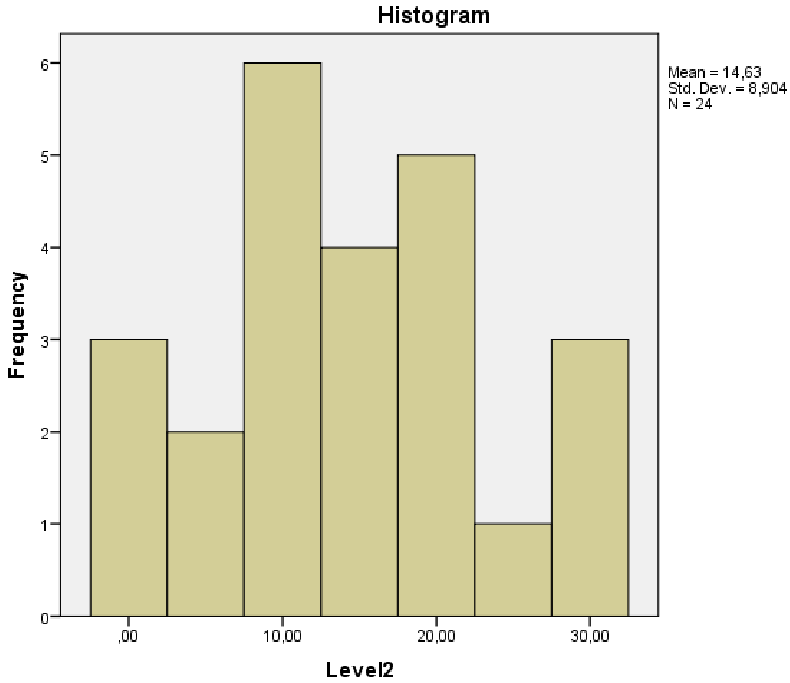

Figure 6.2: Histogram for scores in Level 2

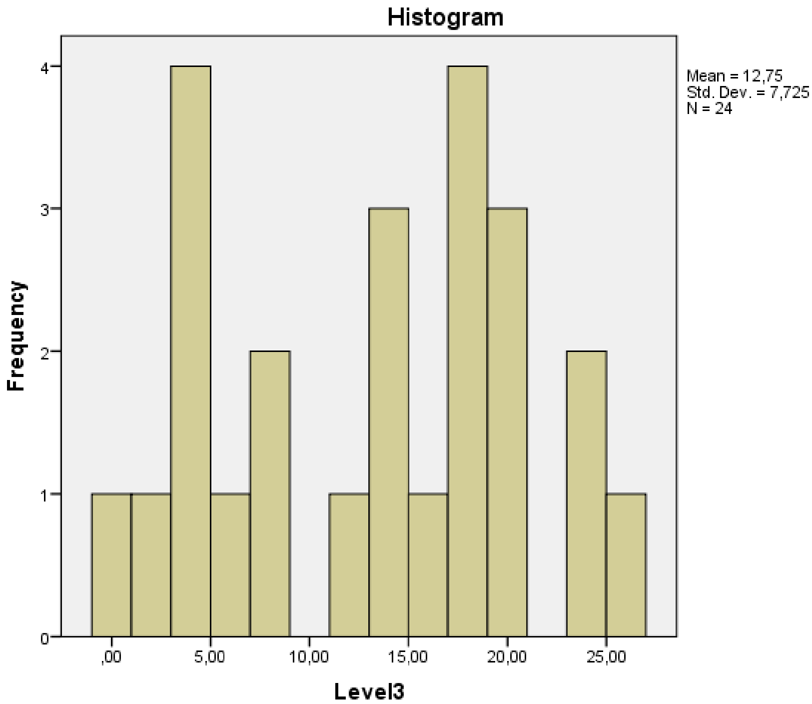

Figure 6.3: Histogram for scores in Level 3

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Level1	,115	24	,200*	,961	24	,465
Level2	,074	24	,200*	,968	24	,626
Level3	,134	24	,200*	,935	24	,124

Table 6.3: Normality tests for levels.

The scores of all levels are normally distributed according to both tests, allowing us to compare level performance based on score through a Student's T-Test. To analyse the difference between player performances for each level we compare the scores of players per level through a paired two-tailed Student T-Test. The test was paired, as we compare the results per level per player, and two-tailed, as we cannot rule out a decrease in difficulty in the levels hypothesized to be more difficult. The p-values for these tests can be found in Table 6.4.

T-Tests	Level 1-2	Level 1-3	Level 2-3
P-Value	0.594	0.570	0.312

Table 6.4: P-Values for Levels compared by score

The P-values confirm what was already expected based on the average required attempts. None of the values is smaller than 0.05, and, as such, there is no evidence for an increased difficulty between levels. Therefore, distractors as implemented in Brain Invaders do not influence difficulty in a way significant.

Overall, when we regard it as a regular P300 speller, Brain Invaders performs on par with the state of the art. The average of 2.3 repetitions to select an element is quite high and shows that the optimisations implemented in the game work. It should be noted, however, that as the game eliminates an element after each repetition, a one-to-one comparison with regular P300 spellers is impossible; accuracy cannot be compared correctly. Nevertheless, the high performance all but rules out that an error in signal processing causes the lack of difference between distractors and non-distractors.

6.2 P300-Signals

Analysis of the amount of attempts required to finish the game – or the corresponding score – does not necessarily paint the whole picture with regards to difficulty. A distractor element will not necessarily break the player's focus from the target element sufficiently, yet it might still be more distracting than a non-distractor element. If this is the case, the P300 response strength to distractor elements should be higher than it is for regular elements.

Therefore, we analyse the BCI signals recorded during play sessions (N = 22) and combine them with the positions of the different elements to calculate the P300 response strength. Because the P300 selection algorithm assigns a value to each element after a flash repetition and consequently selects the element with the lowest value, the values closest to the selected value are more likely to be distracting to the player. Hence, we compare these values by taking the mean response value per element type in a single gameplay session and then using a Student's T-Test to compare these mean values. This results in the p-values for element types for a single user. We combine these per player results using the Fisher method, resulting in the p-values as found in Tables 6.5 through 6.7, corresponding to the values for level one, two and three respectively. The tables compare all separate types of alien elements, including the three white non-distractor elements that all have a different sprite, the target element, and the two distractor elements (blue and red). Elements not present in a level are omitted from the respective Tables.

	Normal 1	Normal 2	Normal 3	Target
Normal 1	-	0.9987	0.9941	0
Normal 2	-	-	0.9072	0
Normal 3	-	-	-	
Target	-	-	-	-

Table 6.5: P-Values for each element in Level 1

	Normal	Target	Distractor 1	Distractor 2
Normal 2	-	0	0.9031	0.2485
Target	-	-	0	0
Distractor 1	-	-	-	0.3153
Distractor 2	-	-	-	-

Table 6.6: P-Values for each element in Level 2

	Normal 1	Normal 2	Normal 3	Target	Distractor 1	Distractor 2
Normal 1	-	0.3241	0.4992	0	0.6970	0.2970
Normal 2	-	-	0.8369	0	0.4445	0.3808
Normal 3	-	-	-	0	0.8425	0.5842
Target	-	-	-	-	0	0
Distractor 1	-	-	-	-	-	0.8529
Distractor 2	-	-	-	-	-	-

Table 6.7: P-Values for each element in Level 3

Much like in the case of attempts and score analysis, there is no significant difference between distractor and non-distractor elements with respect to the P300 response, as all p-values comparing between them show a value greater than 0.05. However, there is a great significant difference between response strength for target and non-target elements. Given that each level contained only one target element – which was hit on average after 2.3 attempts – this is of little surprise. The P300 response to the target element is strong and, therefore, averages much higher than a group of elements, even if a few elements of that type had a similarly strong response.

6.3 Responses

Besides data gathered from the play sessions, the experiment also consisted of a questionnaire. The responses to these can give insights into how difficulty was perceived by players, rather than comparing difficulty based on performance. Difficulty is often in the eye of the beholder, as both the skill level and the tolerance for errors will differ from player to player. Through answering a seven point Likert-scale users reviewed the difficulty of the game and the influence of certain game elements on the difficulty level.

Rather than evaluating each question individually, we combined the results of questions regarding difficulty and concentration after testing their internal consistency. While analysis of individual distractor elements questions (e.g. testing internal consistency on questions regarding moving and coloured distractors separately) shows a low Cronbach's alpha value for coloured distractors – but not to movement distractors –, the combination of all questions regarding concentration and difficulty prove reliable (Cronbach's alpha = 0.741, N = 21). Therefore, we average the answers to these five questions to assign a difficulty score based on user response. According to this score, participants rate the difficulty of the game at 3.64

out of 7 (standard deviation: 0.98). With regards to difficulty, the answers given in the questionnaire, therefore, show a similar result to that of the objective data. Overall, players consider the game slightly easy. Since there is no internal consistency for questions regarding individual distractors, we refer to the median response and Inter Quartile Range (IQR) for individual difficulty questions. When inquired about the difficulty of coloured distractors, players gave a median rating of 4 (IQR: 1, N = 24). Movement distractors see a median of 5 (IQR: 2, N = 24).

In the end, difficulty is only a means to an end. The real goal of creating a higher difficulty is to get players in a proper state of flow. That means that player enjoyment should also be measured. Much like in the measurement of difficulty we combine the results of questions regarding enjoyment and immersion for both coloured and moving distractors (Cronbach's alpha: 0.795, N = 24). This results in an average enjoyment rating of 5.25 out of 7 (Standard deviation: 0.92). Much like in the questions regarding difficulty, there is no internal consistency for the enjoyment questions on individual distractor elements. Therefore, we again present the median rating of the individual responses. Coloured distractors see an enjoyment rating of 5 (IQR: 2, N = 24), while movement is rated 6 (IQR: 1, N = 24).

While distractors as implemented in Brain Invaders do not increase difficulty, they might make the game more engaging. This is reflected in the user response on enjoyment score. Distractors seem to increase the enjoyment participants experienced during gameplay. However, without the increase in difficulty the paradox of control cannot explain this increase in enjoyment. Therefore, visual diversity of levels seems a more likely explanation.

Finally, Table 6.8 shows the level rating given by players as well as the level that showed the worst performance (e.g. the level resulted in the lowest score). This shows the level deemed most difficult as well as the level considered most fun.

While we see no evidence for the effect of distractors on difficulty, level rating clearly shows a user bias towards levels with more distractors implemented. Although the levels in which players performed worst are split almost equally, a clear majority of the players indicate they found the third level to be the most difficult. The remainder of the users often felt that all levels were equally difficult, a notion that is supported by the actual performance results.

	Deemed Most Difficult	Liked Most	Actual Worst Performance
Level 1	4	0	8
Level 2	2	4	6
Level 3	13	16	10
All Equal	5	4	0

Table 6.8: Level Rating

Even more users favour Level 3 when inquired about their favourite level. Since distractors improve user enjoyment, this is a logical consequence. More distractors increase the enjoyment gained from a level and may even slightly influence perception of difficulty, although they do not, in fact, influence difficulty in a significant way.

CHAPTER 7

Conclusions

In a broad sense, this thesis is about finding the paradox of control for a P300 controlled game. This can prove to be a difficult task, as the range of options for achieving such a control balance may be limitless. Based on literature and knowledge of the characteristics of the P300 response, we proposed the usage of distractors or, to be more specific, the usage of colours and movement to break player focus. We assumed that events happening in the peripheral view of the player can sufficiently distract an unfocussed player in a P300 selection procedure and, as such, increase difficulty. The balance between control and difficulty are of vital importance to achieve Flow, the ultimate goal of a good game.

The distractors as described in this thesis have been the foundation of a game we developed. In turn, we used this game for an experiment to test whether distractors increase the difficulty of the game. Data gathered during the experiment consisted of observation of the attempts required to finish a level, the BCI signals we recorded during play sessions, and player response in the form of a questionnaire. We have processed this data into results that allow us to rate the difficulty of the game, both with and without distractors. In the first section of this chapter we analyse these results and use them to reflect upon the hypotheses we posed at the beginning of the thesis. This leads us to our conclusion.

The next section will see our reflection on the research, based on the conclusions we draw. This includes discussion of the consequences that follow from the conclusion, the factors that may have influenced the experimental results, and some directions that future research could take with regards to the paradox of control in P300-based games.

We reserve the broader discussion of the future direction to take in research related to P300, BCI, and gaming for the final section of this chapter. In this section we recommend which direction for future research we see as the most favourable way to go.

7.1 Conclusions

First of all, let us review Hypothesis 1:

> Using colour and movement to modify non-targets in a P300-selection game will result in a higher level of difficulty without making the player feel out of control, thereby creating a paradox of control.

The hypothesis can be slit up in two parts. First, it assumes that the usage of distractors will increase the difficulty of the game. Second, it expects that this increase in difficulty will not result in a lost sense of control. To prove the usefulness of the distractors with regards to the paradox of control, we, therefore, test both the difficulty and the sense of control. We did the former though both the objective and subjective data we gathered during the experiment.

So do distractors increase difficulty in Brain Invaders? Based on the results from the experiment, the answer to this question seems to be negative. When we consider the difference in the amount of attempts between levels, there seems to be none. The inclusion of distractors in and of themselves is of no significant effect, as is evidenced by the score assigned to player performance and the comparative T-Tests we have done.

Analysis of the brain signals also shows the ineffectiveness of the distractors to increase difficulty. Although each level shows a clear difference in response strength between the target element and any non-target element type, there is no difference to be found between distractor and non-distractor element types. Therefore, from an objective perspective, there is no difficulty increase caused by distractors.

Perception with regards to difficulty does not fare much better, as is evidenced by the answers to questions on difficulty. Overall, the game was rated as slightly easy, based on response to questions regarding difficulty and concentration. Based on the median response to questions regarding individual distractor values, coloured distractors show no effect on difficulty whatsoever, while movement distractors might result in a slight increase in difficulty. Based on the overall difficulty assessment, this effect seems negligible, however.

When considering the difficulty rating for the levels, over half the players indicated that the third level – which included the most distractors – was the most difficult. Since the actual worst performance is more equally distributed between levels, the level may, therefore, increase the perception of difficulty. However, since none of the other answers given in the questionnaire reflect this result, the reasoning behind this rating is unknown.

Since the difficulty seems unchanged, the actual sense of control is irrelevant with regards to testing the paradox of control as both are required. The low rating of overall difficulty does seem to indicate that players felt in control, however.

Without a paradox of control one of the key factors in the enjoyability of the game has been removed. This does not necessarily mean that the game is considered unenjoyable or that distractors have no effect on the amusement the game provides. Thus, Hypothesis 2 might still prove true:

> Using colour and movement to modify targets in a P300-selection game will increase player enjoyment of the game.

Enjoyment is a purely subjective rating and as such we can only rely on answers given by participants. Based on user response both colouring and movement have a positive influence on how much the game is enjoyed, although they are no real contributing factor to difficulty. The overall enjoyment rating is a positive one, and questions regarding individual distractors show that movement distractors are rated slightly more positively than coloured distractors.

This is further evidenced by the preference of levels with respect to enjoyability. When asked which level they liked most, a large majority of the users indicated to favour the third level. Although there may be many contributing factors to the preference of the level, distractors are likely one of them.

In short the distractors as implemented in Brain Invaders do not seem to create a paradox of control, causing Hypothesis 1 to stay unproven. A full rebuttal is impossible due to the limited implementation of the distractors ad experimental flaws described in Chapter 5. However, hypothesis 2 is proven, although not through the paradox of control as originally hypothesised. Therefore, the underlying reason for the enjoyability of distractors is not known.

7.2 Discussion

There are many reasons that may explain the lack of a paradox of control through the usage of distractors as applied in Brain Invaders. We thus ought to analyse the experiment, not just to explain the reasons for the lack of proof for the hypothesis, but also to find adjustments that can be made that might eventually lead to a proven paradox of control in a P300 game.

The first question to ask ourselves is the following: is there anything that could have gone wrong during the experiment? Although this holds true for most experiments, it should be noted that the experiment for Brain Invaders was set up on relatively short notice, due to the fact that bug fixing the game took much longer than anticipated. With strict deadlines approaching, the experimental set up was relatively rushed and as such error prone. This is notable for instance in the lack of some logging options in the game that might have given more detailed information on difficulty, response to specific elements, and timestamps (which could have helped in comparing play sessions). Furthermore, additional time might have prevented the signal drift that necessitated a time limit and stopping in between levels. Such changes could have greatly improved the accuracy of test data. The questionnaire was created in a short amount of time and as such was never properly evaluated before the experiment took place. This resulted in some missing questions as well as preventing a proper test of the validity of the questionnaire itself.

Most of the flaws in the experimental set up have been described in section 5.6. However, as we noted there, we remain confident that despite these flaws, which potentially skewed the data, a general tendency with regards to the effect of distractors can still be identified. Since the results indicate that distractors as implemented in Brain Invaders do not influence difficulty, we theorise that a better executed experiment would also have resulted in data indicating as such.

During the experiment itself some issues occurred as well. The most notable of these is an error in signal processing that occurred for some of the participants, causing their data to be invalid and omitted for the result analysis. Although the relatively high accuracy overall suggests that no such problems occurred on a smaller scale for the remainder of the play sessions, latency may have influenced them on an unnoticeable scale. If this is the case, the latency may have been of a much larger influence than the distractors in the selection process. This, however, seems unlikely as the average amount of repetitions required to make a selection (2.3) is on par with the previous version of Brain Invaders.

The main reason that might explain the lack of a notable effect is most likely in the design of the distractors themselves. Although we theorised that effects in the peripheral view disturb the concentration in a significant way, this had not been properly researched before the beginning of this thesis. As such, the parameters required for a peripheral view distraction were mostly unknown when the experiment was designed. With respect to colouring this means that the colours selected may simply be as distracting as the base colour. The bright white flash of the regular Aliens can be just as noticeable (or perhaps even slightly more noticeable) as the cyan and yellow coloured distractor flashes. In much the same way, the layout of the levels was untested and partially flawed and can be unfavourable to properly compare performance.

Since there was no prior research regarding distracting effects it is, therefore, possible that the effects of distractors as implemented in Brain Invaders are simply not breaking player focus enough. The chosen colours can be inefficient, movement can be too slow, or additional factors might be required for the elements to become truly distracting. As such, although the implementation in Brain Invaders does not prove the effect of distractors, a broader form of distractors may still be effective in achieving the paradox of control for a P300 controlled game.

The opposite may also be true: the target could simply be too attracting. Many additional effects are applied to the target so accuracy is as high as possible, such as a slight size increase during flashes, random flashing patterns, and the usage of a notable colour. This could make the target element so noticeable that distracting effects of other elements are relatively insignificant.

Although not fully intended as such, the high accuracy of the game overall is of note. With an average of 2.3 repetitions for the selection, Brain Invaders provides for a very fast P300 selection process. This is likely influenced by elements such as the random flashing and size increase for the target, as well as eliminating a single element after each flash. While not the scope of this research, the game may have given a good example of high accuracy P300 selection, which in itself is also of importance to P300 gaming and P300 research in general. Any influence on the selection accuracy by distractors is not tested in this thesis, although the similar results between levels suggest that they are of little effect.

This leaves us with some adjustments to the experiment and to the game itself to consider. If all the potential explanations as described above influence the paradox of control in some way, they may be anticipated in a new experiment. Some suggestions for optimising the distractors are given below.

A first attempts with regards to distractors could be made by changing the parameters. The concentration breaking effects that multiple colours may have if they appear in the peripheral view should be tested properly beforehand. If a difference is found in such as test, it seems like a valid option to sort elements based on the effect they have on the P300 response; the non-distractor elements could be the elements that see a less distracting effect, while distractor elements should be the elements that see a stronger response in the experiment.

Alternatively, it is possible to not change the colour of the element itself, but rather only the flashing colour. Elements that flash in a different colour than expected might surprise the player and, as such, cause a distracting effect in the peripheral view. A sudden colour change might, therefore, have a stronger impact than a constant colour effect, since it is more surprising. Much like the option of using alternative colours, this is a direction that ought to be researched.

With respect to movement, which is considered slightly more distracting based on user response; adjustments could mostly be made with regards to speed and randomness. Although moving elements in Brain Invaders saw a slight speed increase over the course of the level, the change was done gradually instead of a more randomised pattern. The movement was done stepwise, as this was assumed to be more distracting, but gradual movement with changing speed and direction might also prove distracting.

It should also be considered to use *external* distractors. Currently the distracting elements are selectable in the game and, therefore, had a constant presence in the game. Random appearance of additional unselectable elements during gameplay might also function as distractors, however, as they might generate a P300-effect. Such elements could serve as replacements for the distractors described in this thesis or as additional elements should alternative colours prove more effective.

The paradox of control which this thesis tried to find might not necessarily be achieved by attempting to break the player concentration. Although this seems like a likely option, it is by no means the only or even most successful way to achieve such an effect. The challenge with finding additional ways in which control might be manipulated lies within the requirement to have players feel in control of the game. For instance, decreasing the target optimisations as done in the game (e.g. growing target, random flashing, etc.) might make selection more difficult, but it will also decrease the sense of control and as such is not a valid option for achieving the paradox of control.

Of course, there is also the possibility that there is no proper method for achieving a specific form of the paradox of control for P300 selection. Much like removing selection optimisations would do, changes to the selection process might simply influence the sense of control and the difficulty of selection in an equal amount. If this proves to be the case, the paradox of control has to be achieved through the same ways it is created for non-P300-controlled games. Like gaming with a standard controller, the paradox would be created by requiring fast input decisions and different input choices.

Both of these ways in which to create a paradox of control have been mostly ignored in this thesis. Although choice was noted by game design theories as a vital factor in good game design, it is mostly omitted in Brain Invaders. The player choice in the game is limited to either focussing on the target or not focussing on it, but this can hardly be defined as a choice as the second option essentially indicates an unwillingness to play the game or achieve its goals.

In the case of Brain Invaders, choice would have to come from the ability to choose which alien to shoot and by having these choices have consequences. While the original Space Invaders had such a choice element, shooting all Aliens in the level proves technically difficult for the P300 selection process. First of all, there should be multiple elements to select in order to have a valid selection process, which would be impossible near the end of the game. Furthermore, the game is unable to check whether the element shot was the intended element and can thus not reset the P300 values once the intended element is shot, creating a lost sense of control. Finally, shooting an element after each flash repetition means there is a constant time to finish the level, which removes the time limit that makes the original Space Invaders challenging in the first place. The two final problems might be removed if a selection procedure where a shot is fired only when a high certainty of selection is present. However, such a game is beyond the scope of this research.

With regards to speed and choice, both a high accuracy and fast selection should be of high importance in order to create a paradox of control, just as they are in a regular game. If choice is too slow or too inaccurate, a sense of control will be lost or the validity of a choice will weaken. A balance has to be found, as fast selection but low accuracy and high accuracy but low speed both influences the paradox of control in some way. Therefore, without distractors or similar effects on control, gaming with P300 most likely requires a more advanced P300 selection process.

7.3 Future Work

Although Brain Invaders did not prove a paradox of control with distractors, it leaves room for many directions in future research. Based on analysis of the experiment, some recommendations can be made with regards to Brain Invaders and P300 gaming in general.

A deeper analysis of the factors influencing the P300 selection procedure without having the player loose the sense of control is perhaps the most important step to make with regards to the game. Different colours might have a stronger influence, just like different movement may. Alternatively, randomly appearing objects or elements flashing in notable colours may also show some influence. Finding the parameters for functioning distractors – if they exist – will greatly help the design of P300 controlled games.

Alternatively, different design approaches that use some form of a paradox of control should be researched. These can range from alternatives for utilising the P300 effect to the implementation of input choice as is used in most games with a standard control modality. At the same time, the requirements for these input methods should be researched, as the inclusion of choice with P300 selection most likely has some requirements with respect to speed and choice.

This holds true for all research related to gaming using new input mechanisms. Without understanding the conditions required for creating appealing games, research in new input mechanisms will be severely limited. As long as input such as BCI brings along both new possibilities and limitations, game design cannot be ignored, for doing so might lead to unforeseen consequences. Although ultimately the design and implementation of games with new techniques is the task of dedicated game developers instead of researchers, some conditions ought to be understood before any commercial game design can take place.

Gaming is primarily a consumer driven technology and as such the usefulness of new input methods will only show itself once they have a similar appeal to consumers. Simple novelty for the sake of novelty or focus on gaming simply because gamers tend to be early adopters will not suffice. Therefore, if the goal of BCI research is to bring EEG devices into households, valid gameplay mechanisms have to be introduced.

Since the attempts made in this thesis have been unsuccessful, the problem remains. The paradox of control, fast and reliable response from BCI, meaningful choice: they all play a vital part in gaming with BCI and, therefore, should play a vital role in research to come. It will be the task of researchers and game designers alike to walk down this path. Hopefully the attempts made in this thesis will serve as a base for all that is to come.

Bibliography

[1] J. Huizinga, *Homo ludens: A Study of the Play Element in Culture*, Boston, Massachusetts: Beacon Press, 1938/1955.

[2] Entertainment Retailers Association. "Games overtakes video as UK's biggest entertainment category in 2011, But video is fighting back," October 10th, 2012; http://www.eraltd.org/news/era-news/games-overtakes-video-as-uk%27s-biggest-entertainment-category-in-2011,-but-video-is-fighting-back.aspx.

[3] S. Coyle, T. Ward, and C. Markham, "Brain–computer interfaces: a review " *Interdisciplinary Science Reviews,* vol. 28, no. 2, pp. 112-118, 2003.

[4] A. Nijholt, D. Plass-Oude Bos, and B. Reuderink, "Turning shortcomings into challenges: Brain-computer interfaces for games," *Entertainment Computing,* vol. 1, no. 2, pp. 85-94, 2009.

[5] S. I. Hjelm, and C. Browall, "Brainball - using brain activity for cool competition," in Proceedings of the First Nordic Conference on Human-Computer Interaction, 2000.

[6] Business Wire. "NeuroSky Lets You Use Your Brainwaves to Control Games and Toys," October 10th, 2012; http://www.businesswire.com/news/home/20110328006931/en/NeuroSky-Lets-Brainwaves-Control-Games-Toys.

[7] D. Plass-Oude Bos, B. Reuderink, B. v. d. Laar, H. Gürkök, C. Mühl, M. Poel, A. Nijholt, and D. Heylen, "Brain-computer interfacing and games," *Brain-Computer Interfaces*, D. S. Tan and A. Nijholt, eds., pp. 149-178, London, United Kingdom: Springer, 2010.

[8] A. Finke, A. Lenhardt, and H. Ritter, "The MindGame: A P300-based brain–computer interface game," *Neural Networks,* vol. 22, no. 9, pp. 1329-1333, 2009.

[9] E. Lalor, S. P. Kelly, C. Finucane, R. Burke, R. B. Reilly, and G. McDarby, "Brain–computer interface based on the steady-state VEP for immersive gaming control," in Proceedings of the 2nd International Brain-Computer Interface Workshop and Training Course, Berlin, Germany, 2004.

[10] D. Oude Bos, and B. Reuderink, "BrainBasher: a BCI game," in Extended Abstracts of the International Conference on Fun and Games, Eindhoven, The Netherlands, 2008.

[11] R. Krepki, B. Blankertz, G. Curio, and K.-R. Müller, "The Berlin Brain-Computer Interface (BBCI) – towards a new communication channel for online control in gaming applications," *Multimedia Tools and Applications,* vol. 33, no. 1, pp. 73-90, 2007.

[12] H. Gürkök, A. Nijholt, and M. Poel, “Brain-Computer Interface Games: Towards a Framework,” in Proceedings 11th International Conference on Entertainment Computing (ICEH 2012), Bremen, Germany, 2012, pp. 373-380.

[13] K. Salen, and E. Zimmerman, *Rules of Play: Game Design Fundamentals*, Cambridge, Massachusetts: MIT Press, 2003.

[14] M. Csikszentmihalyi, *Flow: The Psychology of Optimal Experience*, London, United Kingdom: Harper Perennial, 1990.

[15] B. Z. Allison, and C. Neuper, "Could Anyone Use a BCI?," *Brain-Computer Interfaces - Applying our Minds to Human-Computer Interaction*, Human-Computer Interaction Series D. S. Tan and A. Nijholt, eds., London, United Kingdom: Springer-Verlag, 2010.

[16] E. J. Langer, “The illusion of control,” *Journal of personality and social psychology,* vol. 32, no. 2, pp. 311-328, 1975.

[17] H. Gürkök, A. Nijholt, M. Poel, and M. Obbink, “Evaluating a Multi-Player Brain-Computer Interface Game: Challenge versus Co-Experience,” *Entertainment Computing*, 2012.

[18] B. L. A. v. d. Laar, D. Plass-Oude Bos, B. Reuderink, M. Poel, and A. Nijholt, *How much control is enough? Optimizing fun with unreliable input,* Technical Report TR-CTIT-11-25, Centre for Telematics and Information Technology University of Twente, Enschede, The Netherlands, 2011.

[19] M. Quek, J. Höhne, R. Murray-Smith, and M. Tangermann, "Designing future BCIs: Beyond the bit rate," *Towards Practical Brain-Computer Interfaces: Bridging the Gap from Research to Real-world Applications*, B. Allison, S. Dunne, R. Leeb, J. D. R. Millan and A. Nijholt, eds., pp. 173-196, Berlin, Germany: Springer-Verlag, 2012.

[20] C. Guger, S. Daban, E. Sellers, C. Holzner, G. Krausz, R. Carabalona, F. Gramatica, and G. Edlinger, “How many people are able to control a P300-based brain-computer interface (BCI)?,” *Neuroscience Letters,* vol. 462, no. 1, pp. 94-98, 2009.

[21] D. Zhu, J. Bieger, G. G. Molina, and R. M. Aarts, “A survey of stimulation methods used in SSVEP-based BCIs,” *Computational intelligence and neuroscience,* vol. 2010, pp. 1-12, 2010.

[22] R. Caillois, *Man, Play and Games*, Glencoe, Illinois: The Free Press of Glencoe, 1961.

[23] C. C. Abt, *Serious Games*, New York, New York: Viking Press, 1970.

[24] E. Avedon, and B. Sutton-Smith, *The Study of Games*, New York, New York: John Wiley & Sons, 1971.

[25] C. Crawford, *The Art of Computer Game Design*, Berkley, California: Osborne / McGraw Hill, 1982.

[26] S. W. Littlejohn, *Theories of Human Communication*, 3rd edition ed., Belmont, California: Wadsworth Publishing Company, 1989.

[27] J. Chen, “Flow in Games (and Everything Else),” *Communications of the ACM,* vol. 50, no. 4, pp. 31-35, 2007.

[28] P. Sweetser, and P. Wyeth, “GameFlow: A Model for Evaluating Player Enjoyment in Games,” *ACM Computers in Entertainment,* vol. 3, no. 3, 2005.

[29] C. Klimmt, T. Hartmann, and A. Frey, “Effectance and control as determinants of video game enjoyment,” *CyberPsychology & Behavior,* vol. 10, no. 6, pp. 845-848, 2007.

[30] N. K. Squires, K. C. Squires, and S. A. Hillyard, “Two varieties of long-latency positive waves evoked by unpredictable auditory stimuli in man,” *Electroencephalography and clinical neurophysiology,* vol. 38, no. 4, pp. 387-401, 1975.

[31] L. A. Farwell, and E. Donchin, “Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials,” *Electroencephalography and clinical neurophysiology,* vol. 70, no. 6, pp. 510-523, 1988.

[32] E. Donchin, K. M. Spencer, and R. Wijesinghe, “The mental prosthesis: assessing the speed of a P300-based brain-computer interface,” *Rehabilitation Engineering, IEEE Transactions on,* vol. 8, no. 2, pp. 174-179, 2000.

[33] H. Serby, E. Yom-Tov, and G. F. Inbar, “An improved P300-based brain-computer interface,” *Neural Systems and Rehabilitation Engineering, IEEE Transactions on,* vol. 13, no. 1, pp. 89-98, 2005.

[34] M. Kaper, P. Meinicke, U. Grossekathoefer, T. Lingner, and H. Ritter, “BCI competition 2003-data set IIb: Support vector machines for the P300 speller paradigm,” *Biomedical Engineering, IEEE Transactions on,* vol. 51, no. 6, pp. 1073-1076, 2004.

[35] P. Meinicke, M. Kaper, F. Hoppe, M. Heumann, and H. Ritter, “Improving transfer rates in brain computer interfacing: a case study,” *Advances in Neural Information Processing Systems,* vol. 15, pp. 1107-1114, 2002.

[36] V. Bostanov, “BCI competition 2003-data sets Ib and IIb: feature extraction from event-related brain potentials with the continuous wavelet transform and the t-value scalogram,” *Biomedical Engineering, IEEE Transactions on,* vol. 51, no. 6, pp. 1057-1061, 2004.

[37] D. J. Krusienski, E. W. Sellers, D. J. McFarland, T. M. Vaughan, and J. R. Wolpaw, “Toward enhanced P300 speller performance,” *Journal of neuroscience methods,* vol. 167, no. 1, pp. 15-21, 2008.

[38] D. J. Krusienski, E. W. Sellers, F. Cabestaing, S. Bayoudh, D. J. McFarland, T. M. Vaughan, and J. R. Wolpaw, “A comparison of classification techniques for the P300 Speller,” *Journal of neural engineering,* vol. 3, no. 4, pp. 299-305, 2006.

[39] J. Jin, B. Z. Allison, E. W. Sellers, C. Brunner, P. Horki, X. Wang, and C. Neuper, “Optimized stimulus presentation patterns for an event-

related potential EEG-based brain–computer interface," *Medical and Biological Engineering and Computing,* vol. 49, no. 2, pp. 181-191, 2011.

[40] G. Townsend, B. LaPallo, C. Boulay, D. Krusienski, G. Frye, C. Hauser, N. Schwartz, T. Vaughan, J. Wolpaw, and E. Sellers, "A novel P300-based brain-computer interface stimulus presentation paradigm: moving beyond rows and columns," *Clinical neurophysiology: official journal of the International Federation of Clinical Neurophysiology,* vol. 121, no. 7, pp. 1109-1120, 2010.

[41] P. Brunner, S. Joshi, S. Briskin, J. Wolpaw, H. Bischof, and G. Schalk, "Does the'P300'speller depend on eye gaze?," *Journal of neural engineering,* vol. 7, no. 5, pp. 056013, 2010.

[42] M. Congedo, M. Goyat, N. Tarrin, G. Ionescu, L. Varnet, B. Rivet, R. Phlypo, N. Jrad, M. Acquadro, and C. Jutten, ""Brain Invaders": a prototype of an open-source P300-based video game working with the OpenVIBE platform," in 5th International Brain-Computer Interface Conference 2011, Graz, Austria, 2011.

[43] G. Gibert, V. Attina, J. Mattout, E. Maby, and O. Bertrand, "Size enhancement coupled with intensification of symbols improves speller accuracy," in Proceedings of the 4th International BCI Workshop and Training Course, Graz, Austria, 2008, pp. 250-255.

[44] A. Kaplan, S. Shishkin, I. Ganin, I. Basyul, and A. Zhigalov, "Adapting the P300-based brain-computer interface for gaming: a review," *IEEE Transactions on Computational Intelligence and AI in Games (Special Issue on Brain/Neuronal-Computer Games Interfaces and*

Interaction), 2013, *in press*.

[45] J. D. Bayliss, "Use of the evoked potential P3 component for control in a virtual apartment," *Neural Systems and Rehabilitation Engineering, IEEE Transactions on,* vol. 11, no. 2, pp. 113-116, 2003.

[46] G. Hakvoort, H. Gürkök, D. Plass-Oude Bos, M. Obbink, and M. Poel, "Measuring immersion and affect in a brain-computer interface game," in 13th IFIP TC 13 International Conference on Human-Computer Interaction, INTERACT 2011, Lisbon, Portugal, 2011, pp. 115-128.

[47] C. Mühl, H. Gürkök, D. Plass-Oude Bos, M. E. Thurlings, L. Scherffig, M. Duvinage, A. A. Elbakyan, S. W. Kang, M. Poel, and D. Heylen, "Bacteria hunt," *Journal on Multimodal User Interfaces,* vol. 4, no. 1, pp. 11-25, 2010.

[48] K. Takano, T. Komatsu, N. Hata, Y. Nakajima, and K. Kansaku, "Visual stimuli for the P300 brain–computer interface: a comparison of white/gray and green/blue flicker matrices," *Clinical neurophysiology,* vol. 120, no. 8, pp. 1562-1566, 2009.

[49] R. Rouse III, *Game design: Theory and practice*, Second ed., Plano, Texas: Wordware Publishing, 2005.

[50] T. Lethbridge, and R. Laganiere, *Object-oriented software engineering*, Second ed., Berkshire, United Kingdom: McGraw-Hill Higher Education, 2005.

[51] G. Junker, *Pro OGRE 3D programming*, New York, New York: Apress, 2006.

[52] Y. Renard, F. Lotte, G. Gibert, M. Congedo, E. Maby, V. Delannoy, O. Bertrand, and A. Lécuyer, “OpenViBE: an open-source software platform to design, test, and use brain-computer interfaces in real and virtual environments,” *Presence: teleoperators and virtual environments,* vol. 19, no. 1, pp. 35-53, 2010.

[53] J. R. Wolpaw, N. Birbaumer, D. J. McFarland, G. Pfurtscheller, and T. M. Vaughan, “Brain-computer interfaces for communication and control,” *Clinical neurophysiology,* vol. 113, no. 6, pp. 767-791, 2002.

[54] Mind Media. "NeXus-32," December 5th, 2012; http://www.mindmedia.nl/CMS/en/products/nexus-systems/item/163-nexus32f.html.

[55] B. Rivet, A. Souloumiac, V. Attina, and G. Gibert, “xDAWN algorithm to enhance evoked potentials: application to brain–computer interface,” *IEEE Transactions on Biomedical Engineering,* vol. 56, no. 8, pp. 2035-2043, 2009.

[56] S. L. Shishkin, I. P. Ganin, and A. Y. Kaplan, “Event-related potentials in a moving matrix modification of the P300 brain–computer interface paradigm,” *Neuroscience Letters,* vol. 496, no. 2, pp. 95-99, 2011.

APPENDIX A

Game Design Document

This appendix contains the Game Design Document for Brain Invaders. As specified in Chapter 3 and 4 the Game Design Document contains an overview of the design of the game. It details its elements, mechanics, and flow. This appendix, therefore, serves to give the reader a clear picture of the Brain Invaders game.

Overview

Brain Invaders is a game in which players are tasked with stopping an alien invasion by using their brainwaves. In the game, the player is given a limited amount of shots to kill the alien leader, resulting in a victory, whereas missing the leader results in the invasion of the Earth.

The game uses the P300 paradigm for control, meaning that the player has to focus on the alien that he desires to shoot. Control is strengthened by silently count the number of times this alien flashes. If the player concentrates strongly enough, the right alien will be shot.

Game Mechanics

The mechanics of Brain Invaders revolve around a grid of Alien elements. The aliens are placed on a black screen and are able to move across the field according to predefined paths. The aliens will flash regularly while moving across the field. After each alien has flashed twice, the alien that the game estimates the player was focussing on will be shot. The level is won if the leader alien is shot using less than the maximum amount of shots allowed by the level.

Training

Before the actual game can be played, the game needs to calibrate the BCI signal, particularly the P300 response. This is done by showing the player a grid of non moving aliens. The game marks one of these aliens as a target and requires the player to focus on it. After all elements have flashed for a total of 16 times (eight times as their virtual row and eight times as their virtual column) a new target is selected. This is repeated for multiple targets (as specified at launch) and allows the game to match up the player's P300 with the flashing of the target so the BCI is properly calibrated.

Main Game

The main game starts after the BCI calibration. In the main game multiple levels can be played. Each of these levels has the same premise: the player has to shoot a target alien in a given amount of attempts by focusing on it. Aliens all flash twice, after which the target is estimated and shot. If the shot is unsuccessful another can be taken until the number of shots specified by the game has been fired.

As the levels progress the aliens start moving in more complex patterns and may appear in different colours. There is only one target alien at any moment, however, ensuring that the player is always able to determine which element to focus on.

Score

The game keeps track of the score of the player. For hitting any non-target alien the player is awarded 250 points. However, the score for hitting the actual target is dependent on the amount of shots required. Hitting it in the first shot results in 16.000 points, but each attempt in which the player misses the target decreases this score by half. So if four shots are required the player is awarded 4000 points for the target plus an additional 750 points for all regular targets that were hit, resulting in a score of 4.750 points.

Controls

The controls are mostly handled through the BCI device, although the player is required to press the spacebar in order to start the main game. Control consists of the flashing of all elements twice (once as their virtual column and once as their virtual row) whereupon the BCI signal is interpreted to find the P300 response. The element linked to the flash that gave the strongest response will be selected by the game.

The responses of the flashes stack up within a level, meaning that after two flashes the element that gave the strongest average response for both flashes will be selected and so on until the target Alien is selected. After a new level starts these values are reset. The target alien will slightly increase in size when flashing to help focusing on it a bit easier.

Artificial Intelligence

The artificial intelligence of the game is limited to preset paths of the aliens. Aliens can move as either a group or as singular entities (essentially a group of one). When moving, aliens take steps towards a point on a path. Aliens can move horizontally or vertically across the grid, but they cannot take diagonal steps. Once one of the aliens in the group reaches the point on the path that is currently being moved towards, the next point on the path is set as the goal. The group movement ensures that if moving to the top of the screen only the top aliens need to reach the destination, whereas moving to the left requires one of the left-most aliens to reach the point and so on. If the aliens reach the final point on the path before all shots have been fired they will simply stop moving. The speed per movement step is dependent on the time, so aliens start moving faster as the time progresses.

Game Elements

In game several elements will appear. Their functionality, behaviour, relations, and attributes will be described below.

Aliens and Distractors

The aliens in Brain Invaders are the most important elements of the game as they fill the majority of the screen during gameplay. Alien elements can be placed anywhere on screen and follow a path as specified by their artificial intelligence. During gameplay all aliens will flash. This is done by virtually storing the aliens in a matrix and getting all the rows and all the columns of this matrix to flash. Only one row or column of aliens can flash at the same time. A randomized time between flashes, which averages around 200 milliseconds through exponential distribution, is calculated for each new flash. After all columns and rows of aliens have flashed, the alien selected through the P300 speller will be shot and explode.

There are multiple versions of the aliens in the game. The three basic aliens are of a greyish colour and function as standard control aliens. These aliens have a colour that is often used for P300 spellers. When the aliens flash they light up in bright white. Besides different sprites there is no difference between the three.

The second type of alien is the target. This big red alien is the main goal of the player. The alien flashes in a cyan colour and is slightly increased in size during flashes. If the target alien is hit, the level is finished successfully.

Finally there are two types of distractor aliens. These aliens have a different colour from the regular aliens in order to make them more noticeable from the peripheral view. The first distractor has the same colour as the target alien, although the sprite differs to allow for easy distinction. Like the target alien it flashes in a cyan (the opposite of red) colour. The second distractor has a blue colour and a yellow (again the opposite) when flashing.

All aliens can be seen in their non-flashing and flashing state in figures A.1 and A.2 respectively.

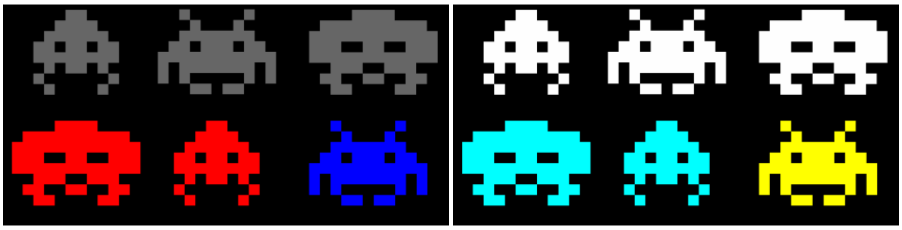

Figure A.1 (left): The aliens in a non-flashed state. From left to right, top to bottom the three basic aliens, the target alien, and two types of distractors. Figure A.2 (right): The aliens in a flashed state.

It should be noted that each alien has two frames which will change every time the aliens move a step on the field. This makes them appear as active elements. Furthermore, before each level starts the target alien is shortly displayed with a red circle around it so the player can easily distinguish it from other aliens, such as the red distractor alien.

Shots

The second element to be shown on the in-game screen is the GUI. One of the major elements in the GUI is a row displaying the amount of shots a player can make. At the bottom of the screen the game shows a row of target images as seen in Figure A.3. Each shot that can be taken by the player corresponds to one of these target images. Initially the target will be coloured yellow, but once a shot has been fired the colour will change to red. The amount of yellow targets at the bottom of the screen, therefore, indicates the amount of shots left. Besides red and yellow, the target can also appear in a grey colour. This indicates that the communications with the BCI device were lost and a random shot was fired.

Figure A.3: Shot indicator. The red colour marks a taken shot, whereas a yellow colour shows a shot can still be taken. A grey colour is also implemented in case communications with the BCI is lost.

Score

The GUI also consists of a score display at the left bottom corner of the screen. This display shows the score as calculated by the game mechanics.

Menu Elements

Outside of the in-game elements there are also some menu screens in Brain Invaders. The most prominent of these is the standard menu, which is shown every time Brain Invaders is booted. This main menu shows the title of the game and a background image to give some context to the game. At the bottom of the screen the text "Press Space to Start" will blink, indicating the player can press space to start playing the game. Pressing escape will close down the game.

Furthermore, the game has two load screens displayed after a level was either finished or lost. In case of the former, the text on the load screen will indicate success and tell the player to prepare for the next level. If the latter, the screen will indicate defeat and instruct the player to focus on the target alien more strongly.

Story

The game stays light on story, as the game only tasks the player with stopping an alien invasion of earth without any further explanation. The aliens prepare multiple waves of their invasion and only taking out their squad leader will result in the assault being deflected.

Game Progression

Having discussed all elements and mechanics of the game, let us consider the average player progression of Brain Invaders.

General Progression

In general, the game plays as follows:

Once the game is booted the main menu is shown. The player presses the "P"-key on the keyboard to start the training – The P is short for practice – of the BCI device. During the training the player focuses on the targets as they appear on screen. Once the training is finished the BCI can be calibrated and the game returns to the main menu.

After the BCI is calibrated the player presses the spacebar and the actual game starts. The first level is loaded and the aliens are placed on screen. The GUI displays a score of 0 and none of the shots have been fired (i.e. all target icons are coloured yellow). The game displays the target alien for two seconds by drawing a red circle around it. After this all aliens may start moving and flashing. A flash lasts for 100 milliseconds and all flashes are separated by an average of 200 milliseconds. Once all rows and columns of aliens have flashed, the game will select the alien to be shot. An explosion is shown and if the shot alien was the target alien the next level will be loaded. If another alien was shot the flash cycle repeats itself either until the target alien was hit or no shots are left. If the latter occurs, the user is shown the screen indicating loss and the level is reloaded. This process repeats itself until all levels have been finished, resulting in the game returning to the main menu. If at any point the player presses the escape-key the main menu will also be shown.

Training

The training consists of a grid of six by six non-moving alien elements. Through a predefined target list one of the elements is assigned the target alien. The user is tasked with focussing on this alien, after which a cycle of multiple flashes across the grid occur. Once all rows and columns have flashed 8 times a new target is selected until the target list is completed. After this is done, the game will return to the main menu automatically and the BCI will be calibrated.

Levels

The game as tested in the experiment contains the following three levels. Note that additional levels can be developed.

In the first level a group of six by six Aliens moves from left to right across the screen. The target alien is placed roughly in the middle of the level. Besides the target there are only regular typed aliens. Level 1 can be seen in Figure A.4.

Level 2 is similar to the first level, where again a group of six by six aliens moves from left to right across the screen. The target is placed near the bottom left corner however and has four distractors, two of each type, placed next to it diagonally. Level 2 can be seen in Figure A.5.

The third and final level is more complicated than the first two. The target alien is placed in the centre, next to three additional red typed distractors. The target and distractors circle around the centre of the screen. Both left and right of the target a group of blue typed distractors is placed. They also circle around each other. The remainder of the grid is filled in with regularly typed aliens. Level 3 can be seen in Figure A.6.

Figure A.4: Level 1

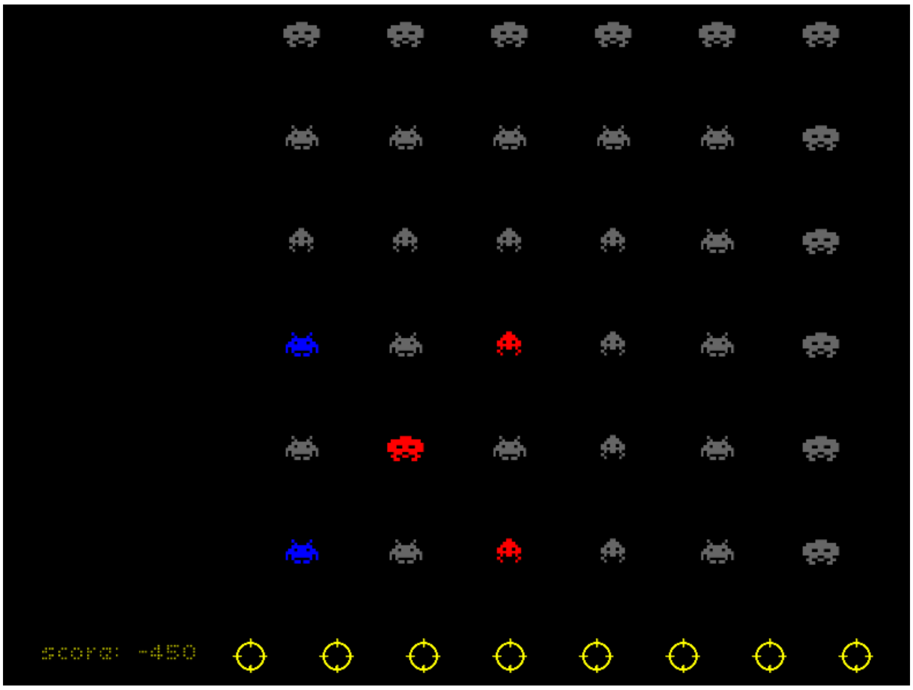

Figure A.5: Level 2

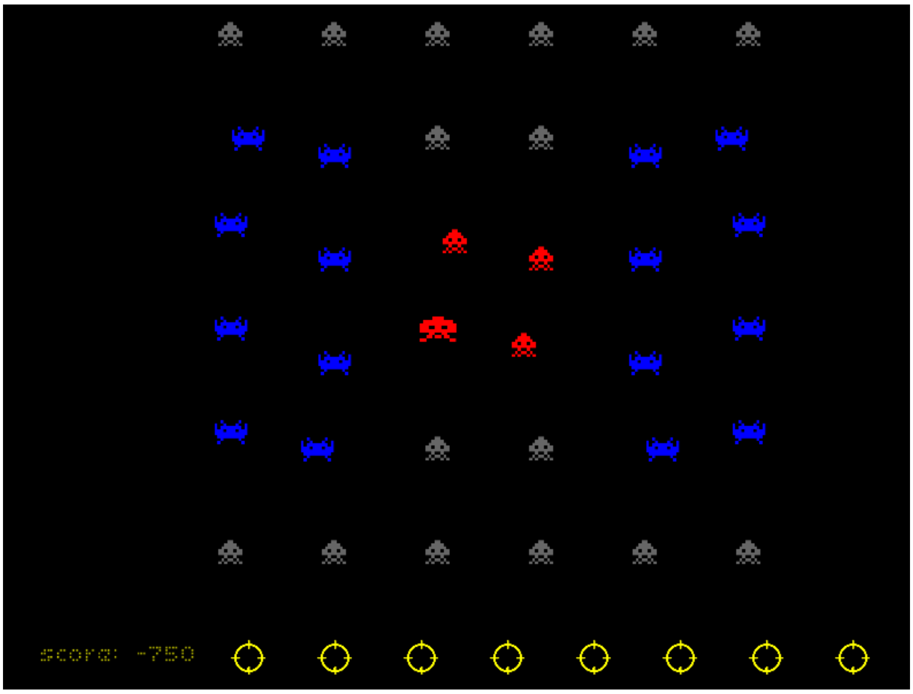

Figure A.6: Level 3

Appendix B

Questionnaire

This Appendix shows the questions that participants of the experiment were asked after they had played the game. The questionnaire was processed by Thesis Tools and as such the formatting of the questions in this Appendix is not how it appeared to the participants. The answers that could be given are placed between brackets.

Age: [Fill in Age]

Gender: [male/female]

Are you to your Awareness Colour-blind?: [No/Yes (red-greed)/Yes (Blue-Yellow)]

Have you ever used a BCI (Brain-Computer Interface) before?: [Yes/No]

Do you play videogames?: [Yes/No]

If yes, how many hours per week do you think you spend gaming?: [hours]

Did you feel it was easy to hit the targets?: [1-7, where 1 is Very Easy and 7 is Very Hard]

Did you feel the different colours influenced the difficulty of hitting the target?: [1-7, where 1 is Much Easier and 7 is Much Harder]

Did you feel the movement of the targets changed the difficulty?: [1-7, where 1 is Much Easier and 7 is Much Harder]

Did the different colours change the immersion of the game?: [1-7, where 1 is Much Less Immersive and 7 is Much More Immersive]

Did the different movements change the immersion of the game?: [1-7, where 1 is Much Less Immersive and 7 is Much More Immersive]

Did the different colours change the way in which you enjoyed the game?: [1-7, where 1 is Enjoyed Less and 7 is Enjoyed More]

Did the different movements change the way in which you enjoyed the game?: [1-7, where 1 is Enjoyed Less and 7 is Enjoyed More]

Did you feel the different colours broke your ability to concentrate on the target? [1-7, where 1 is Not at All and 7 is Very Much]

Did you feel the movement broke your ability to concentrate on the target?: [1-7, where 1 is Not at All and 7 is Very Much]

Which level did you find the most difficult?: [1st/2nd/3rd/All the Same/Other:] [1]

Which level did you like playing the most?: [1st/2nd/3rd/All the Same/Other:] [1]

[1]Note that the participants were not aware of the levels being switched compared to other experiments. Answers have thus been corrected according to the sequence in which levels were encountered.