Hacking as a Playful Strategy for Designing the Artistic and Experimental BCI-VR Game: Ride Your Mind

A project submitted in fulfilment of the requirements for the degree of PhD

Jens Moritz Stober

Diploma of Media Art, University of Arts and Design Karlsruhe, Germany

Diplom der Medienkunst, Hochschule für Gestaltung Karlsruhe

School of Media and Communication

College of Design and Social Context

RMIT University

April 2018

Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the project is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

Jens M. Stober

10 April 2018

ACKNOWLEDGEMENTS

First I would like to thank my primary supervisors Prof. Dr. Steffen P. Walz and Dr. Jussi Holopainen. It has been an honour to be your PhD student. You have done a tremendous job as supervisors and friends. I also would like to thank my supervisor Dr. Stephan Schwingeler. Thank you all for supporting me and helping me realise this hackish, playful, crazy, maniacal, funky, fancy, awesome and gameful artistic research project.

I would like to thank all members and colleagues of the former Games & Experimental Entertainment Laboratory (GEElab) Melbourne and especially the super awesome members, colleagues and friends of GEElab Europe in Karlsruhe, Germany. I would like to thank the team of the Centre for Game Design Research, the School of Media and Communication, the School of Graduate Research and RMIT University.

I would like to thank Victoria Gosling for professional proofreading, as I am not a native English speaker. I would also like to thank Dr. Steffen P. Walz, Dr. Jussi Holopainen, Dr. Stephan Schwingeler, Carola Böhler, Dr. Frieder L. A. Ganz and Prof. Dr. Heiner Mühlmann for your great feedback and comments on my project. Special thanks go out to the TECO research group of the Karlsruhe Institute of Technology (KIT) and the ZKM | Center for Art and Media in Karlsruhe, Germany.

Last but not least, I would like to thank my family. My mother Gisela Gamer-Stober – a born Gamer –, my father Peter Stober – a creative all-rounder –, and my deceased big brother Dr. Kai L. Stober, who introduced me to computers and to the world of computer games. I would also like to thank my beloved Carola, who supported me with love, endless patience and wisdom. And of course thanks to all of my friends who supported me during my PhD.

elorx | Jens M. Stober

TABLE OF CONTENTS

ABSTRACT

Hacking is an ambiguous term. Over the past 50 years, its meaning has been constantly expanded and refined, filtered through several disciplines from divergent fields of application such as, for example, technology, computers, media, art, design, games and more. First used to describe what can be called a playful strategy employed to (creatively) solve a problem (Levy 1986), in public discourse the term hacking now often connotes a form of illicit behaviour in cyberspace. Today, the common perception is that hackers are rule-breakers and system-intruders who seek to do damage or even commit acts of war.

In the 1950s, hackers helped transform computers from military devices into entertainment devices. This context swap (military to entertainment) forms the cradle of digital games and functions as the starting point of my research, which will seek to trace the history of hacking as a design strategy and to discover artistic strategies contained within the act of hacking itself. Hacking is, in fact, directly and historically related to computers and particularly to digital games. The first hacks were algorithmic visualisations and interactive programs, specifically interactive games; Spacewar! (1962) is the most famous example.

To understand hacking as a strategy for designing games, I will explore historical and artistic approaches that have been used by hackers. In the late 1950s and early 1960s, hackers at the Massachusetts Institute of Technology (MIT) – more specifically, the students of the Tech Model Railroad Club (TMRC) – were introduced to MIT's early digital computing machines. The members of TMRC launched a creative examination of this emerging computing technology; they were equipped with neither instructions nor experience, but they were driven by their goal of using the computer to create "art and beauty" (Levy 1986, p.31). Hackers do not have to be passionate computer users. As Eric S. Raymond (2013) asserts in *The Jargon File*, anyone can become a hacker. Hacking combines several creative strategies that are related to art, design and other creative disciplines.

Like a hacker, I will create my own tools for conducting the proposed research, especially methodological ones. My basic methodological approach is to look at hacking in a chronological and historical way, in order to identify recurring design principles that are representative of hacking understood as a form of design practice. Many other fields intersect with the history of hacking, such as, for example, the history of computers and the history of computer games. Each of these three fields is also linked to fields such as philology, art history, the history of science, telecommunications engineering, economics and communication studies. The result is an as-of-yet undefined field of enquiry. This multi-dimensional context in which hacking exists poses a challenge: it is tempting to take detours in all manner of fascinating thematic and historical directions. To avoid straying from my topic, I will concentrate on the origins of hacking by investigating historical records like Steven Levy's (1986) and Raymond's (2013) and by comparing these to the broader context of hacking in the spirit of, for example, Claus Pias (2002b; 2002a; 2013) and Stephan Schwingeler (2012; 2014) and others.

I will then synthesise the design elements I have identified and use them to outline a strategy for designing artistic games that will serve as the theoretical backbone for my own work as a media artist and, hopefully, for others' work as well. I will combine the main strategic elements with an artistic approach into a game, which will constitute the practical element of this research. The outcome is based on the concept of an interactive, hackish neurofeedback real-time virtual-reality game art installation, or in brief, an artistic BCI-VR Game, titled Ride Your Mind (RYM).

In the spirit of the early hackers, my research project Ride Your Mind (RYM) playfully explores, examines and hacks the possibilities of an emerging consumer technology, Brain-Computer Interfacing (BCI), from the perspective of a game artist and a game designer who is seeking to potentially create a BCI-VR Game.

Initially, Brain-Computer Interfacing (BCI) games (games controlled/influenced by BCI) were used in medical and BCI research to successfully treat diseases such as ADHD (Nijholt et al. 2009, p.88). In the last years, hardware manufacturers such as Emotiv or Neurosky have begun producing consumer BCI technology, and the focus group for BCI has shifted to healthy users (Nijholt et al. 2008; Nijholt et al. 2009; Tan & Nijholt 2010; Loup-Escande et al. 2015; Martišius & Damaševičius 2016; Kerous et al. 2017; Chavarriaga et al. 2017; Vourvopoulos et al. 2017).

The concept of RYM (Stober 2013) was developed in 2012 and presented in 2013 at the FROG Games Conference (Mitgutsch et al. 2013). RYM integrates various methods from academic and artistic disciplines, such as experimental and artistic game design, artistic practice, game design research, HCI and BCI research, computer science and neuroscience. Therefore, the approach in this PhD by project is quintessentially transdisciplinary. My work primarily links art and science as creative and artistic research and as an approach of research-through-design (Zimmerman et al. 2007; Zimmerman et al. 2010; Batty & Berry 2015; Gaver 2012; Ylirisku et al. 2016; Barab & Squire 2004; Bateson & Martin 2013; Hjelm 2003; Klein 2010; Balkema & Slager 2004; Mäkelä et al. 2011; Busch 2009; Hellström 2010; Lesage 2009; Ladd 1979; Borgdorff 2007).

In summary, the aim of RYM as a research project is to (1) expand traditional digital game design with new knowledge on how to design future BCI games with more sophisticated consumer BCI technology; and (2) to test the possibility of designing an experimental BCI-VR game with existing consumer grade BCI hardware based on hacking as a creative and artistic design strategy.

Research with respect to gaming and playful characteristics has previously been done in cognitive sciences and in particular human-centred computing; however, research from a game design point of view is limited. Thus far there are no available guidelines or strategies for BCI game design from a game design research perspective. Apart from its merit as a research-practical exercise in hacking, the work on RYM has revealed current and future possibilities and issues related to consumer BCI technology in the gaming context, and as such contributes knowledge to the chosen field of application. Since there is practically no material on BCI game design, I hope that the insights provided by this game art and game design-centred creative research project will be game-changing for an arising research field within game design research (Gürkök et al. 2015; Loup-Escande et al. 2015; Bos et al. 2010; Nijholt 2016).

This exegesis is a resubmission of the original version from October 2016. The following documentation has been restructured and updated, incorporating recent research material.

1 INTRODUCTION

This doctoral exegesis is written from the perspective of a trained and practising media artist with a strong interest in playfully combining and hacking emerging technologies such as Brain-Computer Interfacing (BCI) and Virtual Reality (VR) to explore future use application. Based on this interest, this work presents and discusses an artistic project-based PhD aimed at examining state-of-the-art technology through the design and creation of a novel BCI-VR game called Ride Your Mind (RYM). The original concept of the game RYM was published in 2013 (Stober 2013) as part of the FROG Games Conference in 2013 (Mitgutsch et al. 2013).

Diverse publications on game art, game design, media art history, media history and hacking (Consalvo 2007; Flanagan 2010; Flanagan 2009; Fuchs 2011; McGonigal 2011; Dragona 2010; Bateson & Martin 2013; Schwingeler 2014; Schwingeler 2012; Levy 1986; Pias 2013; Pias 2002a; Pias 2002b; Kwastek 2013; Bianchini et al. 2016; Lankoski & Holopainen 2017; Waern & Back 2015; Avellino et al. 2003; Linderoth & Mortensen 2015; Huizinga 1949; Salter 2010; Walz & Deterding 2015; Sharp 2015) implicitly indicate a relationship of hacking to play, playfulness, digital games and digital media art. Building on these foundations, in the present work I will explicitly research hacking as a playful strategy for designing artistic games. Furthermore, I will discuss the work of the original hackers as originators of digital media art and digital games.

In detail, in the present exegesis, a documentation of my practice-based PhD, I will:

1. examine the history of the term hacking in relation to digital media art and game design;
2. elaborate and define design elements of hacking that can be used as creative and playful strategies for designing and/or researching games;
3. apply the resulting design strategies of hacking to develop a concept for an experimental and artistic BCI-VR Game[1] called Ride Your Mind (RYM);
4. benchmark consumer BCI gaming hardware while prototyping experimental and artistic BCI games;
5. describe and reflect on the experimental and artistic game design process of RYM;
6. investigate BCI game design and future possibilities from the perspective of a game artist and hacker;
7. present the outcomes and issues of working with emerging BCI gaming technology while operating on the edge of prospective game design research.

In chapter 1 (Introduction) the research context and design including my personal research motivation will be outlined. The second chapter (Methodology Review) describes the theoretical, academic and artistic backbone of this research project, including a historical examination of hacking as a playful strategy for designing artistic games. Chapter 3 (Literature Review) provides an overview of related research, BCI games and other examples. Then, in chapter 4 (Ride Your Mind) the concept of RYM and the application of the design strategies identified in chapter 2 will be described. Chapter 5 (Documentation) provides and overview and detailed examination of the creative design process of RYM and the playful exploration of BCI technology. In chapter 6 (Discussion) the findings of chapter 5 will be outlined and discussed. Chapter 7 (Reflection) classifies and reflects on the findings in the broader research context of game design, game art and media art. In chapter 8 (Research Outcome) the results of the artistic research project Ride Your Mind will be listed and explained. The last chapter (Conclusion) provides a summary of this PhD by project.

[1] A BCI-VR game uses a combination of BCI gaming and virtual reality technology to control, influence and display the game.

Hacking is an ambiguous term and therefore needs further specification. At the end of the 1950s and the beginning 1960s members the Tech Model Railway Club (TMRC) at the Massachusetts Institute of Technology (MIT) playfully explored digital computing hardware provided by the military. These hackers created playful and artistic software and described their activities as “hacking” (Levy 1986, p.10). I identified four strategic design elements used in hacking: *addition*, *appropriation*, *expansion* and *disruption*. These elements have subsequently been used to design the artistic and experimental research game RYM. The game combines neurofeedback with virtual reality (VR) and is consequently labelled as a BCI-VR game. The game makes use of emerging consumer grade Brain-Computer Interfacing (BCI) technology, namely an Emotiv EPOC EEG (Electroencephalogram) Headset, often referred to as a BCI-Headset in this work. The BCI-Headset is combined with an Oculus Rift Head Mounted Display (HMD). The methodology used to create the concept of the experimental BCI-VR game, as well as the methodology to design the game, are related to the strategic design elements used in hacking. The elements were carefully extracted from literature on early hackers at the Massachusetts Institute of Technology (MIT) and their activities in the late 1950s (Stober et al. 2013).

In the 1970s the first Brain-Computer Interface was developed (Vidal 1977). Research then focused on BCIs as tools used in assisting and augmenting technology for handicapped people. During the last five years BCI technology has become increasingly entertainment and consumer oriented. Companies such as Emotiv and Neurosky began to offer low cost consumer EEG headsets (Bonaci et al. 2015). This shift to healthy users, in particular to gamers, stimulates the development of new BCI technologies and supports BCI research (Nijholt et al. 2008; Nijholt et al. 2009; Tan & Nijholt 2010; Loup-Escande et al. 2015; Martišius & Damaševičius 2016; Kerous et al. 2017; Chavarriaga et al. 2017; Vourvopoulos et al. 2017).

The aim of Ride Your Mind as an artistic research project is to benchmark the design elements of hacking in order to create an artistic and experimental BCI-VR game. The research project highlights the possibilities of designing a BCI-VR game with already existing consumer BCI hardware. This approach also includes opportunities as well as issues related to BCI technology for future gaming applications. Exploring BCI technology in combination with game design has revealed that there is virtually no research material on BCI games that is formulated by the game design research discipline (Björk & Holopainen 2005; Björk & Holopainen 2004; Björk 2015; Lankoski & Holopainen 2017). Loup-Escande et al. (2015) describe a framework for user-centred BCI videogame design, mainly focussing on the problem of how to evaluate BCI games or prototypes of this genre with ergonomic criteria from a BCI research perspective. As an artistic and experimental BCI game design prototype, Ride Your Mind exists in a world beyond these criteria. As an art project, RYM does not follow ergonomic criteria and was not intended to do so. The proposed framework is useful as a general guideline for designing BCI games. From a game design perspective, there is a lack of detailed information on how to design a BCI game, e.g. which BCI paradigms can be used and how these can be used to influence the gameplay or the game environment. Thus far, there are neither guidelines nor strategies for BCI game design from a game design research perspective. The following discourse makes a modest attempt at filling this research gap. From a game art and game design perspective, the insights provided by the research project RYM can be (BCI) game-changing and highly relevant for a potentially arising research field within game design research.

The work at hand documents the artistic research project Ride Your Mind (RYM) and describes, illustrates and elucidates the different stages of the project (supported by video material that is linked in the footnotes). The findings are discussed, summarised and examined in a broader context, for the latter specifically see chapter 7.

It should be noted that the research by project is intended as an artistic and playful experiment. This does not, however, preclude the possibility that it could be expanded for use in other contexts.

1.1 RESEARCH CONTEXT

Although hacking has occurred in many different technological contexts since the beginning of the twentieth century (Levy 1986), it is particularly strongly connected to the origin and development of digital games and digital media art. The research of this PhD utilises hacking as the starting point and foundation for further investigation of adjacent research fields such as digital games, game design, game art and media art, ultimately to examine and research the emerging discipline of BCI game design. The following figure (1) demonstrates how hacking is used to link the interdisciplinary research fields and how the following research is situated.

Figure 1 - Research Scope

1.1.1 PERSONAL BACKGROUND

All throughout my childhood, my education and my years as a media artist working with games as a toolset, I have considered myself – romantically, perhaps – a hacker.

Computers have fascinated me my entire life. My father and my late brother introduced me very early on to computer technology and, of course, computer games. As a four-year-old boy, I played Flight Simulator 3.0 (Microsoft 1988). My brother introduced me to somewhat more competitive and action-orientated games such as Doom (GT Interactive 1993), but also to strategical games such as the Command & Conquer Series (Virgin Interactive 1995) and point and click adventure games such as The Secret of Monkey Island (Lucasfilm Games 1990) or Sam and Max Hit The Road (LucasArts 1993). I received my first computer at the age of six, an i386. When MS-DOS was replaced by MS-Windows, a whole new world of possibilities opened up to me; I went from a console-based operating system on which I could start games and copy files, to a graphic interface with which I could control the computer.

A few years later, at the age of 11, I began modifying files of the real-time strategy game Command & Conquer: Red Alert (Virgin Interactive 1996), creating new units and reducing their cost and building times. When first-person shooter games appeared, I was immediately fascinated by Unreal Tournament (GT Interactive 1999), which included a level editor to create three-dimensional worlds. One of the first playable levels I created in the editor was a map based on the swimming pool of my former school. On the one hand, it was a singleplayer scenario in which the player had to reclaim a swimming pool infiltrated by aliens; on the other, it was a multiplayer science fiction playspace where my friends and I could compete in online and LAN battles. I began to see games in the same way I saw my LEGO bricks from the material world: small individual pieces that could be modified to create something larger and unified. Ever since, I have used games as a creative toolset for my own artistic work in the field of digital media art.

Almost immediately I began to think of myself as a hacker. During my studies as a media artist I began to work artistically with Half-Life 2: Deathmatch (Valve Corporation 2004) and the Source Engine (Valve Corporation 2004), and created an artistic serious game modification about the Inner-German border situation: 1378(km) (Stober 2010) (Anděl & Zimbardo 2011; Belting et al. 2013; Serexhe & Schwingeler 2013; Linderoth & Mortensen 2015; Park et al. 2017; Grabowski & Cermak-Sassenrath 2018). Furthermore, I worked with CryEngine 3 (Crytek 2011) from the Crysis 2 game (Electronic Arts 2011) and developed the game art installation shade (Stober 2012) that combines stereoscopic 3D vision on a cave-like multi-projector setup with stage lighting illuminating the physical room (Figure 2). Over the years, I've become more and more interested in how the term hacking and the many nuances of its meaning have evolved, how artists practise hacking and, most importantly, how hacking relates – deeply, as I've discovered – to the history of computer games and the way they were and continue to be designed. This, in turn, bears directly on the question of how I myself may eventually "hack games" as an art practice.

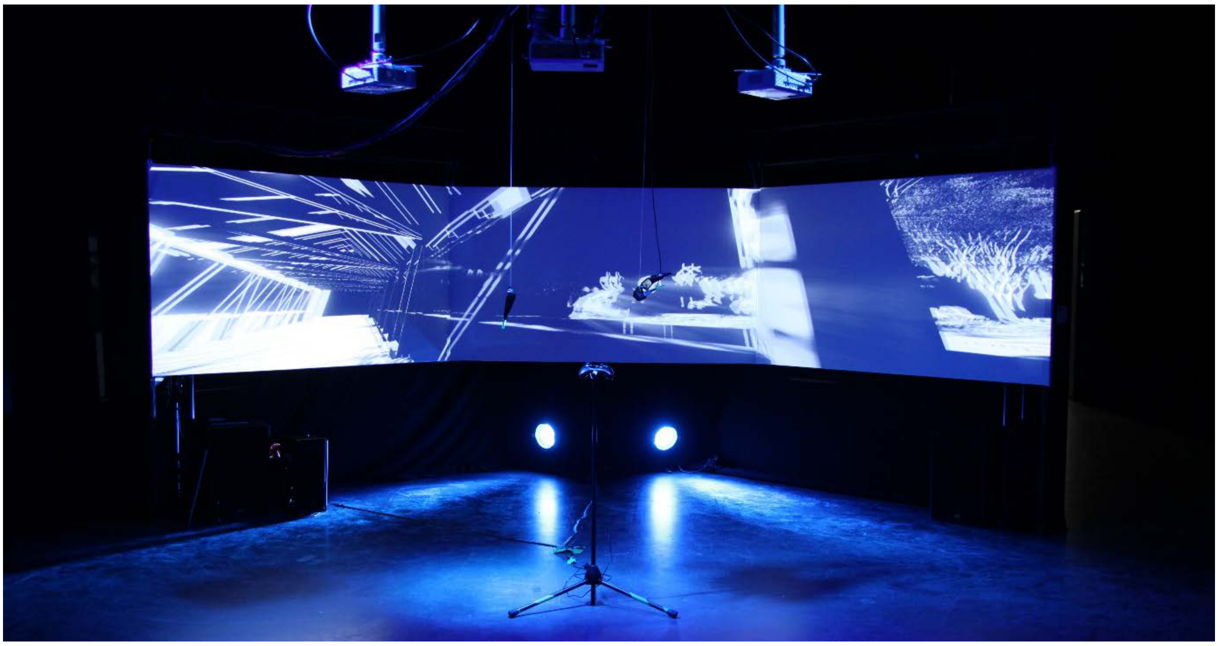

Figure 2 - Game Art Installation: shade (Stober 2012)

This interest of mine coincides with a gap that exists in the research and practice of game design, both of which have paid insufficient attention to the way in which hacking and designing games (especially designing them with an artistic intention) are related.

During my studies and first steps as a professional media/game artist at the University of Arts and Design in Karlsruhe, I came into contact with neuroscience and EEG technology from the medical world. The Neurolabor HfG Karlsruhe (cf. Pezer 2017) was one of the first artistic research institutions to carry out neuroscientific experiments related to architecture in cooperation with the TRACE research group (Oppenheim et al. 2010; Oppenheim et al. 2009; Mecklinger et al. 2014; Pezer 2017).

Years after playing Sam and Max Hit The Road (LucasArts 1993), I realised at the end of this PhD research that the game includes a device similar to the concept of the BCI-VR Helmet that was developed later (see chapter 5). At one level of the game, the character Sam (the dog) enters a virtual reality environment linked to a brain that controls the security system of the villain's home. The following figure (3), a screenshot from the game, shows this crucial situation, which might have influenced me subconsciously as a boy and later inspired me to create the "hackish", artistic, experimental and gameful research project Ride Your Mind.

Figure 3 - Sam & Max: Hit The Road (LucasArts 1993) showing a Virtual Reality Brain-Computer Interface

1.1.2 RESEARCH MOTIVATION

During the initial period of my PhD journey, I worked on the historical examination of hacking and its relation to digital media art and digital games. I realised that digital media art and digital games are historically connected through hacking. Based on the historical research into hacking I found hints that both disciplines (media art and game design) spring from the creative well of hackers in the late 1950s (Levy 1986). This finding based on my theoretical work on hacking formed a crucial insight for my personal practice as a media and game artist and of course the work on my emerging PhD project Ride Your Mind (RYM), an artistic and experimental BCI-VR game.

As mentioned in the introduction, many researchers implicitly refer to hackers and the playful use of technology. Digital games are described as an "area of early adoption" that enable technology to be accepted by a broader community (Nijholt et al. 2008; Nijholt et al. 2009; Tan & Nijholt 2010; Loup-Escande et al. 2015; Martišius & Damaševičius 2016; Kerous et al. 2017; Chavarriaga et al. 2017; Vourvopoulos et al. 2017). BCI games could be called an emerging genre of digital and playful entertainment. But in spite of my extensive research, I have not been able to find any available guidelines on how to design them, nor any reflections on the design possibilities and strategies from a game design perspective. As Tan & Nijholt (2010, p.150) state, "there is still a big gap between these research games and games developed by the games industry at this time." From the perspective of BCI research, Loup-Escande et al. (2015) elaborated a framework for user-centred BCI game design.

I hypothesise that the history of hacking and the early work of hackers contain further knowledge that can be helpful in describing a playful interaction with technology and the creation of playful, gameful and/or artful digital content, and that the playful interaction with technology can also lead to hardware and software innovation in diverse application fields. This is to say that my theoretical work on hacking and the present exegesis describing the application of the playful design strategies extracted from the history of hacking merely form a starting point for further research.

1.1.3 RESEARCH SCOPE

This work focuses on hacking as a playful and creative strategy to solve design problems. During the research-through-design process of the proposed project Ride Your Mind I faced several challenges, which will be discussed in later sections of this document. Throughout this exegesis, I apply hacking to research BCI gaming technology in an artistic and experimental manner. Methodologically, hacking serves as the central theme of this exegesis. Employing hacking as a creative practice I created a playful prototype of the BCI-VR game Ride Your Mind, for which I hacked consumer BCI technology from a game design and game & media art perspective. As such, the academic fields of Human-Computer Interaction (HCI), Brain-Computer Interfacing (BCI) and neuroscience will be introduced. However, these broad research fields will not be discussed in detail, as this would exceed the research scope of this artistic PhD by project. An introduction into these research fields will be given from my personal perspective as a practising media artist.

1.1.4 RESEARCH QUESTIONS

In keeping with the scope and objectives of the proposed research, the following questions will serve as general guidelines:

1. What design methods and/or elements can be methodically traced and extracted from a semantic, historical and media-archaeological examination of hacking and how can these unlock artistic and/or creative potential?

2. How can these design methods and/or elements be strategically applied to the artistic and experimental PhD project Ride Your Mind (RYM)?

3. What issues and discoveries emerge from the attempt to design the artistic and experimental BCI-VR game Ride Your Mind with consumer grade BCI gaming technology from the perspective as a game artist, game designer and hacker?

1.2 RESEARCH DESIGN AND METHODOLOGY

The research design of this PhD by project combines three different academic perspectives, which are briefly explained in the following section.

1.2.1 HISTORICAL EXAMINATION

At the onset of this PhD the precise research topic and project were not yet defined. I started out with theoretical work on the history of hacking, searching for artistic and creative strategies that I could use to describe my own artistic practice as a media and game artist. The historical examination and media archaeology of design elements and/or methods of hacking form the theoretical origin and backbone of this PhD. From this historical research perspective, I proceeded to extract and distil strategic design elements used in hacking that are directly related to media art and game design. These elements will be described in the methodology review (chapter 2). In total four elements have been identified: addition, appropriation, expansion and disruption.

1.2.2 FROM RESEARCH-THROUGH-DESIGN …

In HCI – Human-Computer Interaction – a common research approach is research-through-design, as described by Zimmerman et al. (Zimmerman et al. 2010; Zimmerman et al. 2007). This approach "employs methods and processes from design practice as a legitimate method of inquiry" (Zimmerman et al. 2010, p.310), and it serves as the methodological backbone of my project-based PhD, in the sense that my design research activity is carried out with the following mindset: "the process of iteratively designing artifacts [sic] as a creative way of investigation what a potential future might be" (Zimmerman et al. 2010, p.313). By playfully examining and hacking consumer grade BCI technology, I investigated how the BCI-VR game Ride Your Mind could be designed and which gameplay features a BCI game can include. As such I employed the creative process as a tool to produce new insights and to carry out research that itself can be or become a piece of art – the following quote illustrates this notion: "The artworld appears to have evolved into a field of possibilities, of exchange of ideas and comparison of outcomes, in which different modes of perception, thinking, and making have a chance to be recognised for their unique potential" (Mäkelä et al. 2011, p.3). Furthermore, in their paper "Constellations and Connections: the Playful Space of the Creative Practice Research Degree", Batty and Berry (2015) outline how creative research can lead to new findings and contribute to research. They argue that "research candidates working in this space move fluidly between thinking and making, allowing their creative practice to become informed and innovative. They draw on a community of practice – of thinkers and makers – to make connections that form constellations in order to extend and expand what they would usually do. Their practice thus becomes their methodology in an environment that is responsive to new concepts and customs" (Batty & Berry 2015, p.1).

1.2.3 ... TO PRACTICE-LED RESEARCH ...

The research-through-design approach allows one to start a creative design process that examines a given research paradigm, particularly in HCI (Zimmerman et al. 2007; Zimmerman et al. 2010). The classification and definition of the strategic design elements that hacking entails, allowed me to use these elements to create a concept for my PhD project. I started with a research-through-design approach by creating the concept of Ride Your Mind (RYM). Thus, I changed my research perspective to practice-led research. The entire process is illustrated in figure 4, with the practice-led research perspective marked in green. Applying the elements of hacking to the concept of RYM also included the integration of knowledge derived from other research fields such as neuroscience, Human-Computer Interaction (HCI) and Brain-Computer Interfaces (BCI). As RYM is a BCI-VR game I also benchmarked existing BCI games as part of this PhD. An overview of the examined games and a discussion on the term BCI gaming can be found in the section on related research and games (3.4).

1.2.4 ... TO RESEARCH-LED PRACTICE

Whereas the practice-led research perspective helped me to create the concept of the BCI-VR game RYM and apply the strategic design elements of hacking, I adopted a research-led perspective to finally create Ride Your Mind. The creation of artistic prototypes of the RYM concept entails a research-led practice perspective within the research-through-design approach. Another shift in the perspective of the research design is based on the historical examination of hacking and the application of its strategic elements from a practice-led research perspective. The creation of playable BCI game and BCI-VR game prototypes forms an artistic research approach of the final phase of the RYM concept. These three academic perspectives are illustrated in its entirety in the following figure (4).

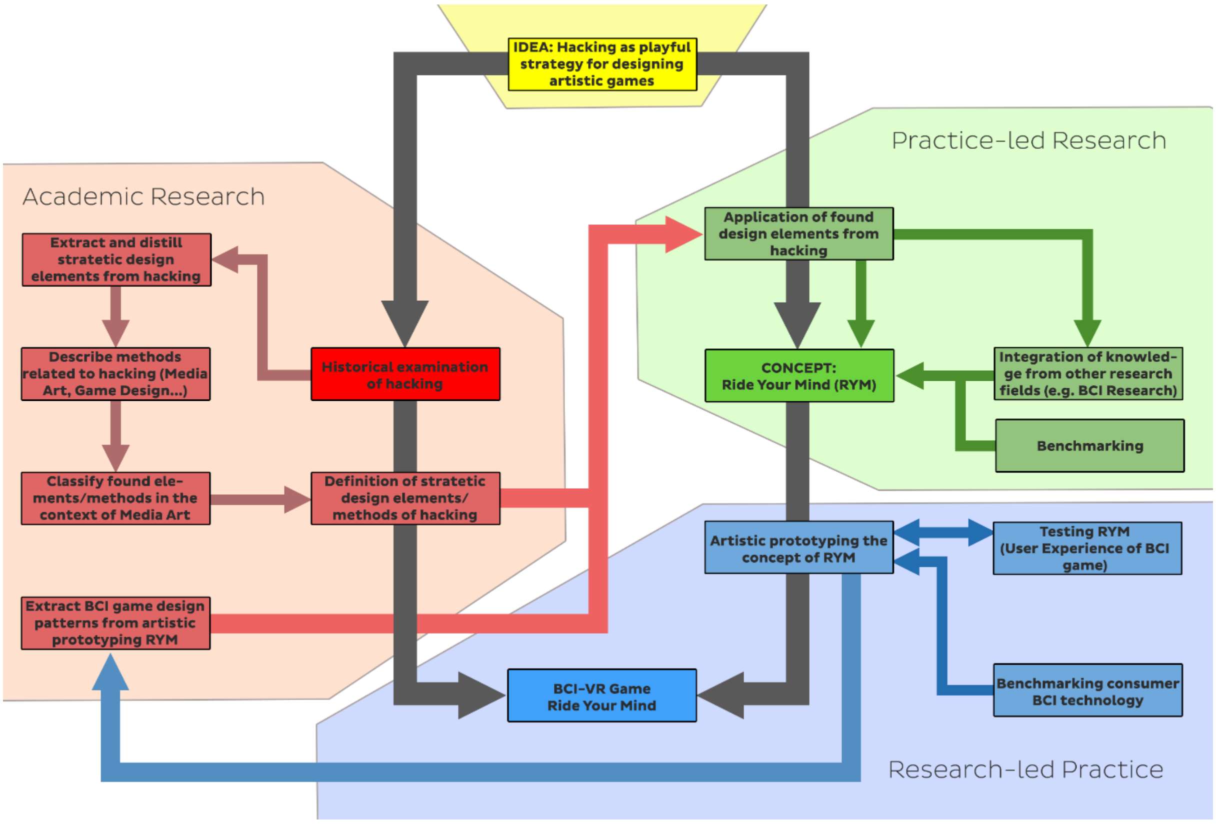

Figure 4 - Research Design

1.2.5 ALTERNATING BETWEEN METHODOLOGIES

After having created BCI game prototypes and experimenting with the hardware and the tools provided, I realised that there is a gap in game design research. Notably, the existing and constantly updated catalogue of Patterns in Game Design (Björk & Holopainen 2005; Björk & Holopainen 2004; Björk 2015) does not yet include a section of BCI game design patterns. The design possibilities of BCI games are extensive compared to traditional digital game design. The use of BCI technology opens up a new layer of interaction possibilities within digital games.

There is a gap in game design research concerning the question how to design BCI games. This issue led me to switch from practice-led research to research-led practice and back, alternating between project-based work on BCI games and academic-based work on the extraction and definition of potential BCI game design patterns. I used this mixed methodological approach to create an academic foundation for BCI game design in order to document my creative prototyping process and to approach the realisation of the concept of Ride Your Mind. The advantage of this approach is that academic research and creative practice work hand in hand. A disadvantage, however, is the large amount of time taken up by switching back and forth between these different methodological approaches. Nevertheless, such a transdisciplinary way of working and thinking is required if not fundamental.

The research gap turned out to have wider implications than was initially expected. Further prototypes and experiments with BCI hardware and software yielded further potential BCI game design patterns. However, the development of further BCI game design patterns and strategies lay outside the scope of this PhD by project. Therefore, only the preliminary stage of the pattern analysis has been outlined in this document. Nevertheless, the knowledge acquired on BCI games essentially supports the design of the BCI-VR game RYM.

1.3 CONCLUSION

Because the proposed project is practice-oriented and intended to serve as a theoretical foundation for my own artistic work, I will apply the four design methods and elements of hacking (addition, appropriation, expansion and disruption) that I extracted from the history of hacking (discussed in detail in chapter 2) to a concept called Ride Your Mind (RYM). In the following pages, I will explain the design-driven research process of RYM. The research-through-design approach that I used for the artistic research project RYM is a proof of concept of hacking (based on the historically extracted strategic design elements) as a playful design strategy for designing an artistic game to create new insights and test emerging consumer grade BCI technology for gaming scenarios. Through hacking, a playful exploration of the BCI technology and its gameful and artistic application, the research project RYM humbly tries to shed light on gaps in game design research with reference to BCI games.

The following figure (5) summarises and illustrates the methodological approach of the research project and how the theoretical and practical part of this PhD is linked through hacking.

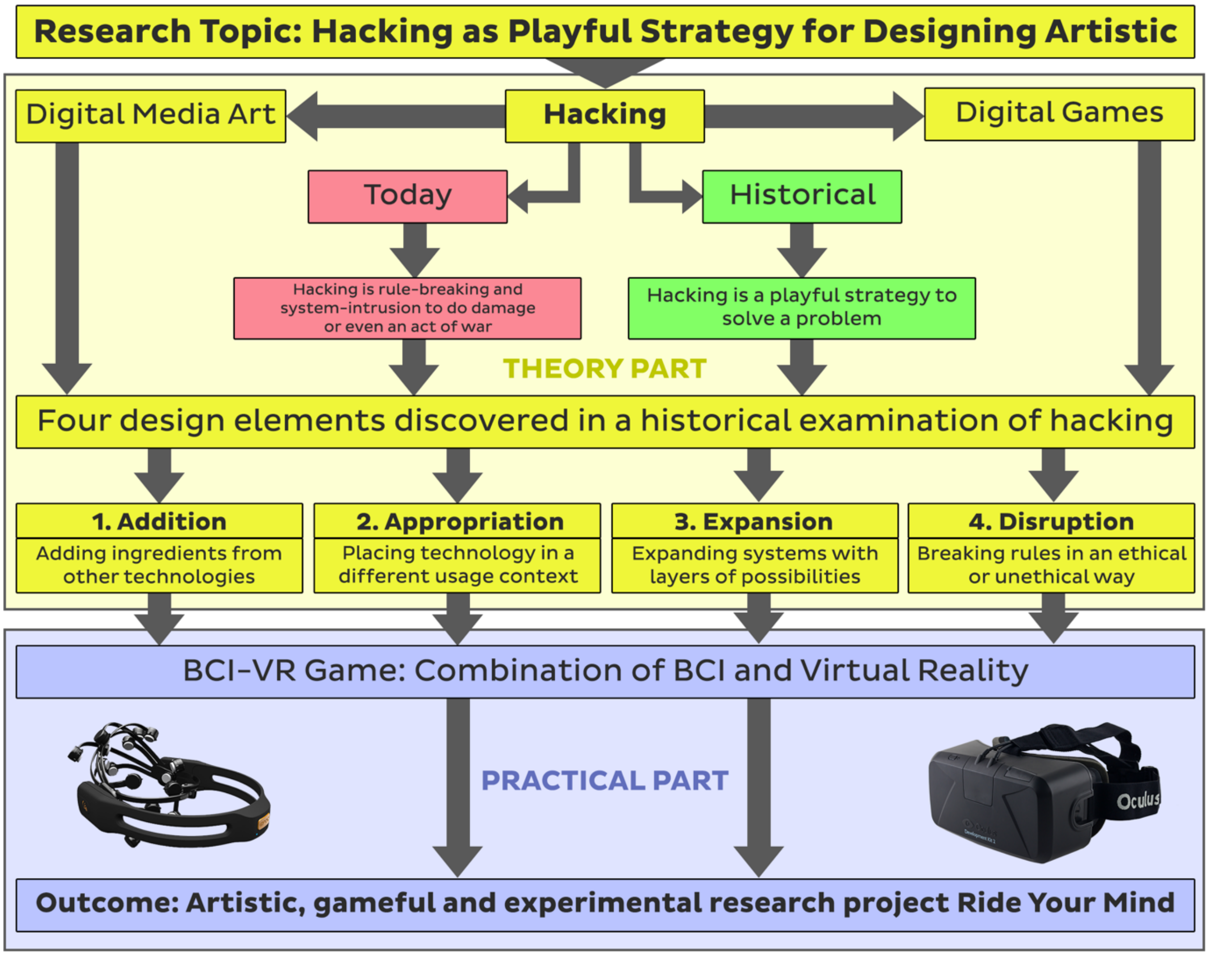

Figure 5 - Overview of the methodological approach through hacking

2 METHODOLOGY REVIEW

At the start of my PhD journey, I began to rethink my former artistic work as a media artist and to search for a coherent theme that connects my various media art and game art pieces. This search turned out to be successful. The key theme I found is hacking, albeit not in the present-day sense of an illicit or destructive act (cf. Mitnick 2012; cf. Perlroth et al. 2017). Early hackers from the 1950s employed hacking as a playful strategy to solve a problem. At that time, they used military technology, computers, to create the first creative digital content such as algorithmic visualisations and playful interactive programs (Levy 1986). To my understanding, hackers originated the first digital media art and digital games while playfully exploring military computing technology which they recontextualised into entertainment systems.

The present work is based on a long paper on “Hacking as a Playful Strategy for Designing Artistic Games” (Stober et al. 2013). The paper was presented at the Future and Reality of Games (FROG) Conference 2013 in Vienna, Austria. It can be found as a single document in the appendix to this exegesis. In the following section I will explain the historical extraction process by which I identified the strategic design elements of hacking. Diverse publications on game art, game design, media art history, media history and hacking (Consalvo 2007; Flanagan 2010; Flanagan 2009; Fuchs 2011; McGonigal 2011; Dragona 2010; Bateson & Martin 2013; Schwingeler 2014; Schwingeler 2012; Levy 1986; Pias 2013; Pias 2002a; Pias 2002b; Kwastek 2013; Bianchini et al. 2016; Lankoski & Holopainen 2017; Waern & Back 2015; Avellino et al. 2003; Linderoth & Mortensen 2015; Huizinga 1949; Salter 2010; Walz & Deterding 2015; Sharp 2015) implicitly indicate a relationship between hacking and play, playfulness, digital games and digital media art. Building on these foundations, in the following I will explicitly research hacking as a playful strategy for designing artistic games.

2.1 INTRODUCTION

Although hacking has occurred in many different technological contexts since the beginning of the twentieth century (Levy 1986), it is particularly strongly connected with the origin and development of digital games. In the late 1950s and early 1960s, the first hackers from the Tech Model Railway Club (TMRC) at the Massachusetts Institute of Technology (MIT) created playful programs by carefully examining the then-upcoming digital computing hardware. In addition to software fundamentals such as compilers and debuggers, these pioneers also developed the first computer games. They used the same term to describe all of their activities: “hacking” (Levy 1986, p.10). Although they worked within tight hardware constraints, these researchers approached the development of games with a playful disposition, a “wild pleasure” (Levy 1986, p.10).

Approaches to researching hacking can be derived from, for example, Pias (2002a), who researches computer games by exploring the history of computers and delving into closely associated fields such as philology, art history, the history of science, communication engineering, economics and communication studies. Together these fields create an as yet undefined space in which hacking exists. Pias (2002a) and others have argued that computers and games share deep structural similarities – so much so that the ongoing computerisation of everyday life by definition implies an attendant “ludofication of society” (Walz 2013). As the literature demonstrates, the idea of *hacking as a historically rooted strategy for systematically designing games* has not yet been explicitly discussed in the research, nor have the ways in which we can learn strategies to create new games or achieve certain artistic goals from hacking.

Hacking, after all, is an ambiguous term and thus also an ambiguous research subject. Consider *The Jargon File*, a compendium of hacker slang that sheds light on the many aspects of hacking (Raymond 2013). The sheer width of approaches to and views of hacking is a reminder of the varying rhetorics of "play" and thus the inherent ambiguity of play, as identified and discussed extensively by Sutton-Smith (2001).

One thing we can state for certain: the understanding of the term hacking varies from discipline to discipline and field to field. But whatever its specific definition, hacking is involved in nearly all areas of our daily life thanks to the ubiquity of modern computing. Hacking as a design strategy can be found in several creative disciplines, including art, architecture and product design (Schwingeler 2012; Schwingeler 2014; Schmidt 2011; Ikeahackers 2013). Its precise definition, however, depends on both the discipline by which it is adopted and the ends it is intended to serve; "one might be an astronomy hacker, for example" (Raymond 2013).

Hacking, as briefly outlined above, also lies at the heart of digital games. Hacking culture has always been closely related to game design. This research will thus serve as an addition to existing game design research and help explicate the important role hacking has played and will continue to play in the evolution of digital games. The design strategies extracted from hacking will help reconnect current game design to its hacking roots.

2.2 HACKING AS RESEARCH-THROUGH-DESIGN APPROACH

Stober et al. (2013) discuss hacking as a playful design strategy for designing artistic games. In late 2015 Goddard and Cercos (2015) examined playful hacking within a research-through-design context. They discuss playful hacking "as a constructive process of play situated within research-through-design" (Goddard and Ceros 2015, p. 1) and highlight playful hacking as "an ultimate particular design process; it is not the way to hack, but a way to hack within research" (Goddard and Ceros 2015, p. 1). What they argue is that hacking is a playful activity that leads to new research findings. They put this theory into practice by adopting various methods of hacking[2] to investigate research problems and then posit the playfully acquired outcomes as research contributions. In other words: they use hacking, in the historical sense of the word, as an artistic and playful research-through-design approach. This approach combines several creative strategies to investigate new design concepts aimed at finding and identifying possible BCI game design strategies.

2.2.1 ARTISTIC RESEARCH

Artistic research is strongly related to research-through-design. The term "artistic research" was coined in 1979 by Ladd (1979) in the article *Artistic Research Tools for Scientific Minds*. A very useful overview of the various forms and perspectives of artistic research can be found in *The Routledge Companion to Research in the Arts*. Balkema & Slager's *Artistic Research* (2004) features several papers from a symposium on artistic research. In *The Conflict of the Faculties. Perspectives on Artistic Research and Academia*, Henk Borgdorff (2012) outlines the ongoing discussion between the traditional research perspective and the artistic research perspective. In *Aesthetics of Interaction in Digital Art* by Kwastek (2013) and *Practicable: From Participation to Interaction in Contemporary Art* by Bianchini & Verhagen (2016), a great many artistic works and discussions related to artistic research and the methodological "hacking" approach of this PhD can be found.

[2] Comparable to the four strategic design elements of hacking described by Stober et al. (2013).

2.3 HACKING AS A CONSISTENT METHODOLOGY

In the following section, I will outline different methodological approaches taken by several authors in their research on computer games and hacking. After a short introduction of each, I will outline my own methodological approach.

Pias divides his methodological approach to the evolution of games into three categories: chronologic, pedagogic and hermeneutic. The chronological approach tracks the history of computer hardware and software development and also catalogues different genres of games; the pedagogical approach uses methods from media sociology and constructivism to analyse the evolution of games, and the hermeneutical approach uses hermeneutics and philology to compare games to one another (Pias 2002a, p.7). According to Pias, the history of computer games intersects with the history of science, art, philology, communication engineering, economics and communication studies in an as yet undefined space (Pias 2002a, p.8). Any analysis of computer games, Pias thus concludes, also entails an analysis of the history of computers. The three elements of his methodological approach thus constitute "entities from disparities" (Pias 2002a, p.12, translated from the German) in an as yet undefined space.

Media theorist Friedrich Kittler (under whom Pias studied) argues that in an age of ubiquitous and networked computing, when virtually all media (including games) somehow involve computers, media studies researchers are almost forced to work retrospectively to register a subject's "patterns and mores: myths, scientific fictions, oracles […] a narrative made of narratives […] that collects, comments and connects" (Kittler 1986, p.4). It is this retrospective methodology that will be adopted in the theoretical portion of my proposed research and PhD exegesis.

Pias' methodological approach to computer game research is complemented by Rajagopal's methodological view that hackers use "an extreme form of metis" (Rajagopal 2011 Loc. 124/1069). In *The Practice of Everyday Life*, French scholar Michel de Certeau explains that the Greeks understood metis as "ways of operation", including "clever tricks, knowing how to get away with things, hunter's cunning, maneuvers [sic], polymorphic simulations, joyful discoveries, poetic as well as warlike" (Certeau 1988, p.xix). According to Rajagopal, hackers use these "tactics" (Certeau 1988) by finding "all kind(s) of unauthorized ways to use a computer" (Rajagopal, 2011 Loc. 124/1069), which explains why they are "incessantly obsessed" (Rajagopal 2011 Loc. 181/1069) with tool-making. Because, despite their unauthorised approach, hackers are effective producers of tools and solvers of problems.

Like a hacker, I will create my own tools – specifically, methodological ones. My methodological approach in this work is to explore hacking in a chronological and historical manner. The history of hacking intersects with many other fields like, for example, the history of computers and the history of computer games. It is also linked to fields such as philology, art history, the history of science, communication engineering, economics and communication studies, all of which intersect to create an as yet undefined space. This multi-dimensional context in which hacking exists poses a challenge; it is tempting to take detours in any number of fascinating thematic and historical directions. Therefore, to avoid straying from my topic, I will concentrate on the origins of hacking by investigating historical records like Levy's (1986) and Raymond's (2013) and placing these records in the broader context of hacking in the spirit of, for example, Pias (2002a; 2002b; 2013) and Schwingeler (2012; 2014).

As mentioned earlier, the term hacking originated in the late 1950s and early 1960s at MIT, where members of the TMRC helped define it in the context of digital computers. In *Hackers: Heroes of the Computer Revolution*, the only resource that focuses on the TMRC and the emergence of hacking culture, Levy describes the early development of the practice, focussing not only on the people and the technology, but also on the culture and ethics created by hackers of the time. To produce this historical record, Levy interviewed and talked to dozens of individuals from the MIT hacker collective of the 1950s and 1960s. His historical account is complemented by Raymond's regularly updated online glossary *The Jargon File*, which provides useful information about hacking terms and related topics. Insight into the broader media-archaeological context is provided by Pias, who offers technological, art historical and philosophical interpretations of hacker culture.

I carefully examined the works of these and other authors in search of design methods and/or elements embedded in the history, culture and practice of hacking, and subsequently defined these design methods and/or elements based on my own experience as a media artist.

2.4 HISTORICAL EXAMINATION OF HACKING

The following literature review will reveal the different approaches to the ambiguity of hacking taken by authors such as Schwingeler (2012; 2014), Raymond (2013), Levy (1986) and Pias (2002a; 2002b; 2013). These approaches include, for instance, the relationship between hacking games and game cheating as well as the arts. Furthermore, broader perspectives such as encyclopaedic, historical and media archaeological approaches are outlined. This review will be helpful later on when it comes to extracting strategic design elements from hacking.

Hacking is related to the history of art and philosophy, particularly in the 1950s, but also to newer disciplines like media art and game art. Schwingeler (2012) offers a very thorough examination of hacking in the context of art – that is, hacking as an artistic practice used to create games. He presents four artistic strategies for handling the "material of computer games" and offers several examples of artworks that have been made with their use (Schwingeler 2012, p.61, translated from the German). The first strategy is to fashion a "new decoration of the material" (Schwingeler 2012, p.62, translated from the German) as a way to modify the given system (i.e. game) and its audio-visual appearance. One example of this strategy is the total conversion of the game DOOM (id Software 1995) named Arsdoom (1995) by Orhan Kipcak and Reini Urban, shown in figure (6). The venue of the media art festival Ars Electronica serves as a virtual playspace.

Figure 6 - Arsdoom (1995)

The second strategy identified by Schwingeler (2012) is the "reduction and abstraction of the material" (Schwingeler 2012, p.63, translated from the German) as executed, for example, in games like Super Mario Clouds (2002) by Cory Arcangel, shown in figure (7). The artist removed specific elements of the game Super Mario Bros (Nintendo 1985), leaving only the moving clouds and the background.

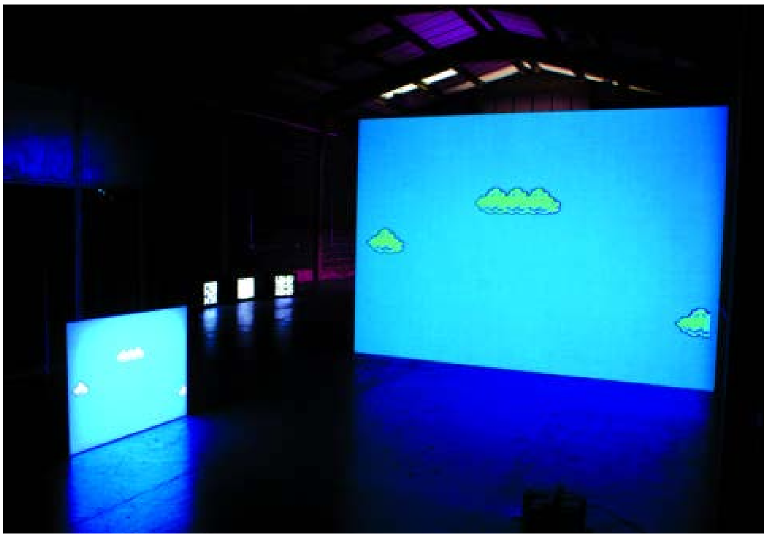

Figure 7 - Super Mario Clouds (2002)

The third strategy is the "modification of game rules and non-game-conform acts in the material itself" (Schwingeler 2012, p.63, translated from the German). A good example of this approach is *Velvet-Strike* (2001) by Anne-Marie Schleiner and Joan Leandre, shown in figure (8), which inserted pacifistic images into the first-person shooter game modification *Counter-Strike* (1999).

Figure 8 - Velvet-Strike (2001)

The fourth and last strategy is the "disruption of the material to the point of unplayability" (Schwingeler 2012, p.63, translated from the German), which can be seen in Jodi's *SOD* (1999), shown in figure (9). This is a modification of *Wolfenstein 3D* (iD Software 1992) which transforms the visual appearance of the game abstractly.

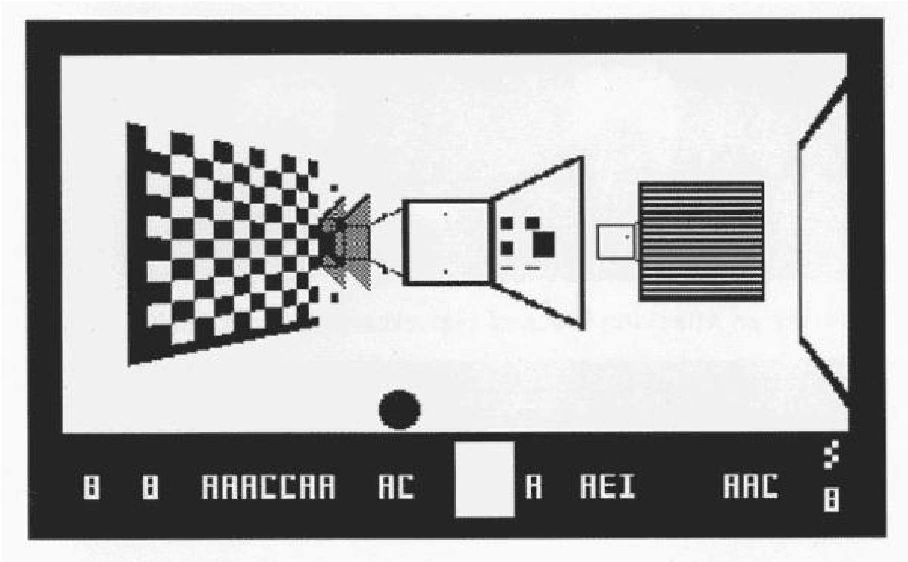

Figure 9 - SOD (1999)

In *The Jargon File,* Raymond collects definitions and terms in order to provide an overview of hacking in the form of an online encyclopaedia. He describes it as “a comprehensive compendium of hacker slang illuminating many aspects of hackish tradition, folklore, and humor” (Raymond 2013). A search in this compendium for the term hacker yields no less than eight primary definitions. The first five definitions are variations of the basic fact that hackers are able to program programmable systems. To varying degrees, they also emphasise the hacker’s enthusiasm for programming. In his third definition, Raymond addresses the capability “of appreciating hack value,” which he explains using the example of the display hack – that is a method to compute hack value (Raymond 2013). He points specifically to *Munching Squares* (1962) (figure 10), a display hack created on the DEC PDP-1 that “employs a trivial computation [...] to produce an impressive display of moving and growing squares that devour the screen” (Raymond 2013).

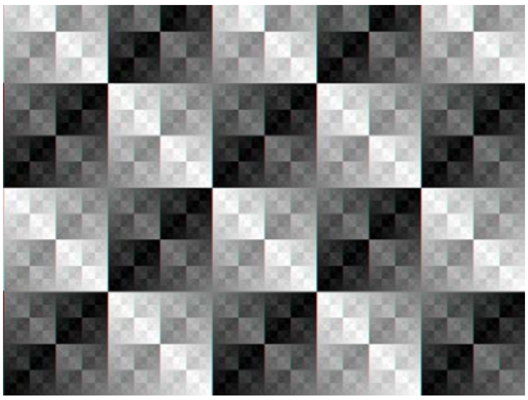

Figure 10 - Munching Squares (1962)

Definitions six and seven of the term hacker extend the sphere of hacker activity from action executed on a computer to any type of expertise motivated by “the intellectual challenge of creatively overcoming or circumventing limitations” (Raymond 2013). The last definition is pejorative; it describes the hacker as “a malicious meddler who tries to discover sensitive information by poking around. Hence password hacker, network hacker. The correct term for this sense is cracker” (Raymond 2013).

Levy (1986) defined hacker ethic in his 1984 book *Hackers: Heroes of the Computer Revolution*, which explored the birth of hacking. Reissued in 2010 with updated material, it chronicles path-breaking developments and the people who made them as well as explores the hacking culture that grew up around them over the past 60 years. The book is the only source that provides a historical perspective on hackers from a playful and game-related perspective and their evolution from improvers of model railroads to creative manipulators of military computer technology. Levy (1986) defines a hack as “a project undertaken or a product built not solely to fulfil some constructive goal, but with some wild pleasure taken in mere involvement.” He further explains that for a feat to qualify as a hack, it “must be imbued with innovation, style, and technical virtuosity” (Levy 1986, p.10). As formulated by Levy, hacker ethic consists of the following six principles:

> 1. “Access to computers – and anything that might teach you something about the way the world works – should be unlimited and total. Always yield to the Hands-On Imperative!” (Levy 1986, p.28).
>
> 2. “All information should be free” (Levy 1986, p.28).
>
> 3. “Mistrust authority – promote decentralization” (Levy 1986, p.29).
>
> 4. “Hackers should be judged by their hacking, not bogus criteria such as degrees, age, race, or position” (Levy 1986, p.31).
>
> 5. “You can create art and beauty on a computer” (Levy 1986, p.31).
>
> 6. “Computers can change your life for the better” (Levy 1986, p.34).

The hacker ethic listed above cites principles according to which a “true” hacker should act, from creatively using computers beyond their intended context to producing art and beauty to manipulating computers so that they can improve peoples’ lives. This ethic is not, however, tied exclusively to those who hack computers.

Media theorist and historian Pias (2002b) places hacking in a broader philosophical and art historical context. According to Pias (2002b), computers are directly linked to hackers and the act of hacking. Hackers owe their existence to computer technology. The hacker’s “*raison d’être* is the digital data processor as a universal machine for play” (Pias 2002b, p.254, translated from the German). He also compares hacking to appropriation art in that both rely heavily on recontextualisation. The best-known representative of this art form is Marcel Duchamp, who first gained fame for his readymade *Fountain* (1917), a common urinal installed in an exhibition space in clear breach of the rules governing traditional museum etiquette. Pias (2013) also cites Guy Debord’s concept of *détournement* as relevant to the discussion of hacker culture, along with the notion of *umwidmung* as employed by Bertolt Brecht and Walter Benjamin (Pias 2013, p.2).

2.5 HACKING: DESIGN METHODS & ELEMENTS

The document at hand describes and explains the methodology used based on hacking as a creative and artistic strategy for game design. The theoretical work on hacking describes four design methods and/or elements that were discovered by means of a historical examination of hacking. In what follows, the elements thus identified will be listed, explained and discussed.

2.5.1 ADDITION

Hackers and computers are historically linked to games and play. The first programs written by hackers at MIT in the early 1960s for machines like the TX-0 or the DEC PDP-1 were games. These games – which their creators referred to as hacks – were developed by playfully designing code. From the very start, hackers were users who began to "tinker, [to] do with multi-million dollar equipment precisely what you weren't supposed to do with it: create starry skies and calculators, typewriters and lighting consoles, flyers and musical instruments" (Pias 2013, p.1, translated from the German). Hacking is "technical virtuosity and informatical elegance" (Pias 2002a, p.80, translated from the German). The original hackers became interested in this so-called "expensive typewriter" without having any knowledge of how to use it; this was the birth of the "digital" hacker. "The students were no longer part of that war generation of mathematicians, physicists and electrical engineers who had built the computer as a 'tool,' but were rather, in a literal sense, 'users' of an existing hardware" (Pias 2002a, p.80, translated from the German). This shift in use and context opened up a whole new playground for the hackers, who were deeply excited by the technology. As early innovators they started working and experimenting and playing around with code on these machines and would go on to develop stunning programs and games like Spacewar! (1962) (Figure 11).

Figure 11 - Spacewar! on the PDP-1 (1962)

Before hackers gained access to the TX-0 or the DEC PDP-1 computer, those who were part of the TMRC were concerned mostly with the technological improvement of model railroads, their primary interest and passion. By adding parts gleaned from different technologies, they were essentially hacking the existing technological base. This type of behaviour constitutes the first design strategy employed by the MIT hackers of the late 1950s and will from here on be referred to as *addition*. When they got in touch with the first programmable computers these early hackers transformed their enthusiasm for improving model railroads into a playful design strategy. Because they did not understand computers as military machines as the inventors did, they started to play around with them and, in the process, discover their other powers and potential uses. Ever since the first hackers were introduced to programmable computers, hacking has referred to the act of playfully designing code. When this code is run, it is called a program, so that the program itself is called a hack. The implicit rules of programming hacks were put on paper in the hacker ethic described by Levy (1986). Designing the hacks – mostly games like the famous Spacewar! (1962) – was a "wild pleasure" (Levy 1986, p.10) for those who did it. The computer changed the lives of the TMRC hackers at MIT; the sixth and last tenet of the hacker ethic is based on the belief that computers can also change the lives of others. Accordingly, Levy (1986) compares the computer to a mythical object that can fulfil virtually all desires: "like Aladdin's lamp, you could get it to do your bidding" (Levy 1986, p.34). Using the power of the computer as their tool, hackers also possess the ability to enhance and improve life.

2.5.2 APPROPRIATION

Spacewar! (1962) was first presented to the public at the annual MIT Open House in May 1962, when the TMRC hackers set up a display to exhibit their work on an oscilloscope. The hackers were successful in their efforts to expand the function of computers into the entertainment sphere (cf. Pias 2002a). As a result, they were able to present the technology of digital computers to the public in a different, non-military context. From that time on, the computer was no longer perceived as an indefinable technological oddity. The recontextualisation of the technology transformed the computer from a war machine into an entertainment machine. The hacks of the MIT students provided the machine with new content, and this content, in turn, drove the development of the machine. Inspired by the pleasure of playing with a new technology, the hackers built programs that helped that technology evolve. Over time, they grew more and more aware of how important their work was becoming. Pias (2013) compares their act of recontextualisation with appropriation art. It is precisely this act of recontextualisation that constitutes hacking's second design strategy: *appropriation*.

Pias (2013) also discusses the evolution of computer games since the 1970s in relation to the mainstream perception of hacking. "Computer games first had to be professionalised and commercialised, commodified and protected, so that they could be appropriated" (Pias 2013, p.2, translated from the German). He goes on to compare commercialised (modern) games to the original hardware available to MIT hackers, both of which were born of enormous effort. Because in both cases the user knows exactly what to do with what is in front of him, Pias (2013) considers both game and hardware as an "invitation for misapplication" (Pias 2013, p.2, translated from the German). Pias' (2013) interpretation of Debord's *détournement* in terms of hacking is not unique; Morgana (2010) asserts that "détournement is also central to hacker culture; taking stuff and making stuff do things it wasn't meant to do. By modding, hacking, exploiting and other strategies of intervention, artists, game designers and players have responded to the pre-set game limits and other practical and creative boundaries" (Morgana 2010, pp.7–8). As these examples demonstrate, and as Erickson (2008) explains, the early hackers understood their actions *in relation to art:* "the original hackers found splendor and elegance in the conventionally dry sciences of math and electronics. They saw programming as a form of artistic expression and the computer as an instrument of that art" (Erickson 2008, p.2).

2.5.3 EXPANSION

Though the hacker ethic may be applicable to non-technological contexts, the ethic as outlined by Levy (1986) refers explicitly to computers as the hacker's tool. Pias (2002b) provides a broader technological classification of hackers: "The hacker is not a trained technician or programmer, but someone who gathers his own knowledge. He does not obey arbitrary rules and programs, system administrators and contexts of use" (Pias 2002b, p.254, translated from the German). In his eyes, a hacker is limited not by his actions, but by the boundaries established by the technology he uses – that is, by an "absolute frontier" (Pias 2002b, p.254, translated from the German). He goes on to assert that in his "innermost impulse, [a hacker] is a player" (Pias 2002b, p.254, translated from the German).

By their actions, hackers were able to expand their field of operation to systems with new layers of possibilities. By competing with computer systems and their boundaries, they were able to create tools and open up new dimensions of interaction. At the same time, they were forced to confront ever tightening boundaries as the software security industry became larger and stronger. But it was not just the software security industry. Many other intervening forces influenced the evolution of the hacker. As Pias (2002b) explains, the boundaries that hackers come up against – and, when successful, transgress – are often created by hackers themselves (Pias 2002b, p.262). The demands of ongoing invention and confrontation require hackers to expand their field of operation. They must find new ways of interacting with the boundaries they are constantly pushing. To confront these boundaries, they must expand their current sphere of activity. This third design strategy of hacking will be referred to as *expansion*. By devising and employing an expanded toolset, a hacker is able to think in several dimensions and thereby playfully challenge existing barriers.

The act of expansion can be found during the development of the game Spacewar! (1962). "The advantage that a world created by a computer program had over the real world was that you could fix a dire problem like faulty torpedoes just by changing a few instructions" (Levy 1986, p.52). The result was a game made possible by the extended boundaries achieved by the hackers of the DEC PDP-1.

2.5.4 DISRUPTION

One possible way to overcome boundaries is to commit an illicit act. In the modern imagination, the hacker is usually a malicious genius who illegally infiltrates a digital system in order to steal information, manipulate the system, do damage or even commit an act of war. According to Raymond (2013) this type of person is more accurately described as a cracker, not a hacker. There is no easy way to differentiate between the two unless the person in question is clearly following hacker ethic as defined by Levy (1986). In any case, Raymond (2013) goes on to say, "cracking for fun and exploration is ethically OK as long as the cracker commits no theft, vandalism, or breach of confidentiality" (Raymond 2013).

An illicit act is an act of rule-breaking conducted in the spirit of the spoil-sport as described by Huizinga (1949). Thus if one player acts beyond the rules of play in order to gain an advantage over other players acting within the rules of play, that person collapses the play-world. Huizinga sees this as a more destructive act than cheating: "The player who trespasses against the rules or ignores them is a 'spoil-sport.' The spoil-sport is not the same as the false player, the cheat; for the latter pretends to be playing the game and, on the face of it, still acknowledges the magic circle" (Huizinga 1949, p.11). Cheats can operate in different ways, but they are always bound by the rules of the game. A cheater can gain an advantage within these rules but not overwrite or manipulate them. To gain advantages like those gained by Huizinga's (1949) spoil-sport, the player must *hack* the game using auxiliary tools that make it possible to manipulate the game itself by expanding or nullifying its rules.

The ongoing challenge of overcoming the boundaries of a system forces hackers to break rules in either an ethical or an unethical manner. In the sense of Huizinga's (1949) spoil-sport, that means hackers are able to transgress the defined rules of a given system in a way that directly initiates its collapse (Huizinga 1949, p.11). Transgressing boundaries within or beyond a system context provides hackers with different points of view, thereby opening up countless hitherto unimaginable possibilities. Often, there is no need to collapse the system in order to overcome a boundary, only to disturb it. This type of disruption is comparable to the artistic strategies described by Schwingeler (2012) (2012) – that is, those strategies that manipulate the "material of computer games" (Schwingeler 2012, p.61, translated from the German). Disruption, in other words, is an artistic strategy that can be used to approach digital games; a strategy for hackers to push the boundaries of a system. Thus the fourth strategic design element of hacking will be referred to as *disruption*.

2.6 CONCLUSION

In this chapter the first research question has been addressed. The following figure (12) illustrates and summarises the four strategic elements of hacking I have identified.

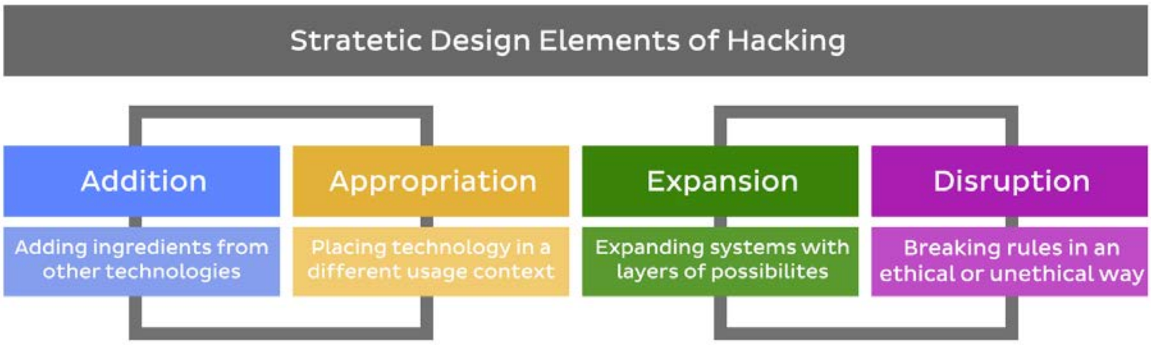

Figure 12 - Strategic Design Elements of Hacking

Furthermore, it has been shown how the original hackers used programming as their tool to produce creative content for the emerging technology of computers, and as such effected a context shift from military to creative usage. The technology developed by these early hackers smoothed the way for digital games as we know them today. The original hackers understood the computer not as a calculator to assist in military operations, but as a machine that could be used to make their dreams come true – a technological means through which to channel their creativity, whether in the form of interactive programs or as a new form of art.

Hackers created their own content by playfully editing and writing code. This content consisted either of tools to support the creation process or of playable material that could be exploited by all users, even those not capable of programming computers. They created this content through their constant efforts to push the boundaries of technology. In the preceding discussion I have identified four strategic design elements of hacking. The first element is *addition*, which means the addition of ingredients from other technologies. The second, *appropriation*, is defined as placing technology in a different usage context. The third is *expansion*, meaning the expansion of systems with new layers of possibilities. The last strategic design element of hacking is *disruption* as an act of breaking defined rules in an ethical or unethical way.

The second part of the first research question asked if and how the identification of design elements can unlock artistic and/or creative potential. As I have argued, hackers made use of playful and creative strategies in their early work. In his hacker ethic, Levy argues that "you can create art and beauty on a computer" (Levy 1986, p.31) and that "computers can change your life for the better" (Levy 1986, p.34). It is precisely this type of thinking that has contributed to the growing awareness of the possibilities presented by digital games. Hackers transformed computers from military devices to entertainment devices, and this context shift can be defined as the cradle of digital games and digital media art. Both creative disciplines share the same origin and arose simultaneously.

Having extracted the four design elements of hacking, the following chapter (3) will introduce a domain (Brain-Computer Interfacing) to which they will be applied. Subsequently, in chapter 4, the strategic design elements of hacking will be applied to the PhD project Ride Your Mind (RYM).

3 A DOMAIN TO HACK INTO: BRAIN-COMPUTER-INTERFACING (BCI)

In the preceding chapter, four design strategies of hacking have been identified. In this chapter these design strategies will be applied to the domain of Brain-Computer Interfacing (BCI). This branch of technology has been chosen for a variety of reasons: (1) BCI is an emerging technology that is expected to have a wide-ranging impact on future consumer HCI and gaming (Rathod 2017; Kerous et al. 2017; Chavarriaga et al. 2017); (2) BCI interests me personally (see section 1.1.1); and 3) BCI unites a variety of different research areas (see 3.1).

To introduce the (complex) topic of Brain-Computer Interfacing, I will begin by discussing related research. I will then reflect on BCI architectures and definitions, and finally give an extensive overview of BCI applications, technologies and findings in the specific context of games.

3.1 RELATED RESEARCH

Fundamental works that provide a reliable overview of Brain-Computer Interfacing (BCI) research are *Brain-Computer Interfaces: Applying our Minds to Human-Computer Interaction* (Tan & Nijholt 2010) and *Brain-Computer Interfaces Handbook: Technological and Theoretical Advances* (Nam et al. 2018). Especially chapter 10 of the first work, on Brain-Computer Interfacing and Games, is relevant for research on BCI games. The authors describe essential knowledge in the field of BCI technology used for games and playful applications in research and/or the gaming industry. They furthermore list all existing BCI-based games and research until the year 2010. The second work provides a great overview of the newest findings in BCI research until the year 2017. In the following part some of the most relevant research material will be outlined.

Next to these publications in the field of HCI and BCI research, there are several research papers on BCI games. Most of these papers approach BCI games and BCI gaming from a HCI, BCI, medical or neuroscientific research perspective. As Bos et al. (2010) explain, BCI research historically focused on paralysed people. There are a marginal number of papers that deal with the game design of BCI games. The most relevant research on BCI and games has been done by Nijholt, Bos and Reuderink. They are part of the Human Media Interaction Research Group at the University of Twente in the Netherlands, and the leading experts in this research field. The work of Bos & Reuderink (2009), as an early example, includes thoughts for potential designers of BCI games. They discuss projects and experiments, as well as outline technological issues concerning professional and consumer BCIs. And yet none of these research contributions are written from the perspective of game design or game design research. The work of Gürkök et al. (2012) constituted the first academic material to propose a framework for BCI game design from the perspective of BCI research. They point to different interaction paradigms that can be used by potential designers of BCI games, and argue that many BCI researchers develop BCI games to test research paradigms without the use of a proper game design approach. On the other hand, they argue, game designers who work with consumer grade BCI-Headsets possess insufficient knowledge of both the technology that is used as well as the neurophysiology involved, which leads to unsatisfactory gameplay (Gürkök et al. 2015, p.373). Loup-Escande et al. (2015) also elaborated a framework for user-centred BCI game design.

I examined the existing literature from my personal perspective as a practising media artist so as to extract knowledge that can be useful in the game design process of the practice-based PhD project Ride Your Mind (RYM), as well as support research on BCI game design strategies and BCI game design patterns. The following figure (13) provides an overview of the diverse areas of BCI research.

Figure 13 - BCI Research Areas - based on (Elsayed et al. 2017)

3.1.1 BRAIN-COMPUTER INTERFACING (BCI)

To understand how the connections between humans and computers work it is necessary to explain what a Brain-Computer Interface (BCI) is. This short introduction does not explain how a BCI works in all technical detail but provides a first overview of the technology. A BCI serves as an interface between the human brain and the computer and is part of HCI (cf. Rathod 2017). BCIs collect signals emitted by the human brain with the use of electrodes, a specific form of biofeedback called neurofeedback. Nijholt et al. further describe the functionality of a BCI as a "novel communication system that translates human thoughts or intentions into a control signal" (Nijholt et al. 2008). Future Brain-Computer Interfacing technology also involves the danger of accessing highly sensitive and super personal data (Nijholt et al. 2008). This topic will be discussed in more detail in chapter 6.1.7. In my research, I work with a BCI that uses the non-invasive technique of electroencephalogram (EEG) signals. EEG records electrical potentials on the scalp produced by brain activity (Wang et al. 2010, p.270). A common scenario is for a BCI to collect brain signals (via EEG) and transform them into control signals. The control signals are then sent to a compiler that translates or interprets the signals. The compiler processes the received brain signals to understandable data and triggers actions in for example a game engine. The compiler can already be part of for example a game engine or a BCI itself. The game engine generates visual, auditory or any other possible type of feedback, which in turn provokes brain signals. A BCI is in itself a feedback loop caused by mental decisions of the user or brain responses to stimuli such as the described feedback (Nijholt et al. 2009). The exemplary functional principle of a BCI is illustrated in the following figure (14).

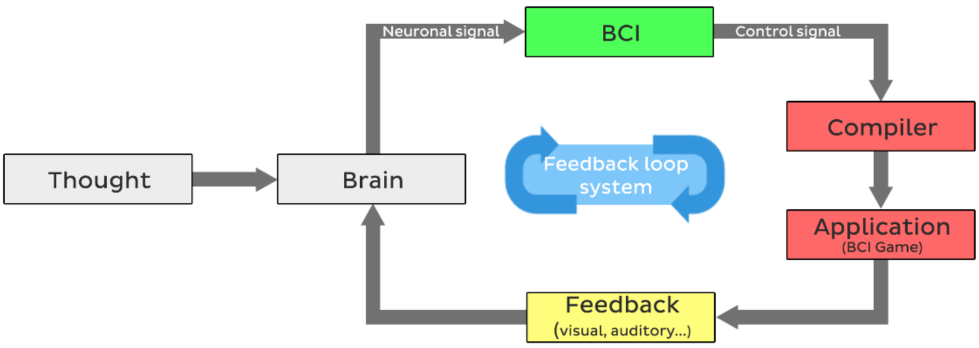

Figure 14 - BCI working scheme (based on Nijholt et al. (2009))

3.2 BCI GAMING TECHNOLOGY

Presently there are only a small number of hardware manufacturers that produce and develop consumer grade BCI (neurofeedback) gaming technology, henceforth referred as BCI gaming technology, which often relies on EEG as dry-cap technology (Nijholt et al. 2009, p.92). In contrast to medical and research grade BCI, the dry-cap technology is significantly more favourable, especially in usability. Grush (2016) describes the pros and cons of the emerging consumer grade BCI technology and states that the functionality of the Emotiv EEG BCI-Headset is more comparable to a gimmick than to a proper working mind-reading device. This statement relies on the imprecision of the consumer BCI gaming technology, which will be discussed in a later section of this exegesis. On the other hand, Childers (2013) compares the functionality and precision of the Emotiv EEG (Figure 15) BCI-Headset to professional BCIs and highlights the imprecision of the Emotiv headset.

Figure 15 - Emotiv EPOC EEG Headset

Beside market leaders in BCI gaming technology such as Emotiv[3] and Neurosky[4], there is an interesting open source and low-cost alternative: OpenBCI[5] (Figure 16).

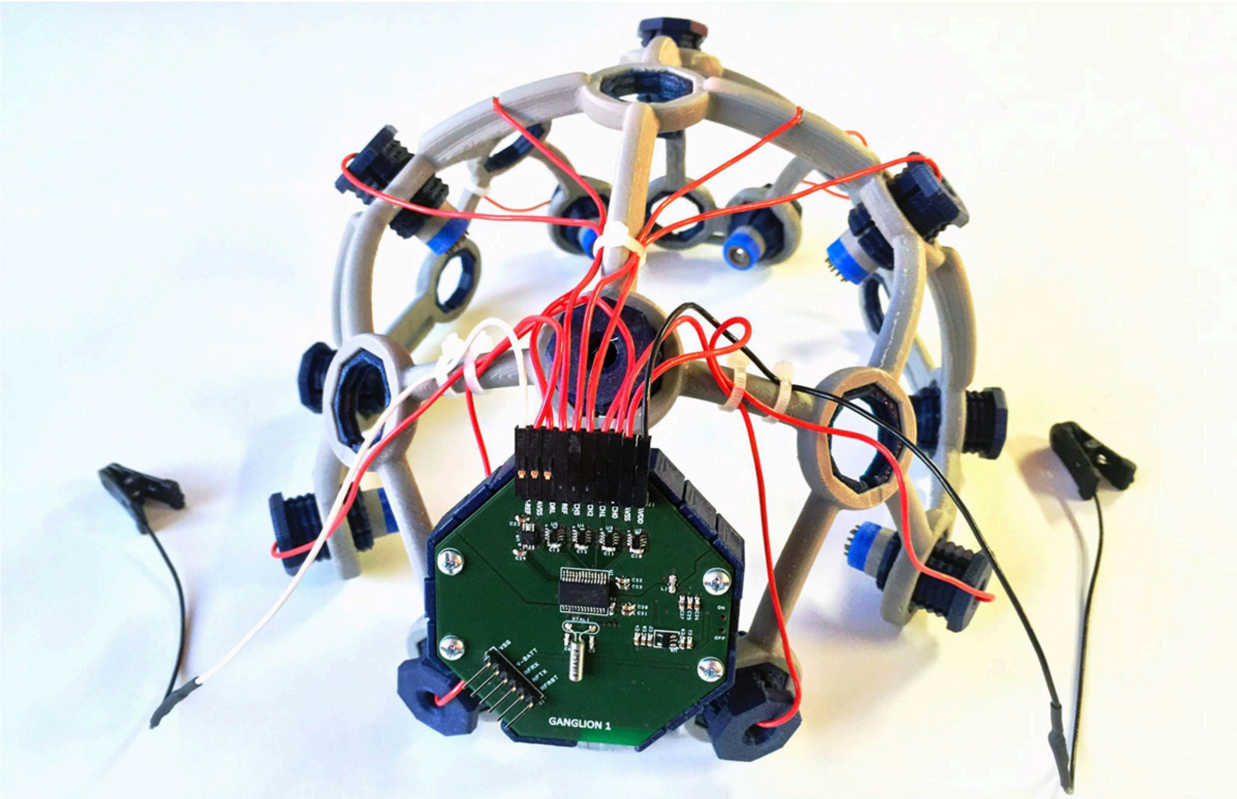

Figure 16 - 3D printed openBCI

Wang et al. (2010, p.270) point out that EEG-based technology has become affordable and user friendly for private use during the last years. As a result, the gaming industry and game designers are now working with the emerging neurogaming technology to produce the first entertaining and serious games. Whereas Brain-Computer Interfaces (BCI) and neurofeedback systems were previously primarily used in medical research to help handicapped persons, they now evoke a great deal of interest from the entertainment industry, which seeks to engage non-handicapped people. As Martisius and Damasevicius have pointed out: "The focus of BCI research should shift from the reliability to usability and user experience. This is necessary to migrate BCI systems out of the laboratory, into society."

[3] More information about Emotiv can be found online at http://www.emotiv.com/
[4] More information about Neurosky can be found online at http://www.neurosky.com/
[5] More information about OpenBCI can be found online at http://www.openbci.com/

3.3 BCI GAMING

This section will explain the terms BCI gaming and neurogaming and how they relate to BCI research. The following definitions are formulated from my own perspective as a media artist.

3.3.1 INTRODUCTION

The term BCI gaming describes games using BCI technology to control or influence the gameplay. Many examples of early BCI games can be found in BCI research aimed at treating disorders such as attention deficit hyperactive disorder (ADHD) or epilepsy (Nijholt et al. 2009, p.88). Neurogaming in turn seems to be a marketing term, created by the industry to describe consumer-oriented and entertaining games designed to target healthy persons. Consumer BCI technology manufacturers such as Emotiv and Neurosky have released affordable hardware (in comparison to medically used BCIs) on the market in order to reach healthy users among gamers and call the playable interactive content BCI games. Game companies such as Sony and Nintendo are currently working on future BCI gaming and neurogaming content (Nijholt et al. 2009, p.88). Since 2013 there is a Neurogaming Conference[6], an industry conference and expo on BCI gaming and neurogaming hosted by Zack Lynch, which takes place yearly in San Francisco.

Figure 17 - BCI-Headset as game controller

BCI gaming can be understood as a playful activity that makes use of consumer grade Brain-Computer Interfaces (BCIs) as input devices for controlling games. By reading out feedback triggered by neuronal activity, brain signals are received by the BCI and used, for example, to trigger events in a game scenario. This process is labelled neurofeedback. Neurofeedback is processed and interpreted to trigger various input types. Neurofeedback, or neuroimaging, is a form of biofeedback. Neuroimaging

[6] The host discusses a number of recent BCI Game examples, both commercial and experimental, online at: http://venturebeat.com/2013/01/17/let-the-neurogames-begin

technology, such as functional resonance imaging (fMRI), magnetoencephalography (MEG), functional near-infrared spectroscopy (fNIRS) and electroencephalography (EEG), can be used as a method to detect brain activity. Primarily EEG is used as the most practicable and low-cost method in BCI games (Lance et al. 2015). The three main forms of EEG BCI control paradigms used in BCI games are: (1) motor imagery (real or imaginary movement of a limb). Motor imagery is also described as event-related desynchronisation (ERD) and is the most popular BCI game control strategy and furthermore the most studied (Gürkök et al. 2015); (2) steady-state visually evoked potential (SSVEP) (looking at a flickering light); (3) P300 (infrequent stimulus, e.g. a specific image within an image sequence). BCI games as a system are controlled or influenced by neurofeedback through the use of a Brain-Computer Interface. As outlined above, there are several BCI paradigms. For example, motor imagery can be used as a means to control BCI games by the sensorimotor rhythm (SMR). In *Brain-Computer Interfaces Handbook: Technological and Theoretical Advances*, Nam et al. (2018) provide further information on state-of-the-art BCI paradigms for the interested reader.

3.3.2 BCI GAMEPLAY

The term BCI gameplay used in this work describes a combination of the genre of BCI game and the traditional understanding of gameplay from a game design (Salen & Zimmerman 2003; Flanagan 2009; Schell 2014; Fullerton 2014; Waern & Back 2015) perspective. While playing a game, the gameplay can be altered by actions of the player and events in the game. These events are either triggered by the player or by the game system itself without any influence or input from the player (Björk & Holopainen 2004, p.418). BCI gameplay, in turn, is influenced by data delivered by a BCI (as additional input device) that triggers events inside the game system. Therefore, BCI gameplay offers an additional layer of interaction possibilities to traditional digital gameplay. The definition of BCI gameplay relies on the first strategic element of hacking, namely: addition. There already exists a term that describes the technological influence of a BCI in a computer system, namely the term "brain-computer game interaction" (BCGI) coined by Coyle et al. (2015). The two terms partly overlap, but differ in this respect: while BCGI describes the interaction possibilities from the technological perspective of BCI, BCI gameplay describes the interaction possibilities from a (BCI) game design perspective.

3.4 RELATED GAMES

In this section several BCI game examples from diverse research disciplines and perspectives will be introduced and briefly outlined. Most BCI games have been developed by BCI researchers and neuroscientists, and as Mishra et al. (2016) point out neuroscientists are often untrained game designers. BCI games are therefore generally limited to accomplishing cognitive training goals and focus less on graphics and gameplay mechanics. Many of the following BCI game examples are designed by non-game designers and merely prove single paradigms while lacking a focus on entertainment, playfulness, gamefulness (cf. Walz & Deterding 2015), novel BCI gameplay mechanics or high-quality graphics. “This leads to BCI games that are reliable but often not enjoyable or entertaining from a gaming perspective” (Gürkök et al. 2015, p.2). I will briefly describe and illustrate a number of BCI game projects in the following section, where I will also present the most interesting approaches to biofeedback and/or neurofeedback projects related to my research project Ride Your Mind. It should be stated that beside the ones listed below, there are many more BCI research projects and BCI games (cf. Kerous et al. 2017) and “serious” BCI games or games for rehabilitation (cf. Plass-Oude Bos et al. 2010) or BCI games and artificial intelligence (cf. Coyle et al. 2013; cf. Ahn et al. 2014).

3.4.1 BIOFEEDBACK GAMES

As BCI games are based on neurofeedback and neurofeedback is defined as a form of biofeedback, it is necessary to begin with several examples of biofeedback games.

Atari Mindlink[7] (1984)

The Atari Mindlink is a game controller that was designed for the Atari 2600 video game console but never released. The Mindlink makes use of the player’s forehead movement as the control input for games. The device, stemming from 1984, was the very first example produced by the entertainment industry to use biofeedback to control a video game.

Figure 18 - Atari Mindlink (1984)

[7] More information about the Atari Mindlink and games that have been designed for this device can be accessed online at the Atari Museum: http://www.atarimuseum.com/videogames/consoles/2600/mindlink.html

Tetris 64[8] by Nintendo (1998)

Tetris 64 is a puzzle game for the Nintendo 64 that makes use of a biosensor to control the game speed based on the user's heart rate. As one of the first commercial biofeedback games, Tetris 64 uses this biofeedback to influence the gameplay by manipulating the speed of the game. When the player of Tetris 64 experiences stress, the speed of the approaching bricks, and therefore the game's level of difficulty, increases. In turn, when the player relaxes the speed of the game is reduced and the level of difficulty decreases. The conceptual gameplay of Ride Your Mind involves several gameplay elements that are related to the player's stress or relaxation levels (outlined in section 4.1.1.). In contrast to the biofeedback approach of Tetris 64 however, RYM makes use of neurofeedback to calculate the stress or relaxation level of its player.

Figure 19 - Tetris 64 (1998)

Virtual Reality Biofeedback[9] by NASA Langley Research Center (2000)

In the year 2000, NASA developed a virtual reality biofeedback system that displays the user's blood vessels in real time. This project is one of the first recorded research projects to combine biofeedback with virtual reality (VR). The visualisation shows the blood flow in the user's finger. What makes this project interesting in relation to the Ride Your Mind concept, is its combination of biofeedback and virtual reality (VR) in a manner comparable to the way that Ride Your Mind combines neurofeedback and virtual reality.

Figure 20 - NASA Virtual Reality Biofeedback (2000)

[8] Further information about the game *Tetris 64* can be accessed online at: *http://uk.ign.com/articles/1999/02/24/tetris-64-import-2*

[9] More information about this project can be accessed online at: *http://mentalhealth.about.com/cs/biofeedback/a/vrbiofeed.htm*

Journey to Wild Divine[10] by Wild Divine (2001)

Journey to Wild Divine is a biofeedback video game aimed at promoting wellness and mental well-being. The game enables the player to perform mental tasks and thereby to achieve a heightened sense of well-being. To progress within the game the player has to manipulate his biofeedback data, for example by breathing deeply in order to reduce his heart rate and calm down.[11]

Figure 21 - Journey to Wild Divine (2001)

3.4.2 BCI GAMES: EEG (AFFECTIVE GAMES)

BCI games that make use of the EEG paradigm as the interaction paradigm are also called affective games (cf. Reuderink et al. 2009; cf. Bos et al. 2010; cf. Fiałek & Liarokapis 2016). The term "affective" describes the use of a player's emotional states to influence game environments and systems. As such for example the player's level of concentration or meditation can be detected and used to influence the gameplay. In this section several examples of EEG-based BCI games will be listed.

Brainball by Hjelm (2003) and Mindball[12] by Interactive Productline (2005)

Brainball is a BCI game for two players. With the help of neurofeedback (EEG), the players are able to control the physical movement of a ball on a table (Hjelm 2003). The game received an honorary mention at Ars Electronica in 2000. Mindball is the commercialised version of Brainball. It is a rentable competitive table game that forces its users to relax in order to win. The player has to calm down to move the ball into the opponent's goal. If player one is stressed, the ball will move in the direction of his or her goal. Only when player one relaxes will the ball move in the direction of player two's goal. Thus all players have to remain relaxed in order to win the game, even if the ball approaches their own goal. The stress levels are calculated by neurofeedback with the help of a single electrode BCI. As mentioned above, Ride Your Mind's conceptual gameplay likewise includes gameplay elements that are triggered by the player's stress or relaxation levels (section 4.1.1.).

[10] More information can be accessed online at: http://www.wilddivine.com/
[11] Gameplay video: https://www.youtube.com/watch?v=uWFOBbm3HQI
[12] More information can be accessed at: http://www.mindball.se/

Figure 22 - Mindball (2005)

Amigdalae[13] by Massimiliano Peretti (2005)

Amigdalae is an art project based on real-time audio-visual processing through biofeedback technology (EEG, body temperature, heart rate and galvanic responses). The project analyses the user's emotional state while he or she watches video art, and plays music specifically intended to first mirror and then distort that emotional state. In a similar way, the concept of Ride Your Mind makes use of a combination of different EEG input signals to alter the gameplay and affect the gameworld. These elements will be outlined and explained in chapter 4.

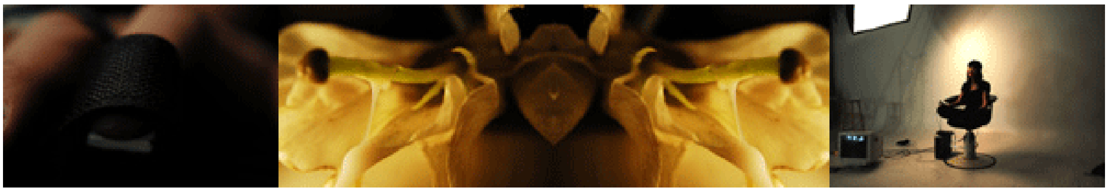

Figure 23 - Amigdalae (2005)

Pacman BCI Game by Krepki et al. (2007)

In 2007 Krepki et al. (2007) rendered the popular video game Pacman (Namco 1980) controllable with the help of a BCI. The player was able to control the movement of the protagonist within the game. An interesting outcome of tests conducted with the game is described as follows: "Users report they sometimes had the feeling that Pacman moves in the correct direction before the user was consciously aware of this decision. This indicates a new level of interaction that can be enabled only by a BCI" (Tan & Nijholt 2010, p.153). The Pacman BCI game overrides the traditional input possibilities (mouse or keyboard) and adds neurofeedback as an input possibility. The concept of Ride Your Mind wants to use BCI technology to consciously and even unconsciously alter its gameplay (section 4.1). Another approach on Pacman as an affective BCI game experiment has been done by Reuderink et al. (2009).

[13] More information can be accessed at: http://cogimage.dsi.cnrs.fr/seminaires/resumes/resume_amygdalae_2005.htm

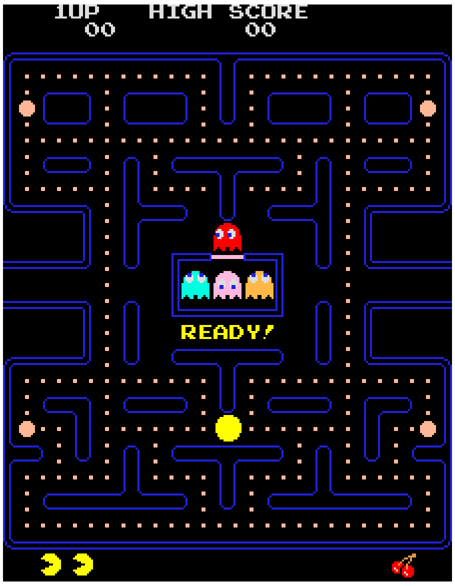

Figure 24 - Pacman (1980) by Namco

Mindflex Duel[14] Game by Mattel (2009)

In Mindflex Duel, the players compete with one another to push a ball navigated by a fan across their opponent's line. The fan is controlled by the player's mind and his level of concentration (EEG). The gaming device is one of the first commercialised and mass-market (analogue and pyhsical) BCI games. The BCI sensor uses the same chip as the MindSet BCI-Headset from the manufacturer Neurosky.

Figure 25 - Mindflex Duel Game (2009)

alphaWoW (2009)

This game makes use of alpha brain activity (EEG) to trigger the shape-shifting abilities of the player avatar within the MMORPG game World of Warcraft by Blizzard Entertainment. "This shape-shifting action has been mapped onto the alpha activity of the brain. As alpha activity is related to relaxation, the relation between the mental task and the result in the game is experienced as quite intuitive by the user. When the user experiences stress, there is little alpha activity, and the character changes into

[14] Further Information can be accessed online: http://www.gizmocrazed.com/2012/11/top-5-devices-you-can-control-with-your-mind/

the powerful bear form. When the user returns to a calm state of mind the character reverts back to her natural elf shape" (Nijholt et al. 2009, p.91). More information about the game[15] and a gameplay video[16] can be accessed online. AlphaWoW uses three different methods to interpret and interpolate the neurofeedback data (EEG) from the BCI.

Figure 26 - alphaWoW (2009)

NeuroWander[17]: Hansel and Gretel by Yoh et al. (2010)

NeuroWander is an interactive fairy tale BCI game that makes use of a Neurosky BCI-Headset. The game follows the linear narrative structure of the Hansel and Gretel fairy tale. The player's attention and meditation levels are calculated on the basis of the neurofeedback data (EEG). As long as the player concentrates, the story will proceed and the avatars inside the gameworld drop pebbles on the ground. When the player does not concentrate, the game will not proceed and no further pebbles are dropped (Yoh et al. 2010, p.390).

---

[15] Information about the game: and a video where the game is played can be found here: http://wwwhome.ewi.utwente.nl/~oudebos/

[16] Gameplay video: http://www.youtube.com/watch?v=JBaru2ZO-yA

[17] A gameplay video of NeuroWander can be accessed at: https://vimeo.com/29252991

3.4.3 BCI GAMES: MOTOR IMAGERY

Another paradigm that can influence BCI games is motor imagery, which can for example enable the player to navigate through a virtual apartment (Leeb et al. 2007).

CircleTime (2015)

Coyle et al. (2015) developed a controller called CircleTime with six simultaneous interaction options using two motor imagery tasks. The user is required to master SMR-based BCI game controllers before playing the game. Similar to RYM, CircleTime turns the often boring and long-lasting calibration phase into a mini game (section 5.4.1). CircleTime was used in combination with several basic progressively challenging action games such as a basketball, spaceship and combat-fighter game to conduct a user study. The games included a progressive difficulty level adjustment, a feature that is also part of the concept of Ride Your Mind (Stober 2013). In order to be successfully combined with the fast gameplay mechanics used in, for example, action fighting games, Coyle et al. conclude that the proficiency of BCI technology must reach a criterion level of 70%. Popular fast action games such as first-person shooter (FPS) games controlled by BCI technology cannot yet compete with the traditional keyboard and mouse setup. For BCI games to become an accepted genre in the digital games world it is essential that the technology improves and the signal processing time is speeded up.

3.4.4 BCI GAMES: VEP & SSVEP

This section briefly discusses several BCI games that make use of visually evoked potential (VEP) and steady state visually evoked potential (SSVEP) as control paradigms.

Vidal (1977)

Designed in 1977, Vidal (1977) was the first recorded BCI game. The game featured a maze that the player could navigate by concentrating on one of four fixed points on the screen using VEP. As such he was able to move in four directions with the help of neurofeedback (Tan & Nijholt 2010, p.152). The following figure (27) illustrates the concept of the game.

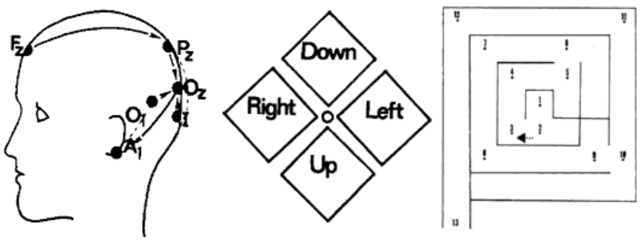

Figure 27 - First BCI Game (Vidal 1977, p.637)

MindBalance by Lalor et al. (2004)

MindBalance, created by the MIT Media Lab Europe, is one of the most comparable research projects to Ride Your Mind. In this game, the neurofeedback of the player controls the balance of the avatar (Lalor et al. 2004, p.63). Moreover, this project also involved designing a custom BCI, “The Cerebus Brain-Computer interface”, which is illustrated by figures 28, 29 and 30. The concept of Ride Your Mind includes the combination of the Emotiv BCI-Headset and the Oculus Rift Virtual Reality Headset in order to create a conceptual prototype called the BCI-VR Helmet (section 4.2). This device combines both technologies and is especially designed for playing the BCI-VR Game Ride Your Mind. Lalor et al. (2004) use the SSVEP paradigm to control a virtual character in a video game. The player needs to keep the balance on a tightrope with the help of two checkerboard SSVEP targets. If the avatar loses balance the player has three seconds to focus on a checkerboard target and to trigger SSVEP to get the avatar back in balance.

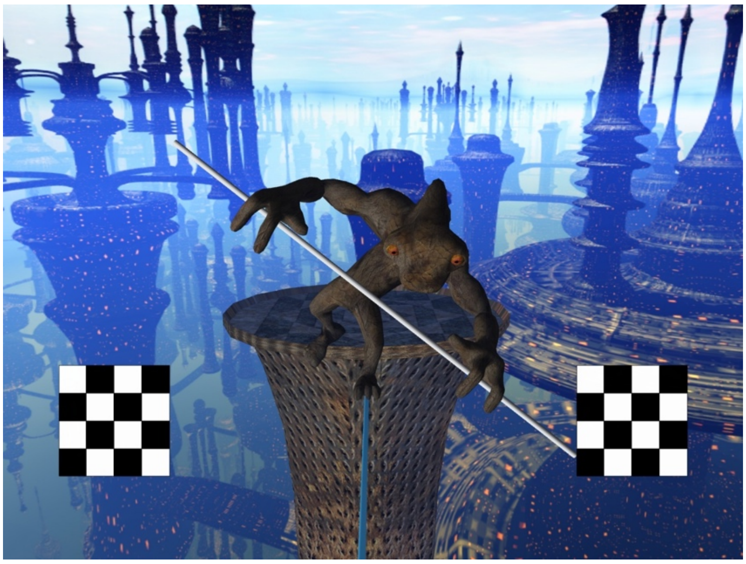

Figure 28 - MindBalance by Lalor et al. (2004)

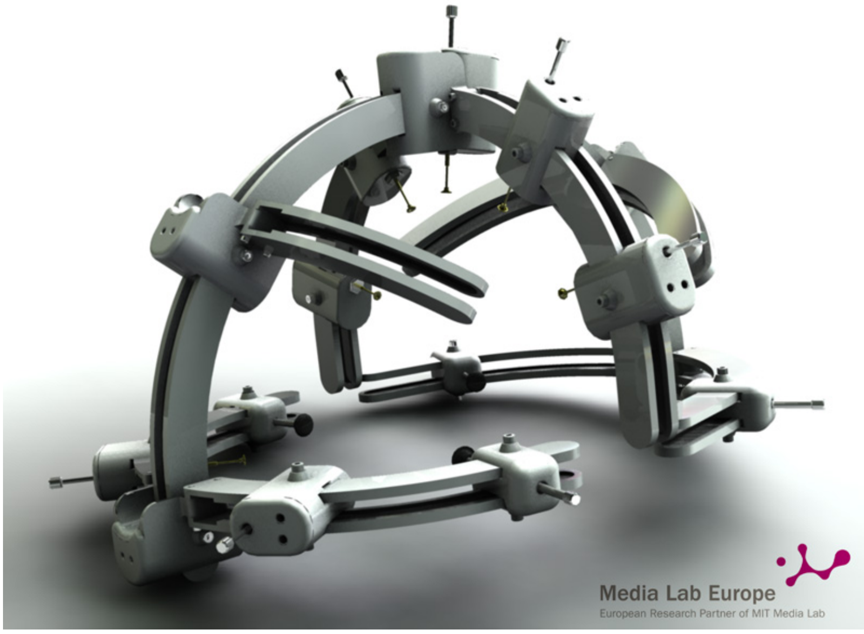

Figure 29 - The Cerebus Brain-Computer Interface (2004)

Figure 30 - The Cerebus Brain-Computer Interface (2004)

Bacteria Hunt (2010)

Bacteria Hunt[18] (Mühl et al. 2010) is a BCI game that makes use of mental state regulation and the SSVEP paradigm: “the players chase fleeing bacteria by controlling an amoeba. It is a mental state regulation game because when the players are relaxed, the bacteria flee more slowly. It is also an evoked response game because when the amoeba catches a bacterium, an SSVEP stimulus (a circle) appears on the screen, and the players concentrate on this circle to eat the bacterium” (Gürkök et al. 2015, p.13)

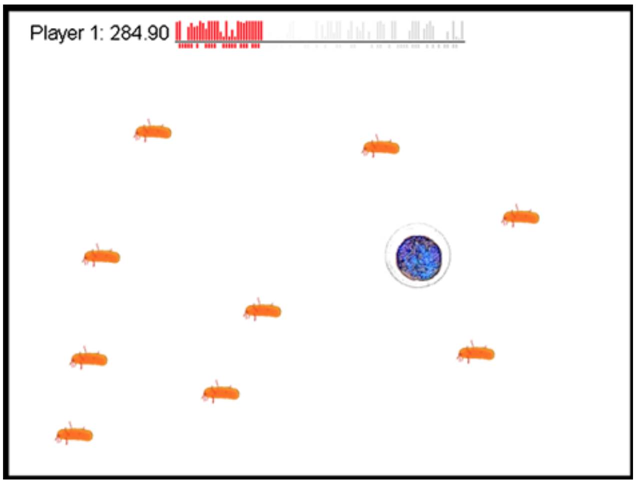

Figure 31 - Bacteria Hunt (Mühl et al. 2010, p.170)

[18] A video of the game Bacteria Hunt can be found online at: https://www.youtube.com/watch?v=uTc6fLUr47E

3.4.5 BCI GAMES: P300

The P300 paradigm is seldom used in BCI games. The following section highlights one example of how P300 can be used to control a game.

Brain Invaders 1 + 2 (2011 + 2016)

Brain Invaders and Brain Invaders 2 are open source "plug & play" singleplayer BCI games that make use of the P300 control strategy and an OpenVibe BCI. Brain Invaders 1 was developed in 2011 and is based on the famous Space Invaders (1978). In 2016 Brain Invaders 2 was developed by the same researchers. They expanded the singleplayer version into a multiplayer game allowing four game modes: "Solo, Collaboration, Cooperation, Competition." Important differences of this game in comparison to other BCI games are the fact that it does not require a calibration phase and the fact that it is based on an open source code and interface (Korczowski et al. 2016).

Figure 32 - Brain Invaders

3.4.6 BCI-VR GAMES

Ride your Mind uses a combination of BCI (EEG) and VR technology – a so-called BCI-VR setup. As Friedman (2015) points out "VR is a natural partner for BCI", and combining the two "offers radically new experiences" (Friedman 2015, p.18), because BCIs can be used to control VR environments, while VR simultaneously provides a safe and rich feedback environment for BCI technology. As such, this setup is ideal to provide users with a novel experience of playful digital content. Friedman (2015) further refers to the Greek term *psychokinesis*, which describes a person being able to influence a physical system without physical interaction. In a BCI-VR environment this physical influence is virtually enabled through a BCI.

3.4.7 MULTIPLAYER BCI GAMES

As Ride Your Mind is intended to be designed as a singleplayer BCI game, the genre of multiplayer BCI games will only be discussed briefly here.

A good overview and discussion of existing multiplayer BCI games can be found in the work of Mühl et al. (2010), Nijholt & Gürkök (2013), and Nijholt (2015; 2016). One example of such a BCI game is Connect Four, which was developed to with the goal of increasing the quality of life of motor-restricted end users and decreasing depression among this group. It is "a strategic videogame with two competitive players in which coins have to be placed in rows and columns with the goal to connect four coins" (Holz et al. 2013, p.113). Another example is the BCI game Mind the Sheep (2013), in which the players must cooperate to fence in sheep as quickly as they can by commanding dogs to herd the sheep (Gürkök et al. 2013).

3.5 CONCLUSION

The history of (BCI) games using neurofeedback (a form of biofeedback) begins in 1977. Existing BCI games or game modifications often use a neurofeedback capability to override input possibilities of existing games by means of paradigms such as EEG, motor imagery, VEP, SSVEP and P300. Of course, a combination of biofeedback and neurofeedback paradigms is also possible. Nelson et al. (1997) employed such a combination to enable navigation in a game environment. Their work, which constituted the first ever BCI navigation experiment, enabled the player to control a plane in a flight simulator by means of single axis control through a combination of EEG and electromyogram (EMG), i.e. electrical signals from muscles. (Nelson et al. 1997). As Ride Your Mind employs a combination of BCI and VR, it can be described as a BCI-VR game, and as it uses EEG as control and influence method – i.e. uses the player's emotional state to manipulate the game system – it can also be described as an affective game. The most accurate description of RYM is therefore an affective BCI-VR Game. The following chart lists the described game examples and highlights their game features.

Related Game/Project	Year	Feedback Type	Game/Project Feature	Paradigm/Mechanics	Number of Players	Game/Project Type
Vidal	1977	Neurofeedback	Movement Control (four directions)	VEP	Singleplayer	Maze Game
Atari Mindlink	1984	Biofeedback	Game Interaction	Forehead Movement	-	Game Controller
Tetris 64	1998	Biofeedback	Game Speed	Heart Rate	Singleplayer	Puzzle Game
VR Biofeedback by NASA	2000	Biofeedback	Visual (VR) representation of blood pressure	Blood Pressure	Singleplayer	Simulation / Visualisation
Journey to Wild Divine	2001	Biofeedback	None	EEG: Meditation	Singleplayer	Wellness
Brainball/Mindball	2003	Neurofeedback	Movement Control	EEG: Concentration Level	Multiplayer (2)	Game of Skill
MindBalance	2004	Neurofeedback	Movement Control (Balance)	EEG: Concentration Level	Singleplayer	Game of Skill
Amigdalae	2005	Bio- & Neurofeedback	Influence video projection and played music	EEG / body temperature, heart rate, galvanic response	-	Art Project
Pacman BCI	2007	Neurofeedback	Movement Control (four directions)	SSVEP	Singleplayer	Maze Game (Pacman)
alphaWoW	2009	Neurofeedback	Shapeshifting of Avatar	Concentration Level	Singleplayer	MMORPG
Mindflex Duel	2009	Neurofeedback	Movement Control	Concentration Level	Multiplayer (2)	Game of Skill
Bacteria Hunt	2010	Neurofeedback	Movement Control, Relaxation	SSVEP	Singleplayer	Maze Game
NeuroWander	2010	Neurofeedback	Story and game progress	Attention & Meditation Level	Singleplayer	RPG
Brain Invaders 1 + 2	2011/ 2016	Neurofeedback	Movement Control	P300	Singleplayer (2011) + Multiplayer (2016)	Arcade Game (Space Invaders)
CircleTime	2015	Neurofeedback	Game Interaction	Motor Imagery	-	Game Controller

Table 1 - Related Games & Projects

In the next chapter the application of hacking as a playful design strategy in the creation of the BCI-VR Game Ride Your Mind will be explained. Furthermore, the conceptual game design will be outlined from an artistic and technical perspective.

4 RIDE YOUR MIND (RYM)

Having discussed a wide range of BCI games and technologies in the previous chapter, the focus of this chapter will be on explaining the concept of the artistic and experimental BCI-VR game Ride Your Mind and its technological components. Furthermore, I will outline my investigation of the technological potential of a BCI gaming headset in combination with a virtual reality display, as well as the building of a prototype of RYM from the perspective of hacking. Waern and Back (2015, p.361) posit that, when it concerns experimental game design, exploring a novel game genre such as a BCI game is an ambitious objective. My artistic exploration as a media artist and hacker has revealed several gaps and hurdles (these findings relate to the third research question of this doctoral exegesis) that will be discussed after the presentation of the concept of the project RYM. The second research question, as to how the identified design elements of hacking can be strategically applied to the concept of Ride Your Mind, will be addressed in section 4.3.

4.1 RYM GAME CONCEPT

RYM is a concept for a singleplayer virtual reality game generated by neurofeedback using a head-mounted display (HMD) to compute a playable visualisation of neurological signals collected by a consumer grade BCI-Headset. These neuronal data will be processed by a specially developed EEG toolchain and Unity3D, a 3D game engine software well-suited to the desired playable artistic data visualisation. As outlined above, the Virtual Reality Headset is an Oculus Rift and the BCI-Headset an Emotiv EPOC EEG. The concept seeks to combine these two devices to create the so-called BCI-VR Helmet. The BCI-VR Helmet is a prototype of a possible future device. Its visual appearance is inspired by steampunk.[19] In chapter 5 of this document the prototyping process of this device will be illustrated and described in detail. The helmet provides stereoscopic 3D vision displayed on the HMD and the built-in head-tracking feature is used to navigate in the game environment that will be described below. Additionally, the BCI-Headset can detect the brain activity of a potential user and provides EEG data that is read out by the 14 electrodes of the Emotiv EPOC device.[20]

The Oculus Rift sends gyroscope data of the head tracker to the game engine Unity3D as control signals. As such the head movement of the player can serve as input control. Simultaneously the game engine uses the HMD as a visual output device to display the game environment.

The BCI-Headset sends EEG data to the game engine Unity3D, which interprets the data as control signals for the (BCI) gameplay on the one hand, and as control signals that influence and/or create the game environment on the other. “BCI can provide a translation between the psychological state of the player in the real world and the dynamics of the game world” (Gürkök et al. 2015, p.7). The combination of VR and BCI technology supports the merging of the real world and the gameworld.

While playing the game Ride Your Mind the player wearing the combined devices steadily produces brain activity that is detected by the BCI-Headset. This brain activity affects the game’s design, the gameplay and the gameworld. Every action triggered in the game RYM provokes further brain activity. This can be caused by visual stimuli but also by the player navigating by moving his or her head. Motor activity, such as moving the head, provokes brain activity. Visual activity on the display of the HMD provokes brain activity. Moreover, also thoughts can provoke further brain activity. The use of a BCI-Headset to play a game opens up a new layer of possibilities for (BCI) game designers, but at the same

[19] Steampunk relies on the visual appearance of technology from the nineteenth century mixed with state-of-the-art technology. In chapter 5.1 steampunk will be discussed in greater detail, as well as how it relates to the design of the BCI-VR Helmet.

[20] Further information about the Emotiv EPOC BCI-Headset can be found in section 4.2.1 and 6.1.

time a steady feedback loop has to be considered. This issue will be discussed in more detail in section 6.1.6.

The RYM concept does not ignore the fact that the game experience is a highly intimate one in which personal sensory data is temporarily stored and processed.[21] The user should have the choice of whether or not to record, display or store this data. If the user *does* allow the collected data to be stored or even anonymously shared, it can be interpreted by medical experts and thereby contribute to cognitive neurological research. Running a game generated by neurological data in real time requires knowledge gleaned from medical and BCI research. In other words, the game itself entails a recontextualisation of medical knowledge into a gaming and art context. Just as hackers transformed military devices into entertainment devices, RYM uses knowledge and devices from the medical world to create an artistic and experimental form of entertainment (comparable to the second element of hacking: appropriation). The concept for RYM is summarised and illustrated in the following figure (33).

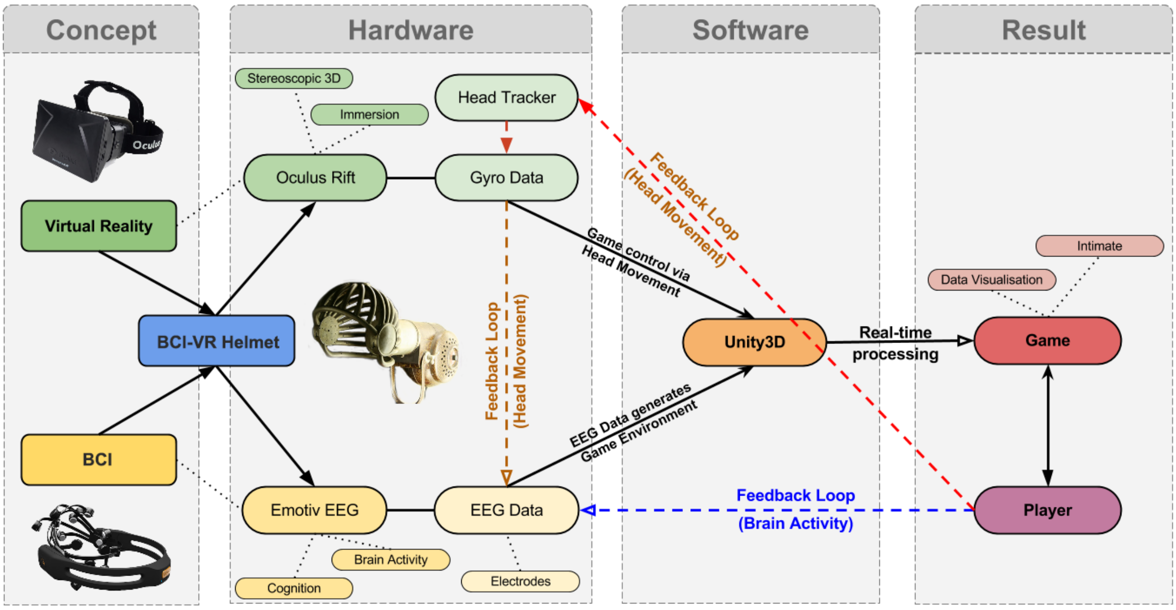

Figure 33 - RYM Concept

4.1.1 CONCEPTUAL GAMEPLAY

Next to this technical approach, the concept of Ride Your Mind also involves a strong artistic approach. The aim of RYM is to imbue the player with an awareness of his or her own brain as a consciously controllable tool, similar to, for example, the hand. Within the gameworld of RYM, the player will be enabled to consciously face his subconscious. It achieves this aim by forcing the player's conscious acts into competition with his subconscious acts; the player receives direct neuronal feedback, which makes his or her unconscious brain activity visible, thereby eliciting a whole new sensation of self. This reciprocal chain reaction will predictably be impossible or hard to control in the beginning, but become easier and easier to manipulate (hack) over the course of repeated play. "Players should work toward finding the right activities to succeed in the game" (Gürkök et al. 2015, p.11). The player of RYM will have to *learn* how to do so. Once they master the game disruptions triggered by their brainwaves, players will gain a new and different awareness of their brain. To overcome the game's feedback loop, the player must hack and/or cheat (cf. Consalvo 2007) his way into gaining conscious physical control

[21] A further discussion on security issues of BCI technology can be found in chapter 6.1.7.

over a game initially controlled by his subconscious. The reciprocal chain reaction is the main artistic message of Ride Your Mind and will be further discussed in chapter 7.

At the same time, the virtual reality environment designed as a *void*, inspired by the game flOw (Sony Computer Entertainment 2006) (figure 34), allows the player to interact by moving his or her head, which, in turn, triggers further brain activity. RYM's game design includes the idea to put the player into a state of flow (Sweetser & Wyeth 2005; Chen 2007). The research on flow in games relies on the more general flow theory proposed by psychologist Csikszentmihalyi (1990). The flow state (from a game design perspective) describes an ideal state between anxiety and boredom within a gameful situation. Ride Your Mind wants to use neurofeedback to detect affective mental states such as anxiety and boredom (calculated with EEG)[22] in the player to keep the player in a flow state by constantly adjusting and manipulating the BCI gameplay.

Figure 34 – flOw (2006)

While playing the game RYM and flying through a visual representation of the human brain generated by brain activity, incrementally environmental effects and objects inside the gameworld get spawned to keep the player in the flow state. At the beginning of the game there will be a playable but hidden tutorial. This tutorial is mandatory in order to train cognitive actions and will be explained in detail in section 5.4.1. Several visual stimuli will be shown that trigger in-game actions, such as boosting the player and temporally increasing his movement speed. While the player is navigating through the void of RYM with the help of the VR-Headset, the movement speed of the player is influenced by his concentration level, which is calculated with the help of the EEG data. When the player is concentrated and the calculated value is high the movement speed is increased. When the player's concentration level is low, the movement speed is decreased. Within the gameworld several visual effects that are directly related to his EEG data recorded by the BCI-Headset will guide the player through the game. The coordinates of spawned objects or effects always lie in front of the player and are orbitally randomised to his current position within the void. Furthermore, the colour and the shape of the effects and/or objects are influenced and altered by neurofeedback. Particle effects within the game environment for example visualise the activity of each single electrode (raw values) of the BCI-Headset but also use the player's affective mental state, such as concentration and meditation level or relaxation. The colour of the game environment is influenced by the player's relaxation level. When the player is relaxed the environment turns green. When he is stressed it turns red. The polygons of

[22] Several BCI paradigms have been introduced in chapter 3.

the geometrical meshes that form the gameworld get procedurally deformed by raw EEG values. At the end the pitch of the in-game sound gets manipulated by the concentration level of the player. When the player's concentration level calculated with the help of EEG is high, the pitch of the sound gets increased. When the concentration level is low, the pitch gets decreased.

Affective mental state (EEG – Emotiv BCI)	**Gameplay/gameworld mechanics**
Concentration level high	Increase player's movement speed
Concentration level high	Increase pitch of the sound
Concentration level low	Decrease player's movement speed
Concentration level low	Decrease pitch of the sound
Relaxation level high (relaxed)	Gameworld turns green
Relaxation level low (stressed)	Gameworld turns red
Raw EEG data (Emotiv BCI)	**Gameworld mechanics**
Raw EEG data – single electrodes	Particle effects (gameworld) visualise activity of each single electrode (BCI Headset)
Raw EEG data values	Procedurally deform geometrical meshes of the gameworld

Table 2 - Ride Your Mind Conceptual BCI Gameplay

The described gameplay features that are influenced or altered by EEG will hereafter be defined as BCI gameplay elements of Ride Your Mind. The following figure (35) illustrates a prototype of the visual design of the affective BCI-VR Game Ride Your Mind (VR view).

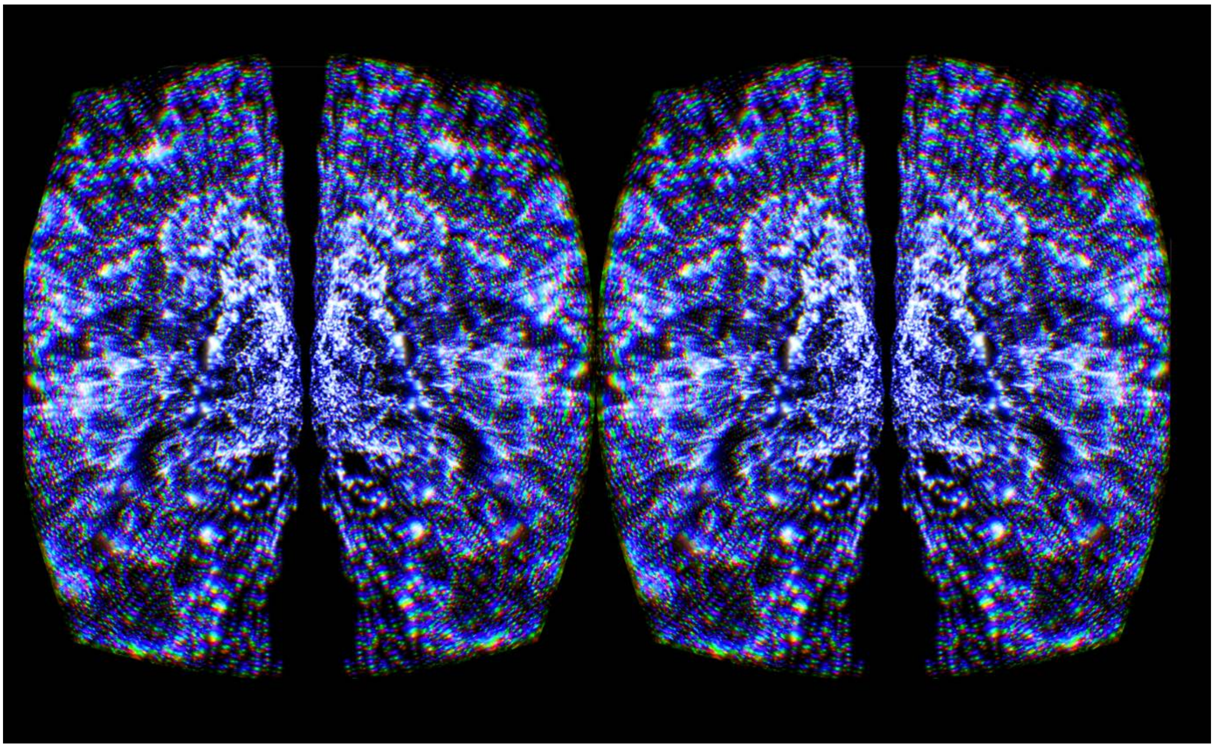

Figure 35 - Ride Your Mind – in-game screenshot of the game prototype

4.2 RYM BCI-VR HELMET

Before I began prototyping experimental BCI games, I playfully explored the hardware components to be used. I first examined the existing functionality and tested a variety of demo content provided by the hardware manufactures of the BCI-Headset, the Virtual Reality HMD and first community projects in 2013. The next step was to connect the emerging technology to the game engine Unity3D. After successfully establishing a connection between the two devices and the software I started experimenting with small gameplay prototypes. These prototypes used hardware functionality such as the head tracking of the HMD and the neurofeedback data (EEG) provided by the BCI. The first prototypes were based on already existing plugins by Emotiv and Oculus for Unity3D. I will now describe the consumer devices that were used to realise the concept of Ride Your Mind, beginning with the Emotiv EEG BCI-Headset.

4.2.1 BCI GAMING HEADSET

Figure 36 - Emotiv BCI-Headset

The Emotiv EPOC EEG Headset (figure 36) holds 14 electrodes that need to be carefully moistened before use. These sensors detect EEG signals and send them to the connected computer via Bluetooth. The software provided by Emotiv displays the data as waves. The data can of course also be used to control games or other applications. The Emotiv EEG headset allows for a variety of EEG data that can then be used or interpreted by further software. The BCI-Headset is used to “sense” EEG data. This data is then processed by a specially developed EEG toolchain which is described in the following section. The toolchain translates the EEG data into commands that are received by the Unity3D game engine. Within the game engine these commands are then used to trigger several gameplay elements but also to influence the game environment. A comparison between other existing BCI-Headsets can be found in Nijboer et al. (2015).

4.2.2 VIRTUAL REALITY HEADSET

Over the last years, virtual reality (VR) has experienced a renaissance set in motion by Palmer Lucky's 2012 Kickstarter campaign[23] to finance the Oculus Rift Head-Mounted Display (HMD), a device designed for gamers and gaming purposes. In 2014 the Oculus was bought by Facebook and the first consumer version of this HMD was is used at the beginning of 2016. The concept of Ride Your Mind uses the Oculus Rift Development Kit (DK) 1 and 2 to playfully hack, explore and design the game. The first attempts and prototypes (VOID series) made use of the Oculus HMD's DK1. This was later replaced with the DK2, which featured more accurate head tracking and was easier to implement in the Unity3D game engine. As the Virtual Reality Headset was not the key device to concentrate on, this change from DK1 to DK2 did not affect any major features of Ride Your Mind.

Figure 37 - Oculus Rift DK1 HMD (2013)

[23] More information can be found online at: https://www.kickstarter.com/projects/1523379957/oculus-rift-step-into-the-game.

Figure 38 - Oculus Rift DK2 HMD (2014)

The combination of virtual reality and BCI gaming offers certain advantages. VR offers complete visual immersion for the user and eliminates the visual connection to the real world. This in turn lets the user focus on the visual immersion.

4.2.3 NOISE-CANCELLING HEADPHONES

To also eliminate potential audio interference and achieve a more complete immersion situation for the potential player of Ride Your Mind, the concept includes active noise-cancelling headphones. This also reduces distractions from the surrounding (real) world. As the noise-cancelling hardware is only used to play sounds, and thus only employed passively, there is no need to outline it in further detail.

Figure 38 – Active noise-cancelling in-ear headphones

4.3 APPLICATION OF HACKING DESIGN ELEMENTS

All of the four identified strategic design elements of hacking (see section 2.5) – addition, appropriation, expansion and disruption – have been carefully applied to the RYM concept. This section will explain how each of the elements has been applied to the concept of the BCI-VR game Ride Your Mind and as such provide an answer to the second research question of this exegesis. In the following I will outline how each element has been applied.

4.3.1 ADDITION

By adding parts borrowed from different technologies, hackers were essentially hacking the existing technological base. This type of behaviour constitutes the first design strategy employed by the MIT hackers of the late 1950s: addition. When they were introduced to the first programmable data processors – i.e. computers – these early hackers transformed their enthusiasm for improving model railroads into a playful design strategy. Because they did not understand computers as military machines, as their inventors did, they started to play with them and, in the process, discovered their other powers and potential uses.

In this historical hacker spirit, I started to combine different technologies to create a prototype of a completely new device: the BCI-VR Helmet. The conceptual helmet is composed of the Emotiv BCI-Headset, the Oculus Rift Virtual Reality Headset and noise-cancelling headphones. The idea of adding together these various elements originated from the obligatory situation that the player of RYM has to wear all these devices while playing. The following figure (40) illustrates the components of the conceptual prototype of the BCI-VR Helmet. The design of the helmet is inspired by steampunk. As part of this work I also created 3D models of the helmet and 3D printed first prototypes. A detailed overview of the creation process can be found in the next chapter (5).

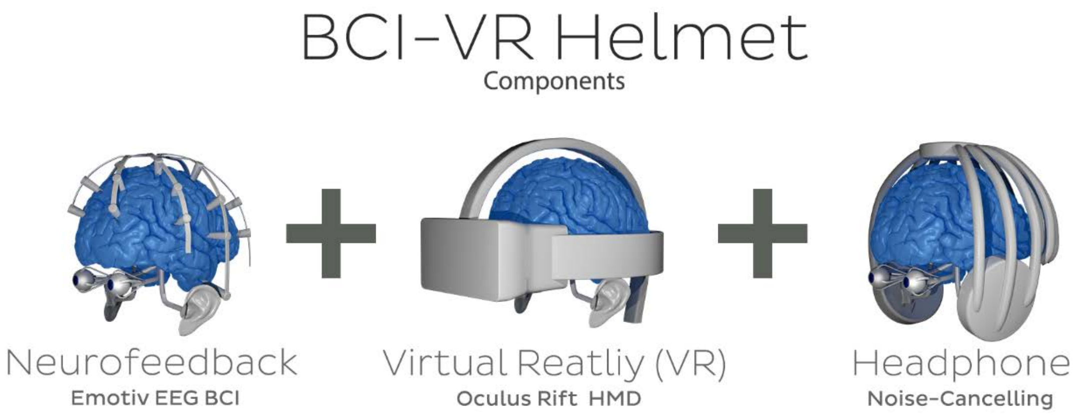

Figure 39 - RYM - BCI-VR Helmet Components

The sensors integrated in the Emotiv BCI collect EEG data, which is then processed by a specially designed EEG toolchain[24] and sent to the game engine. The data is used to generate an immersive real-time environment and to trigger the BCI gameplay. The game environment is displayed in stereo-3D on the Oculus Rift Head-Mounted-Display (HMD), which simultaneously serves as second input device. The player navigates in the gameworld of RYM through his head movement. The HMD provides a fortunate advantage, in that the user is isolated from the real world while wearing a Virtual Reality

[24] The EEG toolchain is described in section 5.3.

Headset. The HMD and the noise-cancelling headphones are intended to help users become fully immersed in the virtual reality controlled by the data collected from their brain and physical actions.

4.3.2 APPROPRIATION

The hackers were successful in their efforts to expand the function of computers into the entertainment sphere (cf. Pias 2002a; Pias 2002b). As a result, they were able to present the technology of digital computers to the public in a different, non-military context. From that moment on, the computer was no longer perceived as an indefinable technological oddity. The recontextualisation of the technology transformed the computer from a war machine into an entertainment machine. The hacks of the MIT students provided the machine with new content, and this content, in turn, drove the development of the machine. Inspired by the pleasure of playing with a new technology, the hackers built programs that helped that technology evolve. Over time, they grew more and more aware of how important their work was becoming. Pias (2013) compares their act of recontextualisation with appropriation art, as described in section 2.4. It is precisely this act of recontextualisation that constitutes hacking's second design strategy: *appropriation*.

Running a game generated by neurological data in real time, such as RYM, requires knowledge gleaned from medical and BCI research and neuroscience. The ongoing research on brain functions as well as BCI technology means that knowledge in these research fields is continuously increasing. Driven by this progress, BCI-Headset manufacturers such as Emotiv and Neurosky are now enabling consumers to have access to BCI technology. This availability of BCI as consumer products enables game designers, for example, to work with BCI technology. The price for an Emotiv EPOC EEG Headset is around 1,000 USD, which is relatively inexpensive compared to medical research devices.

The artistic and experimental BCI-VR Game Ride Your Mind itself entails a recontextualisation of medical and BCI research knowledge into a gaming and art context. Just as hackers transformed military devices into entertainment devices, RYM uses knowledge and devices influenced by the medical world to create an artistic and experimental form of entertainment. The technological progress of BCIs is a growing field in HCI. The research on BCIs is driven by interdisciplinary work that involves knowledge from neuroscience and computer science. By combining knowledge from neuroscience and medical research I created the concept for the game. As it turned out, the technological possibilities provided by the BCI-Headset are not comparable to medical BCIs. But I was able to use the features of the BCI-Headset and expand them with features provided by an EEG toolchain specially developed by KIT TECO's computer scientists.

4.3.3 EXPANSION

Through their actions, hackers were able to expand their field of operation to systems with new layers of possibilities. By competing with the boundaries of computer systems, they were able to create tools and open up new dimensions of interaction. At the same time, they were forced to confront ever tightening boundaries as the software security industry became larger and stronger (Schwingeler 2014, p.15). But it wasn't just the software security industry; many other intervening forces influenced the evolution of the hacker. As Pias explains, the boundaries that hackers come up against – and, when successful, transgress – are often created by hackers themselves (Pias 2002b, p.262). The demands of ongoing invention and confrontation require hackers to expand their field of operation. They must find new ways of interacting with the boundaries they're constantly pushing. To confront these boundaries, they must expand their current sphere of activity. By devising and employing an expanded toolset, a hacker is able to think in several dimensions and thereby playfully challenge existing barriers.

The tracking feature of the HMD recognises the user's head movements and serves as a controller for the game. When the user moves his head to control the game, he triggers neuronal data in the motoric sector of his brain, which in turn triggers neuronal data (EEG) that has a direct effect on the game. The interactive journey through the user's mind is controlled by his body and generated by his mind. This expansion converts subconscious neurological activity into an entire gameworld. The generated visualisation is an ongoing feedback loop. Every conscious action of the player in the game causes an instant neurological action in his brain. Further, every neurological action in the player's brain causes an action inside the game in real time. It is an endless feedback loop that the designer of the game needs to consider carefully. This is one of the main differences of BCI game design compared to traditional game design, and it illustrates the need for an expansion of the toolset of game design. The transgression of this boundary opens up a new dimension for game design and expands its possibilities[25].

4.3.4 DISRUPTION

One possible way to overcome boundaries is to commit an *illicit* act, which is not the same as committing an *illegal* act. An illicit act is an act of rule-breaking conducted in the spirit of the spoil-sport, as described by Huizinga (1949) in *Homo Ludens*. The challenge of overcoming the boundaries of a system forces hackers to break rules in either an ethical or an unethical way. In the case of Huizinga's spoil-sport, this means hackers are able to transgress the defined rules of a given system in a way that directly initiates its collapse (Huizinga 1949, p.11). Taking a step across a boundary within or beyond a system context provides hackers with different points of view, thereby opening up countless hitherto unimaginable possibilities. Often, there is no need to collapse the system in order to overcome a boundary, only to disturb it. This type of disruption is comparable to the artistic strategies described by Schwingeler (2012) – that is, those strategies that manipulate the "material of computer games" (Schwingeler 2012, p.61, translated from the German). Disruption, in other words, is an artistic strategy that can be used to approach digital games, a way for hackers to continually confront their procedural boundaries.

RYM is designed to provide a unique gaming experience time after time. In the beginning, the user will not be able to control the game; he will have to *learn* how to do so. Once he becomes master of the game disruptions triggered by his brainwaves, he will gain a new and different awareness of his brain. To overcome the game's feedback loop[26], the player must hack and/or cheat (cf. Consalvo 2007) his way into gaining conscious physical control over a game initially controlled by his subconscious. This is a very intimate and highly private action.[27] It is the task of the player to master the game and to enhance his brain activity to the point where he can consciously control the EEG signals. This feature was part of RYM's concept, however due to the lack of precision of the consumer BCI-Headset it proved impossible to implement this feature in the final prototype of the game. Further issues with BCI technology will be discussed in chapter 6 of this doctoral exegesis.

At the end of the design process, I decided to refrain from working with data from the BCI-Headset. One could argue that the main feature of Ride Your Mind is therefore missing, and this would be technically right. But from my perspective as a hacker and practising media artist, it is not. Instead of using data and values from the BCI-Headset, RYM now makes use of randomly generated, or cheated values to generate the gameworld and to trigger the (BCI) gameplay. Potential users of RYM of course have to wear the BCI-Headset nonetheless, in order to obtain the illusion of being controlled by

[25] Further discussed in section 7.8.2.
[26] Further discussed in section 6.1.6.
[27] Security issues with BCI technology are described in section 6.1.7.

neurofeedback. The artistic strategy and art historical references describing this disruption are discussed in chapter 7 of this doctoral exegesis, which discusses and reflects on the artistic research project Ride Your Mind.

4.4 CONCLUSION

Ride Your Mind (RYM) is a concept for a singleplayer affective BCI-VR game generated by neurofeedback using a head-mounted display (HMD) to compute a playable visualisation of neurological signals collected by a consumer grade BCI-Headset (Emotiv EPOC EEG). The combination of these various technologies has produced the concept of the BCI-VR Helmet. All four identified design elements of hacking – addition, appropriation, expansion and disruption – have been successfully applied to the artistic game concept. Ride Your Mind involves a strong artistic approach which will be further outlined in chapter 7. The aim of RYM is to imbue the player with an awareness of his or her own brain as a consciously controllable tool, similar to, for example, the hand. The player of RYM will be enabled to consciously face his subconscious within the gameworld. After creating the concept of RYM, I started hacking the BCI gaming and VR technology, and then created the first BCI and VR game prototypes, which will be described in the following chapter (5).

5 DOCUMENTATION

This section documents the practical work on hacking BCI gaming and VR technology and later playfully prototyping BCI and BCI-VR games. Hacking the technological components also includes the software that bridges the Emotiv BCI-Headset (BCI) and the game engine (Unity3D). A software solution was developed in cooperation with the Karlsruhe Institute of Technology's (KIT) TECO research group as an open source EEG toolchain for future BCI game designers. Further video material is linked in the footnotes.

5.1 RYM BCI-VR HELMET PROTOTYPING AND HACKING

The combination of the different devices and technologies created a new conceptual hardware device: the BCI-VR Helmet. The consumer grade BCI-Headset that is used is not nearly as sophisticated as professional BCIs used in the medical or research world. This issue informed the design decision to make the BCI-VR Helmet isolating, in order to reduce EEG signal artefacts or disruptions, which can be seen as a hack to overcome the limits of the consumer grade BCI technology.

5.1.1 EXPERIENCING VR WITH NOISE CANCELLATION

The following figures (41-45) illustrate the conceptual and physical prototyping of the BCI-VR Helmet. First I began to experiment with a pilot helmet to experience the isolating effect of noise cancellation in combination with the Virtual Reality Headset – the Oculus Rift DK1. The following picture shows me wearing the devices and playing a virtual reality prototype of the VOID Series. The experience was highly immersive as I navigated the virtual void by moving my head. This small experimental setup helped me to successfully test and experience the chosen technological combination of VR and active noise cancellation.

Figure 40 - Experimental setup of VR in combination with noise cancellation

5.1.2 COMBINING BCI GAMING AND VR TECHNOLOGY

After having successfully tested the first pair of chosen technologies I began to examine and experience a combination of the Emotiv EPOC BCI-Headset and the Oculus Rift DK2 VR HMD. The first tests consisted of simply strapping on the VR Headset first and then placing the BCI-Headset on top. The difficulty consisted in making sure the electrodes of the BCI-Headset touched my scalp and established a proper connection. When wearing the VR Headset, the field of vision is completely shielded. Overall this setup is experimental and not consumer ready. The following figures show me wearing both devices, thus presenting the technological prototype of the BCI-VR Helmet.

Figure 42 - Combining BCI Gaming and Virtual Reality Technology

Figure 41 - BCI-VR Helmet - Technological prototype setup

The final technological prototype of the BCI-VR Helmet required to experience the BCI-VR Game Ride Your Mind is composed of three different devices in total. Firstly, an Emotiv EPOC EEG BCI-Headset, secondly, an Oculus Rift Virtual Reality HMD, and thirdly, noise-cancelling in-ear headphones. All three components of the BCI-VR Helmet are shown in the following figure (44).

Figure 44 - BCI-VR Helmet – Technological Components

5.1.3 STEAMPUNK ART SCULPTURE

The visual appearance of the potential new piece of hardware is inspired by steampunk. Steampunk follows design strategies that are related to hacking. In particular, to the first and second design elements of hacking: addition and appropriation. On a flea market in Germany, I found an antique hair dryer (approximately from the 1920s) that was originally connected to a stovepipe and operated with hot air. I used this object and with the help of ingredients from a hardware store converted it into an artistic steampunk-influenced prototype for the conceptual BCI-VR Helmet.

Steampunk is defined through do-it-yourself craftsmanship (Donovan 2011), which means that a steampunk artist uses ingredients or parts from everyday life objects to achieve a unique look. Further, the steampunk artist recontextualises these original objects and places them into a different setting to realise a fantasy design. Steampunk artists can thus be defined as hackers. Both love playful tinkering with different types of technology to achieve innovative and artistic results. With this analogy in mind, I decided to use a steampunk design approach for the BCI-VR Helmet.

Steampunk relies on the visual appearance of technology from nineteenth-century Victorian England. These “fantastic steam-powered machines” and “surreal electro-mechanical contraptions” are often mixed with state-of-the-art technology (Donovan 2011, p.24). Donovan explains that the first part of the word steampunk – steam – refers to the visual appearance of steam-powered machines, and the second part – punk – to the do-it-yourself attitude of the engineer, artist or designer of steampunk (Donovan 2011, p.24). In the context of gaming there are several examples, such as BioShock Infinite (Games 2013), Machinarium (Amanita Design 2009), Thief (Square Enix 2014), or films like *Wild Wild West* (1999), *Sherlock Holmes* (2010) or *The League of Extraordinary Gentlemen* (2003) that are based on the idea of steampunk. But the greatest contribution to the development of the steampunk movement comes from its vast fan base, especially cosplay enthusiasts, and the tinkers among them.

The decision to make an art sculpture of the BCI-VR Helmet was motivated by the desire to create a piece of technology that would attract attention. The steampunk version of the BCI-VR Helmet looks very martial and experimental (figure 45 & 46). Viewing the device, one is likely to identify it as a brain interface from the last century which is recycled to enable potential users to play the artistic and experimental BCI-VR game Ride Your Mind. The intention behind the design was to attract attention and at the same time shock spectators by making them think about wearing such a device and playing a game that simulates the player's mind.

Figure 42 - Art sculpture of the BCI-VR Helmet - side view

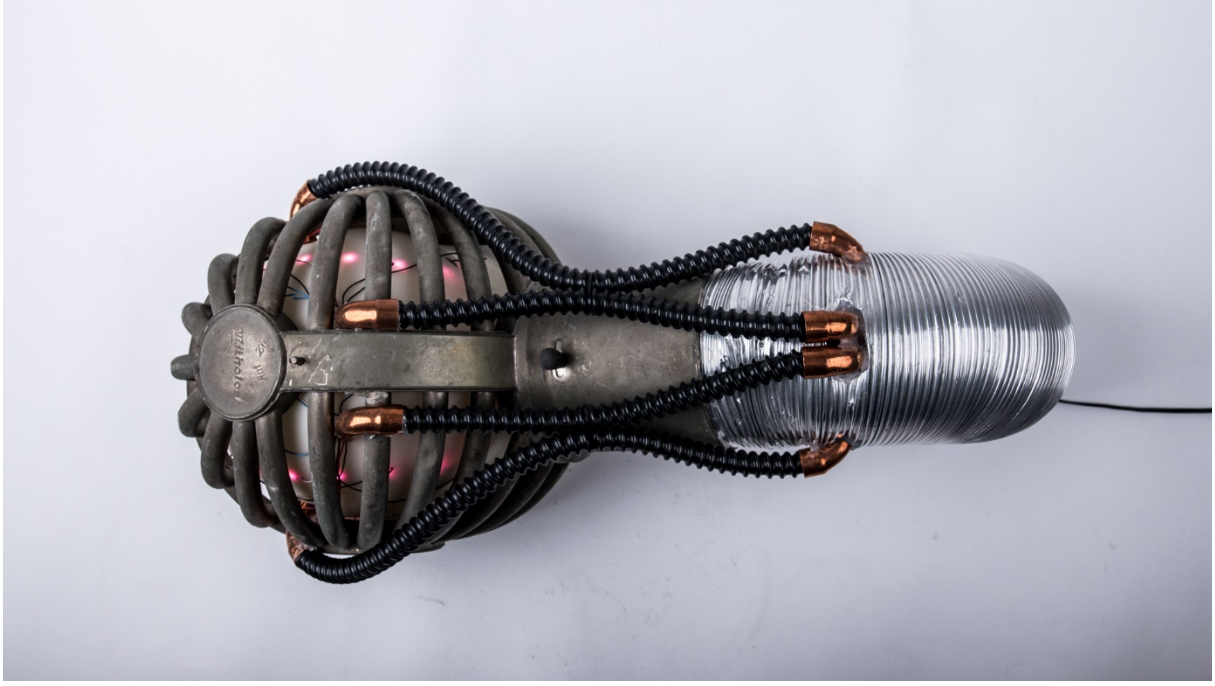

Figure 43 - Art sculpture of the BCI-VR Helmet - top view

5.1.4 STEAMPUNK ART & TECHNOLOGY

The next step after the creation of the art sculpture of the BCI-VR Helmet was to combine it with the technological components. The next figure (47) shows the different devices and objects that are combined and placed on top of my head in the figures that follow it (48-49).

Figure 44 - BCI-VR Helmet - Steampunk Prototype, BCI-Headset and VR-Headset

Figure 45 - Conceptual Physical Prototype of the BCI-VR Helmet

Figure 46 - Conceptual Physical Prototype of the BCI-VR Helmet

5.1.5 VIRTUALLY PROTOTYPING

Having physically created a working and artistic prototype, the next step was to create a virtual prototype of the BCI-VR Helmet to illustrate and communicate the idea behind it better. The steampunk art sculpture and the technological devices of the BCI-VR Helmet served as design inspiration for the virtual prototype shown in the following series of figures.

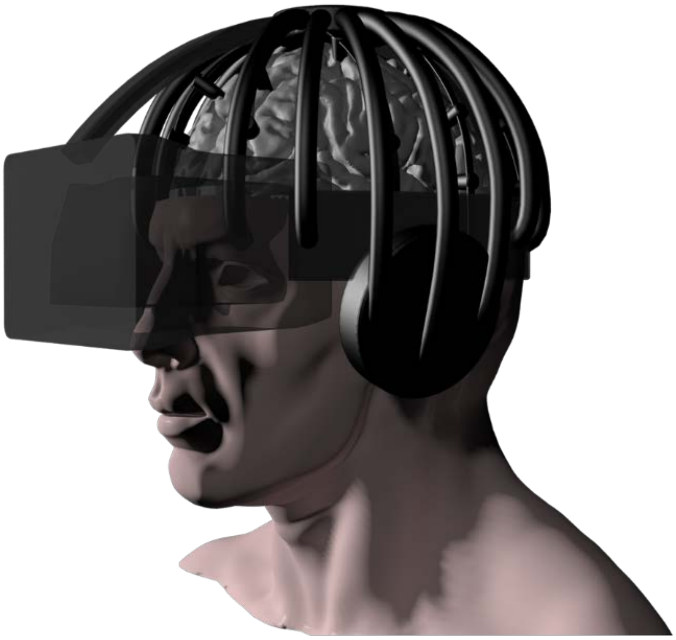

Figure 47 - Virtual Prototype of the BCI-VR Helmet

As outlined in the previous section, the design process of the BCI-VR Helmet was based on the first design strategy of hacking: addition.[28] In order to properly communicate the idea and the concept of the BCI-VR Helmet, the following figure highlights the three different technological components that form the helmet.

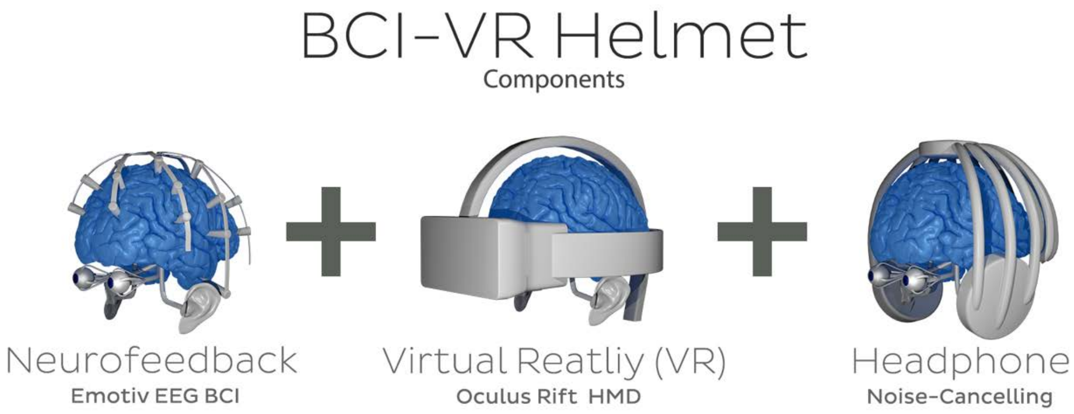

Figure 48 - BCI-VR Helmet – Components

The following figure (52) shows a combination of the technological components and the final virtual concept of the BCI-VR Helmet[29] required to play and experience the artistic and experimental BCI-VR Game Ride Your Mind.

Figure 49 - BCI-VR Helmet - Concept 3D rendering

[28] The manner in which the first element of hacking was applied to the concept is outlined in section 4.3.1.
[29] An animation illustrating the combination of the different components of the BCI-VR Helmet can be seen here: https://www.youtube.com/watch?v=Cjz0BhSfKBA

5.1.6 HARDWARE COMMUNICATION ARCHITECTURE

The virtual BCI-VR Helmet was not merely designed to serve as an art sculpture and attract potential players. The idea behind the experimental and hackish device also includes a technological and BCI-VR gaming related component. The following figure (53) explains the hardware communication architecture of the BCI-VR Helmet. As such the figure illustrates the functionality of the virtual but also the technological prototype of the helmet.

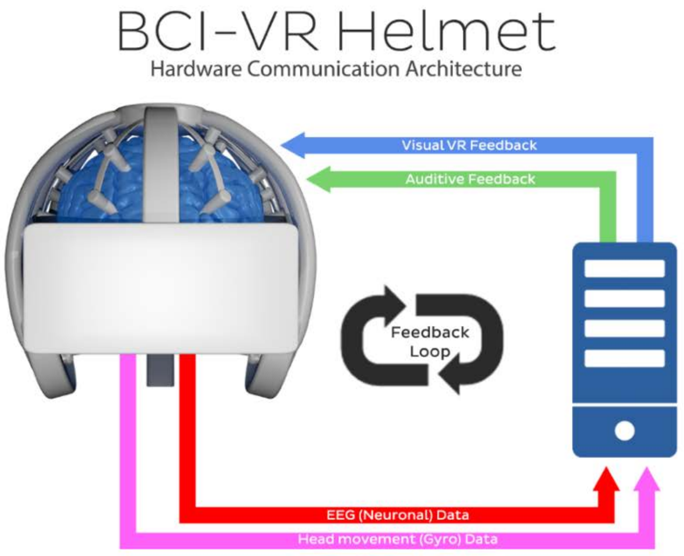

Figure 50 - Hardware communication architecture of the BCI-VR Helmet

5.2 VOID SERIES: EXPERIMENTAL (BCI-VR) GAMES

The act of hacking (i.e. artistically, playfully and experimentally examining) BCI games involved the creation of experimental gameplay prototypes for further research and the hacking of interaction and input possibilities of BCI and VR hardware. These experimental prototypes are named VOID. They are based on the methodology of hacking as a game design strategy. "In particular, game design research will often use explorative and interpretative experiments rather than classical controlled scientific experiments" (Waern & Back 2015, p.363). Furthermore, it was necessary to explore the potential of the consumer BCI technology to experience possible gameplay paradigms. VOID was used to benchmark the single gameplay and input paradigms of potential BCI games but also virtual reality with a view to the creation of the experimental and artistic BCI-VR game Ride Your Mind. The prototypes were designed with the game engine Unity3D, the visual scripting tool Playmaker, the Oculus Rift plugin for Unity3D and the Emotiv plugin for Unity3D. In this section, the design process of the game on the basis of this framework will be explained in detail.

Ride Your Mind offers a new gaming experience. The user tries to control the game with his head movements and by making conscious gameplay decisions, all while operating in a gameworld generated by his subconscious as it reacts to the conscious gameplay decisions. The artistic game RYM compels the player to discover his brain as a tool that he can and must learn to control to be able to master the game itself.[30]

[30] The game concept or RYM is described in section 4.1. The artistic elements and hacks used in RYM are outlined in 7.8.

The following table (3) gives an overview of the different prototypes that were designed, as well as two further experimental prototypes, including a description of the gameplay features that were tested.

V:O:I:D Version Tag	Short Content Description	Fundamental Prototype Settings (YES/NO) Graphics (2D/3D), Visualisation (V), Physical Interaction (PI), Mental Interaction (MI), Gameplay (G), Virtual Reality (VR), Affective Data (A), Cognitive Data (C), EEG Raw Data (R)									Gameplay Elements / Interaction Possibilities AE (Affective controlled Environment), AO (Affective controlled Objects) EEGE (EEG controlled Environment), EEGO (EEG controlled Objects) CHM (Controls by Head Movement - only VR), Random Events (RE)								Affective Data from Emotiv Software ("A_") Med (Meditation), Fru (Frustration), Bor (Boredom), STE (Short Term Excitement), LTE (Long Term Excitement)				
		2D/3D	V	PI	MI	G	VR	A	C	R	AE	AO	EEGE	EEGO	CHM	RE	..	...	A_Med	A_Fru	A_Bor	A_STE	A_LTE
VOID_A01	Med, Fru, Bor, STE, LTE values represented as sliders from 0 to max	2D	X	-	X	-	-	X	-	-	-	X	-	-	-	-	-	-	X	X	X	X	X
VOID_AV01a	2D visualisation of Fru (blue dots) and STE (red dots) over time. Generates moving diagram	2D	X	-	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-	X	-	X	-
VOID_AV01b	Circular visualisation of Fru (blue balls) and STE (red balls). A Mandala like 2D shape gets generated over time	2D	X	-	X	-	-	X	-	-	-	X	-	-	-	-	-	-	-	X	-	X	-
VOID_AV02a	Flight through VOID. Blue balls (Fru) and red balls (STE) are spawned in the 3D VR space. Balls generates 3D Helix shape/level	3D	X	X	X	-	X	X	-	-	-	X	-	-	X	-	-	-	-	X	-	X	-
VOID_AV03a	Flight/Movement speed through VOID is controlled by affective value (Fru). Environment generated by values of Fru+STE. Circular Spawn while movement generates 3D Tunnel	3D	X	X	X	X	X	X	-	-	X	X											
VOID_AV04a	Two materials change their color (RGB values) according to the affective data of the frustration, boredom and short time excitement values	3D	X	X	X	-	X	X	-	-	-	X	-	-	X	-	-	-		X	X	X	

Table 3 - VOID: BCI Gameplay Prototypes

5.2.1 GAMEWORLD PROTOTYPES

The first games of the VOID series were gameworld prototypes. These prototypes also tested the continuous movement of the player through the designated endless void. The player moves at a constant speed through a visualisation of his brain consisting of neurons. In the first prototype, navigation was enabled with the help of a computer mouse and mouselook functionality. In other words, the movement of the mouse was translated into control signals to enable a free look and feel for the player. According to their point of view, players were continuously moved forward through the void. This first prototype was necessary to test the basic idea of having the player fly through the visual representation of his brain, thereby provoking a state of flow (Csikszentmihalyi 1990; Sweetser & Wyeth 2005; Chen 2007) formed by the BCI gameplay that will be explained later in this document. The following figure (54) depicts one of the first prototypes of the VOID series (see video material).[31]

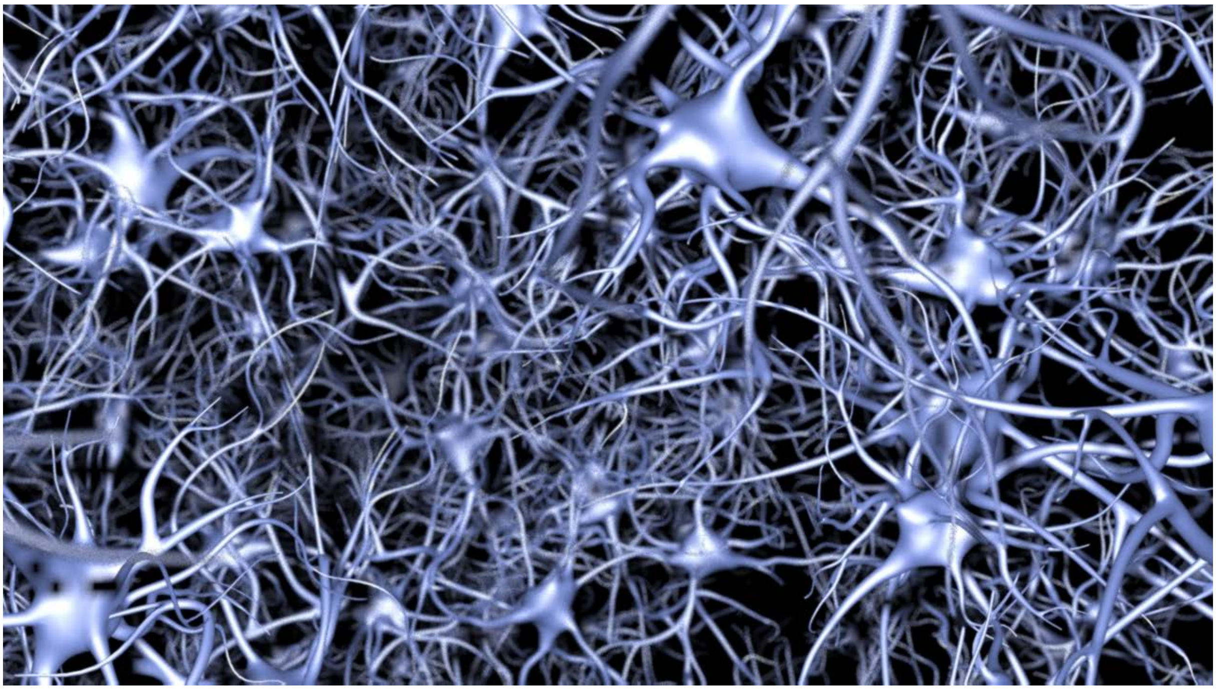

Figure 51 – VOID: Prototype with mouselook

[31] A video illustrating the experimental gameworld with neurons can be accessed online: https://www.youtube.com/watch?v=1UMdRkJiB5Q

5.2.2 VR GAME PROTOTYPES

The next step was to integrate the Virtual Reality Headset and its input and output functionality. This was achieved by integrating the freely available Unity3D plugin for the Oculus Rift Virtual Reality Headset. The plugin offers a template for a preconfigured stereo 3D camera setup which enables stereoscopic vision output on the device. It also enables the integrated gyroscope of the headset to translate the player's head movement into the virtual world. This gives the player a natural sense of controlling the field of vision inside the gameworld.

After having successfully established the technological features of the VR-Headset, I began designing the first experimental gameplay prototypes. The mouselook feature was replaced with the gyroscopic feature of the VR-Headset. The player could now steer through the natural movement of his head. Within the concept of Ride Your Mind this input is the only non-neurofeedback input functionality of the BCI-VR game. To test the virtual reality setting in combination with the existing gameworld, I replaced the neuronal structure with spheres so as to reduce the workload for the computer and support direct visual stereo 3D feedback. The next figure (55) shows a VR prototype of VOID.

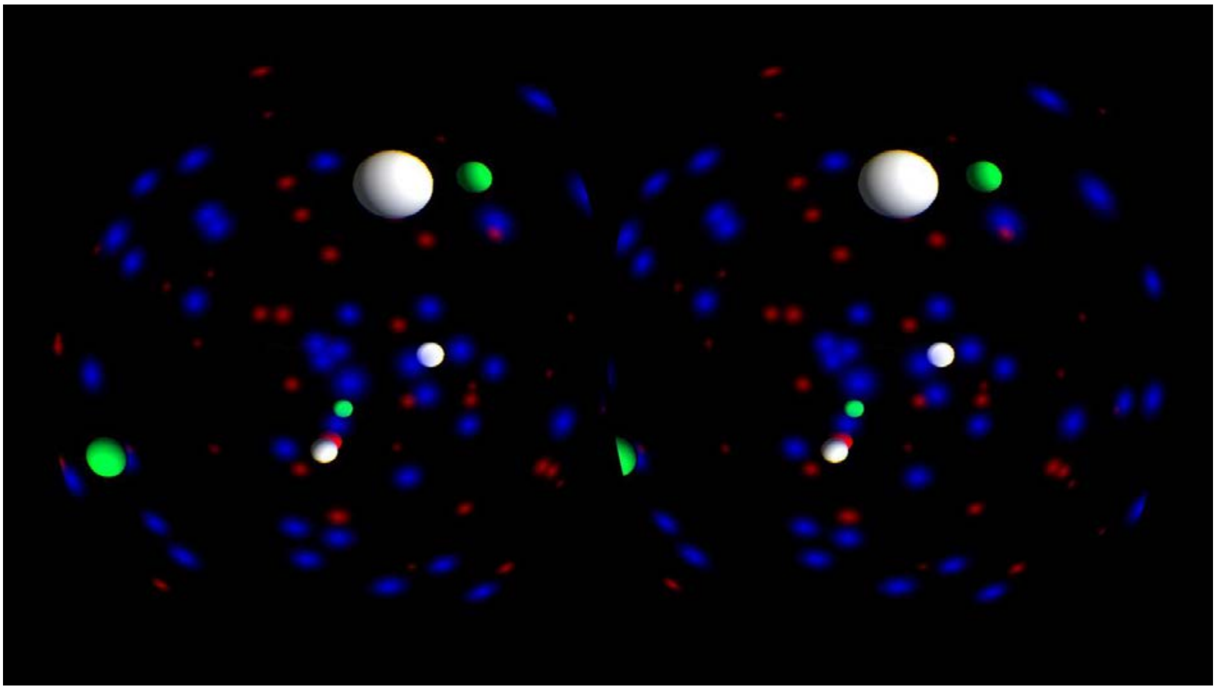

Figure 52 – VOID: VR Prototype

In the VR prototype of VOID the player moved through an endless void at a constant speed. The player was able to change direction by moving his head. The gameworld was randomly created. The spheres appear in front of the player, with each colour modifying the player's speed differently. By flying or steering through a sphere, the player activates a multiplier that affects his speed. As a result, the sphere will explode and create environmental effects. Every play session of this prototype creates a unique experience and environment for the player. This was another crucial part of the concept of Ride Your Mind's game design.

The next VOID VR prototype examined randomly created and influenced environmental effects. Later this technical framework based on randomness was to be changed to environmental effects influenced and controlled by neurofeedback. The following two figures (56 & 57) show particle effects randomly created according to the player's point of view.

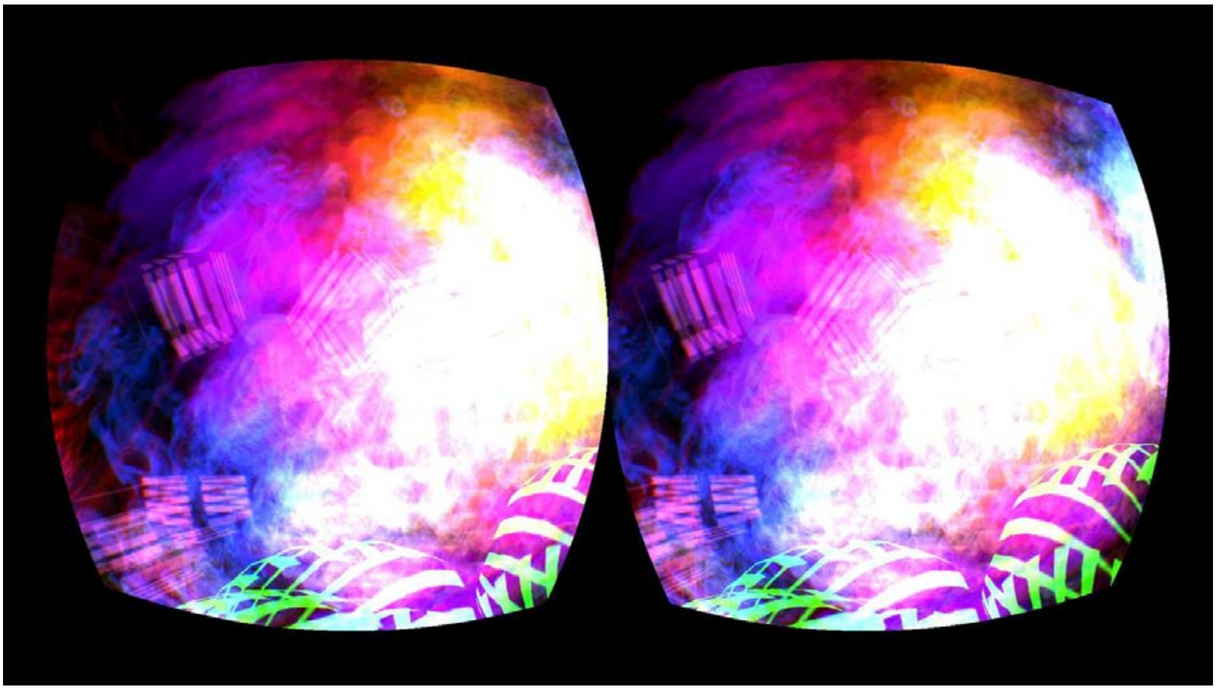
Figure 53 - VOID: Randomly triggered environmental effects

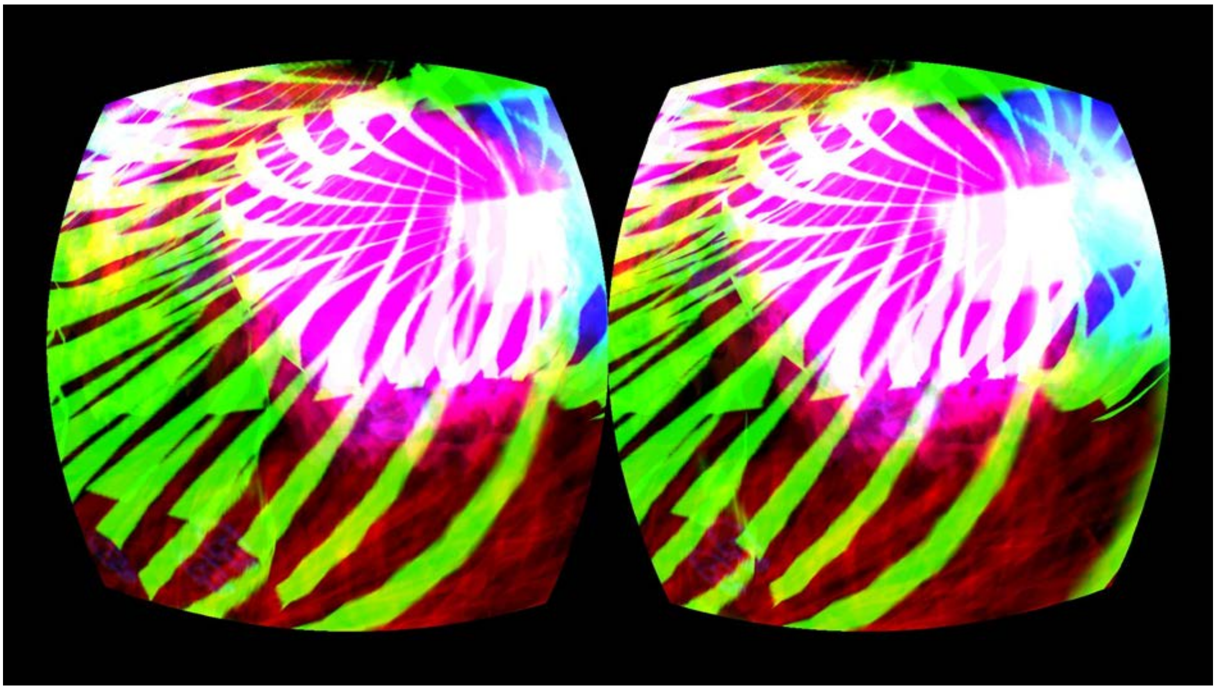
Figure 54 - VOID: Randomly triggered environmental effects

5.2.3 BCI GAME PROTOTYPES

After successfully implementing the virtual reality functionality, testing certain gameplay paradigms and creating the randomly-based gameplay framework, I started to work with the Emotiv BCI-Headset. The next technological step was to integrate the neurofeedback of the BCI-Headset with the help of an existing plugin developed by Emotiv for Unity3D. Additionally, the plugin requires the Emotiv Control Panel in order to run. Additional video material of the prototypes is linked in the footnotes.

The first prototype of VOID (VOID_A01) with neurofeedback functionality was a simple test scene running in Unity3D with access to the data provided by the Emotiv BCI-Headset, which included no actual gameplay. As such a small test scene was created that showed the values for Meditation, Frustration, Boredom, Short Time Excitement and Long Time Excitement accessible via the Emotiv plugin in Unity3D as sliders from zero to a maximum value. These affective states are comparable to the EEG paradigms listed in chapter 3.

The second prototype (VOID_AV01a[32]) also did not include actual gameplay. It places red and blue dots on a two-dimensional canvas that changes over time. In this manner a graph of the current values for Frustration (blue dots) and Short Term Excitement (red dots) is created. The prototype is illustrated in the following figure (58). Additionally, I produced some videos that show me playing the neurofeedback VOID prototype games. They can be accessed by clicking the links in the footnotes.

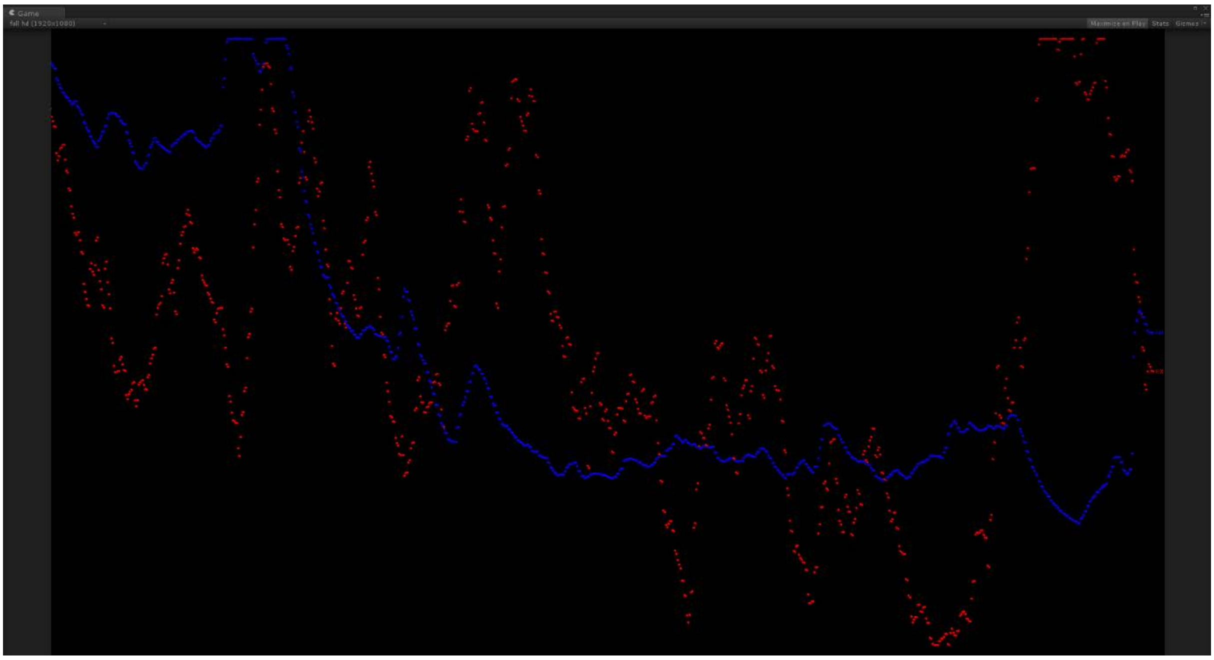

Figure 55 - VOID_AV01a Neurofeedback Prototype

VOID_AV01b[33] is a variation on the prior prototype, also not including gameplay, that places the red and blue dots in a circle, clockwise, in the three-dimensional void of the game engine. Again the values of Frustration (blue dots) and Short Time Excitement (red dots) are used to generate the dots. The

[32] Video Link (VOID_AV01a): https://www.youtube.com/watch?v=5okCtYHRU7M
[33] Video Link (VOID_AV01b): https://www.youtube.com/watch?v=DCbuBQZf58U

higher the value, the further the dots are placed from the centre. The result of a five-minute test was an artistic diagram of the two values as illustrated in the next figure (59).

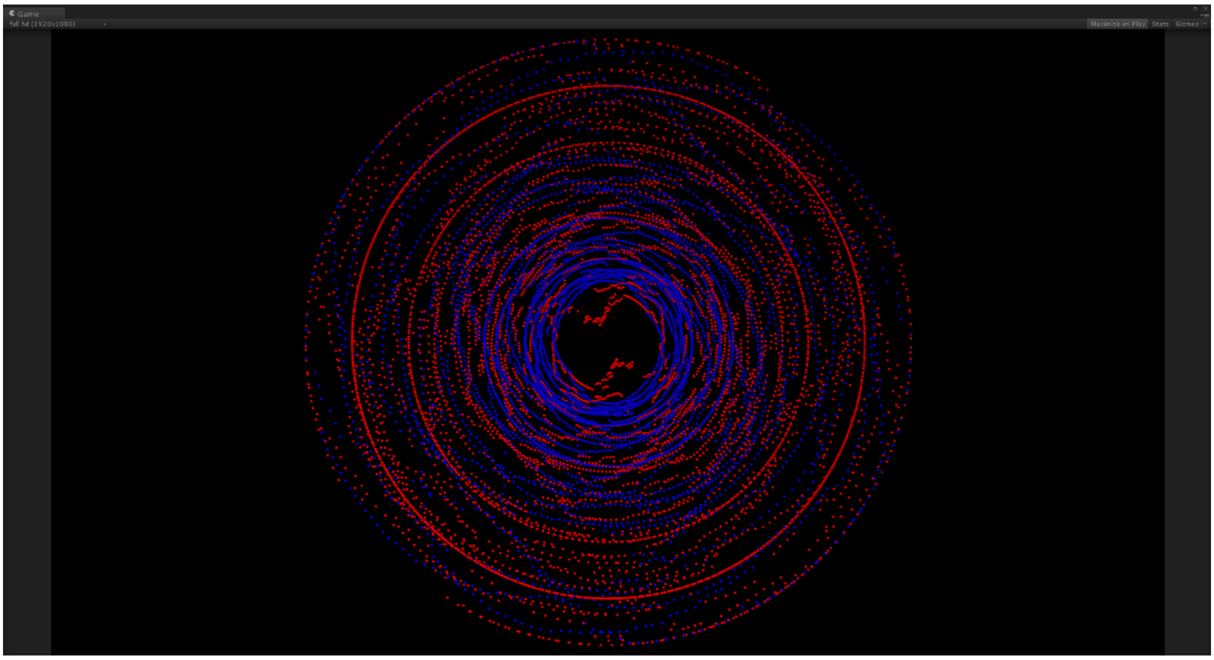

Figure 56 - VOID_AV01b Neurofeedback Prototype

5.2.4 BCI-VR GAME PROTOTYPES

VOID_AV02a[34] is the first VOID prototype to combine neurofeedback with virtual reality. Still, there is no BCI gameplay involved. The prototype tests the functionality of the VR Headset and the experience for the user. It takes the movement feature successfully applied in the VR prototype and combines it with the neurofeedback interaction of AV01b. The result is a VR flight through a dynamic helix that visualises the Frustration and Short Time Excitement levels in real time. The next figure (60) illustrates the prototype.

[34] Video Link (VOID_AV02a): https://www.youtube.com/watch?v=TV5BplCOrhU

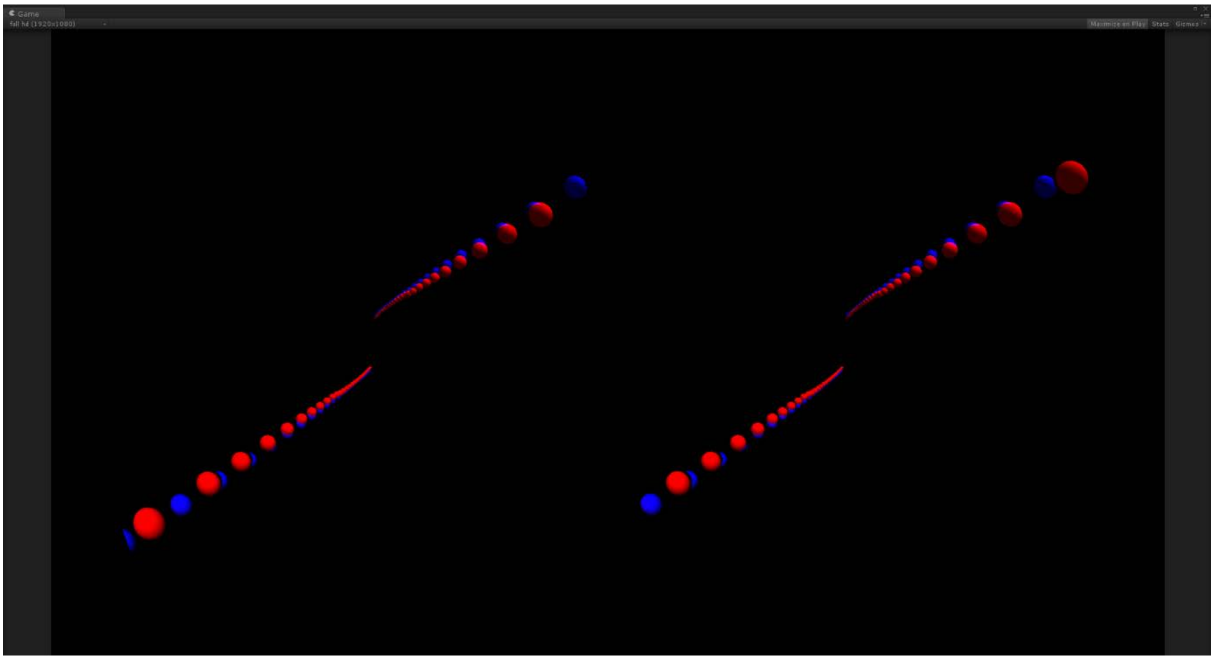

Figure 57 - VOID_AV02a Neurofeedback Prototype

5.2.5 GAME COMMUNICATION ARCHITECTURE

The communication between BCI and game engine was based on tools provided by the manufacturer of the BCI-Headset, Emotiv. Combining the visual scripting plugin Playmaker with the game engine Unity3D enabled me as a game artist and designer to access data from the BCI and use these in the experimental setup of the VOID series. The next figure (61) illustrates the communication architecture of the VOID series.

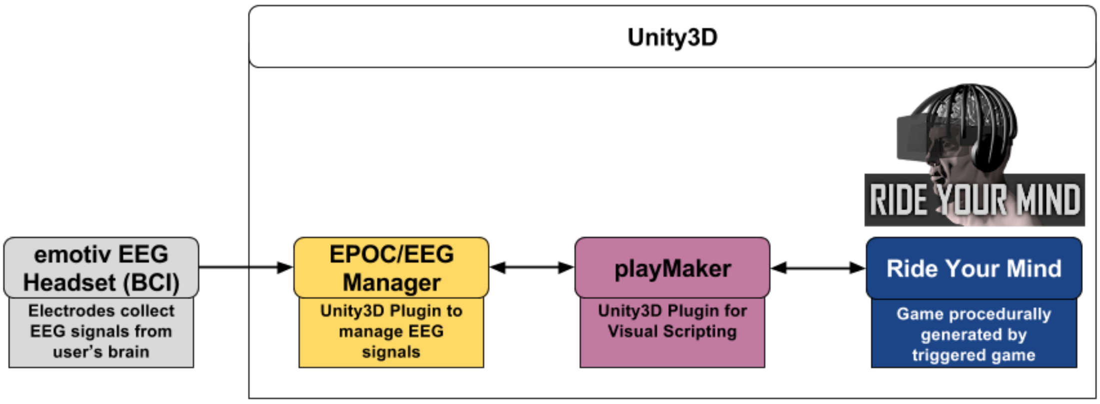

Figure 58 - VOID: Experimental communication architecture

To communicate with the game engine, I used and hacked the existing communication possibilities. The following figure (62) gives an overview of the triggers and actions provided by the Emotiv software and illustrates how it is used by the interim toolchain I designed and visually programmed.

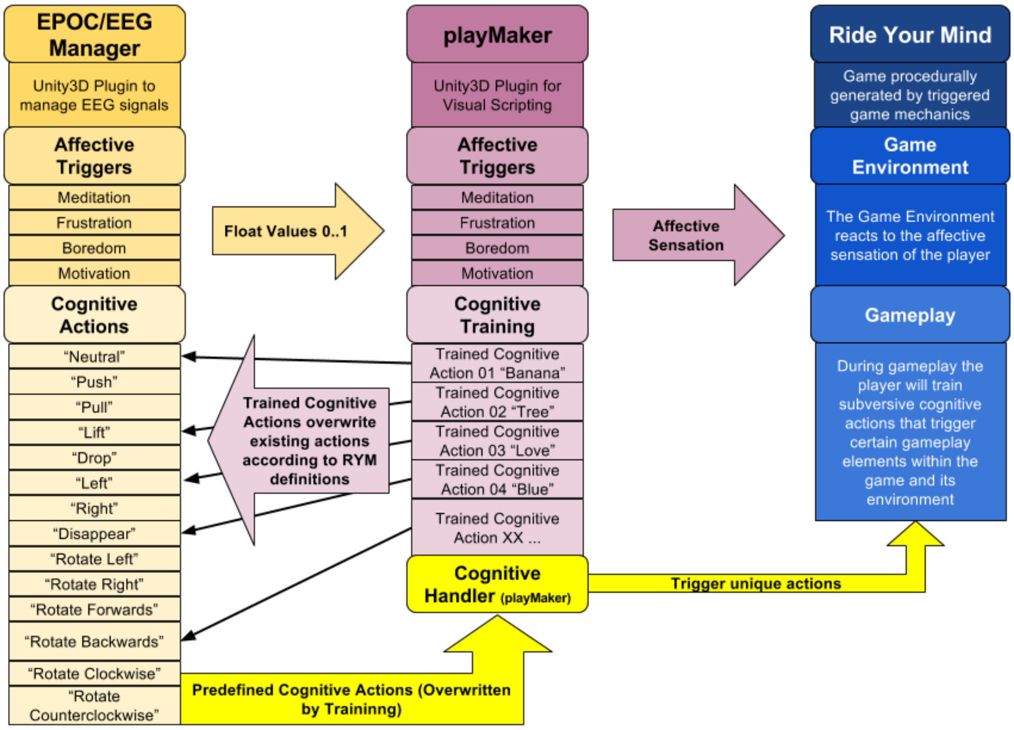

Figure 59 - VOID - BCI to Game Engine communication possibilities. Example of the processing within the VOID game series on how EEG signals can trigger gameplay elements.

The Emotiv EPOC/EEG Manager provided several values, triggers and actions. The affective triggers deliver float values that are used via the visual scripting tool Playmaker to affect the gameplay and the gameworld inside VOID. The VOID series thereby generated a solid framework and foundation for the future experimental design process of Ride Your Mind. Beside these so-called affective triggers there were also predefined cognitive actions. These actions have been defined by Emotiv. Each action, for example cognitive states like "neutral" or "push", can be trained and calibrated with the help of the Emotiv EPOC/EEG Manager. As the concept of Ride Your Mind does not include any of these predefined cognitive states, I created a cognitive handler with the help of Playmaker. This enabled me to relabel the cognitive actions and replace them with actions I defined myself, such as "banana". I used the labels of the predefined Emotiv actions and relabelled them with the help of Playmaker to trigger unique cognitive actions in the VOID and later prototype of Ride Your Mind.

5.3 KIT TECO'S EEG TOOLCHAIN FOR BCI GAME DESIGNERS

Dealing with BCI games implies transdisciplinary work that is preferably carried out by a team consisting of a neuroscientist, a computer scientist, a BCI hardware expert and of course a game designer. Originally, the research project RYM was not designed to involve a team. To achieve the essential functionality of the BCI-VR Helmet the communication with the computer formed a crucial part. As an artist, I lacked the skills and knowledge in computer science and HCI required for this specialised work. For this reason I decided to cooperate with computer science experts who examined this crucial part of the concept of Ride Your Mind.

In cooperation with TECO Research Group, a computer science department and sensor experts at the Karlsruhe Institute of Technology (KIT) in Germany, an open source EEG toolchain was developed to enable the game designer and the game artist to work with the Emotiv BCI-Headset in the game engine

Unity3D. In her dissertation titled *Examination of Consumer EEG Headsets for Experimental Game Design,* diploma candidate Birnbaum (2015) examines consumer EEG technology and develops a prototype of an open source EEG toolchain for game designers. In cooperation with TECO a hypothetical guideline for designing the tool was developed. The focus of this was not on improving the user-friendliness, detection, speed or accuracy of a BCI or the control mechanisms of EEG, but on supporting experimental game design processes and to create an understanding of the boundaries and difficulties of consumer BCI technology in relation to potential BCI game design approaches (Birnbaum 2015). The following figure (63) illustrates how the EEG toolchain is embedded in the Ride Your Mind concept and its software communication architecture. The EEG toolchain runs on the computer and is linked between the Emotiv EEG headset and the Unity3D game engine used to generate the game RYM.

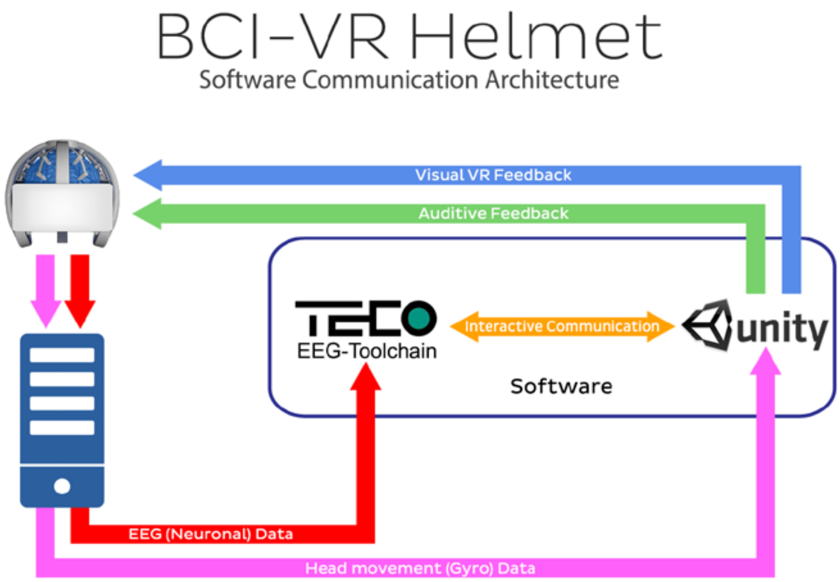

Figure 60 - TECO EEG Toolchain

5.3.1 DESCRIPTION

A detailed technical and computer scientific description of the EEG toolchain and its features and development process can be found in Birnbaum's dissertation. As the work is written in German, I will summarise parts of it here in English to give the reader a first impression of the research.

In her dissertation Birnbaum (2015) describes how EEG signals read out by a consumer BCI-Headset can be analysed and interpreted with computer science methods. With the help of open source tools, she developed a toolchain that enables game designers and artists working with Unity3D to gain access to neurofeedback from the Emotiv EPOC EEG Headset. By using machine-learning methods to analyse the signals, potential designers may be able to use complex pattern recognition with relative ease in order to create experimental BCI games controlled by consumer BCI technology. The tool was designed to create experimental gameplay prototypes of BCI games. Birnbaum examined the tool in two studies. The outcome of Birnbaum's (2015) research was the successful development of a working prototype of the EEG toolchain. As an outlook for further research she suggests that potential game designers working with the tool require a detailed explanation of the possibilities to create innovative BCI gameplay and BCI games (Birnbaum 2015, p.88).

5.3.2 EXPERIMENTAL BCI GAME PROTOTYPING

Once the first prototype of the TECO EEG toolchain was available – developed by Birnbaum in cooperation with myself – I started working with the tool and created an experimental BCI game prototype. The game is described and illustrated briefly below.

Due to the fact that the preparation of the Emotiv BCI-Headset takes around 5-15 minutes, the idea was to integrate this procedure into the game experience. The first stage or level of the experimental game consists in establishing a proper connection for each single electrode of the Emotiv Headset. The potential player has to establish a working connection for each electrode before he can proceed with the game. During the second stage a sphere appears on the screen and the player has to relax so that this sphere disappears. The player's level of relaxation is calculated by his actual alpha wave value. Once the sphere has disappeared the player moves forward and enters a hilly landscape, where the game prototype comes to its conclusion.

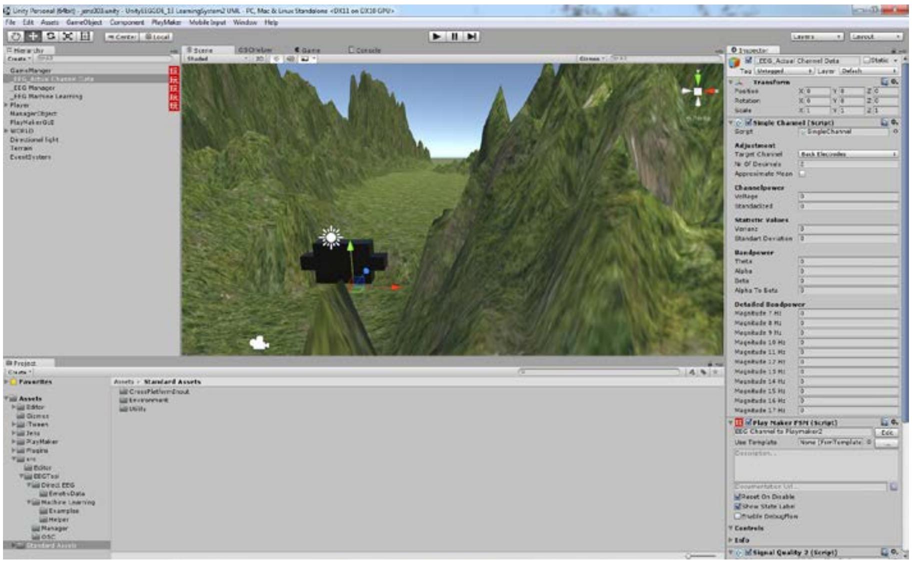

Figure 61 - Screenshot of the Experimental BCI Game based on the TECO EEG Toolchain

5.3.3 PERSONAL REFLECTION

Working with the EEG toolchain as a game designer and artist was challenging because of all the non- or not yet existing terminology and features of the tool, which Birnbaum (2015) also describes in her dissertation. The tool was designed by a computer scientist as a prototype that requires the careful installation of crucial software modules. Accessing the data and values provided by the BCI-Headset and the machine learning module was less complicated for me as a game designer working with Unity3D. Birnbaum implemented a small plugin in Unity3D that made the values available. Operating and adjusting the machine learning module and linking it with Unity3D was very challenging however, and proved nearly impossible without further assistance. The machine learning settings were handled by a dedicated application and required accurate adjustment as well as repeated training, depending on the chosen machine learning mechanism. Due to the Emotiv BCI-Headset's lack of precision it was anticipated that the use of the EEG toolchain instead of the tool provided by the manufacturer would yield an unsatisfactory result. Although the attempt to design such a toolchain especially for game designers and artists working with BCI gaming technology is great, it needs further support from BCI researchers and game design researchers. It is a proof of concept and a necessary initial step in the development of further software tools that enable creative and artistic disciplines to work with emerging BCI gaming technology in a satisfactory manner. Unfortunately, due to several delays during the development of the EEG toolchain, I could not integrate the toolchain into the technical setup of my research project Ride Your Mind.

5.4 RYM BCI GAME DESIGN

The game design process of Ride Your Mind is based on my historical examination of hacking and the four strategic design elements of hacking I identified. The conceptual design of the game and the application of the four hacking elements to the RYM concept have been outlined in the previous section. In the present section the game design process of the playable prototype of Ride Your Mind based on the results of the VOID series will be elaborated.

The design of the BCI-VR game Ride Your Mind is based on the artistic and experimental prototype series VOID. It combines certain elements and results of these prototypes and includes several BCI gameplay features influenced, triggered and manipulated by EEG data from the player's brain and read out by the Emotiv EPOC EEG BCI. The feature description is based on the examination of the hardware and the features of the accessible development tools used in the VOID series. The concept of RYM incorporates BCI gameplay features that unfortunately proved impossible to realise in the final prototype.

The initial idea of using a void filled with neurons was discarded and replaced with a representation of a human brain created by a particle effect system. This visual and artistic decision was made to reduce the workload of the computer running the game, as well as to visually underline the idea of flying through your mind. The following figure (65) illustrates the visual appearance of Ride Your Mind.[35]

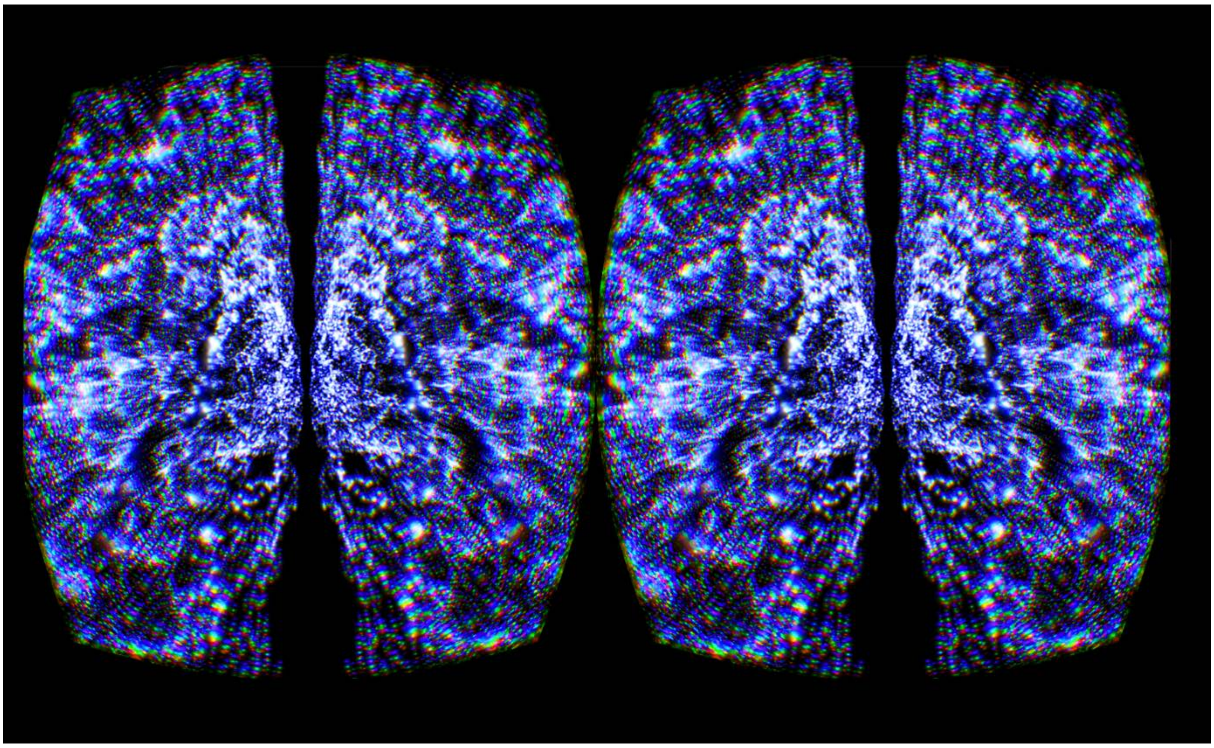

Figure 62 – Ride Your Mind – in-game screenshot of the prototype

[35] Additional gameplay footage of a prototype of Ride Your Mind can be accessed online here: https://www.youtube.com/watch?v=QubVsRJO-0k

While playfully exploring BCI gaming technology its lack of precision and its inapplicability to design such as Ride Your Mind became evident. Based on the findings of the work on the VOID series, the design decision was made not to include actual EEG neurofeedback to trigger the BCI gameplay of Ride Your Mind. The neurofeedback was replaced by random data and values, as per the first VOID prototypes. As a small experiment demonstrated, the illusion of being in control of actual neurofeedback can also be achieved with randomised data and still fit in the artistic concept of Ride Your Mind. The following table (4) describes how BCI gameplay and gameplay features of the Ride Your Mind prototype have been applied or replaced.

Conceptual Gameplay Feature	**Applied in Ride Your Mind?**
Train a cognitive action through a visual stimulus that triggers an in-game action boost (Boosting the player in a forward direction).	Not applied due to insufficient access to relevant data. Not able to implement the feature in the game engine in connection with the BCI-Headset.
Actual concentration level of the player controls the speed at which the virtual player moves. Low concentration level = higher speed. High concentration level = lower speed.	Replaced with randomised and interpolated values. The actual implementation of EEG data from the Emotiv Headset to compute the concentration level resulted in high signal peaks that disrupted a smooth gaming experience.
Particle effects within the game environment that visualise the activity of each single electrode of the BCI-Headset.	Replaced with randomised data. The data stream of the EEG BCI-Headset often collapsed completely because of the wireless Bluetooth connection.
Changing the colour of the game environment according to the player's mental state. When player is relaxed the environment turns green. When stressed it turns red.	Detecting the player's mental state with the BCI-Headset was often impossible because of data stream interruptions. Neither could the feature be applied with the help of random data because of issues with the particle system used.
Polygons of the geometrical mesh of the game environment are procedurally deformed by EEG values.	Unfeasible because of coding skills required to achieve a procedural mesh deforming system that can be influenced by either random data or neuronal data.
The pitch of the sound is controlled by the player's concentration level. Low concentration level = higher speed. High concentration level = lower speed.	Replaced with randomised and interpolated values. The actual implementation of EEG data from the Emotiv headset to compute the concentration level ended in high signal peaks that disrupt the data stream.

Table 4 - Gameplay features of Ride Your Mind

5.4.1 HIDDEN TUTORIAL AND CALIBRATION

The BCI game design of RYM incorporates a hidden tutorial that is used for calibration and to train cognitive actions of the Emotiv SDK to link them with predefined gameplay actions. Hidden means that it is not visible or recognisable for the player, that the player does not get distracted by the tutorial and that the tutorial does not disrupt the gaming experience. The calibration phase of the consumer grade BCI can take up to 30 minutes.[36] Because of this time-consuming issue, I created a hidden tutorial so that the player can already play the game while the game is reading the player and linking cognitive actions with gameplay actions. The following illustration describes a potential cognitive action training process of RYM's tutorial.

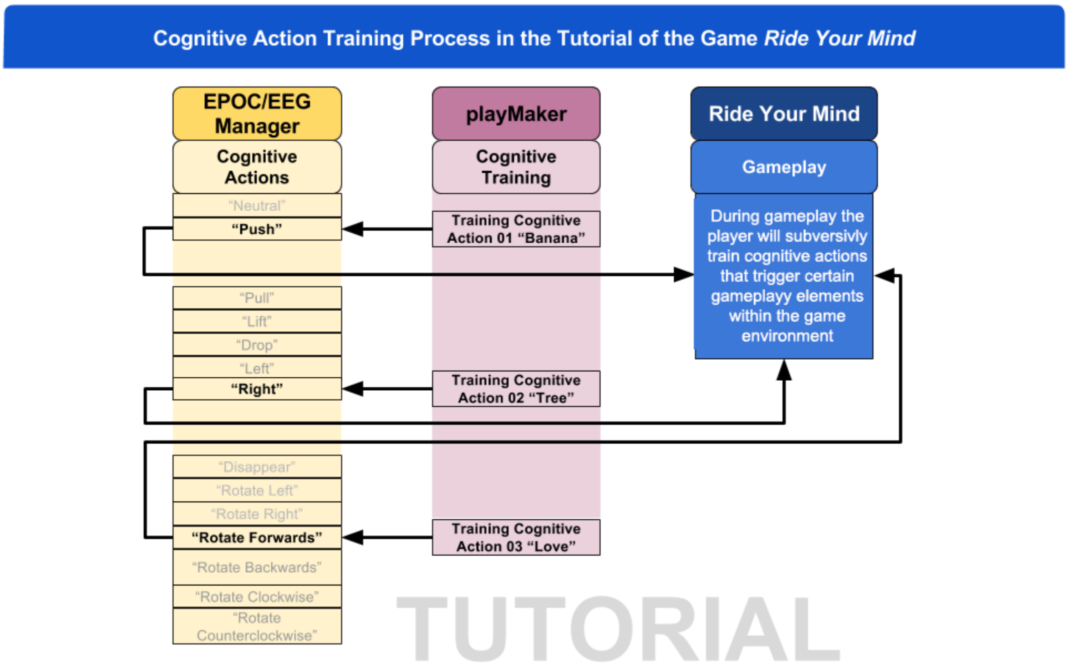

Figure 63 - Ride Your Mind: Calibration Tutorial

5.5 CONCLUSION

In this chapter the playful exploration and hacking of BCI and VR technology has been documented. The origination and design process of the BCI-VR helmet, and how they relate to the four elements of hacking, have been described. After I created the first prototype of the steampunk-inspired BCI-VR Helmet, I tested it on several playful game prototypes of the VOID series. Subsequently, the VOID series and the insights produced during the creation of the BCI and VR game prototypes were applied to the concept of the BCI-VR game Ride Your Mind. Furthermore, I have described how KIT TECO's EEG toolchain has been designed and how it is implemented in RYM's hardware and software communication architecture. Finally, the BCI game design of Ride Your Mind has been outlined, as well as how a conceptual hidden tutorial within the game is used to calibrate cognitive actions with gameplay actions without disrupting the player's game experience. While hacking and experimenting with the different technologies and creating (BCI) game prototypes, I made several discoveries and mapped a number of issues related to BCI gaming technology and BCI game design. These findings will be discussed in the next chapter (6).

[36] This issue will be discussed in more detail in section 6.1.4 and 6.1.5.

6 DISCUSSION

While playfully hacking the different technologies and creating the (BCI) game prototypes that were documented in the previous chapter (5), I made several discoveries and ran into a number of issues. These findings will be discussed in this chapter. To begin with, I will discuss the BCI gaming technology that I used, namely the Emotiv EPOC EEG Headset. This will be followed by a discussion of the BCI game design patterns I identified and the BCI game characteristics of Ride Your Mind. This chapter provides answers to the first part of the third research question: what issues and discoveries emerge from the attempt to design the artistic and experimental BCI-VR game RYM with consumer grade BCI gaming technology. In the next chapter (7) these discoveries and issues will be examined from several different perspectives, such as media art, game art, hacking and game design.

6.1 BCI GAMING TECHNOLOGY: EMOTIV EPOC EEG

A big hurdle while working with BCI technology – in my case with the Emotiv EEG BCI-Headset – was to understand how these devices generally work and how they communicate with computers and software. In their research article *A Prototype SSVEP Based Real Time BCI Gaming System*, Martišius & Damaševičius (2016) list the advantages and disadvantages of the Emotiv EPOC EEG headset that is also used by RYM: "The Emotiv headset, however, is wireless and therefore offers free range of motions allowing for easy transport and setup, which is very important in an everyday use setting. Another advantage is that the EPOC does not require conductive gel for electrodes, making it easier to put on and use. Users do not have to wash their hair after using the headset. The main benefit is that it is relatively inexpensive. There are several disadvantages to the EPOC headset as well: it only uses 14 sensors, while many medical grade devices use up to four times that amount. This results in less data coming in from the brain" (Martišius & Damaševičius 2016, p.6). The same authors also evaluate the Emotive Software Development Kit (EDK) for the headset: "It is primarily written in C, but the company also provides wrappers for accessing the Application Programming Interface (API) in C++, C#, Java and MATLAB" (Martišius & Damaševičius 2016, p.7). To hack a BCI it is necessary to know where potential entry points to the system of a BCI are located. After having researched the bigger picture of BCIs and the multiple research disciplines that are involved to further understand BCI technology and its functionality, I decided to stop reading too deeply into this interdisciplinary research topic. Nijholt et al. (2009) point out that "BCI game research requires the integration of theoretical research on multimodal interaction, intention detection, affective state and visual attention monitoring, and on-line motion control, but also the design of several prototypes" (Nijholt et al. 2009, p.92). This research definitely would have exceeded the possibilities of my research candidature and would have gone far beyond the scope of this project-based PhD and the artistic research related to it, which focusses on the act of hacking to create the artistic BCI-VR game Ride Your Mind.

6.1.1 ISSUES AND POSSIBILITIES

The hardware manufacturer Emotiv provides a Software Development Kit (SDK), the Emotiv Software Development Kit (EDK), as described by Martišius & Damaševičius (2016), and programs for their BCI-Headset to display EEG data. The purpose of the software is not just displaying EEG data; in addition it can interpret and process the information and forward it to – in our case – a game engine such as Unity3D with the help of a special plugin. But these programs are sealed and the compiling process of the EEG data is not accessible. Therefore the workings of the compiling process remain elusive. For example, it cannot be established which machine learning patterns or which interpolation techniques are used. In short, this means that all functional parts of a BCI-Headset that are interesting for a game artist, game designer and hacker are controlled by the software part that processes the EEG data and sends it to the game engine. Accessing or manipulating this software poses a challenge while working with BCI gaming technology. This technological challenge is comparable to the challenge faced by early hackers dealing with military computers without instructions, as well as to media artists that were hacking and manipulating[37] existing games in the 1990s (Pias 2002a; Schwingeler 2012; Pias 2013; Schwingeler 2014).

While hacking and playfully investigating BCI gaming technology, a list of key elements and central questions emerged that are essential to forming a proper understanding of the compiling process of BCIs working with games:

1. Understanding the processes inside the human brain and the cartography of important brain structures and centres.
2. What kind of signals are triggered in the different brain sections and what kind of data emitted from there can be used?
3. How can the collected EEG signals be interpreted?
4. Which strategies from computer science can be used to process the collected EEG signals (for example pattern recognition and interpolation of values over time)?
5. Defining the message of the processed data.
6. How can this message be used to trigger actions inside a game?

6.1.2 CONNECTIVITY

The BCI hardware that was used – the Emotiv EPOC EEG Headset – includes sensors that are placed on top of the human scalp. This non-invasive method can be characterised as less than ideal. Invasive BCI technology delivers more accurate signals and less interference but requires surgery (Nijholt et al. 2009, p.92). As consumer grade BCI technology surely will not become invasive over the next couple of years, the electrodes or sensors need to touch the skin on the human scalp to detect EEG signal activity. Actually, this detection method is slow and does not allow for the complex real-time interaction that is necessary for controlling for example robots or games (Tan & Nijholt 2010, p.74). Recent BCI gaming technology such as the Emotiv EEG Headset is categorised as a wet BCI system. The sensor pads of the BCI need to be wetted in order to provide a good enough connection to the human scalp to detect EEG signals. But even if the electrodes are wetted, there is no guaranteed signal transmission. Hair length plays an important role, and baldness is an immense advantage but only if the hair has recently been shaved, otherwise the thickness of the skin on the scalp is disruptive. Other external problems are distractions to the users. Outside of a laboratory situation, gamers will get

[37] While hacking and modifying existing games these media artists produced game art. Game art as a subcategory of interactive media art is discussed in more detail in chapter 7.

distracted more easily by everyday life actions and habits, but also smaller actions like moving a hand, moving the eyes or even blinking can interrupt EEG signal detection by the BCI-Headset.

6.1.3 SIGNAL QUALITY AND PRECISION

Signal distortion can be caused by various circumstances such as environmental issues or irritation caused by brain activity. In a laboratory situation, subjects are placed in isolated rooms to avoid signal interferences from other electrical sources (Tan & Nijholt 2010, p.169). BCI gaming situations may never be comparable to medical research conditions in isolated rooms. A user at home will be surrounded by various technological devices, such as their mobile phones or wireless LAN connection, that cause electromagnetic waves that lead to EEG signal distortion. The Emotiv BCI-Headset uses wireless signal transmission via Bluetooth technology, a setup that is highly sensitive and error-prone (cf. Martišius & Damaševičius 2016).

Another type of interfering EEG signals is produced by the brain's activity in general. Eliminating brain activity without harming or even killing a person is nearly impossible and definitely not desired. But there are ways to reduce certain activities in different regions of the human brain and to stimulate other desired activities triggering EEG signals. The use of a Virtual Reality Headset was not only an artistic and game design decision, but also a hack to visually shield the user from his surrounding environment.

In summary, this means that possible future BCI gaming technology will also have to overcome these issues produced by brain activity and the surrounding environment in order to function properly. Leading BCI researchers such as Nijholt et al. (2009, p.89) indicate that a lot more research is required on the gameful application of BCIs.

6.1.4 SETUP AND PREPERATION

The first step to setup the Emotiv EEG Headset is to prepare all fourteen single electrodes by wetting them with a conductive fluid. Emotiv recommends contact lens solution, which works pretty well.

Figure 64 - BCI-Headset setup

After this preparation, all electrodes need to establish a good connection, as indicated by a green dot within the provided control panel application. The interface is shown in the following figure (68).

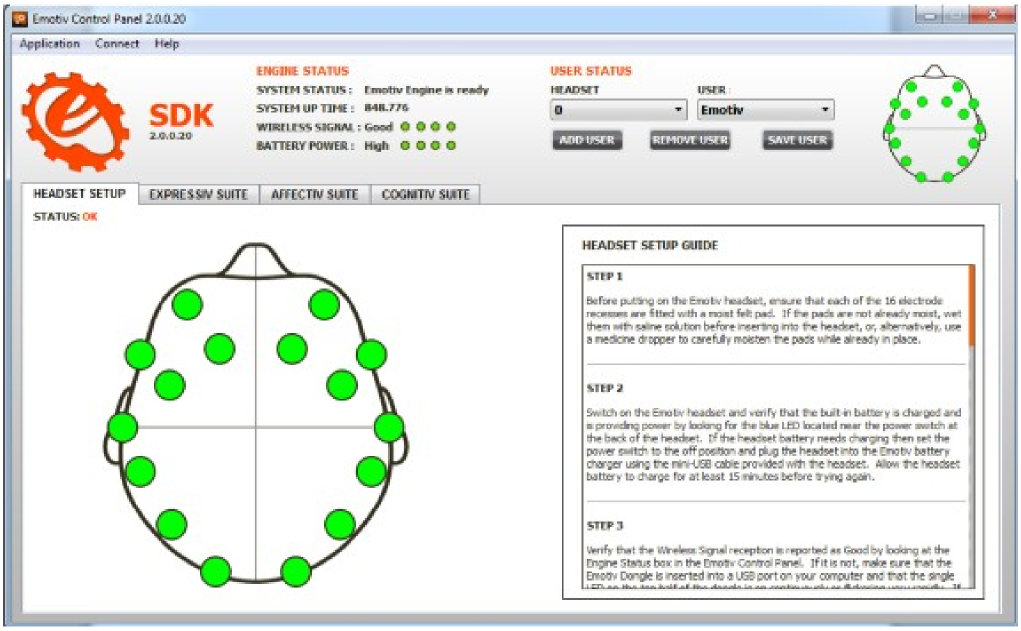

Figure 65 - Emotiv control panel

This procedure can take up to 30 minutes in total and is not suitable for consumers that potentially expect a plug and play setup (Nijholt et al. 2008). The setup can take more time than actually playing the game.

Calibrating and adjusting the BCI-Headset to ensure that all electrodes provide an adequate signal quality is mandatory, in contrast to the hidden software calibration of game Ride Your Mind.[38] The in-game calibration can be understood as an interactive and subversive tutorial, or to put it more accurately the game calibrates itself and its BCI gameplay is triggered corresponding to the user's brain. The player will not be aware of the fact that the game is calibrated while he is playing it. This hidden calibration means the player of RYM will not get confused, and the conceptualised BCI game is able to handle multiple users by providing personified and unique game experiences without any noticeable software calibration.

6.1.5 CALIBRATION AND TRAINING

The processing of EEG signals into meaningful control signals can be compared to a signal sensing rather than a (meaningful) signal translation. There is no universal catalogue or guideline that describes how EEG signals can be interpreted or translated. Each manufacturer or researcher defines his own sensing parameters to process the EEG signals into meaningful control signals. Researchers and game designers define actions triggered by EEG signals with the help of their own or existing knowledge.

To use a BCI-Headset (BCI) as a game controlling or influencing input device, the user has to train several previously defined in-game actions which translate brain signals into meaningful control signals

[38] The conceptual subversive tutorial including a software side calibration is further explained in section 5.4 of this document.

(Tan & Nijholt 2010, p.164). This calibration is mandatory for every single user that wants to play the game. “BCIs require prior training before playing, which is hurtful to immersion and player experience in the game” (Kosmyna et al. 2015, p.1). Apart from the setup phase of the headset, this calibration phase also takes up a certain time, approximately five to ten minutes, depending on the amount of actions required for the training or calibration.

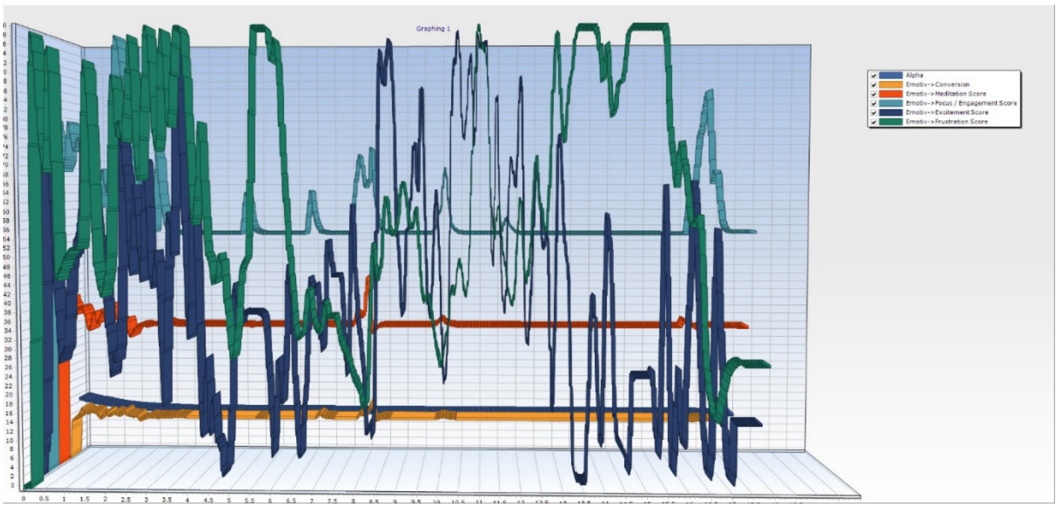

Figure 66 - Emotiv control panel - data view

6.1.6 FEEDBACK LOOP

As I have explained before, a BCI itself is a feedback loop system. Using a BCI in the context of gaming shifts the feedback loop effect to the act of playing and directly affects the design of the BCI game. BCI game designers must be aware of the fact that the BCI gamer becomes part of the feedback loop through the usage of the BCI-Headset (BCI) and take this into account when designing BCI gameplay features. When a gamer, for example, moves his eyes over the screen or uses his hands to control input devices such as keyboard, mouse or game controller, this activity causes changes in the EEG signals. In a virtual reality gaming situation, the gamer uses even more parts of his body to control the particular game, wearing a head-mounted display (HMD) such as the Oculus Rift, holding a motion controller in his hands and being caged in a treadmill such as the OMNI to transform his real world movements into the virtual world. In the context of BCI gaming, occurring errors (e.g. faulty interpretation of signals) can be more easily handled and probably overwritten by random values such as described in the Ride Your Mind design process. The research project MindBalance by Lalor et al. (2004) was one of the earliest examples to examine this feedback loop issue (Figure 70).

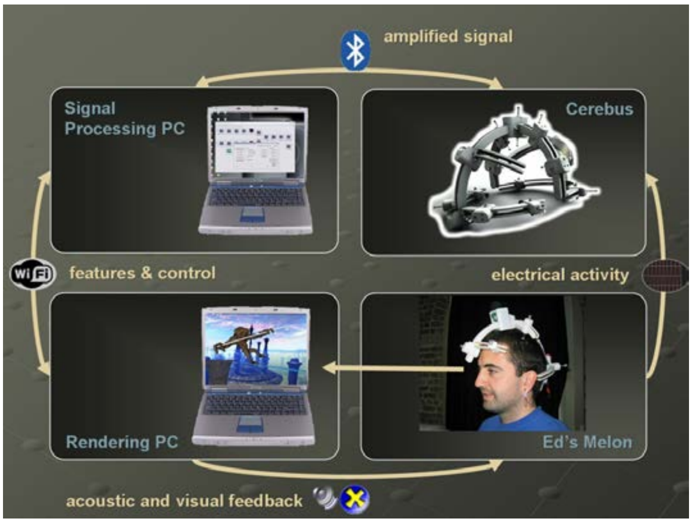

Figure 67 - Mind Balance feedback loop (2004)

6.1.7 SECURITY

BCI game experiences are highly intimate because personal sensory data (EEG) is temporarily stored and processed. “BCIs might be the most private communication channel possible” (Nijholt et al. 2008). Even if the signal quality nowadays is poor, the recorded data could probably be interpreted and used differently in the near future. Future BCI applications need to be designed and considered carefully with regard to security issues. In their article *App Stores for the Brain*, Bonaci et al. (2015) discuss several issues related to emerging consumer BCI technology. Already in 2012, research demonstrated how “brain spyware” is able to extract highly private information, such as credit card PIN codes, from user’s EEG signals. On the other hand, in the future BCI technology could also be used as identification and authentication method. Users of BCI technology should be aware of this issue and be given the choice whether or not the data is recorded or stored. If the user allows the collected data to be stored or even anonymously shared, it could be interpreted by medical experts and thereby contribute to cognitive neurological research. Just like the famous experimental research game Foldit (2011) from the University of Washington, future BCI games could help to support neuroscientific research and the understanding of processes in the human brain. While playing games, BCI gamers could contribute to ongoing neuroscientific and BCI research by generating data that could for example be used to create and extend a translation catalogue of EEG into meaningful control signals. Foldit is a representative example of how games can help research to find novel problem solutions. As BCI games are heavily related to medical, neuroscientific and BCI research these emerging forms of digital and playful entertainment could be applied to solve neuroscientific problems in a playful manner. Hacking could therefore be applied as a playful strategy to help solving research problems.

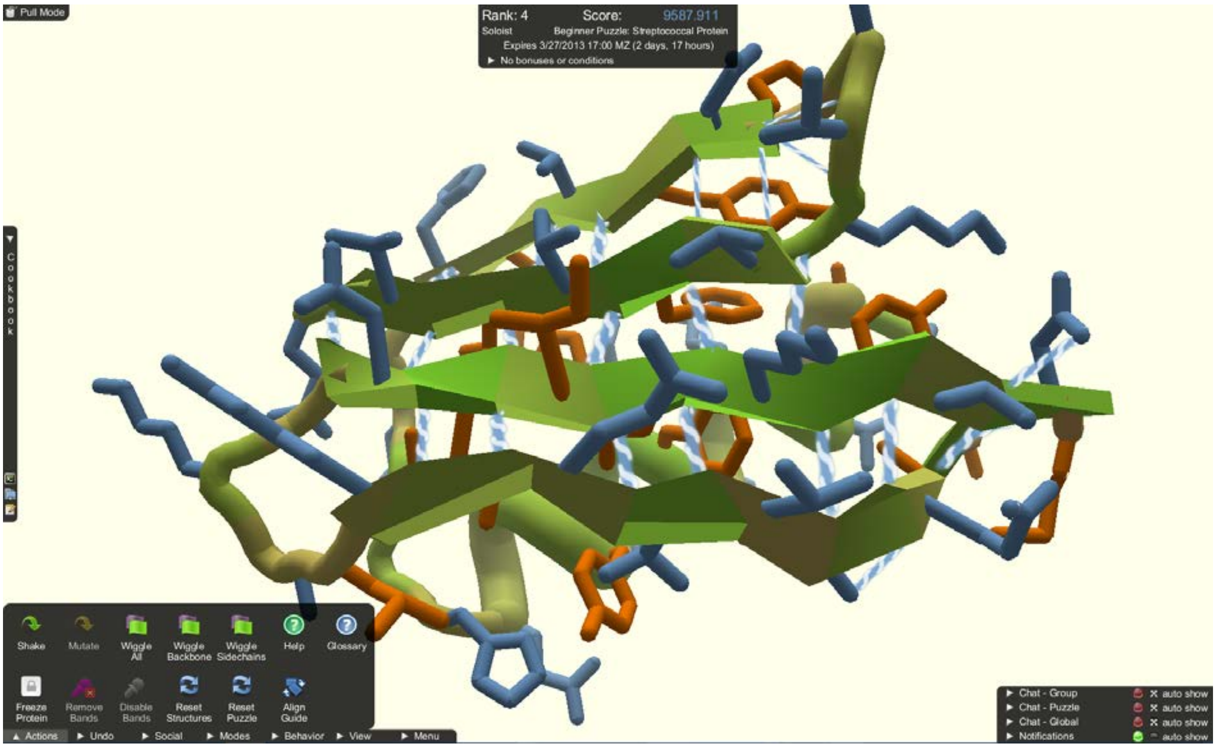

Figure 68 - Experimental research game Foldit (2011)

6.1.8 CONCLUSION

By hacking BCI gaming technology I made several discoveries and ran into a number of issues, which enabled me to provide answers to the third research question of this PhD. Finding solutions to overcome these issues will surely define the coming years of BCI game research and technology development. Aside from the issues with BCI games that have been described here, there are many others, especially related to medical applications, where very high precision is required. In the context of BCI gaming, errors (e.g. faulty interpretation of signals) can be dealt with by replacing the signals with random actions. The calibration and lack of precision of today's BCI gaming technology (cf. Vourvopoulos et al. 2017) is the most challenging issue to overcome. The experimental setting of such games puts the user in laboratory conditions. As the target group of the entertainment industry are gamers who obviously find themselves in a completely different situation than patients, future BCI technology needs to be adaptive and succeed in supressing environmental radiation and other electromagnetic interferences that can disturb EEG signal detection. Hacking as a playful problem solving strategy could be further applied to help with certain neuroscientific and BCI research paradigms.

6.2 BCI GAME DESIGN PATTERNS

During the work on the game prototype, and while writing this section which describes the standards and patterns that were used, another gap in game design research became apparent. As it is impossible to describe all features of the BCI game RYM in terms of the current academic terminology, the existing definitions in game design research require the addition of a new set of BCI game standards and design patterns. This elaboration of the game design research discipline is a necessary step towards an academic discussion about BCI game design, and it is based on the design element and/or strategy of hacking defined earlier as *expansion*. The research project RYM and its documentation shall serve as the starting point for an academic discussion about BCI game design standards, design strategies and design patterns.

The conceptual adaptive game design of Ride Your Mind can be described with the help of the online game design pattern catalogue (Björk 2015). This catalogue, based on Björk and Holopainen's (2004) work on game design patterns, is continually updated. Potential future game design patterns that can be used for BCI game design are listed in the following matrix (5). The matrix provides the firsts hints for further research on BCI game design patterns. The different game design patterns and short descriptions are quoted from Björk's online catalogue (2015).

Game Design Pattern	**Short Description**	**Ride Your Mind's gameplay**	**Potential elaboration of definition as BCI Game design pattern**
Attention Demanding Gameplay	*Gameplay where players can easily suffer bad consequences for being inattentive at any given point.*	RYM registers the player's attention level via the BCI-Headset and alters the BCI gameplay accordingly.	The player's actual attention level can be used to alter gameplay with positive and/or negative consequences.
Critical Gameplay Design	*Game designs where the game system is intended to cause critical reflection.*	As an artistic game, RYM wants to use emerging BCI gaming technology to make people aware of the dangers of data sharing.	Future BCI games could be used to manipulate the player's perceptions and opinions.
Delayed Effects	*The effects of actions and events in games do not occur directly after the actions or events have started.*	Current BCI gaming technology suffers from significant delays for certain in-game actions triggered by the player's mental activity.	This feature of BCI gaming technology could presently be incorporated into gameplay, as long as the technology evokes communication delays.
Dynamic Difficulty Adjustment	*Games that during gameplay adjust their difficulty depending on how well the player progresses.*	RYM is based on the idea of flow, where the player experiences a state of enjoyable, playful activity without specific difficulty levels.	Future BCI games will be able to adjust difficulty levels according to the player's emotional state. If a player is frustrated, the level of difficulty will be decreased.
Expansion	*A phase where the focus is upon increasing the amount of a gameworld on controls.*	RYM expands the traditional input interface with the help of the BCI-Headset.	As expanded input functionality, neurofeedback creates a new layer of possibilities in game design.
Emotional Attachment	*The ability of agents to have noticeable emotional relations inside the*	The concept of RYM enables the emotional state of the player to	BCI games can use the emotional state of the player as an input parameter to affect

	gameworld to the diegetic phenomena in that world.	affect the gameworld and the game environment.	the gameworld and also agents.
Environmental Effects	*Changes to how actions or events function due to being in a specific part of the gameworld.*	RYM uses unconsciously provoked EEG information to affect the game environment.	Environmental effects can be consciously or unconsciously affected by neurofeedback.
Events Timed to the Real World	*Gameplay events are initiated by specific real-time events occurring.*	RYM as simulation uses real-time evoked EEG signals that are used to form and influence the gameworld.	Neurofeedback is timed to evoke potentials of the human brain.
Experimenting	*Exploratory actions performed to learn the rules or state of a game, or to practice one's skills or strategies.*	RYM does not provide the player with any instructions on how to play the game or how to control the BCI gameplay. The player has to experiment with the provided game system.	The player of future BCI games needs to obtain direct feedback on the neuronal actions he performs in-game. To enable further research, experimental BCI games will have to be designed.
Cross-media Gameplay	*Games that make use of several different media to provide one game instance.*	To be able to play RYM, one is required to wear a BCI-Headset.	BCI gaming technology might enable the emergence of a new type of cross-media gameplay that is influenced by neurofeedback.
Exaggerated Perception of Influence	*Players perceive that they can influence the outcome of the game, regardless of whether this is the case or not.*	The player of RYM receives no direct feedback on whether his EEG signals and mental activity influence the gameplay or not.	To distinguish the influence of neurofeedback on gameplay, meaningful or subliminal BCI gameplay elements have to be elaborated.
Extra-Game Input	*Effects on game states whose sources are neither internal nor directly from players.*	In addition to the VR-headset, which translates the user's head movement into control signals, a BCI-Headset is used.	Neurofeedback is an additional type of input for gaming. With this a new layer of interaction possibilities is created.
Extra-Game Consequences	*Consequences outside game states that result from actions or events within those game states.*	The concept of RYM entails a potential change in the player's sensation of his brain as a controllable tool.	The effects of BCI games on the human brain require further research.
Further Player Improvement Potential	*That players have the possibility to increase their skills in handling the gameplay.*	RYM requires repeated play for the player to achieve meaningful control of the BCI gameplay features.	Playing BCI games can have effects on the player's mental constitution.

Game System Player	*A passive player controlled by the game system.*	The player of RYM is controlled by the game system.	BCI games have the ability to control the player.
Game Time Manipulation	*Actions that let players influence how game time progresses in a game.*	The game time of RYM is directly influenced by the player's level of concentration.	The game time of BCI games can be influenced by the player's mental or emotional state.
Helplessness	*Gameplay situations where players cannot themselves affect their situation.*	As there is no guidance on how to play the game, the RYM player finds himself in a situation of helplessness.	Due to the fact that BCI games lack output feedback, the player can be trapped in a situation of helplessness.
Mediated Gameplay	*Gameplay where the player's interaction with the game state and/or each other is done through a system.*	The BCI gameplay of RYM is generated by the processing of EEG signals into meaningful control signals.	BCI games make use of a BCI that translates EEG signals into control signals, which in turn can be interpreted by a game engine.
Private Game Spaces	*Parts of the game space that only a single player can manipulate directly.*	The experience of playing RYM is highly intimate and differs from player to player and from play session to play session.	BCI games make use of highly sensitive data collected from the human brain. Even if at present this data is cryptic, future applications will need to consider this security issue.
Randomness	*Effects or events in the game cannot be exactly predicted.*	When playing RYM one does not know if one is in control of the BCI gameplay or if it is based on randomness.	BCI gameplay cannot be differentiated from random gameplay due to the lack of an output feedback channel.
Sanctioned Cheating	*Cheating which either is supported by the game design or is seen as acceptable to a certain degree by other players.*	RYM incorporates cheating or hacking as a game design feature. The player has to cheat the game system to gain control.	In BCI games cheating and hacking can occur on a technical or mental level by hacking the game system or hacking the player as a system. In the latter case, the player has to hack himself.
Uncertainty of Information	*The case when a player cannot be certain of the reliability of information he or she has.*	RYM's BCI gameplay features are not transparent; the player has no access to the information that is used.	The registration of mental activity or emotional states through EEG signals leads to uncertainty of information.
Varying Rule Sets	*Games where the rules governing gameplay change over time from within a closed set of rules.*	The rule set of RYM's BCI gameplay is hidden from the player and depends on the player's EEG signals. Therefore, the gameplay varies.	The rule set of BCI games can vary according to the mental task performed by the player and/or his emotional state.

Table 5 - BCI Game Design Patterns

6.2.1 ADAPTIVE BCI GAMING

BCI technology can be used to create BCI games as personalised entertainment. The player's cognitive processes (e.g. motor imagery) and emotional states (e.g. concentration, boredom, anxiety or happiness) can be used to create and control an adaptive gaming environment. Researchers have already described adaptive BCI gaming elements without categorising them from a game design perspective in game design patterns. For example: "The challenge that the BCI game poses should increase as the player skills increase" (Gürkök et al. 2015, p.12). Another example can be found in the study conducted by Mladenovic et al. (2017), which focusses on how adapting the difficulty level and changing the background music in a motor imagery BCI game influences the flow of the game. Adaptive BCI gaming seems to be a very promising field for future research within game Design Research.

6.2.2 CONCLUSION

While prototyping BCI games (the VOID Series), I came to the conclusion that, in order to properly describe the characteristics of the artistic and experimental, affective and adaptive BCI-VR game RYM, it is necessary to expand the existing definitions – a conclusion that forms an answer to the third research question of this PhD. Just as hackers expanded computer systems with new layers of possibilities, the work on Ride Your Mind, as part of the emerging genre of BCI games, expands the existing game-characteristic description possibilities with a new layer of BCI game-characteristic description possibilities. This work forms a starting point that aims to identify knowledge gaps in game design research and enable further research on BCI game design. To enable a discussion about BCI games, the existing definitions and descriptions need to be expanded. When I tried to describe the conceptual background of RYM's game characteristics and design patterns, it became clear that the present characterisation of design patterns and elements does not offer the precise vocabulary to do so.

The indicated research gap complicated my research design and methodology based on hacking. I began by alternating between playfully hacking the BCI-Headset and a theoretical description of potential BCI game design patterns, but when I recognised that I was trapped between these two approaches, I decided to cancel the research on BCI game design patterns. It would have required more time than I had to conduct solid research into these game design patterns. This field turned out to be an entire research topic in its own right, and it would have included proper academic research, including user studies and a more detailed elaboration on how to examine, reveal and define the particular design patterns. Further research on these potential new BCI game design patterns, on affective and adaptive gameplay elements and how they are related to the traditional design patterns catalogue, would certainly be worthwhile, but it exceeded the scope of this project-based PhD. By playfully hacking the EEG consumer technology, which was the primary goal of this artistic research project, I gained sufficient basic knowledge to continue to work on the research project Ride Your Mind.

6.3 RYM BCI GAME CHARACTERISTICS

The (artistic) intention of RYM is to enable players to use their unconscious actions as conscious actions, as well as to communicate an awareness regarding the security issues of future BCI gaming technology. This inspires the player to train and use his brain as a controllable tool comparable for example to the use of his hand. Similar to learning to play the piano through coordination and repetition of the pianist's hand actions, a player of RYM might be able to condition his brain by learning to control the EEG signals he transmits. The BCI-VR game is not designed for the mass market. It is an experimental playable artistic prototype examining the possibilities of current consumer hardware. The results shall serve as a starting point for further academic game design research aimed at defining BCI game design strategies and expanding the current academic discourse, as well as the understanding of BCI games from a hacking, game design and game art perspective.

Ride Your Mind as a game obviously includes gameplay. In order to properly describe the gameplay of the RYM prototype developed as part of this PhD, first the characteristics of the final game will be explained. In this section the general description of the characteristics of games that can be found in the work of Elias et al. (2012), will be used as a guideline to describe the game characteristics of Ride Your Mind. To understand how a game is played it is necessary to leave behind the perspective of the game designer or artist and adopt the perspective of the potential player. Potential players raise questions, such as for how many players the game is designed, or for how long one can play it. To help potential players understand more of what a game is about, the meta-descriptions are very helpful, often even more so than a detailed description of the gameplay (Elias et al. 2012, p.3). The following section first outlines the characteristics of Ride Your Mind and then goes on to describe its gameplay and rules in detail.

6.3.1 NUMBER OF PLAYERS

One of the first categorisations in the game characteristics catalogue by Elias et al. (2012) is the number of players of a game. Ride Your Mind is designed as a pure one-player (singleplayer) game. These are games where you play against the system instead of an imaginary opponent (Elias et al. 2012, p.22). Tetris (1984) and Spacewar! (1962) are examples of this category. The one-player is split into two categories: (1) the pure one-player outlined above (against the system), and (2) the "one human, simulated opponents ("one and a half player")" (Elias et al. 2012, p.22). The difference between these categories lies in the behaviour of the game and its gameplay. The second category uses artificial intelligence (AI) to simulate a human opponent.

RYM can only be partly described with these definitions from the catalogue. It is a one-player game in which the player consciously plays against himself (his own subconscious). Conscious behaviour causes direct unconscious actions in the gameworld to be triggered by the EEG signals (BCI Gameplay) read out from the player's brain. The game forces the player to create a constant feedback loop between his conscious and unconscious actions. For example, if the player moves his head, this movement evokes a reaction in the motoric centre of the brain. This action in turn produces EEG signals that can be detected by the BCI gaming headset and thereby directly influence the gameworld or the BCI gameplay.

Based on this characteristic, RYM is a one-player game that fits both existing subcategories (playing against the system and an imaginary opponent). As a BCI game, RYM introduces a new aspect to the categorisation catalogue of Elias et al. that will need to be taken into account. Even if it is not yet the case today, BCI gaming will eventually make it possible for a player to compete or play against himself. To properly explain the characteristics of a BCI game, and in particular Ride Your Mind as the object of this research, an extension of the already existing game characteristics catalogue is required. The second subcategory refers to artificial intelligence that simulates human opponents. Of course the EEG signals used by BCI games are interpreted by software and therefore are a form of artificial intelligence. But using BCI gaming technology can also enable the play against yourself – a hidden second player present in a one-player game, representing the unconscious behaviour of the conscious player. As soon as a potential player masters the BCI gameplay of RYM and can hack his EEG output and therefore the sensation of his own brain, he might be able to consciously reveal the hidden second player and gain control over him. This hypothetical outcome requires serious practice in order to develop the skill (Elias et al. 2012, p.29) required to master the BCI gameplay and consciously alter the EEG signals. The experimental BCI game RYM not only allows the player to create rules of thumb for the game, it also allows him to actually condition his brain and hypothetically use it as a controllable tool. The hypothetical outcome is currently unlikely to occur, but it will become more likely with a future BCI gaming setup. Further research on this paradigm is being prepared.

6.3.2 INPUT TYPES & TYPES OF CONTROL

RYM uses two devices as input controls for the gameplay. First the Oculus Rift HMD and the built-in gyroscope that synchronises the player's head movement with the player's virtual view direction, and secondly the Emotiv EEG BCI-Headset used to influence the BCI gameplay elements of RYM. Because the EEG signal processing is too slow and inaccurate, a weightless responsiveness as proposed by Elias et al. (2012) is currently impossible. The player does not have any reference regarding how to control a BCI game and how it feels to actually play it. Therefore the design decision was made to create a playable adaptive prototype version of RYM by incorporating random gameplay instead of EEG-triggered BCI gameplay. Players cannot predict the behaviour of a BCI game and they are tricked by the technological setup, even if there are no conscious effects in the gameworld per se.

6.3.3 PREPARATIONS TO PLAY THE GAME

In order to play Ride Your Mind, the player has to prepare the hardware. This includes wetting several electrodes of the Emotiv EEG BCI-Headset; establishing a proper connection of these to the player's scalp; strapping on the Oculus Rift Virtual Reality Headset; putting on the noise cancellation headphones and, last but not least, starting the game by launching its executable. This preparation ritual, the so-called "busywork" (cf. Elias et al. 2012, p.183), forms an essential part of the artistic illusion of Ride Your Mind. The setup takes time and this ritual of gearing up this emerging type of technology is part of a performance taking place in a museum exhibition space. This playful ritual of preparing the player to play RYM can furthermore be understood as a metagame (cf. Elias et al. 2012, p.203). The metagame of RYM entails the illusion of the BCI gameplay capabilities of the BCI-VR game. Even if the game does not work with the intended BCI gameplay triggered by EEG, a potential player might be persuaded by the metagame ritual of preparing the required technologies. As such the player will be convinced that BCI gameplay features exist, even if he will not be able to perform conscious gameplay actions. With this ritual or artistic strategy the player's expectation and sensation of the game is hacked, that is to say it is altered by means of the fourth strategic element of hacking, namely: *disruption*.

6.3.4 GAME HEURISTICS

Elias et al. (2012) identify two kinds of heuristics that can be used to characterise a game. Firstly, positional heuristics to evaluate the state of the game and who is winning (Elias et al. 2012, p.30), and secondly directional heuristics to evaluate which strategy the player should follow (Elias et al. 2012, p.30). Ride Your Mind does not at any stage inform the player if he is winning or losing, and neither does it tell the player what strategy or tactic he should follow to master the game. Furthermore, the game does not provide any information on how to control the actions triggered in the gameworld by the EEG signals (BCI gameplay), and there is no point at which the player has won or lost. The game ends after a certain timespan based on the player's concentration level as registered by the EEG signals. Therefore, it can be labelled as a "nonorthogame": a game that has "no formally defined winners and losers. Typically, players of such games define their own victory criteria" (Elias et al. 2012, p.82). By determining the player's concentration level by means of EEG, the duration of the game is influenced and manipulated. As such, the player subconsciously defines his own victory condition within the RYM game system. After repeated sessions with RYM, players might succeed in unveiling this fundamental rule and begin to manipulate their own concentration levels. The victory and/or end condition of RYM is comparable to that of sandbox games such as the Sim City Series (1989 – today) or Minecraft (2009), where players determine it individually (Elias et al. 2012, p.83). An important difference however is that the RYM player will determine this condition unconsciously, and that the game will end abruptly until he unveils how to consciously manipulate or hack it.

Beginners playing Ride Your Mind can improve their skill by repeatedly playing the game so as to acquire increasingly "sophisticated heuristics" (Elias et al. 2012, p.34). The player is not provided with any instructions or explanations, except for a general description of the game itself as an artistic and experimental BCI-VR game. Like the early hackers of the 1950s, who were introduced to military computers without access to instructions or manuals, the Ride Your Mind player has to explore the game system's input and gameplay possibilities in a playful manner. The second game heuristic defined by Elias et al. (2012, p.34) matches this explorative gameplay component of RYM, where the player has to explore both gameworld and gameplay, but also the different input features described below in the gameplay section of this document. The first two design methods and/or elements of hacking apply to the game characteristics outlined above and they informed the decision on how to create the gameplay of Ride Your Mind. *Addition* and *appropriation* were used as strategic design elements in the creation of an explorative gameplay for RYM. The mandatory hardware setup consisting of a combination of BCI-Headset and VR-headset evokes curiosity in potential players and motivates them to explore the artistic and experimental experience of RYM.

As the player of RYM receives no guidance and remains unaware of all the possible BCI gameplay interactions, he will never be able to fully master the game. This stands in contrast to the claim by Elias et al. (2012, p.34) that the heuristics should never leave the player without guidance. The only guidance provided by RYM is the description of an explorative gameworld that is influenced, controlled and manipulated by the player's EEG signals. This design decision is related to the third design method and/or element of hacking: *expansion*. "The hacker is not a trained technician or programmer, but someone who gathers his own knowledge. He does not obey arbitrary rules and programs, system administrators or contexts of use" (Pias 2002a, p. 254, translated from the German). The RYM player is placed in the position of an early hacker who has to find out how to play the game himself. Moreover, the player has to increase his knowledge while playing the game so as to determine the boundaries of the provided technology and game system. Ultimately, RYM does not offer players a satisfying outcome, which again goes against the game heuristics proposed by Elias et al. (2012, p.34). Therefore, those who play RYM might come to the conclusion afterwards that everything in the gameworld was randomly generated. This reaction is inherent to the design of the game: RYM seeks also to address the frustrating elements and important security-related issues of future gaming technology powered by neuronal activity. This game characteristic of RYM can be characterised as an application of the fourth design method and/or element of hacking, namely: *disruption*.

6.3.5 GAME RULES

The rules of Ride Your Mind remain mostly unknown to the player, thus creating a hidden game system infrastructure. The rules of a game restrict the actions and/or choices of players within a game system (Consalvo 2007, p.85; Elias et al. 2012, pp.71 & 120). This holds true for the BCI gameplay features of RYM and their underlying ruleset triggered by EEG signals. The rules of RYM cause immediate actions within the gameplay. Various EEG signals interact with the game and the underlying rules that trigger the BCI gameplay. There is no identifiable game state by which the player can determine whether he is losing or winning the game. This game design decision further underlines the hackish, playful and explorative nature of Ride Your Mind.

The game does not offer any visible or obvious gameplay choices. As RYM is based on BCI gameplay, the gameplay itself is triggered by EEG signals and mostly unconscious and/or unintentional mental tasks. With regard to RYM's game rules, there are hidden choices that appear to be non-existent for the player. Therefore the player is not in charge of performing meaningful (cf. Elias et al. 2012, p.120) choices within the BCI-VR game RYM. The available number of choices within RYM remains hidden as the result of a conscious design decision. As a media artist I fully anticipated that players might experience the game as frustrating, which in turn would affect the game's end condition, or even boring because they are under the impression that the number of choices is limited – or sparse (cf. Elias et al. 2012, p.122).

The only thing that indicates that RYM features gameplay, or even that it is a game, is the project's subtitle, which identifies it as an experimental and artistic BCI-VR game. Players are not at any given time provided with an explanation of the gameplay details or available choices. This is the result of an artistic and hackish game design decision to hide the gameplay, especially the BCI gameplay within the explorative gameworld. This decision can be defined as another disruptive element in the manner of the forth strategic design element of hacking. Ride Your Mind is identified as a game, meaning that it entails gameplay elements; to be specific, it is a BCI game and thus includes BCI gameplay elements. Players of the game will not be able to recognise these BCI gameplay elements or the game's behaviour, until they learn how to master their EEG output, which is near impossible. The BCI gameplay manipulated by the player's EEG signals does not offer meaningful choices to the player. He might feel as if he is part of an artistic visualisation of his brainwaves, unaware of the fact that hidden gameplay elements are triggered and his behaviour, intended and/or unintended mental tasks are influencing the gameplay and the gameworld. The BCI-VR game RYM will never unveil its gameful features to the player directly. In this way the game plays with the role of the player and unwillingly puts him into the role of a spectator.

6.3.6 RANDOMNESS

The BCI gameplay of RYM is randomly altered instead of altered by actual EEG signals. This adjustment is the result of a small hackish experiment I performed on myself while playing RYM without knowing if the BCI gameplay features were being manipulated by the EEG data or randomly generated. I was not able to distinguish between actual EEG influenced BCI gameplay or randomly affected BCI gameplay. Because of this finding, it is necessary to also incorporate randomness as a game characteristic of Ride Your Mind. The game characteristics of randomness (Elias et al. 2012, p.143) can also be used to describe current BCI game characteristics, because the accuracy of current consumer BCI-Headsets leads to an indistinguishable result for the player controlling actual BCI gameplay or randomly altered gameplay. Elias et al. (2012, p.147) explain that random elements or randomness can be attractive and exciting to players. Costikyan (2013, p.85) argues that randomness can be a strength which breaks the symmetry of a game and therefore attracts players, but also a weakness when it causes frustration. Players are attracted by BCI gameplay in the same way they are attracted by randomness, and within the new genre of BCI gaming players accept randomness more readily than in existing game genre (Elias et al. 2012, p.149). As an emerging game genre BCI gaming can make use of random elements to overcome hardware and performance issues. There are virtually no conventions as yet when it comes to BCI games and, moreover, potential players have very little or no preconceived notion of them or their gameplay. They are fascinated by the idea of controlling a game with their thoughts through the use of new technology. In the game design process of RYM this current state of affairs is used advantageously to overcome technological issues by replacing the BCI gameplay features influenced by EEG signals with randomly generated data. As noted above, this solution is based on the artistic hacking strategy called disruption and enabled me to realise a playable prototype of Ride Your Mind.

6.4 USER STUDIES

The artistic BCI-VR game Ride Your Mind is highly experimental. No user studies have been realised. This practice-based research project investigates the possibilities of current consumer BCI and VR technologies to create an artistic BCI-VR game, and is situated on the edge of current game design research to identify future possible BCI game design elements and patterns. Its goal is to realise a game with a strong artistic foundation that is not intended to compete with games from BCI research or the gaming industry. Notably, BCI researchers warn against BCI applications or games that lack a proper and detailed preparation: “Just as in any computer game, the long-term effects of BCI game activities should be carefully considered. Especially in mental state games, positively affective activities should be preferred. Otherwise, long durations of play may change functioning in an unwanted direction” (Gürkök et al. 2015, p.13). In light of this, it is important to reiterate here that properly prepared user studies would have exceeded the scope of this practice-based and experimental artistic PhD.

6.5 CONCLUSION

In this chapter the third research question has been successfully answered. Several discoveries and issues relating to BCI gaming technology, but also to BCI game design, have been successfully identified though a playful exploration and hacking of BCI technology and prototyping BCI games, as documented in chapter 5. As has been outlined in the previous sections of this chapter, the BCI gaming technology by Emotiv produces more issues than possibilities. BCI game design patterns have been identified and described as an outcome of the prototyping and experimentation with affective and adaptive BCI gaming, and finally RYM's BCI game characteristics have been explained. Unforeseeable technical issues (as described in the previous sections) with the consumer BCI technology interfered with the intended gameplay and game design of RYM and therefore prevented a fully working prototype. In the following chapter (7) the various discoveries and issues will be examined from different perspectives, such as media art, game art, hacking and game design.

7 REFLECTION

As an artistic work Ride Your Mind incorporates several artistic strategies rooted in art history. The following chapter will outline and discuss these artistic strategies. I will also examine the discoveries and issues discussed in the last chapter from different perspectives, such as game art, game design, media art and hacking, in order to answer the third research question of this PhD by project.

7.1 HACKING AS PART OF MEDIA ART HISTORY

In his book *Entangled: Technology and the Transformation of Performance*, Salter (2010) outlines the evolution of theatre over the centuries in light of the influence of transdisciplinary artistic approaches and available technologies. For example, he describes how, in the 1960s, media artist Nam June Paik produced video art works incorporating screens and televisions. Paik's first exhibition, which took place in 1965, was entitled Electronic TV + Color TV Experiments and was shown in New York (Salter 2010, p.118). Paik experimented by using televisions to engage with the audience. Later, screens, televisions and projections were used in the theatre by other artists. Salter's book does not, however, make any mention of the creative work of early hackers in the 1950s and 1960s (as outlined in section 2.4 on the history of hacking) and their seminal and innovative use of digital technology.

In *Aesthetics of Interaction in Digital Art*, Kwastek (2013) details the history of digital art in the 1990s. She outlines different approaches to digital art and its different subcategories, such as interactive art and the overarching term of media art. Ride Your Mind can be categorised as interactive art, the category in which game art has been situated within the media art universe. Media art, an encompassing term, was coined as a result of works in the field of video art by artists such as Paik. Digital art, on the other hand, is a term coined later on in the 1990s by artists such as Jeffrey Shaw. Kwastek researches media art and related art forms and their historical origins, as well as discusses the relationship between interactive art and the aesthetics of play (Kwastek 2013, p.71), concluding that "the reception of interactive art is similar to the activity of play" (Kwastek 2013, p.261) but that interactive art includes disruptive elements. Disruption is one of the artistic strategies I have extracted from the history of hacking, and hacking as a creative strategy may be a key element of the relation between interactive art and play. In spite of this, as with Salter, Kwastek's book does not reference the history of hacking or the digital creative works of early hackers.

As RYM is based on hacking as a methodological design strategy, it also involves the artistic strategies that are part of hacking. As I have argued earlier, hacking can been seen as a playful strategy in problem solving (cf. Levy 1986), and early hackers produced digital media art and digital games (interactive art) at the same time. The playful element of hacking (which also led to the invention of digital games) is rooted in artistic strategies such as performance (Salter 2010), *détournement* (Pias 2013) and those found in Dada, Surrealism, Situationism and Fluxus (Dragona 2010), as will be discussed hereafter.

Schwingeler references William Higinbotham's Tennis for Two (1958) as the earliest example of an analogue computer game. The game, which runs on an oscilloscope, is labelled a hack by Schwingeler (2014, p. 14). In 1962 Steve Russel, one of the original hackers from MIT (Levy 1986), created the first digital computer game, Spacewar!, on the PDP-1 computer. This development is outlined by Schwingeler (2014, p.14) and also referenced in the historical examination of hacking undertaken earlier in this document. Spacewar! appropriated technology to turn a military-use computer system into an interactive entertainment machine. Hackers were creating algorithmic and interactive visualisations rendered in real time on digital computers, such as Munching Squares (1962) and Spacewar! (1962) at the same time as famous media artists such as Paik were working with televisions and screens to display pre-recorded or live-streamed video signals. The early hackers from MIT were exploring the artistic potential of computer technology and playfully creating interactive and algorithmic media art works decades before the 1990s, when computer systems reached the masses and famous media artists began using digital media to create their interactive and playful works. According to Schwingeler, artists have been using digital computer games to artistically reshape existing games since 1995. He explains that between the 1960s and 1990s the computer game industry locked computer systems so that they could not be modified in order to maximise company revenues. This continued until the 1990s when modifying computer games was made partially possible by the gaming industry (Schwingeler 2014, p.15). Schwingeler is also one of the curators of the exhibition ZKM_Gameplay (2013) at the ZKM | Center for Art and Media in Karlsruhe (Germany). The ZKM Media Museum has been collecting and exhibiting digital games since 1997 and is one of the leading media art institutions of the world. The curators (Serexhe & Schwingeler 2013) explain that digital games became important during the 1990s, citing Pong (1972) as one of the first commercial games. But they make no mention of the work of the early hackers at MIT. In their online publication (Szope 2016), relating to the 2004 exhibition *Welt der Spiele: Reloaded, Die Algorithmische Revolution*, Tennis for Two (1958) and Spacewar! (1962) are listed, but not referred to as artistic or creative works.

It can be stated that hackers were creative, artistic and playful innovators ahead of their time. Nearly 30 years before the art world started to pay serious attention to digital media art (Kwastek 2013), hackers were creating algorithmic visualisations such as Munching Squares (1962) – digital media art before the name had even been coined. And nearly 50 years before the art world started to engage with digital games as art (Schwingeler 2014; Sharp 2015), hackers were creating interactive and playful digital media art such as Spacewar! (1962). What can be concluded from this is that, although the question whether digital games can be considered art at all is still subject to a lively and ongoing debate, and hackers are not currently regarded as having a place in modern art history, they definitely should be included in the discussion around digital art. If digital media art and digital game design can be said to have come into being around the end of the 1950s and the beginning of the 1960s, it is clear that hackers (the model railroad tinkers!) and their playful and creative approaches to digital technology were there from the start.

7.1.1 GAME ART

As I have outlined, hacking is situated between digital interactive media art and game design. Within media art, game art is the common term used nowadays to describe artistic gameful works. Game art originated in the 1990s and its roots are connected to the accessibility of the World Wide Web and the rise of hacktivism (Dragona 2010, p.26). Computer games such as Doom (id Software 1993) provided artists with such tools as level editors and modification possibilities, which allowed for the creation of game art such as ArsDoom (1995). Sharp (2015) differentiates between game art, art games and artist's games. He historically examines and defines the three terms over three separate chapters. In the first chapter, he describes various artists and their work, such as Julian Oliver and his work ioq3aPaint (2010), Cory Arcangel and his work Super Mario Clouds (2002) and JODI and their work SOD (2002). With the help of these games, Sharp (2015) analyses and defines the genre of game art. Dragona (2010) situates game art within the historical context of twentieth-century art movements, referring to the playful spirit of Dada, the imaginary work of Surrealism, the unplayable games of Fluxus and the influence of the Situationists' concept of play as an act of resistance (Dragona 2010, p.27). Modern game artists play with the rules and boundaries of the game, breaking and transgressing them so that the game as system becomes artistically modified and disrupted. Dragona (2010, pp.27–28) describes this mix of creativity and playfulness which forms the artistic strategy of game artists by referring to the term *détournement*, which was originally coined by the Situationists to describe an act of artistic and playful appropriation. Pias (2002a) compares hacking to appropriation art, noting that both rely heavily on recontextualisation. The best-known expounder of this art form is Marcel Duchamp, who first gained fame for his readymade Fountain (1917), a common urinal installed in an exhibition space in clear breach of the rules governing traditional museum etiquette. Pias (2013) also cites Guy Debord's concept of *détournement* as relevant to the discussion of hacker culture, along with the notion of *umwidmung* as employed by Bertolt Brecht and Walter Benjamin (Pias 2013, p.2). It is possible that game art was originated by the work of early hackers who created algorithmic visualisations (digital media art) and interactive playful programs (games) in the spirit of appropriation art. Of course this is hypothetical, but first indications have been found that suggest further media-archaeological and art historical research would be well-worth undertaking.

Fuchs, as a media artist and researcher, gives a profound and insightful overview of media art works and the playful appearance that led to the term game art (Fuchs 2011, p.54). He highlights works such as The Legible City (Jeffrey Shaw 1988), Giant Joystick (Mary Flanagan 2006), Wargame (Leif Rumbke 2005) or The Center of the Universe has Infinite Paths of Approach (Jess Kilby 2007), and describes them as art games with unconventional but playful interfaces (Fuchs 2011, p.54). He calls these experimental and artistic interfaces "ludic interfaces", and uses this term to distinguish them from traditional interfaces such as keyboards, mice or joysticks. Furthermore, he offers the definition that ludic interfaces are based on artistic experiments with interactive media and also relate to the modding culture (Fuchs 2011, p.54). Interactive art works often created confusion when they were merely seen as playful. "Media artist and theorist Peter Weibel points out that often a confusion happened with interactive art pieces, when they were only called to be playful. While certainly several interactive installations from the 1990s do have playful aspects and encourage active involvement, it is the algorithmic quality and the metaphor of the open process that is more important and which can also be linked to earlier participatory art forms of the 1960s and 1970s" (Sommerer et al. 2015, p.3). The prototyping stage of Ride Your Mind included an artistic and experimental examination of the consumer BCI-Headset and the virtual reality headset to create the BCI-VR Helmet and the final concept for a game art installation. Based on Fuchs' definition, the BCI-VR Helmet can be defined as a ludic interface, even if the hardware is itself a piece of technology. With the help of hacking as an artistic and playful strategy, the hardware was artistically applied and used in adherence with the RYM concept. Creating an artwork as an interactive game art installation enables the artist to fully customise both the game system and the interface necessary to play or experience the game (Avellino et al. 2003, p.12 [Bizzocchi]). With all its technological components, the BCI-VR game RYM is a customised game art installation. The system, the devices and the software were especially designed for the game. Since consumer BCI gaming technology is still only a distant possibility, this was a necessary step to create the illusion of a working game.

Ludic interfaces can include an artistic statement[39] that addresses HCI paradigms and processes in a playful manner (Fuchs 2011, p.55) and as such are related to the attitude of the trickster or spoil-sport (Fuchs 2011, p.56). However, the notion of the spoil-sport is also related to hacking. The disruptive element of hacking breaks the rules and tries to overcome boundaries or extend them. Fuchs identifies spoil-sporting as a common artistic practice that drives the development of the arts (Fuchs 2011, p.56). This is another indication that game art and hacking are related. If spoil-sporting is a common artistic practice, and if spoil-sporting is also part of hacking, hacking may be considered an artistic practice. Using hacking as an artistic strategy can lead to novel ludic interfaces and innovative game/media art

[39] Ride Your Mind includes an artistic statement which is described in chapter 2 of this document. At the end of the game session (game session duration is influenced by EEG data) the player will see the following message: **"Thanks for the highly personal data that was read from your mind while you were playing.**" This message is used to raise the player's awareness of security issues in relation to future BCI gaming technology.

works and games. It is highly recommended that further research is done into the connection between hacking and media art through game art.

7.2 HACKING, PLAY AND PLAYFULNESS

Let us look at the playful element of hacking. In their book *Play, Playfulness, Creativity and Innovation,* Bateson and Martin (2013) discuss the meaning of play to humans. This work is used to define the term play in relation to hacking. Hacking is about breaking the rules of a system and dealing with and pushing its boundaries: "Play involves breaking rules" (Bateson & Martin 2013, p.57). Play itself involves breaking the rules of the play system, which indicates that the disruptive element of hacking (the fourth strategic design element) is based on the nature of play. The player of Ride Your Mind also has to playfully break the rules of the game (i.e. hack it) in order to assume control of the BCI gameplay and consciously trigger certain game elements. The player of RYM has to playfully explore the BCI gameplay possibilities by repetitively playing the game. Even if the player is not immediately able to hack and consciously control the BCI gameplay, he may be so after some time. Alternatively, he may never be able to take conscious control of the BCI gameplay. This play behaviour is rooted in the nature of play as described by Bateson and Martin (2013, p.88). Play and playfulness can produce new ideas to solve problems (Bateson & Martin 2013, p.4). The main intention of hacking is to playfully solve problems (Levy 1986). The explorative setting of Ride Your Mind enables the player to discover how to play the game without any instruction and to take control of the BCI gameplay. The player has to explore the possibilities of the game and to learn its central secret: that he may never be able to control RYM because the BCI gameplay is altered at random. Hacking and play seem to be directly connected: "Play involves novel combinations of actions or thoughts" (Bateson & Martin 2013, p.122). In relation to hacking, play is crucial to all the design elements found in the history of hacking: addition, adaption, appropriation and expansion. Through playfully prototyping BCI games and hacking the technological components, I utilised all the elements of play that were used by early hackers to drive their creative and artistic work. Of course, this conclusion requires further academic research, but there do seem to be overlaps between the nature of play and the act of hacking. Another potential outcome, as I have outlined above, is the employment of hacking as an innovation strategy, since hacking is by nature a playful activity and play leads to creative innovation. To reiterate, playfully solving problems was the driving spirit of hackers, and the early hackers at MIT were driven by play and playfulness.

7.3 HACKING AS PLAYFUL STRATEGY FOR EXPERIMENTAL BCI GAME DESIGN

Designing a game prototype that is both experimental and artistic runs contrary to expectations; experimental and prototype games are not supposed to have a focus on satisfactory graphics or smooth-running gameplay, nor attempt to convey an artistic message. The games are usually small experiments that prove certain research paradigms and they are designed just for this purpose without paying attention to visual, playful or artistic attractiveness. Waern and Back (2015, p.363) suggest that "experimental game design should aim to explore design factors that are novel or may be problematic, rather than strive to generate good games." However, this was not my aim. As a hacker and artist, I wanted to design an artistic experimental game that additionally satisfied my visual and gameplay demands while seeking to deliver a message to the player. This decision contradicts current suggestions on how to design a research game (cf. Waern & Back 2015, p.362). Researchers (Waern & Back 2015, p.362; Gürkök et al. 2012, p.373) warn experimental game designers that the aim of creating a "good game" based on emerging technology such as Brain-Computer Interfacing may not result in an experience satisfactory to gamers. However, the playable prototype of Ride Your Mind integrates experimental and artistic aspects. Games can bring together art and science, but while the science of a game is often hidden, it is the art that the audience perceives (Avellino et al. 2003, p.11 [Garfield]). The scientific aspects of Ride Your Mind are definitely concealed; the only hint given to the player is the BCI-Headset placed on his head, which the player logically assumes has functionality. Nonetheless, since the visual feedback displayed by the VR-Headset is the only direct feedback, the BCI gaming functionality indicated by the BCI-Headset is imperceptible to the player. The BCI-VR game RYM sets the benchmark for a new kind of experimental game that is both visually and game-playfully convincing and implies an experimental technological setup with BCI. The design process of RYM, which is based on hacking, could be used as a blueprint for the design of experimental games that likewise satisfy the visual and gameplay demands of gamers.

7.4 BCI GAMING: PERSONAL REFLECTION

When I first starting working with the consumer grade BCI, I was excited to get acquainted with the possibilities of this emergent technology. Inspired by the attractive features of the "mind control" games advertised by companies like Emotiv, I began investigating, hacking and exploring the new technology. In creating the experimental BCI-VR game Ride Your Mind, several issues and possibilities related to BCI technology came to the fore.

The first tests with the Emotiv BCI were promising. After setting up the hardware and establishing a connection with the computer, I was able to see EEG signals as well as to master certain actions, such as triggering the up arrow key by thinking of the command "forward". But attempting to master a further action, such as "left", then caused the first problems. The action would be triggered without the player (me) having thought of the specific command. Confused, I made some further attempts. In the end I was left frustrated and decided to give up the calibration of further actions. Moreover, after wearing the headset for 15 minutes my head started to hurt. This was caused by the electrodes pressing into my scalp.

I then created the first BCI game prototypes – the VOID series described in chapter 5.2. Over time the functionality and in particular the precision of the technology proved disappointing. None of the planned BCI gameplay features of RYM could be realised because the technology to do so was not available. But I did not give up the hope to build a working prototype of the BCI-VR game.

Since the BCI I used did not allow me to design the features proposed in the concept of Ride Your Mind, I decided to design a game with various BCI gameplay features that appear to be triggered and/or influenced by the player's EEG signals, but in reality are based on random values. This artistic hack saved me a lot of time and resulted in a game that provides players with the feeling as if the gameplay is manipulated by their actual EEG signals. As such RYM serves as an example of what future digital games and BCI gaming might look like.

7.5 BCI GAMING AS EMERGING FORM OF DIGITAL ENTERTAINMENT

Current consumer grade Brain-Computer Interfacing technology is impractical for (BCI) gaming and (BCI) game design purposes. The target group of gamers expects plug and play capabilities to include the quick setup of hardware. As long as the setup consumes more time than the potential gameplay, the hardware is not suitable for the consumer market. However, ongoing research is aimed at developing new and more practical BCI hardware, in particular for gamers (Tan & Nijholt 2010, p.76).

Future advancements will almost certainly mean that the game design possibilities of BCI games and/or games influenced by BCI technology will be enormous. For example, a BCI game could adapt itself during play to the player's mental state to keep the player in a steady state of flow (Csikszentmihalyi 1990; Sweetser & Wyeth 2005; Chen 2007; Nijholt et al. 2009, p.86; Mladenović et al. 2017); specifically EEG data relating to concentration and motivation levels could be used to adjust the difficulty level of a game in real time (Lotte 2011, p.327). BCI gaming could also be used as a form of mental training, teaching players to cope with stress or mental disorders (Nijholt et al. 2009, p.91). In this case, BCI gameplay could react to players' emotional states, amplifying positive emotions or provoking negative emotions as necessary.

Endless possibilities for game designers will be realised by future consumer BCI technology. Therefore, work on BCI game design patterns is mandatory to create a guidebook for this new field of interaction possibilities. As the work on the BCI-VR game Ride Your Mind has revealed, there is great potential in combining technology intended for gaming with hacking as an innovative strategy.

7.5.1 THE FUTURE OF BCI GAMING TECHNOLOGY

BCI gaming technology needs to transform complex brain activity data, such as that provided by EEG signals, into easily manageable control signals that can then be used and accessed by a game such as RYM to influence or form gameplay. Gameplay influenced by neuronal activity – BCI gameplay – in turn can become very complex for players and designers. The BCI game designer needs to consider how he can transform these complex control actions into easy to understand and communicable BCI gameplay actions for a potential player. Therefore, a BCI game designer needs a profound understanding of how these control signals can be influenced and how they might correlate with so-called feedback loops in BCI game design. Fundamental work on defining BCI game design standards and patterns is necessary to transform BCI gaming technology into persuasive technology (cf. Fogg 2002) that will be accepted by the consumer audience. "Brain-computer interface, in theory, has the potential to become the ultimate interaction device – just 'think' of something and it happens. Current state of the art in BCI is, of course, very far from that vision; at the moment, BCI should be referred to as 'brain reading' rather than 'mind reading', i.e., it is often bad on decoding brain waves rather than decoding mental processes ('thoughts'). Eventually, there may be a one-to-one mapping from brain waves to mental processes, but with the current recording techniques, the brain patterns that can be detected are much coarser than specific thoughts" (Friedman 2015, p. 3). The question of how to connect the human brain with a machine with the help of a BCI system is a big hurdle to overcome within the next years. Scherer et al. (2015) describe this issue as the *Man-Machine Learning Dilemma*. Translating brain signals from a user with the help of machine learning and pattern recognition is a crucial part of current and future BCI. Beside the technological aspects of sensors and the signal data, the processing of brain signals for use in applications such as games is highly challenging. Scherer et al. indicate how BCI games could be used to train BCI systems and how to collect "high-quality data from motivated and engaged users as needed for reliable pattern recognition" (Scherer et al. 2015, p.16).

As the process of setting up the BCI-Headset is time consuming, a version that could be sold on the mass market is still a long way off. Professional BCIs cannot easily be used for consumer gaming experiences. "The high sensor count and wires make such as a system impossible to use outside the laboratory, because the setup requires one or several assistants and preparation time. Another drawback is the fact that conductive gel needs to be used for leaving residue in the user's hair" (Martišius & Damaševičius 2016, p.6). But as soon as cheap dry cap technology is available the era of BCI gaming will begin, doubtlessly accompanied by a hype comparable to that which heralded the recent evolution of virtual reality (VR) technology. Lance et al. (2017) posit that "there are no current serious BCI technologies in widespread use due to the lack of robustness in BCI technologies" (Lance et al. 2017, p.2). They further claim that "the key neural aspect of this lack of robustness is human variability, which has two main components: (1) individual differences in neural signals and (2) interindividual variability over time" (Lance et al. 2017, p.2). Exactly as VR did, BCI gaming technology first has to prove its right to exist to a potential mass market via technological progress. Faller et al. enumerate several future possible BCI applications combined with augmented reality (AR) that are comparable to VR: "the combinations of AR and BCI technology can introduce a valuable, additional communication or control channel for user groups that require or benefit from hands free operation (e.g. due to temporary situational disability) like pilots, astronauts, drivers or office workers" (Faller et al. 2017, p.5). After these formidable hurdles are overcome, the most important challenge must be addressed: the BCI game content must be convincing. As long as this challenge is not met, BCI technology will not be persuasive and will not find its way onto the mass market.

7.5.2 IDENTIFIED TYPES OF BCI GAMEPLAY

In this section identified types of BCI gameplay will be described. BCI gameplay can be categorised into two types: firstly, there are conscious BCI gameplay elements and secondly, there are subliminal BCI gameplay elements. In the case of the former, the player is able to identify and assign BCI gameplay triggered elements or in-game actions, to wit, conscious BCI gameplay elements are triggered by consciously performed mental tasks. These mental tasks translate as neuronally evoked signals which are read by a BCI (e.g., via EEG) and processed into meaningful control signals. These control signals are then used to perform conscious BCI gameplay actions inside the gameworld. For example, a player thinks of moving his avatar to the right and the avatar performs the designated movement. The concept of Ride Your Mind includes conscious BCI gameplay elements such as the described automatic calibration. To reiterate, automatic calibration takes place when, in response to stimuli, certain in-game triggers become calibrated – actively learning and becoming trained as play continues. However, as a result of the limitations of the consumer grade BCI-Headset, the conscious BCI gameplay elements could not be realised.

Subliminal BCI gameplay elements arise from unconscious actions inside the gameworld; these elements affect or alter BCI gameplay without the player's conscious volition. To give just one example, the designer of a BCI game could use this type of BCI gameplay to create environmental effects. The concept of Ride Your Mind did use these subliminal BCI gameplay elements to trigger environmental particle effects and procedural mesh deforming, influenced by actual neuronal activity. Subliminal BCI gameplay elements had been applied during the prototyping of experimental BCI games of the VOID Series. These elements could also be found in an earlier prototype of the game Ride Your Mind. The subliminal BCI gameplay of RYM that is conceptually influenced by neuronal data delivered from the BCI-Headset is overwritten in the current prototype by random data, achieving a comparable result.

7.5.3 RESPONSIBILITY OF FUTURE DEVELOPERS

The programmer as author of the compiler of the BCI is also the architect and definer of the signal message that is provided to the application (game engine). "When using brain activity directly, one needs to be more aware of this activity and to develop new levels of control" (Bos et al. 2010, p.151). Developers define actions triggered by patterns and cue values based on the recorded signal from the EEG headset. Furthermore, this means that using an existing compiler module does not implicitly allow access to understanding the processing of the existing architecture. Nowadays, it is no longer necessary for game designers to possess programming skills to design games. The hardware manufacturer Emotiv provides software and a plugin for Unity3D with features that can be used to trigger actions inside a gameworld. As long as this sequence is not comprehensible to non-programming specialists, such as game designers, and does not allow them the possibility of making alterations to the sequence, the design possibilities of BCI games are limited by the features of the provided software and tools.

7.6 ILLUSION OF CONTROL OF A BCI GAME

The illusion of being in control of a game is essential when it comes to BCI games. Observations on user experience of BCI games have been made by Van de Laar et al. (2013; 2013). BCI technology must convince players that they are in control in order to create a persuasive gaming experience. Gürkök et al. (2015) describe that current consumer grade BCI gaming technology, such as for example the Emotiv EPOC EEG headset, makes use of unknown and encrypted signal processing techniques. Details of how signals from the user's brain are turned into signals to control a game are not accessible for BCI game designers. "This leads to BCI games that are potentially entertaining but unsatisfactory in term of feeling in control." This perceived lack of control is an important issue to take into account when designing entertaining BCI games. Gürkök et al. (2015) warn that the gaming community could come to perceive BCI games as "futile applications" if this issue is not resolved. During the design and prototyping process of Ride Your Mind I ran into this same problem with the Emotiv EPOC EEG headset, and to overcome it I decided to use the lack of control as a game design element. This solution will be discussed in more detail in the following chapter (7.8). "BCI games are intrinsically aBCI applications. Still, it is possible to design a pBCI game in which the involuntary player state influences the games. But as soon as the player realizes the relation, they will start manipulating their state to gain an advantage in the game. Thus, the game will turn into an aBCI application" (Gürkök et al. 2015, p.12). This accurately describes one of the BCI gameplay features of Ride Your Mind. The player must hack himself to master the game, which means that RYM is both an aBCI and pBCI application (game). The player has to cheat the BCI to gain full control of the game and its mechanics. This infinite bipolar situation between an active (aBCI) and passive (pBCI) game turns the player of RYM into an active part of the game. This artistic game design element is part of the artistic and experimental concept of RYM. Other artistic hacks will be outlined in the following section (7.8).

7.7 BCI GAME DESIGN

BCI game design combines the disciplines of game design, HCI, BCI research and neuroscience. Therefore Mishra et al. (2016) note that future commercial BCI games need to be methodically developed and scientifically validated when enhancing brain functions is intended. These prototypes are often intended to test single gameplay paradigms and experiment with the mechanics. BCI games open a new layer of interaction possibilities in the digital gameworld. Therefore, it is necessary to creatively prototype gameplay and interaction scenarios with EEG-based technology to identify limitations of BCI technology, but also to identify mechanics to further define potential BCI game design patterns. These patters can then be used to expand the existing game design patterns catalogue continuously updated by Björk and Holopainen, which has been (2015) discussed in chapter 6.2.

In the *Handbook of Digital Games and Entertainment Technologies*, Gürkök et al. (2015) outline three different interaction paradigms that are used in BCI games. (1) The first interaction paradigm category is *Mental State Regulation*. It uses the player's mental state of relaxation or concentration to influence the game mechanics. Games designed to relax the player can be an outcome. From a BCI game designer's perspective, it is very important to consider, that "the speed with which one can change his or her state of relaxedness or concentration is much slower than the speed with which one can press buttons or use any other modality. Mental state games usually allow only binary control" (Gürkök et al. 2015, p.9). (2) The second interaction paradigm category is *Movement Imagery*. "Movement imagery games require no physical movement but imagery of limb movements, mostly the hands, fingers, or feet" (Gürkök et al. 2015, p.9). In comparison to the mental state of a player, the detection of imaginary movement can take place at much greater speed, which means it is much more suitable for action games where quick interaction and intervention with game mechanics is required. However, a BCI game designer still needs to consider that "the number of commands in these games is limited to the number of distinguishable imaginary actions players can perform" (Gürkök et al. 2015, p.9). Beside this limitation the training of these diverse control commands needs to be considered. As I have outlined in chapter 4, the training of BCI game controls can be used as a game design element and take place while the game is being played. (3) The third and last interaction paradigm of BCI games is called *Evoked Response Generation*. "This class of games is dominated by SSVEP games, accompanied by rare examples of P300 games" (Gürkök et al. 2015, p.9). SSVEP and P300 BCI games use brain reactions to flickering light or visual stimuli such as images. From a BCI game designer's perspective it is very difficult to use this interaction paradigm in the design of an attractive game. The visual markers and stimuli (e.g. images) need to be placed into a 3D gameworld with caution. While the potential player must be able to see the stimulus immediately in order to interact with the BCI game, he is probably navigating through a 3D gameworld full of different elements that distract him from potential stimuli and therefore BCI game mechanics.

7.7.1 THE FUTURE OF BCI GAME DESIGN

Future BCI games and their design may have many fields of applications. In their paper *Video Games for Neuro-Cognitive Optimization*, Mishra et al. (2016) describe how future BCI games could be used to optimise cognitive performance in healthy or handicapped players. They argue that scientists and game developers need to cooperate to create attractive BCI games. The rapid evolution of technology driven by the gaming industry "presents a huge opportunity for neuroscientists to design targeted, novel game-based tools that drive positive neuroplasticity, accelerate learning, and strengthen cognitive function, and thereby promote mental well-being in both healthy and impaired brains" (Mishra et al. 2016, p.214). The creative and playful approach to designing experimental and artistic BCI games, such as RYM, based on the four strategic elements of hacking can support the development of future BCI games. "The additional inner state information can strengthen the feeling of presence [in a game world]" (Gürkök et al. 2015, p.7).

To further support the development of BCI technology and BCI game design research, Lance et al. (2017) from ARL (US Army Research Laboratory) propose to use serious games: "By embedding BCI paradigms in GWAP [Games with a purpose] and recording neural and behavioural data, it should be possible to much more clearly understand the differences in neural signals between individuals and across different time scales, enabling the development of novel and increasingly robust adaptive BCI algorithms" (Lance et al. 2017, p.2). In line with these findings, the concept of Ride Your Mind (Stober

2013) demonstrates that the possibility to record neural data that neuroscientists and HCI researchers can use to enhance BCI technology can support future research from a game design perspective. The translation but also interpretation of BCI signals into meaningful (game) control signals, e.g. to achieve an increased BCI gaming experience for future players, is a huge but very interesting field of research in both research areas.

7.8 RYM'S ARTISTIC HACKS

In his book *Kunstwerk Computerspiel*, Schwingeler (2014) uses the terms transparency and opacity to describe an artistic strategy used by game artists. Artists substitute the intended transparency of a computer game with opacity by modifying it and thereby questioning its suggestive power (Schwingeler 2014, p.159). The artistic computer game fluctuates between these two terms. Opacity describes transparent media properties and therefore the invisible media properties of a computer game that push to the surface from concealment and thereby become visible properties (Schwingeler 2012, p.69). He goes on to say that game artists use this strategy to shift the mode of a computer game from looking through (transparency) to the mode of looking at (opacity). Ride Your Mind uses this shift as a play with the player. The player of RYM looks at the game, receiving visual feedback but not being able to look through the game and understand the underlying BCI gameplay and how to effect or alter it. The BCI-Headset placed on the player's head subversively suggests neurofeedback functionality and hacks the player's expectations of the game. This artistic strategy is used to conceal the non-interactivity of the headset and thus occlude the player's ability to look through the game and identify this cheating. Instead of using real values from the BCI-Headset, random values that simulate output from the BCI-Headset are used. The player is not able to consciously influence or alter the BCI gameplay of Ride Your Mind.

Ride Your Mind uses the outlined artistic strategy to hack the spectator's impressions of the game through its futuristic technological framework. Of course, this admission of the artistic strategy reveals the non-existence of BCI gameplay features of the final prototype of Ride Your Mind. But without this admission, the illusion of control via neurofeedback would be sufficient to persuade a potential player of RYM of its existence. Costikyan (Avellino et al. 2003, p.10) argues that games engage the audience in an interactive art experience in contrast to the passive role engendered by traditional art. The game artist provides a structure and the spectator creates the experience. The game RYM, as an active experience, engages and challenges the player within the given game system, i.e. the structure. As it does not explain how it has to be played, the player creates his own experience within the system of RYM. The following three warning illustrations are artistic comments on the possible effects of playing BCI games but also seek to bring the technology of BCI itself into question. The artistic BCI-VR game wishes to alert the potential player's attention to the unpredictable effects of emerging BCI games on the human brain.

Figure 69 - Warning Signs

The book *The Dark Side of Game Play* (Mortensen et al. 2015), offers game design and game studies perspectives on gameplay; the approaches and analysis offered therein also serve to illuminate the controversial situation of the player that plays Ride Your Mind.

As a game, RYM places the player into an abusive relationship to the game and its gameplay. This situation is defined as dark play and is related to not only performance but also to Dada experiments (Linderoth & Mortensen 2015, p.4). As described earlier, hacking bears a strong relation to the artistic work of Dada. Sicart describes the purpose of Dada as shocking contemporary culture and the establishment with the breaking of taboos (Sicart 2015, p.106). The Surrealist movement was also notorious for its creative play and its transgression of the boundaries and traditional relationship between artist and audience (Sicart 2015, p.106). Once again, we should underline the connections between the artistic strategies of the performance art movement and its historical continuity with play, game and hacking. The play between player (spectator) and game (system created by an artist) in the BCI-VR game RYM is abusive in character, its nature rooted in an artistic strategy employed by the Surrealists. The player of RYM is, in fact, played by the game itself, even if he thinks he is playing and consciously controlling the game. This second form of play described by Sicart is between conscious and subconscious (cf. 2015, p.106), which parallels how in RYM the player's subconsciousness is drawn into the game. The game hacks the player and gives him the impression of being in control by enabling the input features of the VR-Headset and suggesting the functionality of the BCI-Headset, whereas the BCI-Headset is in fact not functional; rather than using data gleaned from the player, it operates at random. As a game, RYM artistically plays with the conscious and subconscious awareness of the player of his own role as a player. When a game plays the player, the opposite of the traditional gameplay scenario, the play situation is described as dark play and the game as an abusive game. This means that Ride Your Mind can be described as an abusive game and the BCI gameplay as dark play.

Ride Your Mind was designed based on hacking as a creative strategy; it seeks to achieve several artistic goals compatible with abusive game design. Ride Your Mind presents the player with gameplay and a gameworld that he needs to explore. Without any instructions, the player can access the game system and attempt to take control of the situation. Each new player and each new game creates another unique experience. Furthermore, RYM subversively breaks with the traditional setting of a game where the player is in control. Unwittingly the player is controlled by the game, putting him – unknowingly – in the role of spectator. The conversational artistic space of RYM is used to alert the player to emerging privacy issues related to new technologies. Ride Your Mind is not designed to be a fun or commercial game. The intention in designing RYM was to create an artistic game that conveys a message: it warns potential players not to use emerging technology thoughtlessly and to consider the potential issues involved, especially those relating to privacy. BCI gaming technology is not yet eligible for commercial application or mass-marketability (cf. Lance et al. 2017), but in the near future this situation will change and computing technology may well be able to access highly sensitive and private data, such as thoughts and memories. Therefore, the artistic message of RYM, which raises awareness of the possibility of the game being able to hack highly personal data directly from the player's brain, is intended to address future security issues of BCI gaming technology, as has been discussed in section 6.1.7.

In the *Brain-Computer Interfaces Handbook: Technological and Theoretical Advances* Sommerer et al. (2015) describe interfaces that control games and therefore their gameplay as neglected aspect of games. The interface (e.g. game controller or in the case of RYM a BCI), which controls a game's gameplay, is often not detachable from the game itself. It regulates the game, influences the gameplay and the player's feeling of being in control (Sommerer et al. 2015). The authors moreover underline the strong link between game interface and gameplay experience: "Carefully designed and reflected interfaces of digital art games have the power to seduce audiences and make them actively participate, and at the same time to convey deeper cultural meanings" (Sommerer et al. 2015, p.25). As they argue, game installations "feature transformational approaches common to modern media art, such as device hacking, decontextualization, and participation" to establish a relationship between interface and game. As an experimental game art installation, Ride Your Mind uses the four design strategies of hacking to realise the game concept and therefore required the creation of the BCI-VR Helmet as a custom game interface that influences the gameplay by neurofeedback. Just as other game art installations RYM is not designed as a business application or consumer product. In the context of media art, RYM is an artistic experiment that researches the gameful and playful possibilities of emerging BCI consumer technology and brings a game art installation into being.

7.8.1 BCI GAMEPLAY VERSUS RANDOMNESS

At the end of the game design process of Ride Your Mind, I recognised that (affective) gameplay actions triggered by EEG signals – the BCI gameplay – sometimes seem to occur at random, both when I was in the role of player and in the role of the game designer. This situation was caused by the imprecision of the Emotiv EEG headset. The actions triggered inside the gameworld sometimes felt as though they arose as a result of my thoughts or mental states, while at other times, they were triggered all of a sudden without any identifiable activity on the part of me, the player. Tan & Nijholt (2010, p.167) address this issue and state that players of BCI games often do not have the feeling that their actions control in-game actions.[40] I then started to playfully explore what would happen when I substituted the BCI gameplay with a randomly driven gameplay. Replacing the EEG-generated values was very easy, thanks to the visual scripting plugin Playmaker used within the Unity3D game engine. My first attempts seemed promising. To further explore this idea, I designed an experiment with myself as the test subject.[41] The test setup included a special prototype version of Ride Your Mind. Upon initiating the test scene, a random switch controlled whether BCI gameplay or random gameplay would be operating. This adjustment took place during the loading of the game and no hint was given during the test phase as to which mode was active. The outcome of this small experiment was eye-opening and influenced my subsequent research on the current possibilities available in the field of BCI game design. It turned out that there is no marked difference between using BCI gameplay (triggered by the BCI-Headset) or allowing randomly generated values to affect the gameplay. As a player, I was not able to tell whether a consciously performed action was influencing the (BCI) gameplay, or whether the gameplay was being operated at random. I later used this insight to design a special non-EEG version of Ride Your Mind as a game art installation for the museum. Moreover, I also incorporated this insight into my artistic strategy with the aim of playing with the player's reception of the game. As an artistic, creative and explorative project, RYM – and therefore this PhD – is meant to inspire future design thinking and research, including user studies, within diverse disciplines.

RYM makes use of random BCI gameplay to cheat the player's illusion of control. The game tries to persuade its player that the BCI gameplay is affected by EEG data, even though it actually operates at random. The game itself becomes a spoil-sport and is in control of the BCI gameplay. At the same time the player isn't entirely passive, since he interacts with the game via his head movements. Still, the player of RYM is unable to recognise whether the BCI gameplay is triggered by actual neuronal EEG data or is, in fact, entirely random. The player thinks he is playing a game[42], but in fact he is simply part of a visualisation based on random values that influence and therefore control the (BCI) gameplay. The only action or interaction that the player is able to perform freely is to look around. The player is a

[40] Comparable to the illusion of control of BCI games in the section 7.7.

[41] As I have mentioned in section 6.4, conducting proper user studies would have exceeded the scope of this artistic research project.

[42] This situation of the player is to be investigated in user studies as part of future research.

voyeur of the simulation that he thinks he is controlling. Fuchs (2011, p.57) states that when a game artist puts players in such a situation they are rejecting the basic premise of a game: that a game has to be played. Furthermore, he refers to interactivity between player and game as a core element of gameplay: if the player cannot interact with the game, the gameplay gets disrupted (Fuchs 2011, p.57). RYM provides interactivity through the use of virtual reality technology (head movement) and simulates interactivity via the BCI-Headset.

Ride Your Mind can be compared to other existing game art projects. For example, Corrado Morgana's CarnageHug (2007) is a self-played game that is based on the game engine of UnrealTournament (Atari SA 2004). The interactivity between the player and Morgana's game is disrupted and disembodied. Fuchs (2011, p.58) defines the game as an interpassive work and compares the artist Morgana to the spoil-sport. Spoil-sporting directly relates to the fourth design element of hacking, that is to say disruption. In contrast to Ride Your Mind, CarnageHug reveals its interpassivity to the player. RYM hides its interpassive characteristics by using emerging consumer BCI gaming hardware to suggest neuronally influenced gameplay. The interpassivity of RYM's BCI gameplay is a disruptive element of the game and serves as an equivalent to the spoil-sport behaviour presented by Huizinga (1949). In this way, the game acts like the player who is a spoil-sport. This changes the perspective of the game system, transforming it into a player-like system. The declared interactive BCI gameplay features are replaced with random interactivity causing interpassive gameplay. The player ceases to be a player and becomes a spectator. Player interactivity is only possible via the use of the Virtual Reality HMD and the translation of head movement into virtual view direction. The apparent BCI gameplay controlled by the EEG BCI-Headset is interpassive for the player.

The BCI-VR game Ride Your Mind could further also be categorised as a kind of VR-Machinima where the player is able to navigate through the game and control the virtual camera without having any other influence on the gameplay. "Machinima puts the viewer into the voyeur's seat and keeps oscillating between cinema and game experience without fully committing to any of them" (Fuchs 2011, p.58). However, with RYM, the player of the game is unaware of his status and may assume he is playing the game and controlling the BCI gameplay (interactivity) by thought alone. The player expects RYM to be a game and not a linear and predefined experience. RYM hacks the role of its player. It makes the player a spectator without the player's knowledge.

The player's expectations are supported by the emerging technology to create the illusion that RYM is a fully functional BCI-VR game. The game RYM itself disrupts its status as a game by offering BCI gameplay that is in fact interpassive (non-interactive). RYM, as a game, destroys the very characteristics which make it a game, making the player think he is playing a game and withholding the information that in fact he is the spectator of a randomised, only partly interactive VR simulation (Figure 73).

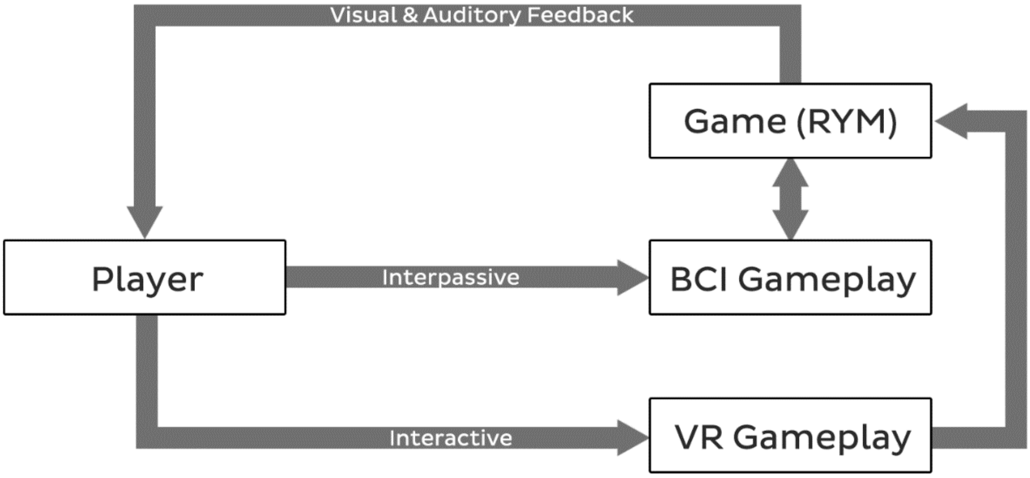

Figure 70 - RYM Game System

BCI gameplay does not possess a representative feedback/output channel and thus BCI games need to be forced into line with existing output channels such as visual (display) and auditory (headphones) feedback. Digital games usually utilise a combination of visual and auditory feedback. Ride Your Mind uses the VR headset to display visual feedback that is directly linked to the player's head movements. BCI gameplay currently needs to utilise existing output channels because direct neuronal feedback as output from the game is not possible with consumer grade BCIs, and even very complicated to realise with professional BCI systems that require invasive electrodes. Thus the BCI gameplay of Ride Your Mind has been replaced with randomly generated gameplay that acts as the conceptualised BCI gameplay.

7.8.2 HACKING THE TRADITIONAL GAMEPLAY SYSTEM

The rules of a game serve as boundaries and define the gameplay, thereby forming a system. Gameplay, when considered as a system, can be hacked along with its boundaries, so the rules of the game can also be extended, deformed or hacked. This methodological concept derived from the historical examination of hacking is used in the following section to describe and illustrate BCI gameplay and in particular the BCI gameplay of Ride Your Mind as a system. The following illustration (74) shows the traditional approach to gameplay as a system.

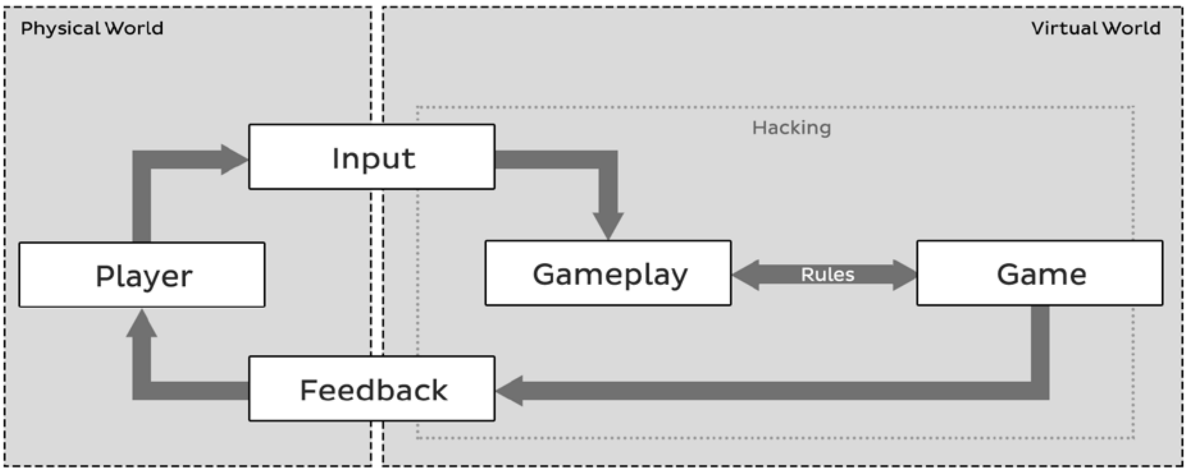

Figure 71 - Traditional gameplay system

The player is positioned in the physical world whereas the game as counterpart is positioned in the virtual world. The player is connected to the game through gameplay and the underlying rule set. The game is controlled via input commands, for example by keyboard or mouse. This input controls the gameplay. The gameplay communicates with the game through its rules and generates visual or auditory feedback that is delivered back to the player. Hacking this system takes place in the virtual world between the gameplay and the game. This theoretical framework will now be used to describe gameplay possibilities using the neurofeedback that forms BCI gameplay. The traditional gameplay system is expanded (second strategic element of hacking) with an additional layer of BCI gameplay that is controlled by a BCI-Headset as additional input device. The proposed model can also be used with other additional input technologies, such as GPS for location-based games. The following figure (75) illustrates the additional input layer and thereby visualises the effect of BCI gameplay on the traditional gameplay system.

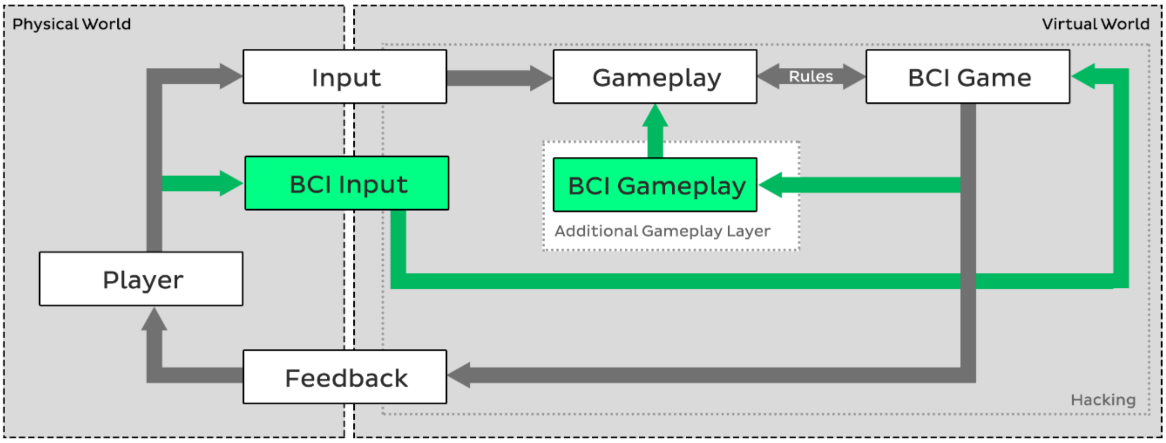

Figure 72 - BCI gameplay system

All components used in the first illustration (74) serve to build the same system. As an additional input device, the EEG BCI-Headset is used to directly communicate with the game. In contrast to traditional input devices such as a keyboard or mouse, a BCI-Headset does not communicate with the game through the gameplay in the first instance. The input signals of the BCI-Headset are directly sent to the game engine. As part of the game engine, the compiler of the BCI processes and compiles the data, turning signals into control commands. These commands are then interpreted as BCI gameplay and influence both the gameplay and the traditional computer input communication. BCI gameplay is a hackish element in the expanded gameplay system. It does not act in the same manner as traditional gameplay. It is an additional layer within the communication between gameplay and the game through its rules. In the following figure (76) this relation between gameplay and BCI gameplay is projected on the artistic and experimental BCI-VR game Ride Your Mind.

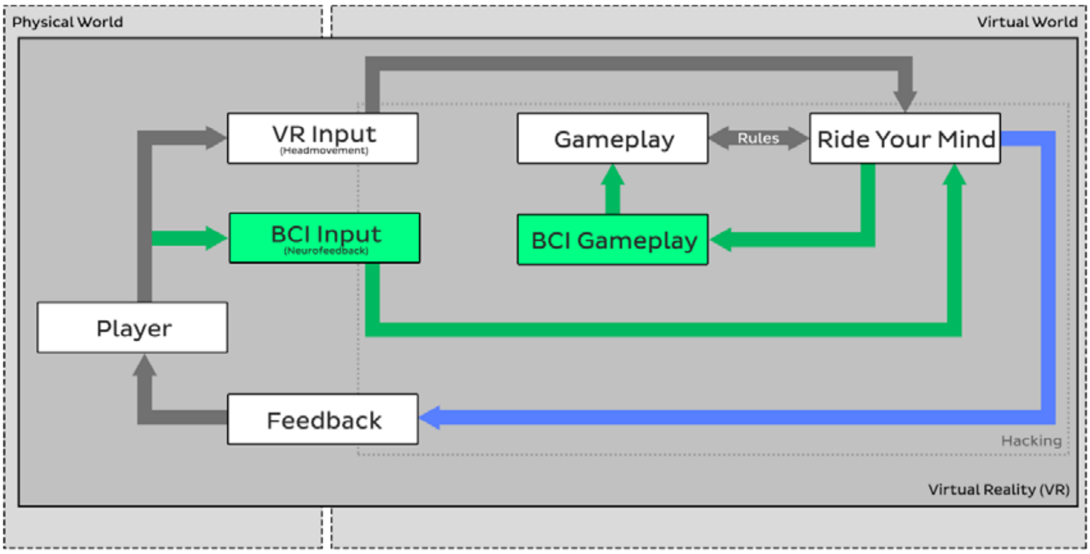

Figure 73 - RYM's BCI gameplay system

Ride Your Mind uses virtual reality as an additional visual feedback channel, and the physical head movements of the player as additional input commands. In contrast to the traditional gameplay system, where the player controls the game, RYM inverses the system and the game takes control of the player. As long as the player is unable to control the EEG output of his brain, which is used as input for the BCI gameplay, he is not able to take control of the game and instead remains under the control of the game RYM. As mentioned, the final prototype of RYM does not include functional BCI gameplay controlled by EEG values due to issues with the BCI gaming technology. Instead randomness is used to control the BCI gameplay. Nevertheless, whether the BCI gameplay is controlled by EEG values or random values, the gameplay system of RYM is the same. The game hacks the player through BCI gameplay and the player has to cheat the game to take control of RYM's gameplay.

8 RESEARCH OUTCOME

The historical examination of hacking and the application of hacking as a methodology/strategy for designing the artistic and experimental BCI-VR game Ride Your Mind enabled me to make a number of academic contributions and successfully answered my three research questions. In the following the answers to my research questions are listed:

1. **What design methods and/or elements can be methodically traced and extracted from a semantic, historical and media-archaeological examination of hacking and how can these unlock artistic and/or creative potential?**

My academic and artistic research has demonstrated that hacking is applicable as an artistic strategy for artistic game design. In the historical examination of hacking four different design strategies and elements have been methodologically identified, extracted and described. The four design strategies of hacking, (1) Addition, (2) Appropriation, (3) Expansion, (4) Disruption, were successfully used as consistent methodology throughout the entire design process of the artistic and experimental BCI-VR game Ride Your Mind. This strategy was reviewed based on a research-through-design approach through its application to the conceptualising, designing and creation of RYM. The history of hacking is rooted in the history of digital and interactive media art. As described in the previous chapters, hacking can be used to unlock artistic and creative potential. As has been demonstrated, this potential can be used to research and experiment with emerging technology, such as BCI, to create valuable insights with regarding how to design future BCI games. This work has also revealed several intersections where hacking meets art history that can be used to generate further research. Further indications that hacking can be used as a playful innovation strategy have been found and elaborated on.

2. **How can these design methods and/or elements be strategically applied to the artistic and experimental PhD project Ride Your Mind (RYM)?**

The prototyping of the BCI-VR Helmet as a combination and appropriation of emerging gaming technology was successful. The four design methods and/or elements of hacking have been applied to create the concept but also the game Ride Your Mind, as outlined in section 4.3. The work on creating prototypes of Ride Your Mind, based on hacking and its design elements and strategies, revealed a gap in game design research relating to BCI game design patterns and strategies. As outlined in section 6.2, this fundamental work on BCI game design patterns will be helpful for further investigation and, of course, can be of use to other researchers. Creating a playable prototype of RYM by using several artistic strategies related to the history of hacking and to the history of media art proved successful. Furthermore, the applied artistic strategies and their relationship to the strategic design elements of hacking have been explored.

3. **What issues and discoveries emerge from the attempt to design the artistic and experimental BCI-VR game Ride Your Mind with consumer grade BCI gaming technology from the perspective of a game artist, game designer and hacker?**

Examining BCI gaming technology from the perspective of a media artist and with a methodological approach based on hacking has enabled me to make various discoveries and map a number of issues. These findings have been outlined and described in section 6.1 of this doctoral exegesis. In section 6.2, I have outlined how consumer grade BCI gaming technology (such as the Emotiv EPOC EEG headset) can be successfully used to design BCI games and identify BCI game design patterns while creating the BCI-VR game Ride Your Mind, that can be used for designing future BCI games. Furthermore, the design process of RYM demonstrates the current possibilities, limitations and issues relating to consumer grade BCIs (BCI gaming technology) in terms of the design and playing of BCI games. In chapter 7 the entire methodological approach based on hacking and the design process of the artistic and experimental game Ride Your Mind have been discussed from several different perspectives.

9 FUTURE RESEARCH

On the basis of this exegesis, further research can evolve. This section lists a number of topics that potential future studies should address.

- **The relationship of hacking to media and game art:** As outlined in this work, there is a relationship between hacking and the history of media and game art. Based on my work, I am convinced that a profound art historical discussion which includes hacking is overdue and definitely worth undertaking. Hacking seems to be deeply influenced by play. Further research on hacking as a form of play is necessary to prove this relationship. Hacking is rooted in play and the playfulness of play. Therefore, the artistic strategies extracted from hacking are adapted by hackers from playful play and the biological potential of play as a creative problem solving strategy. Hacking as playful play can also serve as innovation strategy and, as art history shows, as artistic strategy.

- **BCI game design patterns:** My work on this research project has revealed that there are no guidelines provided by game design research on how to design BCI games, nor does the existing game design pattern catalogue include BCI gaming. Work on BCI game design patterns is essential in order to initiate a discussion about BCI game design strategies.

- **Randomly influenced BCI gameplay:** A user study investigating this paradigm would be very helpful for further research and would lead to improvements in player control within BCI gaming situations. An interesting aspect that was revealed by the artistic research project RYM is the player's perception of control while playing a BCI game. Do BCI games give players an illusion of control even if they are not working with actual EEG data? More research on this issue will need to be done. While testing the features of the BCI-Headset and playing my own BCI game prototypes, it was often impossible to differentiate if I, my brain, my mind or my surroundings triggered an action in the game, or whether it was unconsciously triggered or just the result of the random behaviour of imprecise technology. A controlled design experiment inspired by the work of Waern and Back (2015) could be developed to shed light on this paradigm and on further paradigms in BCI game design research.

- **The application of hacking strategies in different fields:** Hacking as a playful design strategy, as investigated in the preceding chapter, turned out to be a solid methodology for technical as well as theoretical innovation in game design and therefore as a motor for new academic findings. The playful exploration of BCI hardware and the successive approximation, exploration and transgression of boundaries by hackers exposed novel possible fields of research, such as those relating to BCI game design patterns and BCI game design strategies. Even overcoming existing boundaries (in the spirit of early hackers) of BCI systems was a possibility enabled by the described methodology based on hacking. Moreover, I am planning a further research paper with the suggested title: Hacking as a Playful Innovation Strategy.

10 CONCLUSION

During the work on my PhD, I began to identify myself as a playful media and game artist or simply a hacker; a hacker who (1) playfully explores and examines emerging BCI gaming technology; (2) gamefully researches future BCI game design strategies based on this technology; (3) artfully disenchants, but also enchants, players with this emerging gaming technology; (4) through his artistic and gameful work raises awareness in the user about the jeopardising of highly personal data due to security issues related to this technology.

The work on how possible (adaptive and affective) BCI games can be designed is important but not yet applicable outside the artistic and/or research space. This impracticability results from (1) the imprecise consumer BCI-Headset hardware, (2) the unavailability of software tools and (3) an enormous knowledge gap relating to the comprehension and interpretation of neuronal signals read from the human brain by digital devices. Neuroscientific and BCI research has to pave the way to allowing computers and other digital devices to understand and process signals from the human brain. Until neuroscience has a fundamental grasp on consumer BCI technology and establishes the communication processes which enable the interpretation of signals, it is nigh impossible to build digital games controlled and/or generated by neurofeedback that perform precise actions triggered by neuronal feedback. BCI game design possibilities are limited by the lack of precision of the current technology and the software tools that analyse the recorded signals. Players of BCI games often cannot differentiate whether controls or actions in BCI games are conscious, unconscious or taking place at random. As a result, players do not have a convincing illusion of control, which means the gaming experience is unsatisfactory.

The consumer BCI-Headset (Emotiv EPOC EEG) that was examined, explored and used throughout the research phase is intended for gaming, but not yet technologically advanced enough for designing adaptive BCI games such as Ride Your Mind. The incoming signals are imprecise and fragmented. Designing BCI games is currently not a satisfactory experience for game designers and therefore neither for potential players. Before game designers can successfully design BCI games, fundamental progress in BCI technology and adjacent disciplines has to be made.

To overcome this issue and the related challenges, I decided to use one of the artistic strategies suggested by hacking. Integrating EEG data into the game was possible but not entirely satisfactory due to the issues with the hardware described in section 6.1. As a result, I then chose to disrupt the spectator or potential player's perceptions of the game by making use of random data that produced a sufficient illusion of control. As there is almost no possibility of incorporating instant feedback into the game RYM generated by a user's conscious actions or decisions, I decided to replace the values from the BCI-Headset with randomly generated values to trigger actions inside the gameplay and the gameworld. Ultimately, it is hypothetically impossible to differentiate the player's gaming experience of RYM with EEG functionality from the gaming experience with the EEG functionality turned off and replaced by randomly generated data.

Ride Your Mind cheats the player and gives him the feeling of being in control, which is supported by the VR-free look. RYM professes to be a BCI-VR game but in fact it is not a real game. It pretends to have player-controllable BCI gameplay. As the player is not able to track the BCI gameplay, he may not question his status as player. The player's expectation is that he is playing an experimental BCI-VR game art installation powered by futuristic BCI technology. These expectations define for him his status as a player, even if the game itself is in control and only pretends to interactivity.

The player's expectations are supported by the emerging technology to create the illusion that RYM is a fully functional BCI-VR game. The game RYM itself disrupts its status as a game by offering BCI gameplay that is in fact interpassive (non-interactive). RYM, as a game, destroys the very characteristics which make it a game, making the player think he is playing a game and withholding the information that in fact he is the spectator of a randomised, only partly interactive VR simulation.

From the initial research right through to the design of the artistic research project RYM, the hypothesis that hacking (based on the historically extracted strategic design elements) could be employed as a playful design strategy to design an artistic game in order to generate new insights and test emerging consumer grade BCI technology for gaming was successfully demonstrated. The application of hacking as a methodology during all phases of the project, from research through to design, was successful. Through the playful exploration and hacking of the BCI technology and its gameful and artistic application, new knowledge in game design research has been generated and, consequently, three research questions in the emerging field of BCI gaming have arisen and have been answered. Hopefully this will lead to further research into BCI games from a game design perspective.

The playful and creative spirit of hackers (Levy 1986; Pias 2002a) is linked to play (Sicart 2014), the ambiguity of play (Sutton-Smith 2001), playfulness (Bateson & Martin 2013), play in relation to the history of art (Flanagan 2010), the history of performance (Salter 2010), Dada, Surrealism, Situationism, Fluxus (Dragona 2010) and *détournement* (Pias 2013), and to digital media art's subgenre game art (Fuchs 2011; Schwingeler 2012; Serexhe & Schwingeler 2013; Schwingeler 2014). "The fluxes and movements within this space are the very features that encourage novel approaches. Its messiness opens up the potential to find the unexpected in terms of both failure and success" (Batty and Berry, p. 192). By including hacking, the discussion relating to digital media art and digital games as an art form can be enriched, new findings unearthed and links to modern digital art history forged.

11 REFERENCES

11.1 LITERATURE

Ahn, M. et al., 2014. A Review of Brain-Computer Interface Games and an Opinion Survey from Researchers, Developers and Users. *Sensors*, 14(8), pp.14601–14633.

Anděl, J. & Zimbardo, P.G., 2011. *Luciferův efekt : střétnutí se zlem*, DOX Prague.

Avellino, N. et al., 2003. *Replay: Game Design and Game Culture* A. Scholder & E. Zimmerman, eds., New York, New York, USA: Peter Lang Publishing Inc.

Balkema, A.W. & Slager, H., 2004. *Artistic research* Lier & Boo., Amsterdam: Rodopi.

Barab, S. & Squire, K., 2004. Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences*, 13(1), pp.1–14.

Bateson, P.P.G. (Paul P.G. & Martin, P., 2013. *Play, playfulness, creativity and innovation*, Cambridge University Press.

Batty, C. & Berry, M., 2015. Constellations and connections: The playful space of the creative practice research degree. *Journal of Media Practice*, 16(3), pp.181–194.

Belting, H., Buddensieg, A. & Weibel, P., 2013. *The Global Contemporary and the Rise of New Art Worlds*,

Bianchini, S. et al., 2016. *Practicable: From Participation to Interaction in Contemporary Art*,

Birnbaum, I., 2015. *Untersuchung der Möglichkeiten von Consumer EEG - Headsets für Experimental Game Design*. Karlsruhe Insitute of Technology.

Björk, S., 2015. Game Design Pattern Cataloque. Available at: http://protagonist.sics.chalmers.se:1337/mediawiki-1.22.0/index.php/Main_Page [Accessed May 5, 2015].

Björk, S. & Holopainen, J., 2004. Games and Design Patterns. In K. Salen & E. Zimmerman, eds. *The Game Design Reader*. Cambridge, MA: The MIT Press, pp. 410–427.

Björk, S. & Holopainen, J., 2005. *Patterns in Game Design*, Charles River Media.

Bonaci, T., Calo, R. & Chizeck, H.J., 2015. App Stores for the Brain. *IEEE TECHNOLOGY AND SOCIETY MAGAZINE*, (June).

Borgdorff, H., 2007. Artistic research within the fields of science. *Sensuous Knowledge*, 6th editio(Unesco), pp.1–23.

Borgdorff, H., 2012. *The Conflict of the Faculties: Perspectives on Artistic Research and Academia*, Leiden University Press.

Bos, D.P.O. et al., 2010. Human-computer interaction for BCI games: Usability and user experience. In *Proceedings - 2010 International Conference on Cyberworlds, CW 2010*. IEEE, pp. 277–281.

Busch, K., 2009. Artistic Research and the Poetics of Knowledge. *Art Research*, 2(2), pp.1–7.

Certeau, M. de, 1988. *The practice of everyday life*, Berkeley and Los Angelos, CA: University of California Press.

Chavarriaga, R. et al., 2017. Heading for new shores! Overcoming pitfalls in BCI design. *Brain-Computer Interfaces*, 4(1–2), pp.60–73.

Chen, J., 2007. Flow in games (and everything else). *Communications of the ACM*, 50(4), p.31.

Childers, N., 2013. The Video Game Helmet That Can Hack Your Brain. Available at: http://motherboard.vice.com/blog/the-video-game-helmet-that-can-hack-your-brain [Accessed January 20, 2016].

Consalvo, M., 2007. *Cheating: Gaining Advantage in Videogames*, Cambridge, MA: MIT Press.

Costikyan, G., 2013. *Uncertainty in Games*, Cambridge, MA: MIT Press.

Coyle, D. et al., 2015. Action Games, Motor Imagery, and Control Strategies: Toward a Multi-button Controller. In *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer Singapore, pp. 1–34.

Coyle, D. et al., 2013. Guest Editorial: Brain/neuronal - Computer game interfaces and interaction. *IEEE Transactions on Computational Intelligence and AI in Games*, 5(2), pp.77–81.

Csikszentmihalyi, M., 1990. *Flow: The Psychology of Optimal Experience*, New York: Harper Perennial.

Donovan, A., 2011. *The art of steampunk*, East Petersburg, PA: Fox Chapel Publishing Company, Inc.

Dragona, D., 2010. From Parasitism to Institutionalism: Risks and tactics for game-based art. In R. Catlow, M. Garrett, & C. Morgana, eds. *Artists Re: Thinking Games*. Liverpool: Liverpool University Press.

Elias, G.S. et al., 2012. *Characteristics of Games*,

Elsayed, N., Zaghloul, Z.S. & Bayoumi, M., 2017. Brain Computer Interface: EEG Signal Preprocessing Issues and Solutions. *International Journal of Computer Applications*, 169(3), pp.975–8887.

Erickson, J., 2008. *Hacking: The Art of Exploration* Second Edi., San Francisco, CA: No Starch Press.

Faller, J. et al., 2017. A feasibility study on SSVEP-based interaction with motivating and immersive virtual and augmented reality. , pp.1–6.

Fiałek, S. & Liarokapis, F., 2016. Comparing Two Commercial Brain Computer Interfaces for Serious Games and Virtual Environments. , 4, pp.103–117.

Flanagan, M., 2010. Creating Critical Play. In R. Catlow, M. Garrett, & C. Morgana, eds. *Artists Re:Thinking Games*. Liverpool: Liverpool University Press, pp. 49–53.

Flanagan, M., 2009. *Critical Play: Radical Game Design*, Cambridge, MA: The MIT Press.

Fogg, B.J., 2002. *Persuasive Technology: Using Computers to Change What We Think and Do*, San Francisco, CA: Morgan Kaufmann Publishers.

Friedman, D., 2015. Brain-Computer Interfacing and Virtual Reality. In *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer Singapore, pp. 1–22.

Fuchs, M., 2011. Ludic Interfaces. In R. Catlow, M. Garrett, & C. Morgana, eds. *Artists Re: Thinking Games*. Liverpool: Liverpool University Press.

Fullerton, T., 2014. *Game Design Workshop*, Milton Park, Abingdon Oxford: Routledge.

Gaver, W., 2012. *What should we expect from research through design?*, New York, New York, USA: ACM Press.

Grabowski, S. & Cermak-Sassenrath, D., 2018. The Potential of the Contradictory in Digital Media. In D. Cermak-Sassenrath, ed. *Playful Disruption of Digital Media*. Gaming Media and Social Effects. Singapore: Springer Singapore, p. 310.

Grush, L., 2016. Those “mind-reading” EEG headsets definitely can’t read your thoughts. Available at: http://www.theverge.com/2016/1/12/10754436/commercial-eeg-headsets-video-games-mind-control-technology [Accessed January 20, 2016].

Gürkök, H. et al., 2015. Brain-Computer Interface Games: Towards a Framework. In R. Nakatsu et al., ed. *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer Singapore, pp. 1–18.

Gürkök, H. et al., 2013. Evaluating a multi-player brain-computer interface game: Challenge versus co-experience. *Entertainment Computing*, 4(3), pp.195–203.

Gürkök, H., Nijholt, A. & Poel, M., 2012. Brain-Computer Interface Games: Towards a Framework. In Springer Berlin Heidelberg, pp. 373–380.

Hellström, T., 2010. Evaluation of artistic research. *Research Evaluation*, 19(5), pp.306–316.

Hjelm, S.I., 2003. The Making of Brainball. *Interactions*, 10(1), pp.26–34.

Holz, E.M. et al., 2013. Brain-computer interface controlled gaming: Evaluation of usability by severely motor restricted end-users. *Artificial Intelligence in Medicine*, 59(2), pp.111–120.

Huizinga, J., 1949. *Homo Ludens: of the Play Element in Culture*, Boston, MA: Beacon Press.

Ikeahackers, 2013. ikeahackers. Available at: http://www.ikeahackers.net [Accessed March 26, 2013].

Kerous, B., Skola, F. & Liarokapis, F., 2017. EEG-based BCI and video games: a progress report. *Virtual Reality*, (123456789), pp.1–17.

Kittler, F., 1986. *Grammophon, Film, Typewriter*, Berlin: Brinkmann & Bose.

Klein, J., 2010. What is Artistic Research? *Gegenworte*, 23(1978), pp.24–28.

Korczowski, L. et al., 2016. ” Brain Invaders 2 ” : an open source Plug & Play multi-user BCI videogame. In *6th Inter- national Brain-Computer Interface Meeting (BCI Meeting 2016)*. Pacific Grove, CA, pp. 2–3.

Kosmyna, N., Tarpin-Bernard, F. & Rivet, B., 2015. Conceptual Priming for In-game BCI Training. *ACM Transactions on Computer-Human Interaction*, 22(5), pp.1–25.

Krepki, R. et al., 2007. The Berlin Brain-Computer Interface (BBCI) - Towards a new communication channel for online control in gaming applications. In *Multimedia Tools and Applications*. pp. 73–90.

Kwastek, K., 2013. *Aesthetics of Interaction in Digital Art*, Cambridge, MA: Mit Press.

Van De Laar, B., Gürkök, H., et al., 2013. Experiencing BCI control in a popular computer game. *IEEE Transactions on Computational Intelligence and AI in Games*, 5(2), pp.176–184.

Van De Laar, B., Bos, D.P.O., et al., 2013. How much control is enough? Influence of unreliable input on user experience. *IEEE Transactions on Cybernetics*, 43(6), pp.1584–1592.

Ladd, G., 1979. Artistic research tools for scientific minds. *American Journal of Agricultural Economics*, 61(1), pp.1–12.

Lalor, E. et al., 2004. Brain computer interface based on the steady-state VEP for immersive gaming control. *Biomedizinische Technik*, 49(1), pp.63–64.

Lance, B.J. et al., 2017. Towards Serious Games for Improved BCI. In R. Nakatsu, M. Rauterberg, & P. Ciancarini, eds. *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer Singapore, pp. 1–28.

Lankoski, P. & Holopainen, J., 2017. *Game design research: An introduction to theory & practice*,

Leeb, R. et al., 2007. Brain–Computer Communication: Motivation, Aim, and Impact of Exploring a Virtual Apartment. *IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING*, 15(4).

Lesage, D., 2009. Who's Afraid of Artistic Research? On measuring artistic research output. *Art & Research. A Journal of Ideas, Contexts and Methods*, 2(2), pp.1–10.

Levy, S., 1986. *Hackers — Heroes of the computer revolution*, Sebastopol, CA: O'Reilly Media.

Linderoth, J. & Mortensen, T.E., 2015. Dark play: The aesthetics of controversial playfulness. In T. E. Mortensen, J. Linderoth, & A. M. Brown, eds. *The Dark Side of Game Play: Controversial Issues in Playful Environments*. Routledge, pp. 3–12.

Lotte, F., 2011. Brain-computer interfaces for 3D games. In *Proceedings of the 6th International Conference on Foundations of Digital Games - FDG '11*. New York, New York, USA: ACM Press, pp. 325–327.

Loup-Escande, E. et al., 2015. User-Centred BCI Videogame Design. In *Handbook of Digital Games and Entertainment Technologies,*. Singapore: Springer Singapore, pp. 225–250.

Mäkelä, M. et al., 2011. On Reflecting and Making in Artistic Research. *Journal of Research Practice*, 7(1–Article E1).

Martišius, I. & Damaševičius, R., 2016. A Prototype SSVEP Based Real Time BCI Gaming System. *Computational Intelligence and Neuroscience*, 2016, pp.1–15.

McGonigal, J., 2011. *Reality is Broken: Why Games Make Us Better and How They Can Change the World*, London: Vintage Books.

Mecklinger, A. et al., 2014. Cross-cultural differences in processing of architectural ranking: Evidence from an event-related potential study. *Cognitive Neuroscience*, 5(1), pp.45–53.

Mishra, J., Anguera, J.A. & Gazzaley, A., 2016. Video Games for Neuro-Cognitive Optimization. *Neuron*, 90(2), pp.214–218.

Mitgutsch, K. et al., 2013. Context Matters! Proceedings of the Vienna Games Conference 2013: Exploring and Reframing Games and Play in Context. In *Vienna Games Conference 2013: Exploring and Reframing Games and Play in Context*. p. 352.

Mitnick, K., 2012. *Ghost in the Wires: My Adventures as the World's Most Wanted Hacker*, Little, Brown and Company.

Mladenović, J. et al., 2017. The Impact of Flow in an EEG-based Brain Computer Interface.

Morgana, C., 2010. Introduction. In C. Ruth, G. Marc, & M. Corrado, eds. *Artists Re:thinking Games*. Liverpool: FACT / Frutherfield, pp. 7–14.

Mortensen, T.E., Linderoth, J. & Brown, A.M.L., 2015. *The dark side of game play: Controversial issues in playful environments* T. E. Mortensen, J. Linderoth, & A. M. L. Brown, eds.,

Mühl, C. et al., 2010. Evaluating multi-paradigm BCI interaction. *J Multimodal User Interfaces*, 4, pp.11–25.

Nam, C.S., Nijholt, A. & Lotte, F., 2018. *Brain-computer interfaces handbook : technological and theoretical advances*, Boca Raton: CRC Press.

Nelson, W.T. et al., 1997. Navigating through virtual flight environments using brain-body-actuated control. *Proceedings of IEEE 1997 Annual International Symposium on Virtual Reality*, pp.30–37.

Nijboer, F. et al., 2015. Usability of three electroencephalogram headsets for brain-computer interfaces: A within subject comparison. *Interacting with Computers*, 27(5), pp.500–511.

Nijholt, A. et al., 2008. Brain-Computer Interfacing for Intelligent Systems. *IEEE Intelligent Systems*, 23(3), pp.72–79.

Nijholt, A., 2015. Competing and collaborating brains: Multi-brain computer interfacing. In A. E. Hassanieu & A. T. Azar, eds. *Intelligent Systems Reference Library*. Cham: Springer International, pp. 313–335.

Nijholt, A., 2016. Multi-Brain BCI Games: Where to Go from Here? A. J. Al., Spink et, ed. *Measuring Behavior*.

Nijholt, A. & Gürkök, H., 2013. Multi-brain games: Cooperation and competition. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 8009 LNCS(PART 1), pp.652–661.

Nijholt, A., Reuderink, B. & Bos, D.O., 2009. Turning shortcomings into challenges: Brain-computer interfaces for games. *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, 9 LNICST(2), pp.153–168.

Oppenheim, I. et al., 2009. Brain electrical responses to high- and low-ranking buildings. *Clinical EEG and Neuroscience*, 40(3), pp.157–161.

Oppenheim, I. et al., 2010. Hippocampal contributions to the processing of architectural ranking. *NeuroImage*, 50(2), pp.742–752.

Park, H. et al., 2017. *New gameplay : Nam June Paik Art Center : 2016.7.20 - 2017.2.19* H. Park, ed., Souel: Nam June Paik Art Center.

Perlroth, N., Scott, M. & Frenkel, S., 2017. Cyberattack Hits Ukraine Then Spreads Internationally. Available at: https://www.nytimes.com/2017/06/27/technology/ransomware-hackers.html [Accessed March 1, 2018].

Pezer, N., 2017. *Neurorhetorik : neurophysiologische Kulturforschung*, Paderborn.

Pias, C., 2013. Appropriation Art & Games. Spiele der Verschwendung und der Langeweile. Available at: http://www.uni-due.de/~bj0063/%5Cttexte/spielekunst.pdf [Accessed March 26, 2013].

Pias, C., 2002a. *Computer Spiel Welten*, München: sequenzia.

Pias, C., 2002b. Der Hacker. In H. Eva, K. Stefan, & U. Bröckling, eds. *Grenzverletzer*. Berlin: Kulturverlag Kadmos, pp. 248–270. Available at: http://www.xcult.org/texte/pias/hacker.html.

Plass-Oude Bos, D. et al., 2010. Brain-Computer Interfacing and Games. In D. S. . Tan & A. Nijholt, eds. *Brain-Computer Interfaces: Applying our Minds to Human-Computer Interaction*. London: Springer-Verlag, pp. 149–178.

Rajagopal, A., 2011. *Hacking Design*, DesignFile.

Rathod, P.S., 2017. Survey on Brain Computer Interface. *Advances in Computational Sciences and Technology*, 10(5), pp.1463–1470.

Raymond, E.S., 2013. The Jargon File 4.4.8. Available at: http://www.catb.org/jargon/ [Accessed March 26, 2013].

Reuderink, B., Nijholt, A. & Poel, M., 2009. Affective Pacman: A frustrating game for brain-computer interface experiments. In *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*. pp. 221–227.

Salen, K. & Zimmerman, E., 2003. *Rules of Play Game Design Fundamentals*, Cambridge, MA: MIT Press.

Salter, C., 2010. *Entangled: Technology and the Transformation of Performance*, Cambridge, MA: Mit Press.

Schell, J., 2014. *The Art of Game Design: A Book of Lenses*, London: Taylor & Francis Ltd.

Scherer, R. et al., 2015. Games for BCI Skill Learning. In *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer Singapore, pp. 1–19.

Schmidt, S.M., 2011. *Hacking the City: Interventionen in öffentlichen und kommunikativen Räume*, Göttingen: Edition Folkwang/Steidl.

Schwingeler, S., 2014. *Kunstwerk Computerspiel*, Bielefeld, Germany: transcript Verlag.

Schwingeler, S., 2012. Störung als künstlerische Strategie: Kunst mit Computerspielen zwischen Transparenz und Opazität. In B. Beil et al., eds. *I am Error: Störungen des Computerspiels*. Siegen: univseri - Universitätsverlag.

Serexhe, B. & Schwingeler, S., 2013. *ZKM_Gameplay: The Game Platform at the ZKM* english., Karlsruhe, Germany: ZKM | Center for Art and Media. Available at: http://zkm.de/media/file/en/zkm_gameplay_broschuere_e_0.pdf [Accessed July 17, 2016].

Sharp, J., 2015. *Works of Game: On the Aesthetics of Games and Art*, Cambridge, MA: Mit Press.

Sicart, M., 2015. Darkly playing others. In T. E. Mortensen, J. Linderoth, & A. M. Brown, eds. *The Dark Side of Game Play: Controversial Issues in Playful Environments*. Routledge, pp. 100–116.

Sicart, M., 2014. *Play Matters*, Cambridge, MA: MIT Press.

Sommerer, C., Brandstätter, U. & Mignonneau, L., 2015. Interface-Centric Art Games. In *Handbook of Digital Games and Entertainment Technologies*. Singapore: Springer Singapore, pp. 1–28.

Stober, J., Walz, S. & Holopainen, J., 2013. Hacking as a playful strategy for designing artistic games. In *Context Matters! Proceedings of the Vienna Games Conference 2013: Exploring and Reframing Games and Play in Context*. New Academic Press, pp. 308–321.

Stober, J.M., 2013. Ride Your Mind. In *Context matters! : proceedings of the Vienna Games Conference 2013 : exploring and reframing games and play in context*.

Sutton-Smith, B., 2001. *The Ambiguity of Play*, Cambridge, MA: Harvard University Press.

Sweetser, P. & Wyeth, P., 2005. GameFlow. *Computers in Entertainment*, 3(3), p.3.

Szope, D., 2016. Welt der Spiele : reloaded. Available at: http://www01.zkm.de/algorithmische-revolution/index.php?module=pagemaster&PAGE_user_op=view_page&PAGE_id=29 [Accessed May 23, 2016].

Tan, D.S. & Nijholt, A., 2010. *Brain-Computer Interfaces* D. S. Tan & A. Nijholt, eds., London: Springer London.

Vidal, J.J., 1977. Real-time detection of brain events in EEG. *Proceedings of the IEEE*, 65(5), pp.633–641.

Vourvopoulos, A., Bermudez i Badia, S. & Liarokapis, F., 2017. EEG correlates of video game experience and user profile in motor-imagery-based brain–computer interaction. *Visual Computer*, 33(4), pp.533–546.

Waern, A. & Back, J., 2015. Experimental Game Design. In P. Lankoski & S. Björk, eds. *Game Research Methods: An Overview*. ETC Press.

Walz, S.P., 2013. Welcome To My Playce. Available at: http://spw.playbe.com [Accessed April 13, 2013].

Walz, S.P. & Deterding, S., 2015. *The Gameful World: Approaches, Issues, Applications*, Cambridge, MA: Mit Press.

Wang, Q., Sourina, O. & Nguyen, M.K., 2010. EEG-based “serious” games design for medical applications. In *Proceedings - 2010 International Conference on Cyberworlds, CW 2010*. IEEE, pp. 270–276.

Ylirisku, S. et al., 2016. Design Research as Conceptual Designing: The Manhattan Design Concept. *Interacting with Computers*, 28(5), pp.648–663.

Yoh, M.-S., Kwon, J. & Kim, S., 2010. NeuroWander. In *Proceedings of the 12th ACM international conference adjunct papers on Ubiquitous computing - Ubicomp ’10*. New York, New York, USA: ACM Press, p. 389.

Zimmerman, J., Forlizzi, J. & Evenson, S., 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI ’07*. New York, New York, USA: ACM Press, p. 493.

Zimmerman, J., Stolterman, E. & Forlizzi, J., 2010. An analysis and critique of Research through Design. In *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS ’10*. New York, New York, USA: ACM Press, p. 310.

11.2 IMAGES

11.3 TABLES

11.4 GAMES

Alexei Paschitnow 1984, *Tetris*, video game, console, PC, Russia.
Anne-Marie Schleiner 2001, *Velvet-Strike*, video game, PC, Germany.
Apogee Software 1992, *Wolfenstein 3D*, video game, PC, USA.
Atari 1979, *Asteroids*, video game, arcade, USA.
Cory Arcangel 2002, *Super Mario Clouds*, video game, Nintendo NES, USA.
Electronic Arts 2011, *Crysis 2*, video game, PC, USA.
GT Interactive 1993, *Doom,* video game, PC, USA.
GT Interactive 1999, *Unreal Tournament*, video game, PC, USA.
Infocom 1980, *Zork*, video game, PC, USA.
Interactive Institute 1999, *Brainball*, neurogame, arcade, Sweden.
Jens M. Stober (elorx) 2013, *Ride Your Mind (RYM)*, video game, PC, Germany.
Jens M. Stober (elorx) 2010, *1378(km)*, video game, PC, Germany.
Jens M. Stober (elorx) 2012, *shade*, video game, PC, Germany.
Jodi 1999, *SOD*, video game, PC, Netherlands.
LucasArts 1993, *Sam and Max Hit The Road*, video game, PC, USA.
Lucasfilm Games 1990, *The Secret of Monkey Island*, video games, PC, USA.
Mattel 2009, *Mindflex Duel*, toy.
Microsoft 1984, *Flight Simulator 2.0*, video game, IBM PC, USA.
Midway Games 1980, *Pacman*, video game, arcade, USA.
Mindball-Verleih Berlin 2005, *Mindball*, neurogame, arcade, Germany.
MIT MediaLabEurope 2004, *MindBalance*, neurogame, PC, Ireland.
Myeung-Sook Yoh 2010, *NeuroWander*, video game, PC, South Korea.
Orhan Kipcak & Reini Urban 1995, *ArsDoom*, video game, PC, Austria.
SETA Corporation 1998, *Tetris 64*, video game, console, Japan.
Sierra Entertainment 2000, *Counter-Strike*, video game, PC, USA.
Sony Computer Entertainment 2006, *Flow*, video game, PC, USA.
Steve Russel 1962, *Spacewar!*, video game, PDP-1, USA.
Uncle Milton Industries' 2009, *Star Wars Science Force Trainer*, toy.
Valve Corporation 2004, *Half-Life 2: Deathmatch*, video game, PC, USA.
Virgin Interactive & Electronic Arts 1995-2012, *Command & Conquer Series*, video game, PC, USA.
Virgin Interactive 1996, *Command & Conquer: Red Alert*, video game, PC, USA.
Vivendi 2004, *World of Warcraft*, video game, PC, France.
Wild Divine 2001, *Journey to Wild Divine*, biofeedback game, USA.

11.5 PROGRAMS

Munching Squares
Unity3D
CryEngine 3
Source Engine
TECO EEG Toolchain
Playmaker
Emotiv EPOC Control Suite

12 APPENDIX

Research Paper: Stober, J., Walz, S. & Holopainen, J., 2013. *Hacking as a playful strategy for designing artistic games*, New Academic Press.