Brain Computer Interface Gaming:

Development of Concentration Based Game Design for Research Environments

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DEDICATIONS

Dedicated to my father and mother, Vandy and Chhunly Oum, who taught me to never give up on my aspirations and were always supportive throughout the roughest patches of my journey.
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Abstract
Brain Computer Interface Gaming:
Development of Concentration Based Game Design for Research Environments
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Paul J. Diefenbach, PH D.

During the last couple of decades, there has been an exponential improvement in neuroimaging technologies that allowed researchers to evaluate cognitive workload, short term memory, and spatial/navigational behaviors in humans. Through the use of new experimental paradigms and brain imaging devices, researchers have gained deeper insight into the neural correlates of emotion, cognition and motor control. Brain Computer Interface (BCI) systems utilize various neuroimaging tools to detect brain activation evoked by a specific thinking process and convert it to a command. We have developed a game environment called “MindTactics” as a test platform for BCI devices to conceptualize experimental cognitive paradigms in ecologically valid environments as well as test BCI gameplay paradigms. Unlike traditional video games where the challenge to the user is the designed game mechanics, BCI based gameplay also involves mastering the use of the BCI device itself. The purpose of this thesis is to develop compelling BCI game design methods. MindTactics is capable of integrating data from multiple devices including the optical brain imaging based BCI developed at Drexel University, and it records behavioral log files for further analysis.
1. KEY TERMS

Attention

The mechanism for continued cognitive processing. All sensory information receives some
cognitive processing; attention ensures continued cognitive processing.

BCI

Brain Computer Interface (BCI) systems utilize various neuroimaging tools to detect brain
activation evoked by a specific thinking process and convert it to a command.

COBI

COBI (cognitive optical brain imaging) studio is a hardware integrated software platform to
acquire and visualize fNIR (functional near infrared spectroscopy) data. It is compatible with all
fNIR hardware versions developed at Drexel University Optical Brain Imaging Lab.

Distraction

Disruption of user attention by an outside source.

EEG

Electroencephalogram is a technique for recording electrical activity of the brain.

Flow

An ideal happiness or “optimal experience” from becoming fully involved in a challenging
activity or task.

fNIR

fNIR stands for functional near-infrared imaging. fNIR is a spectroscopic neuro-imaging method
for measuring the level of neuronal activity in the brain. The method is based on neuro-vascular
coupling, that is, the relationship between metabolic activity and oxygen level (oxygenated
hemoglobin) in feeding blood vessels.

Game Mechanics

The rule sets that make the game enjoyable.

Game Play

Gameplay describes the users overall experience playing the game.
Neurosky

*Neurosky is a consumer EEG brain computer interface (BCI) device.*

XML

*Extensible Markup Language is a text format for creating structured documents.*

Gamer

*Users that frequently play games.*
2. INTRODUCTION

2.1. Gaming Controllers

Over the years there has been a wide array of controller types used for different gaming platforms each of which built upon their predecessors. In the 1970s the controller type most popular was the joystick and button, derived from aeronautics designs, which was used in arcade machines and the home console Atari 2600[1]. The joystick control consisted of a hand-held stick which could be pivoted up to 45 degree angles (see Figure 1). The user’s angle control would then be translated into motions by the game console [1]. These translated motions were typically character controls within a game. This control schema proved successful as the limited controls were adequate for the simple two-dimensional games at the time.

With the release of the Nintendo Entertainment System (NES) the directional pad or D-Pad was added and became an industry standard for game control[1]. The D-Pad replaced the joystick, as it gave the user the same wrist control as a joystick using only little pressure from the thumb (see Figure 1) [1]. The introduction of the D-Pad allowed gamers to play longer with less strain leading to longer games. Nintendo’s competitors, such as Sega and Sony, followed its’ lead and developed ergonomic but more complex controls for games.

As 3D gaming became more prevalent, the simple D-pad became insufficient for the controls needed. Nintendo then introduced the analog stick with its N64 console, which allowed the gamer to have 360 degrees of control along with the ability to apply various pressures for precise control[1]. The previous and current series of game consoles use this controller design as a basis with improved ergonomics (see Figure 1). However, the latest console controllers (e.g. Microsoft Xbox 360 and Sony Playstation 3) have also added more buttons and labels as games have become more complex. This puts up a barrier for casual gamers who aren’t dexterous enough or don’t have the time to study the
controller and familiarize themselves with its layout. Though through training such as manuals and tutorials, users can eventually obtain basic proficiency with the complex controllers. With this trend of complex controllers, there have been rise to alternate controllers types for different games. These different games include Guitar Hero, Dance Dance Revolution, and Sony's Eye Toy [1]. The first two games discussed are rhythm games that use controllers relevant to their subject matter. Guitar Hero uses a guitar shaped controller and Dance Dance Revolution uses a dance mat which are intuitive to their game types. The Sony's Eye Toy uses allow resolution USB camera [1]. This camera uses motion tracking allowing the detection of player movement, such as punching and swinging, to be translated into in game actions [1]. This concept leaves a lot of room for experimentation in translating real world movements into virtual games.

The alternate controller games mentioned have been very successful commercially (e.g. 3.1 million sold guitar hero II) due to their intuitive controls, subject matter, and targeted casual audience[2]. However, the issue with each of these controllers is the limited game libraries available. Though these game maybe successful, the only people that develop games for these controllers are the developers of the controllers themselves.

As other companies improve on their past designs, Nintendo again took a radical step in controller types announcing the motion-controlled Nintendo Wii. The Nintendo Wii uses gestural motions for intuitive control- replacing buttons with arm motions[1]. Just as with the original Nintendo Entertainment System (NES), they aimed to make a simple controller which appealed to wide age range. This was met with initial criticism for being a system with less graphical power; however the system has enjoyed tremendous commercial success along with developer support[2]. As before, Nintendo has become the leader in innovation. Other companies have followed their example, such as Sony announcing their Move motion controller and Microsoft announcing Kinect a camera based motion controller [3, 4].
While there are many differences between the game controllers, they also share many commonalities as well. These commonalities are the translation of controller motions into game commands. For example, when a player presses a button on a controller there is an expected outcome such as Jump. This jump command is mainly a one-to-one correspondence, meaning there is not much uncertainty when a player presses a button. As games increased in complexity, the controllers gained more of these buttons to facilitate more in game commands (see Figure 1). The game commands used in motion controllers are primarily the same, as each gesture is mapped to a specific function. Currently, the game commands are still primarily based on the motion of a user either being a button press or a swing of the arm. This thesis will focus on another controller type that veers away from past controllers discussed. This controller type, which is based on the mind, doesn't use the motion of the player. Instead it is dependent on the variability of their concentration.

Figure 1: Timeline of Console Game Controllers[1]
2.2. Brain Devices as the Next Generation Controller

Through this brief glimpse of the evolution of game controllers, there is an iteration of innovation in the game system generations that focuses on simpler and more intuitive control types. This example can be seen from the progression of navigational controls of the joystick, from the D-Pad, from the analog, and now motion controls. The use of Brain Computer Interface (BCI) is a tantalizing possible next step in this continued evolution forgoing gestures and other outward signs of control for a purely mental interface system. Numerous BCI concepts, such as mental cursor control and concentration control are already being applied by cutting edge companies such as Emotiv and Neurosky which are releasing their brain devices for the consumer market [5, 6].

Using BCI devices for gaming control is unique compared to other controls because rather than having a physical device for control, it is a person’s mental activity that is used for control. In addition, unlike a controller where a push of a button or stick directly effects the input to the game, there is not the one-to-one correspondence of a user response to the resulting input data due to limitations of the device and lack of understanding of the brain itself. Therefore, because of the difference in controls, a user must first learn to master the device itself while learning the mechanics of a game. With this in mind, the mechanics of a game should be created to challenge the user’s mastery of the device and mastery of the game in general. For example, the use of distraction mechanics during mental concentration periods of the game can challenge the user and also can be used to study the user’s behavior. As these devices become more sophisticated, BCI has the potential to be the next step of intuitive gaming with its novel controls and applicability to the many types of games in the future.
2.3. Overview

This thesis addresses two major areas, the application of BCI for gaming, and the application of gaming for BCI research. To better understand the significance of these contributions, some background on gaming and BCI is required. Chapter 3 discusses the importance and application of games in Section 3.1 and Section 3.1.3 examines the psychological basis for creating engaging games for these areas. Section 3.2 discusses the emerging field of BCI research by examining the devices, methods, and results of associated brain studies. Section 3.3, BCI Games, details prior research into applying BCI to games, and critiques the shortcomings in both research applications as well as meaningful gameplay that motivated this thesis.

The next two chapters discuss the approach of creating a BCI based game for research and for entertainment. Chapter 4 discusses the protocol guidelines, rules, and theory behind the thesis game "MindTactics". MindTactics is then discussed in terms of core design choices and new game mechanics, in this case distractions, which focuses on adaption of user strategy while adhering to protocol guidelines. Chapter 5 discusses the creation of the game in terms of a platform, environment, and code base. This chapter explains how the game mechanics were implemented via code and how research elements were implemented based on prior studies.

Chapter 6 discusses the pre-pilot study done to test the game mechanics the thesis proposes. This includes testing how effective the distraction game mechanic was on users versus no distraction elements in play. This pre-pilot study also introduces the structure of how future studies can be done for this type of platform.

Chapter 7 summarizes the contributions in creating a research based universal BCI game prototype. This chapter also discusses future work for the thesis and the future of BCI gaming.
Chapter 3: Background

3.1. Game Design and Application

The video game format has many intrinsic qualities that make it ideal for experimentation. In terms of technology, video games offer a development platform. This platform contains the tools needed to setup 3D environments, real world physics, programming logic, and other core aspects of game creation. This type of creation tool allows developers, be it in the field of entertainment or serious industry, to quickly design software without having to develop their own simulation platform. The game engine also allows for expandability, meaning that the software developed can be altered and expanded upon for future iterations of software developed. This thesis uses this technology primarily for these reasons; a creation tool for necessary functionality and as a tool for expansion.

3.1.1. Game Technology

At first military simulation software was used as a reference in developing game technology, however over the years game technology has become the innovator in warfare simulation. These innovations are from utilizing key technologies that digital games provide. One of these technologies is 3D game engines. The 3D game engine is responsible for the interpretations of 3D models, environments, visual effects, code, and ambient sounds/sound effects for the game [7]. Game engines also provide a middleware platform or toolset for other game designers to develop on or outside industries to develop on. This thesis uses the game engine technology as a development platform for MindTactics for building the base structure of the game. With the base structure developed within a game engine, MindTactics can be easily updated in terms of general maintenance of the game and balancing of game mechanics. The game can also be expanded upon using the game engine in future
additions of game mechanics and functionality for research or general entertainment. This can include the integration of new BCI methods or updated research components developed in current or future studies. These game engines have become vastly more sophisticated over the years, continuously innovating the field in terms of graphical ability and overall computations. Through these improvements, game engine developers have created an evolving tool for not only games but for creating virtual environments that realistically simulate the world.

Many game engines now incorporate realistic physics through the inclusion of physics engines. Physics engines are used to calculate the various properties of physical game objects, such as weight and size, and how they affect the game world [7]. By utilizing these properties of objects, users can feel more physically connected to the game atmosphere as it reacts similar to their real environment. If a research environment needs to include physics, using this game engine feature saves on cost and time for development allowing the researcher to focus on other necessary tasks.

In terms of non physics based interactions and competition within games, virtual opponents or NPC (non playing characters) are utilized. These virtual opponents can be programmed with an advanced AI to simulate how real people would react to the user [7]. This can include adaptive enemies that create strategy against the user or an ally working with the user to accomplish a goal. Advanced AI has progressively become more complex to create a more realistic atmosphere and challenge for the user. In warfare simulation, if the enemy moves and reacts like a believable soldier the user maintains immersion. This immersion can be broken if the user encounters unrealistic behavior (bad pathfinding) or glitches (collision issues) [7]. Through unrealistic behavior and glitches, computer controlled characters limitations are exposed. Due to these limitations, this thesis uses networked users over virtual opponents for the creation of constant adaptive game play.

Through the adoption of broadband internet connection and rise of online capabilities, games now can connect users to millions of other users to play either cooperatively or competitively.
online users connect either though the method of user hosting or dedicated hosting. If it is user hosting, one of the users hosts a session of the game on their computer while others connect to that user. If it is dedicated hosting, a non-user computer is dedicated to host a session of the game which the online users connect to. Dedicated hosts are preferred as they are more appropriated for the task of multiple online connections and for overall game efficiency/security. This thesis utilizes the user hosting method, but has been structured to be able to use the dedicated method for future work.

Game technology has many intrinsic benefits that can be adapted to many other non-entertainment industries. In this thesis, the non-entertainment industry impacted is within bio-medical engineering. By combining the game technology with a research platform, this thesis shows the beneficial qualities of digital games and how they can positively impact other industries. This impact would be the use of digital games as a research platform for existing or new protocols within the field of bio-medical engineering.

3.1.2. Game Impact Theory

Through the advancement of technology and social acceptance, digital games have expanded into “serious” industries. These industries include “defense, medicine, architecture, education, city planning, and government applications” (see Figure 2)[7]. By adopting game technology as a software/hardware solution, these industries can save on cost and utilize the technologic foundations games offer. Smith, by analysis of game technology and impacts on other industries, has proposed a theory that highlights the driving forces in game technology adoption. Game impact theory describes five forces that create an impact on non-entertainment industries. The five forces are “cost advantage of hardware platforms, sophistication of software applications, social acceptance of game tools, success in
other industries, and innovative experiments in the adopting industry” [7]. A flow chart demonstrating how these forces work can be seen in Figure 3.

<table>
<thead>
<tr>
<th>Industry</th>
<th>Game Technology Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Military</td>
<td>Training soldiers and leaders in the tactics and strategies of war.</td>
</tr>
<tr>
<td></td>
<td>Three dimensional modeling of equipment to illustrate or explore its capabilities.</td>
</tr>
<tr>
<td>Government</td>
<td>Ethics training for NASA. Project management training for the State of California</td>
</tr>
<tr>
<td>Education</td>
<td>Augmenting classroom instruction in nearly every subject – English, math, physics, history, etc.</td>
</tr>
<tr>
<td>Emergency Management</td>
<td>Training emergency responders, firefighters, FEMA agents, and others to deal with disasters.</td>
</tr>
<tr>
<td>Architecture</td>
<td>Visually promoting major hotel, casino, and office spaces to potential clients.</td>
</tr>
<tr>
<td>City &amp; Civil Planning</td>
<td>Lay out and experimentation with public services for a population of constituents.</td>
</tr>
<tr>
<td>Corporate Training</td>
<td>Orienting people to company products, facilities, and policies. Pilot and safety training.</td>
</tr>
<tr>
<td>Health Care</td>
<td>Educating patients on treatments, rehabilitation, and managing anxieties. The next generation of workout videos.</td>
</tr>
<tr>
<td>Politics</td>
<td>Presenting political issues and consequences of political decisions. Promoting candidates.</td>
</tr>
<tr>
<td>Religion</td>
<td>Interactive versions of sacred texts. Tools to teach religious history.</td>
</tr>
<tr>
<td>Movies &amp; Television</td>
<td>Alternative form of storytelling known as “machinima”. Tools for creating animation and 3D worlds.</td>
</tr>
<tr>
<td>Scientific Visualization &amp; Analysis</td>
<td>Rapid display of objects under experimentation and physical forces acting on them. 3D display of data collected and analyzed.</td>
</tr>
<tr>
<td>Sports</td>
<td>Recreate live sporting events for review and for prediction of potential outcomes. Rehearse for critical “one time” events like Olympic ceremonies. Fantasy sports leagues in 3D.</td>
</tr>
<tr>
<td>Law</td>
<td>Illustrate crime scene activities for judge and jury. Analyze crime scene data.</td>
</tr>
</tbody>
</table>

Figure 2: 6 Industries impacted by game technology [7]
Figure 3: Game Impact Theory Flow Chart [7]

As stated previously, warfare simulation has begun to utilize game technology in their development. One of the major reasons is the cost advantage that games provide as a platform. By using games as a platform, the military can develop their simulations for less expensive consumer grade machines instead of having to build professional workstations. This can bring hardware cost down from the range of $20,000 – $50,000 to the range of $2,000 – $5,000 [7]. If the software can run on home consoles, the hardware cost comes down to the range of $200 –$ 500 [7]. High hardware cost usually comes from having to build hardware specific workstations for the software that was developed for the specific application. Computer game software are designed and optimized to take advantage of varying levels of consumer grade machines. By optimizing software for these machines, they can reach the most customers and be the most efficient as possible based on customer hardware. These “serious” industries can substantially save on hardware cost by utilizing computer game software.
Game technology offers many solutions to problems across the various “serious” industries; an example is an easily comprehensible and functional user interface. A user interface in games is meant to be understood without a manual and be constructed within the game itself. The game usually employs the use of tutorial levels or masked tutorial gameplay to help educate the user. This way the user is taught how the software goals can be completed and the user interface works without it being abrasive. This thesis utilizes this concept in its development of its game mechanics to train the user how to adapt to the BCI device and become proficient enough to compete in the more challenging modes of MindTactics.

There has been a social stigma that games were only meant for entertainment and for children, but as stated previously games offer many different qualities that benefit “serious” industries. These industries have used game technology for various projects such as scientific visualizations or flight simulations. These projects have shown critics that games can be a viable solution to project development. Games are have become more accepted by the general public as past game players have grown up and taken leadership roles in major industries [7]. The general public also has become accustomed to viewing 3D representations in various places such as “medical facilities, museums, building designs, and military systems” [7]. People have become more accepting of game technology in “serious” industries by their exposure to games themselves. By offering a platform that users are accustomed too, the users will have a easier time learning the basic game principles offered in MindTactics along with general knowledge associated with the game type the game is founded on.

Currently, many industries have begun to use game technology in their productions. Two of the first adopters of this technology were the military and the television industry [7]. Television shows have used game technology for many of their 3D visualizations and physical models to demonstrate natural science, technology, and space. These shows include “Modern Marvels, Nova, National Geographic, and shows on the Discovery and History channels”[7]. The military uses game technology in many of their
training systems including training tanks crews and company commanders [7]. These training programs utilize all the features previously mentioned such as game engines and advanced AI. The success these industries have had with game technologies support the platform as a viable solution for other non-entertainment industries.

As outside industries adopt game technology, their employees start to experiment with the technology creating new products and services. These can include new methods of studying chemical reactions, understanding stress between aircrafts and atmosphere, evaluation of architecture design, and city delivery services in growing suburbs [7]. By experimenting internally, these new products and services can become established and improved upon. Through experimentation in game technology and implementation of the software in the field, both “serious” industries and the game industry can benefit one another through the fostering of innovation. This concept of a reciprocal process through experimental innovation is one of the key concepts of this thesis in terms of the success of future BCI game development.

With this establishment of how game technology can affect other industries positively through innovation, the focus shifts to the actual software or game developed. The software or game created must be a "fun" or engaging experience to be successful. This thesis addresses the concept of engagement with a combination of Csikszentmihalyi’s flow theory and general game theory in terms of game structure.

3.1.3. Game Theory: Flow and Immersion

Two of the most important core components of games are game mechanics and gameplay. The term game mechanics describes a set of rules that make the game enjoyable and gameplay describes the users overall experience playing the game. Gameplay can have multiple interpretations, as they are
made of a large number of different elements, but this thesis will focus on describing gameplay as an experience [8]. Gameplay experience is context dependent, as the user interprets the experience as “fun” based not only on the predefined game mechanics but on past game experiences [8]. These past experiences shape what the user defines as enjoyable, such as a user can enjoy a particular game genre, like real-time strategy (RTS), based on experience while another user can find the same game genre dissatisfying because of lack of experience. These gameplay experiences consist of player’s senses, reactions, comprehension, and decision making to overcome challenges and acquire necessary skill to meet challenges [8]. Challenges have two dimensions which are “pace”, or speed of the game, and “cognitive challenges”, challenges of the mind [8]. The balance of these two dimensions creates an optimal gameplay experience or flow, which is a theory on enjoyment and creative action [8].

In the 1960s, Mihaly Csikszentmihalyi, a positive psychologist, researched how enjoyment could be derived from everyday activities which lead to the development of Flow theory [9]. Flow theory, through research about intrinsic motivations, proposes that people enter an ideal happiness or “optimal experience” from becoming fully involved in a challenging activity or task [9]. Flow consists of several characteristics, “balance of challenge and skills, clear goals, explicit feedback, indistinct sense of time, loss of self-consciousness, feeling of enjoyment, and control in an autotelic (i.e. self-sufficient) activity”[10]. This theory has been applied in many different fields of study including gaming. Digital games are great model for demonstrating flow theory as they incorporate many of these flow characteristics, such as gradually rising challenges and skill, immediate feedback to the user, and clear goals which can be the activity of completing the game itself [9]. The original flow model was revised as a four-channel flow model which was used to evaluate games and gameplay experience (see Figure 4) [10].
In the flow model, it shows how the balance between skill and challenge is necessary to maintain flow. Flow is disrupted if the challenge is too high, creating anxiety, or if the user has mastered the skills necessary to play the game which leads to boredom. Though the flow challenges and skill required can be difficult, they are never perceived as taxing because flow state is a highly rewarding experience [8]. Within gaming, this rewarding experience or enjoyment can be accomplished through user trial and error. Though failure can discourage a user, they can find their failing as enjoyable. This enjoyment can be explained through Zillmann’s excitation transfer theory. This theory proposes that users can translate negative feelings, such as anxiety and frustration, into positive feelings though anticipation of completing the task or winning the game [9]. When users have adapted correctly to the challenge, the stimulation of adaptation turns euphoric [9]. This cycle of frustration and euphoria is
repeated, as the user is introduced to new challenges within a game. This cycle is an important factor when developing game mechanics which are challenging to the user yet possible to achieve, which flow theory requires.

Another important component to gameplay experience is immersion. The term immersion is used in many media studies to explain a user’s experience; however the term’s definition has been vague because of its many interpretations. The closest interpretation in media studies is the concept of “presence”. Presence has many definitions also, but overall can be defined as “a psychological experience of non-mediation, i.e. the sense of being in a world generated by the computer instead of just using a computer” [8]. In the same way, immersion can be generally defined as “the sensation of being surrounded by a completely other reality [...] that takes over all of our attention, our whole perceptual apparatus” [8]. The term immersion is preferred in this thesis because it is more applicable to describing gameplay experience.

Immersion can be separated into sub categories, “sensory, imaginative immersion, and challenge-based” [10]. Sensory immersion can be defined as the audiovisual stimuli that the game provides. The audiovisual stimuli can include the overall game atmosphere, game environments, game characters, and ambient sound and sound effects. The game environment should focus on being compelling to the user; meaning being able to draw the user in by having realistic environments and environments that compliment the game mechanics. Game characters, either realistic or stylized, need to fit within the context of the game environment. Other ways to augment the visual experience is utilizing larger screens, stereoscopic screens and glasses, or heads up displays (HUD) [10]. The ambient sound or sound effects are important in a convincing presentation of the game environment and to give user feedback for actions (ie. Ring sound for obtaining an item). Sound can also be augmented by the using of surround sound or specialized sound cancelling head phones [10]. These in combination can
give the user one of the strongest impressions of immersion through audiovisual atmosphere and can be seen as prerequisite to immersion [8].

A strong atmosphere is also necessary for the sub category of Imaginative immersion. Imaginative immersion is how the user incorporates the narrative of the game or identifies with a character, which then allows them to empathize with and be engrossed in the atmosphere that the game provides [10]. This concept is main component in the genre of role playing games (RPG) [10]. By having a combination of a strong narrative and game mechanics that compliment the narrative, the user can become more engaged on player action and atmosphere reaction.

The challenged-based immersion is similar to what was explained in Csikszentmihalyi’s flow theory. As in flow theory, focus is on the balance of the user’s abilities with the game challenges based on user motor and mental skills [10]. The motor skills required of the user are based on their aptitude of the physical control (ie. game controller or mouse and keyboard combination) and their overall physical ability to react to the game. The mental skills are based on how the user interprets the challenges and how they develop solutions the challenges offered. By having challenges that require working memory, users have shown increase immersion (ie. Increasing game difficulty which then leads to heightened feeling of presence)[10].

Digital games incorporate many different intrinsic qualities (immersion, flow). These qualities also include technology, such as game engines and advanced artificial intelligence (AI), which can be leveraged in other industries or fields of study. With the rise of popularity of video games, progress has been made to a point that games can cross beyond entertainment and into other “serious” industries or fields of study [7]. By laying down both technological development and game design foundation, this thesis can begin to create a compelling game design for devices in research. The research devices used in this thesis are brain computer interface (BCI) controllers.
3.2. BCI Devices and Research

There are a variety of medical technologies that are used for neural imaging and brain monitoring; each with their own advantages and disadvantages. Many devices in brain monitoring studies have used electroencephalography (EEG), which is a method that reads electrical neural activity in the brain. EEG is even being used in the first consumer brain monitoring devices by companies such as Emotiv and Neurosky. Other brain monitoring and neural imaging methods include magnetoencephalography (MEG), position emission tomography (PET), functional magnetic resonance imaging (fMRI), and optical imaging (functional near infrared spectroscopy or fNIR) [11]. However, this thesis will focus on non-invasive EEG and fNIR methods, as the other neural imaging and brain monitoring methods are still hindered by high cost, size, and restrictions to only medical applications [11]. Through lower cost, portability, and non-invasiveness, EEG and fNIR based devices have become a realistic possibility for future brain computer interface (BCI) controllers.

BCI controllers are brain monitoring devices that allow the communication between the brain and an external device[5]. This communication is usually done by taking the readings from the brain and translating them as commands to be used in an interface or program through brain signal analysis. There are two ways to implement BCI controllers, invasive (medical procedure which penetrates the skin or a body cavity) and non-invasive methods. Early objections to the use of non-invasive BCI technology included the inability to represent more than two signal alternatives, such as ‘yes’-‘no’, ‘select’-‘ignore’, etc [5]. However, the EEG-driven BCI experiment by Wolpaw and Mcfarland, have shown these objections to be irrelevant by employing a five-directional cursor control with SMR (SensoriMotor Rhythm) and scalp EEG [5]. Even though patients would require long training periods with the device to become more attuned to the controls, healthy people could achieve control within one or two BCI control sessions[5]. For this thesis, the BCI controllers used for development are Neurosky’s Mindset
EEG device and Drexel’s fNIR device. The main focus is on the fNIR device due to accessibility, Drexel’s established research in subject area, and the benefits that the device offers such as concentration control. As understanding the data and corresponding brain functions these devices map is critical in designing BCI games, the following sections examine these two devices including the current cognitive research and methodologies.

3.2.1. Functional Near Infrared (fNIR) Technology

Functional near infrared spectroscopy, or fNIR, is a non-invasive optical technique that measures neural activity related hemodynamic response within the cortex [12]. fNIR technology uses light within 700nm to 900nm introduced at the scalp, to enable the noninvasive and safe measurement of changes in the relative ratios of deoxygenated hemoglobin (deoxy-Hb) and oxygenated hemoglobin (oxy-Hb) in the capillary beds during brain activity. Both, oxy-Hb and deoxy-Hb are correlates of brain activity through oxygen consumption by neurons [11-16]. fNIR technology allows the design of portable, safe, affordable, noninvasive, and minimally intrusive monitoring systems. These qualities make fNIR suitable for the study of hemodynamic changes due to cognitive and emotional brain activity under ecologically valid, natural conditions.

The fNIR device developed at the Optical Brain Imaging Lab of Drexel University is a continuous wave system. The control box hardware is connected to a flexible sensor pad that contains 4 light emitting diodes (LED) and 10 photo-detectors [11]. This sensor pad is positioned over the forehead of the user and designed to sample cortical areas underlying the forehead at 2Hz [11] (see Figure 5). Future iterations of the device will employ wireless connectivity along with new types of sensor geometries.
3.2.2. BCI Study: Close-looped feedback regulated CW-fNIR based System

In this thesis, the fNIR based BCI system incorporates the use of a Protocol-Computer, control box, data acquisition computer, and the fNIR sensor prototype device discussed in the previous section [12]. The fNIR device is placed on the forehead of the users who are placed in front of the Protocol-Computer. Information is then transmitted through the control box to the data acquisition computer. The software, Cognitive Optical Brain Imager (COBI) studios software, collects the raw fNIR data and transmits them back to the Protocol-Computer either by Ethernet or by wireless network via TCP/IP [12]. The software on the Protocol-Computer receives this information, calculates the raw fNIR data, and detects the changes in oxygenation which in turns changes the visual feedback completing the closed loop (see Figure 6)[12]. This thesis uses the same set up for users but the game software is deployed on the Protocol-Computer.
The experimental protocol used in the study was a task called bar-size-control. This task was meant to test users on control of timing, display visual feedback, and save the user’s information [12]. When beginning the task, users were given 20 seconds of a blank screen to gain a baseline. After the user is done with the blank screen they are shown visual feedback (vertical or horizontal bar). The user then concentrates on the bar for 120 seconds, which is then followed up by a cognitive self assessment screen which ranged from 0-10; 0 being the easiest and 10 being the most difficult [12]. This screen is shown for 30 seconds, the trial in total was never longer than 170 seconds [12].
Through current and post signal analysis, the two states of rest and task can be classified. By classifying these two states, a switch or binary system can be set up based on the desire of the user through prefrontal cortex [12]. This is the initial information gathered from the study which is ongoing.

3.2.3. Cognitive Workload Tasks

Drexel has used their fNIR device along with monitoring applications to test memory, attention, and cognitive workload [6]. In the cognitive workload task, users were asked to go through a simulation program called Warship Commander Task (WCT) while the fNIR assesses their cognitive state [6]. The WCT was designed by the Pacific Science and Engineering Group as a simulation of naval air warfare management [6]. The point of WCT is for the user to monitor the number of "waves" of airplanes (see Figure 7) to identify the unknown planes (yellow), friendly (blue), or hostile (red) where they were warned and destroyed based on rules of engagement [6]. Task load and task difficulty was manipulated by the number of planes, or waves, that the user must manage. The participants manage four waves of planes, with 75s between each wave, where the rest periods were used to measure oxygenation relative to their beginning baselines [6]. After the task was complete, blood oxygenation levels were averaged across eight voxels (three-dimensional versions of pixels) between both hemispheres of the brain. The fNIR data was analyzed based on user performance, cognitive workload, blood oxygenation levels of the dorsolateral prefrontal cortex, and the effect of divided attention. It was found that blood oxygenation levels in the prefrontal cortex increased as task load increased with positive marks in performance [6]. When attention was divided by the secondary audio task, warning the hostile planes, the mean of oxygenation dropped [6]. If the user can handle the task loads given by the simulation, a correlation can be drawn that successful task load management increases blood oxygenation levels for appropriate parts of the brain. If the user cannot handle the task load the user disengages and concentration lowers based on the example of the secondary audio task.
3.2.4. Working Memory and Attention Tasks

For the working memory and attention tasks, the n-back tests were applied where a series of stimuli were shown to a participant. The participant would click a button with their dominant hand when the intended stimuli would appear. Each visual stimuli were shown for 500 ms[6]. In total, the n-back tests offers four conditions of varying working memory loads; the 0-back condition, the 1-back condition, the 2-back condition, and the 3-back condition [17]. In the 0-back condition, the participant would respond to the targeted stimuli (e.g. "X"). In the 1-back condition the participant would be asked
to remember the stimuli from one trial back. The 2-back and 3-back conditions the participant would be asked to remember the stimuli from 2-3 trials back.

The average blood oxygenation level for all the subjects, as in the previous cognitive work load task, suggested that workload and oxygenation are positively linked [6]. The drop in oxygenation as seen in the 3-back test (the most difficult level), reinforces the theory that if participants become overwhelmed with a tasks they will disengage and lose concentration [6].

3.2.5. Maze Suite: Spatial/Navigational Tasks

Maze Suite is a toolset which allow researchers to develop spatial and navigational behavioral experiments for interactive 3D environments [13]. The 3D environments were developed to be easy to create for researchers and are highly extendable by the versatile toolset offered. The toolset is broken into three parts; the environment constructor (MazeMaker), the rendering module (Maze Walker), and analysis tool (MazeViewer) [13]. With these three tools, developed on .Net architecture, quickly deployable interactive 3D environments can be created for researchers.

MazeMaker is the simple graphical user interface to design and edit 3D maze environments [13]. To view a maze created by the MazeMaker, there is a top down editor. The top down editor shows a top down view of the 3D environment created with the lines and shapes (see Figure 8). By using lines and shapes, the researcher can better visualize and understand the possible paths available to the user. Researchers can also place items or objects along the paths for the user to interact with. These interactions can be visual pop ups such as textual boxes and are managed by MazeListBuilder. The MazeListBuilder lists what items or events are within the scene, enable the combination of multiple mazes, and allow control of textual events to generate experiment protocols [13]. After the layout and events are confirmed and saved, the 3D maze environment is visualized with MazeWalker.
MazeWalker is the presentation software and 3D engine that renders the maze using open GL as its graphical output [13]. MazeWalker’s 3D engine incorporates collision detection, lighting and shading, object importation, and texture loading (see Figure 9). By having these attributes, the user experience will become more visual engaging along with being flexible for researchers creating a unique maze.

While navigating the 3D maze environments, user behavioral data is logged with time stamps. These time stamps use a query performance counter method that provides up to sub-millisecond resolution timing [13]. During run time MazeWalker sends time synchronization signals based on the experiential protocol defined by MazeMaker that tracks user progress through markers [13]. A marker contains event information which can be defined by an initial settings dialogue such as com port, video,
control, visual, maze, and logging [13]. With behavioral data and video playback of user sessions, researchers can bring their user information into post analysis with MazeViewer.

![MazeWalker](image)

**Figure 9: MazeWalker**

MazeViewer is the post-analysis tool. This tool visualizes log files created by MazeWalker. With the log files, researchers can analyze the behavior of their subjects which includes subject’s path, focus of view, time of completion, and number of errors measured in milliseconds (see Figure 10) [13]. Mazeviewer contains a playback feature which draws the path of a subject when they enter and exit the maze. Mazeviewer can also parse though multiple log files and redraw singular mazes [13]. For each session, a summary file is created that contains the list of the maze, enter and exit time, and total time taken which then can be exported to other programs such as Microsoft Excel for further analysis [13].
Currently, there are many commercial stimulus presentation systems used for neuroscience research, such as E-Prime (psychology software tools), Stim (NeuroScan), SuperLab (Cedrus), and Presentation (Neurobehavioral Systems) [13]. Though these programs use a PowerPoint-like editor which makes them easy to use, the Maze Suite toolset offers greater accuracy recording as it is not built on independent layers (kernel, applications) [13]. This makes Maze Suite a valuable tool set for testing and evaluation. For this thesis, Maze Suite will serve as a base model in how to develop a credible research platform for testing protocols in terms of software design and research implementation.

The focus of this thesis is to not only develop a platform for fNIR research, but for any BCI device that can read a user’s concentration or attention. In building the steps towards a universal BCI game design, other devices must be used and tested for compatibility. This device is the consumer based EEG device, Neurosky Mindset.
3.2.6 Consumer EEG device: Neurosky’s Mindset

Neurosky’s Mindset device uses the EEG method of analyzing brain signals. The device uses a single electrode that reads electrical neural impulses based on brain activity (see Figure 11). The device filters two types of brain signals, attention and meditation, which is inferred from processing beta and alpha waves [18]. The attention meter represents how much the user is concentrating and the mediation meter represents how relaxed the user becomes. By having only one electrode, the device control’s complexity is limited. However for the purpose of this thesis, these controls are suitable in its demonstration of concentration analysis for gameplay.

![Figure 11: Current Neurosky Mindset](image)

3.2.7 Neurosky Mind Set: Usability and Attention Detection Assessment Exercise

With new consumer BCI devices on the market, a study was done to examine and assess the Neurosky Mind Set’s usability to detect attention levels in a user. The users in the study would answer a questionnaire in the form of a Artificial Intelligence (AI)-driven virtual character or avatar within Second
Life, a popular online virtual simulation [18]. Within the simulation, the avatar would ask ten multiple choice questions for the users to answer, while simultaneously gathering data about the user. This data includes the number of questions answered correctly, incorrectly, along with the overall response time. Based on the user's response and their attention from the device, the virtual avatar would then play predefined reaction animations and limited conversations [18].

The study on the usability of the Neurosky Mind Set device is separated into three sections; comfort, ease of use, and degree of frustration [18]. The questions given to the users were tailored with these three sections in mind. After the questionnaires were completed, analysis was done on the user generated data and the readings gathered from the device. Based on the collected readings, researchers noticed a few issues with the mindset device. The first issue is pace, programmers for the device must use an algorithm that compensates for hardware delay when measuring attention [10]. If not, there will be a chance of time fluctuation between attention measurements in the created logs. The second possible issue is general difficulty wearing the device. If the device loses connections, there is a delay of about 7-10 seconds before the devices obtains new readings [18]. The third issue would be the suitability of the mindset as a input device for an interface [18]. When programming for the device, the algorithm used should consider that each person has different general level of attention and should compensate. The future work for this project would like to combine other technologies such as gaze, body posture, and facial expression similar to ongoing BCI game projects discussed later.

In comparison to the fNIR device, this Neurosky mindset lacks the complexity necessary for appropriate BCI studies in terms of its lack of signal complexity and locked nature. This locked nature refers to the black box concept that references a device that can take input and output, but it's internal workings is unknown. This is due to the Neurosky Mindset's nature of being a consumer device. A consumer device must protect its property hence researchers can never gain an understanding on how the signals of "attention" and "meditation" are derived from. This device isn't true BCI and can be seen
more as a intermediate stepping stone to true BCI devices for the consumer market in the future. This thesis uses the fNIR devices as its focus for testing because of its complexity, research, and availability within the Optical Brain Imaging Lab of Drexel University.

By having fNIR or EEG BCI studies conducted on healthy users, these neural devices can be promoted as possible controllers beyond the medical field. These fields can be within the realm of biofeedback monitoring for serious industries, entertainment, or home use.
3.3. BCI-Driven Video Games

3.3.1 BCI Applications for Healthy Users

Current EEG BCI applications have been used mostly for cursor control and communications between letters or items on a computer screen. The goal of most BCI is to give people with neuromuscular disorders, such as Amoytrophic Lateral Sclerosis (ALS) or spinal injuries the ability to communicate with the world through interaction with a computer interface [20]. Some aim to use BCI as a form of therapy in which brain signal analysis can be used for specific types of psychiatric and neurological remedies [20].

There has been research on healthy subjects in the context of combining the capabilities of BCI with therapy and entertainment [21]. In terms of entertainment, BCI have been studied in combination with the field of gaming. Certain aspects of creating a game can be coupled with the use of therapy, as these brain wave signals can be used to better a person’s health, performance, and quality of life. For instance, a game can be created that utilizes meditation and relaxation to deal with the high stress in certain societal living environments [21]. With the concept of BCI for healthy users, new kinds of BCI prototypes can be developed, in which this thesis will focus on coupling BCI research platforms with game development.

3.3.2 BCI and Game Research Projects: BrainGain

A current project in the Netherlands, called BrainGain, are researching how BCI controls can be applied to gaming and human computer interface (HCI) designs. The project focuses on research topics such as attention monitoring and adaptation, classifying images, motion control for virtual or remote worlds, and multimodal measures of the user experience [22]. By exploring these topics, researchers
hope to develop new control schemes using neural devices beyond what has been seen previous studies, such as cursor control and concentration analysis.

When addressing BCI and gaming, the project addresses that brain activity of users or “gamers” can be used to affect the game environments in two ways. The first way is allowing the game environment to track the user’s experience and adapt to keep the user “in a flow”, which is a discussed theoretically in the thesis. The second way is adding brain controls to already existing controls in the game environment [22]. By having a BCI game mechanic that adds or augments current controls as a requirement of gameplay, the users must master the new skill to be able to accomplish a goal or win the game. Through challenge and interest in the game, users become willing to commit the time needed to master the new BCI controls in a natural way that are intrinsic to games [22]. This concept of balance between challenge and skill is another core concept in the development of immersion found in games.

In terms of game development, this thesis uses both these concepts of flow and immersion in the creation of engaging play.

The BrainGain project currently is working on a game that utilizes both a neural device and a camera to move an avatar around a game environment [22]. At the moment, BCI games must be multimodal as they require a secondary control device as the BCI devices themselves are not responsive enough to be the only control type [22].

3.3.3. Multi-Modal Human Computer Interface

Multimodal human computer interaction (MMHCI) is the use of multiple inputs (e.g. controllers) for a particular interface. Multimodal, in the context of this research, is defined as a system that takes in multiple inputs such as audio, visual, and touch. In MMHCI, there are three key concepts that should be addressed: the user, the system, and the interaction between the two [23]. At this point in time, multiple
inputs may be necessary for BCI gaming to be fully possible. These can be in the form of visual controls such as camera tracking, audio inputs such as vocal input and recognition, or motion controls such as a controller type that uses gyroscope methodology [23]. The two BCI devices aiming for the consumer market, *Emotiv* and *Neurosky*, both use multimodal interfaces. Though both read brain waves, their controls are slow in response, so another method of control is added; *Emotiv* uses facial recognition and *Neurosky* uses gyroscope motion controls [19, 24].
3.3.4. BCI Game Prototypes: Neurosky’s Judecca and Drexel’s LazyBrains

Though BCI devices have not reached the sophistication yet to be used as sole game controllers, there have been prototype games developed that use known research protocols as game mechanics, such as BCI indexes (concentration control). Neurosky, the company which develops the Neurosky Mindset, have partnered with Square Enix, a prominent Japanese game company, to create “Judecca” (see Figure 12) a first person shooter game that uses a player’s concentration as a key part of the gameplay [19]. The main game mechanic consist of using a player’s concentration to make enemies visible enabling the player’s “Devils Eye”, in which they then must eliminate the newly visible threats [19]. The game is still in early development and was first shown at the Tokyo Game Show 2008 [19]. Another BCI game prototype that uses concentration as its main game mechanic is the fNIR based LazyBrains.

![Figure 12: Neurosky Game: Judecca](image)

Figure 12: Neurosky Game: Judecca [19]
In 2008, Drexel University seniors in the Digital Media program developed a biofeedback BCI game project called LazyBrains. Through their exploration of various possible devices to be used within gaming, the fNIR device of Bio-Medical Engineering department was chosen to be used as a form of controller. Working closely with Hasan Ayaz, a doctoral student developing the device, the group tested various functionality and game play. The result was the first 3D video game prototype (see Figure 13) for the device using a game engine written in the same language as the device, Digini’s Blade3D.

Where the game succeeded was the use of concentration as a necessity for game play, keeping the user involved. The game offers a unique challenge- using a player’s concentration level as a form of control in the game. For instance, when the user approaches a closed sewer grate they must lift it which requires raising their concentration levels to accomplish the task without the use of a normal game controller. This confirmed that concentration levels could be used as a type of control in BCI game play. The challenges the player faces are linear in nature, lowering the learning curve, as the game helps guide you through the necessary steps to learn the device. The game also offered visual feedback to the user for every action done, along with the user interaction using a bar indicator to represent the player concentration level. At the beginning of the game, the player must get a baseline for the fNIR device as a reference value. To actually use concentration, most of the game tasks required the player to raise their concentration a certain percent above that baseline. When that percentage was met, the task would be accomplished such as the sewer grate lifting or a platform moving.

However one of the game’s major shortcomings was the similarity of all the challenges offered. The challenges the game used were to lift a sewer grate, move a platform, and a concentration jump which was all built on increasing a user’s concentration level to a certain percentage. Visually the challenges looked different, but the game play was the same. A controller was implemented along with the device, which lowered immersion, but was necessary for moving the character along. Though the
challenges were linear in nature, the goals were still unclear as there was no guidance given through the user interface. This resulted in the user relying on trial and error, which could have resulted in frustration for the user. Finally there was too much narrative in the game, which was beyond the scope of the project and barred the user from playing forcing them to listen to the guide.

The unique qualities of the fNIR device as a controller type is different from its predecessors as it evaluates constant varying levels of concentration input instead of pre-defined button responses. With a regular controller, pressing a button is attached to a known function response, while relying on concentration levels attaches varied or adaptive function responses. The novel control scheme shifts the focus away from the player’s hands and focuses on the player’s mental attention. This concept employs new forms of game play that optimizes using the brain as an active tool for game mechanics. In Lazy Brains, even though there is a reliance on a secondary controller due to delayed oxygenation responses, the concept of mind controlled game development becomes a real possibility. In the future, there will be expansion on the concentration mechanics through the coupling of the other voxels-- Lazy Brains uses only voxel 6. New propositions of control schemes can be developed based on future data gathered on the fNIR technology.

*Lazy Brains* is an example of how a research protocol, such as the bar-size-control task, can be developed into a type of gameplay mechanic. This thesis builds on its foundations and applies a model of research practice into its architecture. This new architecture is a gaming platform for researchers to test their protocol, but also utilize the immersive nature that gaming offers for more genuine results from the user.
Figure 13: Lazy Brains Sewer Task
Chapter 4: Approach

As seen in the prior chapter, BCI gaming is in its infancy due to several factors. First, BCI devices are still fairly limited in their ability to gather targeted brain data, and that data itself is still not well understood. Second, BCI gaming requires a new gameplay paradigm due to the uncertainty in the data and the variability from user-to-user in how the user influences that data. This thesis is attempting to address these current limitations by creating one research platform game, *Mind Tactics*, in order to pursue two concurrent goals 1) How can game design support the field of BCI research? 2) How can BCI devices are used in meaningful gameplay.

4.1. Game Concept: Mind Tactics

The fNIR BCI prototype game, *Lazy Brains*, is the original foundation for this project in its use of the bar-size-control task [12]. This task, in conjunction with the *Lazy Brains* game prototype, showed that the experiment protocol could be adapted as a game mechanic. In this case, the game mechanic was the user's concentration control or BCI index. Through the consultation of previous fNIR research at Drexel as well as ongoing BCI research elsewhere, additional conceptual game mechanics were created based on protocols that were previously developed for the fNIR device. These new mechanics led to the development of a single and multiplayer game called *Mind Tactics*.

*MindTactics* was created to investigate using concentration as both a gameplay mechanism as well using the game itself to supplement the clinical studies of concentration levels. As described earlier, concentration based game play has been established from past projects, therefore the focus of this thesis is shifted towards how this game type could be intertwined with current BCI protocol. By using the same format as these protocols, specifically the bar-size-control task, this thesis promotes the exploration of new BCI game mechanics while simultaneously testing research by following researchers' experimental guidelines. These guidelines refer to adhering to important elements within an
experimental protocol structure. This thesis, for example, incorporates elements of the bar-size-control task such as the concentration bar and assessment screens within the game.

*MindTactics* consists of two modes of play: single player and multiplayer. The single player mode is meant primarily for researchers to test subjects and for subjects to learn the game. The multiplayer strategy mode is designed more for the "gamer" population, and includes a multiplayer archetype with research elements. These two modes are different in pace, yet they consist of the same structure and share the same basic game principle: territorial control.

### 4.2. Mind Tactics: Basic Game Play and Game Mechanics

*MindTactics* uses one of the most basic multiplayer archetypes as its foundation of play: capture points (CP). Capture point gameplay is a competition of territory control on a game map. Like other multiplier archetypes such as death match, capture the flag (CTF), and king of the hill (KOTH), capture points is meant to be an intense competition between human players that promote both strategy and quick thinking [18]. This thesis uses the concept of human competition in its multiplayer design, however in terms of single player design the competition is against oneself.

The main reason for picking CP as a design foundation was its scalability from multiplayer to single player while being compatible with past developed BCI game mechanics. In *Mind Tactics*, the basic game mechanic uses player concentration to obtain territory within the game. Territory on the game map is represented by flag points. These flag points are captured when the user, based on vicinity, uses their concentration to raise a flag to the point of capture (see Figure 14).

The flag capture mechanic uses the calculated BCI index of the connected device (referenced through device drivers) as a method of raising the flag. The flag's progression is dependent on this index which can range from a value of 0-100. By having a BCI index or concentration level of 50 or above the
flag progresses upwards, if not the flag digresses downwards. Because the flag moves downwards as well as upwards, users must develop a personal method of concentration that is effective in raising the flag. This concept of maintaining an optimum concentration is the basic challenge of the game.

![Figure 14: Concentration being applied to a flag point](image)

4.3. Mind Tactics: Single Player Mode

The single player game mode is a third person perspective capture the territory environment. The environment is arranged into three sections separated by inclined planes (see Figure 15, Figure 16). The user must navigate the 3D terrain and capture the three territories which are represented as flag points. Flag points are labeled by number, which are visible in the environment, and laid out to guide the user to capture the flag points sequentially. When the user completes the game goal, capture all three flag points, they win the game and are shown a special win case screen. Though this game mode seems simplistic; it is important in terms of research, game play, and user adaptation to challenge. Before discussion on the core aspects of this game mode, the graphical user interface (GUI) should be explained and established.
Figure 15: Single player Short Map

Figure 16: Single Player Long Map
The graphical user interface is the 2D images on the user's screen which display various indicators that reveal the status of various elements of gameplay that the BCI game incorporates. The single player default GUI consists of two elements (see Figure 17). The first element is the flag user interface (UI) map on the top right of the screen indicating which flag points are open, being captured, or already captured. The second element is the concentration bar or BCI index indicator which was used in the bar-size control task [3]. This bar shows the current level of user concentration or attention that effects how quickly the points are captured. There are other elements that can be toggled such as a timer, however these elements are set to be off by default. By having minimal UI elements, the user can better concentrate at the task at hand.

![Figure 17: Single Player GUI](image)

The single player game mode serves as a general introduction to acclimate the users to the game controls. These controls include basic navigation, camera alignment, and general BCI control. Though navigation and camera alignment are secondary; mastery of these controls are important for
other modes of play, specifically multiplayer, which demands urgency when traversing to each flag point. Each flag point also serves as an introduction to BCI control. By experimentation and repetition, users can become more proficient at raising their BCI index or attention. The BCI index and attention are shown to the user in the form of a UI concentration Bar. This bar is a good tool in guiding the user, which is an example of user feedback.

Feedback allows the user to understand how the game operates and the consequences of their actions. When the user moves their game character into the area of a flag point; several events occur (see Figure 14). A glowing ring appears around the flag which represents the area of effect of the user. The area of effect is how far away the user can be from the flag point to raise the actual flag. When the user is capturing, the flag in the scene will begin to move up or down and change color based on the player affiliated team. The UI flag will also change color based on which flag point the player is currently capturing. Lastly, the concentration bar appears allowing the user to optimize their method of concentration to capture the flag point. In terms of introduction, feedback is very important in teaching the user game controls. The learning curve of game controls and BCI controls can also be eased by the overall level design.

The single player level design was built to be very simplistic. By having the flags labeled sequentially and having only one path, users could easily navigate the environment and comprehend the game goals. The flag number labels in the environment also serve as a type of landmark to give the user a sense of direction and location. Designing around past protocols, the environment was kept very non-stimulating so attention wasn't split from the BCI task. This was done through the use of environmental minimalism and color. The overall color palette for the single player environment was muted grays; only having color on objects that the user could interact with. By having an environment that was simple and non-distracting, the user could appropriately complete the BCI task and training to master the device.

In single player mode, two different levels are offered; short and long. The short version is
meant for quick sessions and general practice for users (see Figure 15). The long version is meant for longer sessions of play which benefit researchers when analyzing user data between sessions (see Figure 16). Both versions of single player maintain the same format of three flag points, however the choice of the level is based on either the user or the what the researcher prefers. In terms of game preferences, *MindTactics* has many in-depth options to choose from created for researchers working with various BCI devices. Game options are discussed later in the chapter.

*MindTactics* uses protocols like the bar-size control task and research projects such as Maze Suite as foundation for its research features. One of the features that is incorporated into single player mode is the use of the cognitive self-assessment screen seen in the bar-size control task (see Figure 18)[12]. This assessment screen is shown when the user captures a flag point, or if the user steps away to retry to capture a flag point. When this screen appears, the user must input difficulty of the task (ie. capture points) between 0 - 10; 0 being the lowest and 10 being the highest. This feature can be toggled off or on based on the researchers needs. Other important research features include data acquisition and logging which will be discussed later in the chapter.

![Cognitive Assessment Screen](image)

*Figure 18: Cognitive Assessment Screen*
4.4. Mind Tactics: Challenge and Game Theory

When developing Mind Tactics, the use of a schema is important. This schema is being the elements of a CP styled game. In CP, the player is introduced to the game mechanic of territory control. This is fairly common within the realm of multiplayer games. By using a preconceived mechanic, users will be able to predict not only how the game works but what to expect. This is important when bringing in unknown elements which in this case are the BCI controls to capture territories. In other CP games, when a user is in the vicinity of a flag point and no opponents are around, that user then captures that point within an allotted time. MindTactics takes that idea, and then introduces the concept of concentration as the capture rate, instead of just vicinity. In single player specifically, there is no true danger of other opponents. The true opponent is the user themselves as they try to adapt to the BCI device and control their concentration. Concentration though is a very vague concept. This concept is different for every person who uses the BCI device.

By using the BCI device as a game controller, the user has to discard their preconceived notions of past button controllers and adapt to a new control scheme that they are unfamiliar with. This leads to the inevitable cycle of trial and error. Users will try many things to find their optimal concentration level, but will likely fail multiple times in their initial experimentation. When a user fails they are introduced to stress and frustration. It is important to make sure that the challenge (i.e. device controls) is possible and the goals are clear [14]. If the challenge is insurmountable the user will disengage, so it is important to give the user feedback to help them balance their concentration. The feedback in MindTactics is the concentration bar. This bar, like in the bar-size control task, measures current BCI index or concentration of the user. It is important in both immediate feedback and for users to cope with stress [12]. So even before the user tries to accomplish the main goal, which is win the game, they must accomplish smaller
goals first such as raising the flag. As stated in Zillman’s excitation transfer theory, as the user begins to understand their goals (i.e. concentrate to capture flag), they gain positive feelings over the negative as they anticipate a resolution in the completion of the goal or task [9]. This leads to a euphoric feeling and the gratification of accomplishing a difficult challenge.

Within the options menu of Mind Tactics, there are ways to augment the challenge of the game. With the fNIR specifically, there is an option to raise the difficulty of the BCI index. Hence, if changed, the flag points will either take more or less concentration to be captured. Another augmentation is the use of a timer. By default, the game has no timer and the game will end when the user accomplishes the task of capturing all three territories. The benefit of having no timer is free reign to explore and learn the device. If a timer is introduced, it changes the game style from exploration to time based challenge. If the time is set to be incremental, the user is tracked on how fast they accomplish winning the game creating additional challenge. The added challenge is trying to best the user’s own previous time with their current time. If the time is set to decrement, the user has a finite amount of time to win the game, which brings about greater feelings of anxiety over the basic challenge of just capturing flag points. These are some good methods of changing the atmosphere of play, however in MindTactics the biggest addition is the use of distractions.

4.5. Additional Game Mechanics: Distraction Events

The distraction game mechanic was developed as a type of opposition component. This component is applied to further challenge users that have become proficient in their use of the BCI device. When users master general concentration and the device, the distraction mechanic is utilized to affect their attention. As attention is strongly linked to concentration, the distraction game mechanic disrupts a user’s ability to retain attention and forces them to adapt quickly to a given scenario [21].
These scenarios are concentration event triggers that occur either based on time or based on percentage of capture completion of a flag point. The main goal of distractions is to change the pace of the game and augment the challenge. Both pace and cognitive challenge are important in maintaining an optimum game flow [8].

4.5.1. Distraction Event Type: Elimination

Each distraction event belongs to a particular type of category. There are three categories in total: elimination, addition, and control based. Each category contains distraction events which theoretically have different effects on the user with varying levels of strength. The first category that will be discussed is elimination, which takes away an element from the game that the user has become accustomed to. The missing element could be user interface graphics, general visual stimuli, or even certain controls. By taking away or augmenting a preconceived visual constant or control, the user will have to reevaluate the situation and find a new way to hone their concentration.

Within the category of elimination there are three distraction events: freeze bar, rearrange, and black out. The freeze bar effects the concentration bar of the user interface (UI), providing an illusion that the bar is neither increasing nor decreasing (see Figure 19). This distraction was developed with the notion that the concentration bar can become a dependent for the users. The user focuses on the bar as a type of feedback of progress. If the current concentration progress is not shown, they must either focus on the physical game space or an alternate method. The same concept can be applied to the rearrange distraction event. This event swaps the position of the UI forcing the player to adapt to each configuration given (see Figure 20). As the player becomes comfortable with configuration of the UI, a sudden change in configuration would conflict with what the user expects. For example if the user is dependent on the bar, the simple shifting of the bar from vertical to horizontal could be very effective in forced adaptation. In this example, the adaptation would be changing their visual focus from raising the
bar from down and up to left and right. The last distraction event blackout is the most extreme. In this event, the entire screen goes black taking away all visual stimuli. When this event occurs, the user must adjust their concentration away from visual dependents and on to complete personal dependence. This means that the user must find a way to raise their concentration by a method that they believe is effective with no guidance from the game. Unlike the other two elimination events, the only feedback the user has of their progress is when the black screen disappears.

Figure 19: Freeze Bar
The elimination events force the player to become dependent on another type of feedback. For example, if the user is dependent on the concentration bar they can shift their focus onto the game environment space. If the game environment space is obscured they can then shift their focus to another alternate form of feedback. This would be an example of how elimination could force adaptation by user dependence on explicit feedback in theory [14]. The next category of distraction events is addition. Addition is the opposite of elimination as it adds elements to the game. By adding elements, the user must reevaluate of how new elements introduces integrate with current game elements.

4.5.2. Distraction Event Type: Addition

The addition category contains two distraction events: trick bar and shock noise. Similar to freeze bar and rearrange, the trick bar distraction exploits the dependency on the concentration bar. Instead of altering the bar, it creates replicas of the bar and places three extras on the screen (see Figure 20: Trick Bar).
Each of these bars randomly changes their value to mimic the change in value of the user's concentration bar. The user then has a choice to either search for the correct bar, or shift their focus to another form of feedback. By introducing more bars and having the user either search or switch, demands that the user shift their attention. If they search, for example, a new immediate goal appears which is to find the correct bar which adds greater cognitive challenge and complexity augmenting the main goal. Their main goal is to capture the flag, but they must first make a decision on how additional elements should be handled when introduced.

Figure 21: Trick Bar

The shock noise distraction event is an auditory stimulation. In the single player levels, because the environment was designed to be non-stimulating, there was no addition of sound. For this category, shock noise is the most extreme. The shock noise distraction uses the characteristic of audio changes to effect the concentration of the user. Information, such as audio, comes into a brief sensory store in the brain. Here that audio information is analyzed for physical characteristics such as pitch or volume, before semantic meanings [25]. Hence even if the user may be ignoring the sound distraction, if the
physical characteristic of the sound changes, the brain automatically shifts attention to that audio [25]. The audio in shock noise is a loud screeching buzzer at a very high volume. Researchers can analyze the effect of audio on users when concentrating on such task as raising the flag point. The addition category forces the user to make decisions and shift their attention. Trick bar adds a new element of game play (i.e. choose the right bar) shifting their attention by choice, while the shock noise distraction forcibly shifts the user attention. The last distraction category, control based, shifts attention and challenges users by augmenting control.

4.5.3. Distraction Event Type: Control Based

Within control based distractions there are four types: invert, time items, sequence, and land shift. Control based distractions either augment the controls the user is accustomed to or demand that they split their attention with additional controls. The invert distraction event is very subtle. This event reverses the concentration of the user, where high concentration is low and low concentration is high. In this scenario, the indicator of the inverse effects is the flag in the game scene and the seemingly malfunctioning concentration bar. The concept of inversion introduces a new type of play which is using meditation to raise the flag instead of intense concentration. Not only will the user have to adapt to the inversion, but they have to learn a new way to control their concentration.

The next control based distraction is time items. Time items introduces the concept of time limits when capturing a flag point. Normally, the user has no time pressure to capture the flag point other than their own pressure. When this distraction occurs, a timer is placed on the screen showing the user the time they have to capture the point (see Figure 22). If the user does not capture the point in time the player is then pushed off to try all over again. By adding time limits, a new form of challenge is created; this challenge being how quickly a user can increase their concentration on command. If the user truly has mastered the device, they should be able to rapidly increase their concentration to match
the time limit. Not only do time limits offer a new challenge, but they change the pace from causal to frantic when capturing a flag.

The next two control based distraction items are sequence and land shift. These distractions require both concentration and secondary controls. The secondary controls can be keyboard, joystick, or a console controller. The use of a secondary controller forces the user to split their attention between the main concentration task and a secondary task. In the fNIR WCT example, when a secondary control of audio was employed, oxygenation levels lowered, as it pushed the user past their cognitive workload [6]. This type of distraction item tries to accomplish the same concept by pushing the limits of cognitive workloads.

The sequence item prompts the user to press buttons or keys described on the screen in a certain sequence (see Figure 23). The user must maintain their concentration to raise the flag, while looking and pressing the appropriate keys. If the keys are not pressed in the right order or not in time, the user will then be pushed off the point to try again. This distraction offers another type of play, or a
mini goal, for the user which adds to the overall goal which is to capture the point. By having the precision and time limit be important in accomplishing the secondary task, the user will have to split their attention as intended. In terms of split attention, the most extreme in the control based category is land shift.

The land shift distraction is an event which moves the flag point around the map (see Figure 24). The user must follow the flag point to continue capturing the point. Every time the user gets too far away from the point, their concentration resets forcing them to split their attention to navigation with the controller. Not only does the user have to maintain their concentration, they have to be aware of the game character's location compared to the flag point's location. This distraction event is the most involving as it requires concentration, game space orientation, and precision.
One core aspect of using the fNIR, or any BCI device, is learning how to use the device itself, as it is unlike any existing game controller. However, just learning how the device works doesn’t make an enthralling game. The game must acknowledge the abilities of the device, which in this case is the adaptation of concentration control in varied scenarios. These scenarios depend on which distraction event is triggered against a user. It is unknown how each user will react to the device, but as with any game controller mastery is important. The use of distraction events challenges that mastery of the device. Distractive measures represent a challenge, in which the user must constantly adapt, which in turns leads the player to create various approaches to accomplishing tasks. There must be a constant challenge to the individual in not just the device, but as an engaging game which promotes the replay of the game itself and the testing of particular protocols (e.g. bar-size task). It is unknown if each distractive item will work against a user, because any factor can really affect concentration; the distractions may even improve the performance of the user. To better understand the distraction effects, a method of data gathering and logging must be created for each session of play. The data logs
must contain a format that is applicable to researchers, easy to parse through, and structured similar to current protocols.

4.6. Data Gathering and Logging

In terms of research, MindTactics can be used as an environment for testing protocols. Currently the protocol the game is tailored for is the bar-size control task. By designing for this task and following its guidelines, the game was made to be expandable for other BCI protocols in the field of research. Research games, like Mind Tactics, utilize the intrinsic quality of games which is immersion and game flow. By designing a BCI protocol into engaging game mechanics, researchers can observe how users react to cognitive challenges through the concealment of a game. If the game focuses on the strengths of the BCI device, the researchers can use a game environment for training which can be augmented for their own purposes. If the game offers a unique gameplay experience, users will return to the game to further progress device mastery and in turn more data about proposed game mechanics will be generated [10]. The term "replay value" is the concept of users returning to the game because of engaging gameplay experience, and it is very important in the design of Mind Tactics. The repetition of play is important for training with the devices and accumulating data on user progress.

In terms of mass distribution, this thesis can incorporate a larger sample size of users through network/online play. User information can then be gathered and analyzed on not just the individual but by a group. Unlike a lab setting, the game platform can reach a larger audience and offer an engaging experience which promotes repeated play and retained attention. This concept of retained attention makes it a qualified candidate as a testing platform for protocols. Past and current protocols can still be followed as intended in a game format but also include the beneficial qualities that games offer. In a game designed around network/online play, not only does researchers benefit from the larger sample size and repeated play, but the built in audience of users familiar with online games. This thesis uses
network play, meaning play that involves more than one user on a local network, in its design but does not include online play which is future work.

*MindTactics* tracks user progress by recording data logs of each session of play, similar to Maze Suite. For researchers, it is important to be able to track all the information from a game session and have the ability to archive information from past game sessions. By time stamping each game session, researchers have an efficient way to look at particular events and analyze different player states for those events. The time stamping of all the information allows a researcher to know when a session started, occurrences during the session, and occurrences at the end exported in a text format. This format is an Extensible Markup Language (XML) document that includes the user information coupled with the time of each user action. The reason why the XML format was chosen was because of its ease of use for parsing data and its compatibility with Microsoft Excel. The compatibility with Excel is mostly for the readability of information and the use of visual charts.

With each game session saved, a researcher can look at the singular game session in detail. This includes the user’s orientation, position, current device value, and events. By having all this information, it is easier for researchers to compare between data logs. The data logs are not strictly set to these parts and can be changed to match the protocol. Similar to Maze Suite, the inclusion of user orientation and position is to analyze the user’s spatial navigation and give the researcher an understanding of user movements [13]. The events are user actions that are not related to navigation. These events can be current device value, entering or exiting a flag point, capturing a flag, assessment, or distractions. These events, along with user’s navigation are captured approximately every 500 ms.

Though the goal is to capture data every 500 ms, the game engine must compile and run various scripts, as well as render graphics to the screen, possibly creating a small delay [13]. To compensate for the possible system delay, another log is created that outputs raw device data using markers. These markers are numerical values that researchers can identify and analyze. The raw data log is similar to
how the regular log works, however instead of just creating the log on the protocol computer the game sends marker data to the data acquisition computer. On this computer, markers are then recorded by COBI which on completion, exports the data back to the protocol-computer in a separate log. These logs contain the raw device values and the markers signifying events.

Each log is recorded and saved on the protocol computer. The computer saves the logs into a folder named "ThesisLog", however the name and system path are arbitrary. Within this folder there are two other folders which are called archive and current. The current folder contains the data log and raw data log of the last played game session. Every time another game session is completed, the current data logs are then moved to the archive folder. This is mostly done for the organization of the researcher. In terms of organization, the log files also follow a naming convention which is name, date, and current time.

By using Maze Suite as a foundation in data acquisition, *MindTactics* incorporates the concepts of multiple data logs to compensate the shortcoming of game engine delay [13]. The structure of the data logs, with the additional events related to the game, were also modeled after Maze Suite's data log structures. By the inclusion of an XML format (see Figure 25), the user information gathered can be parsed much easier when looking for particular events or when comparing multiple session data. The data can also be visualized in graphical format (see Figure 26, Figure 27) that the researcher requires. By analysis of multiple sessions and multiple trials, researchers can better understand user behavior or distraction effects on users.
Figure 25: XML Log File and XML data log imported into a spread sheet

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<th>Time</th>
<th>PlayerPosition</th>
<th>PlayerOrientation</th>
<th>DeviceValue</th>
<th>EventType</th>
<th>Log</th>
<th>assessmentValue</th>
</tr>
</thead>
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<td>65.65711</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>1.79</td>
<td>68.70565</td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>(2.3, 42.3, -99.0)</td>
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<td>68.70565</td>
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<td></td>
</tr>
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<td></td>
</tr>
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</tr>
</tbody>
</table>

Figure 26: Chart of BCI Index over time for Trial 1
4.7. Mind Tactics: Multiplayer Mode

It is common for games to offer different levels of difficulty. These levels are meant for users that want to challenge themselves when they have become adept at the game mechanics. This also serves the purpose of keeping the user engaged by balancing their learned skills against new challenge. *MindTactics* offers a new challenge in its alternate multiplayer mode. This mode is meant for users that have gained a high level of proficiency with the BCI device and the game mechanics of single player. In multiplayer, the user is always being offered varied levels of challenge based on other human opponents and the focus on strategy. This mode introduces competitive game play and the concept of multiple user data logs via network play. In terms of research, it follows the same guidelines as single player but offers
the potential to gather a larger sample size of users based on a network/online infrastructure. In terms of game design, it is engaging to the "gamer" population due to competition and familiarity with the game type in multiplayer mode.

The multiplayer mode is a third-person capture the territory game. This game mode incorporates multiple human users in a competitive atmosphere. Though the atmosphere has changed, the core mechanic of the game has not. As in single player mode, the user's concentration is still used to raise the flag the point. Also, when the user captures three flag points in total, they win the game. Even though that goal sounds easy, the user has more pressure and challenges in multiplayer mode with the introduction of opponents. At the start of a multiplayer session, the user and the opponent both are given team colors which are red and blue. In this thesis, if the user hosts the game they become red, if the user is joining a game they become blue. In this game mode, users must be aware of their own progress along with the progress of opponents. This is done by introducing new elements to the GUI of the game.

The multiplayer GUI consists of four elements (see Figure 28). The first element is the flag map on the top right of the screen indicating which flag points are open, player captured, or opponent captured. This flag map will show the capture status of each flag point in real time. This way a player can either choose to capture a open flag point or battle opponents for the contested flag point. Also the flag map contains more flags then in single player mode. In multiplayer mode there are 5 flag points in total that the user can capture. This means the user must be more aware of the flag map and use the flag map for situational navigation. In single player mode flag maps were used to track user progress, however, in multiplayer mode the flag maps are mainly used to track user progress versus the opponent's progress.

The second GUI element is the concentration bar on the right of the screen which works the same way as in single player. The third element is a simple disconnect button to leave the multiplayer
game after either the user joins or hosts their own game. The last element is the item holder on the top left on the screen which tracks which item the user currently has. These items will be discussed in detail later.

Figure 28: Multiplayer GUI

The multiplayer environment is arranged in an arena format (see Figure 29). Within the arena there are 5 flag points which the user can capture spanning between two floor levels. The first level has two flags points which are east and west. The second level contains the north, south, and center flag points. By having only two flag points on the lower level, the user cannot win by staying on the first floor. This promotes exploration and strategy. In terms of fairness, the flag points are arranged to be equidistant from one another to give an equal chance for each user participating in the multiplayer game session. Also, the flag points are labeled by direction which helps users decipher character orientation. The UI flag map is also useful for player orientation. Though orientation can be an issue,
part of the challenge of a arena match is finding orientation and planning navigational strategy under pressure of competition.

Figure 29: Multiplayer arena capture points setup

In terms of design, multiplayer mode is not restricted to the same rule set of design as single player. This includes the notions of simplicity and non stimulation. The arena style was designed to look like a reactor warehouse. This reactor warehouse design was similar to other capture point maps which stands in contrast to the more abstract feel of single player. By designing an environment that users are accustomed to based on genre, the user has a higher chance of having "fun" based on prior experiences of that game genre [9].
With this notion of context dependent game experiences, not only does prior experience bolster the concept of “fun,” but familiar game mechanics as well [9]. In this case, the familiar game mechanic is capturing points. To capture points however, the user must have become proficient at using the BCI device for concentration control. Unlike single player difficulty, multiplayer difficulty is past introductory into advanced levels. This means that the user must have a certain level of skill proficiency. Skill is a main component of flow, so when the skill of the user matches the task at hand (i.e. capture flag before opponent), the user becomes engrossed in the flow of the game [14].

In single player mode, the only other challenger to the user was the device and themselves. Either they are basically trying to reach an optimum level of concentration or they are training to adapt to distractive elements while concentrating. In multiplayer mode, the user has the chance utilize their skill against another human opponent. The opponent offers a new type of challenge which this thesis terms, "Cogni-Clash" (see Figure 30). To initiate a Cogni-Clash, the user must step on the same flag point as the opponent. When this occurs the user must hone their concentration to raise the flag to the point of capture before the opponent does. The cogni-clash system is very simplistic, if the user has a current level of concentration that is higher in comparison to the opponent their flag moves upwards. If the opponent has the higher concentration, then the flag will rise based on their levels. When the user or opponent captures the flag the loser of the battle is pushed off the point. When this occurs, the loser can then try to either reclaim the flag point or move on to another flag point. Though cogni-clashes are the most direct way to battle an opponent, the user can also utilize distraction items against opponents.

The distraction element introduced in single player has become repurposed in multiplayer. The distraction events do not occur based on time or percentage as in single player, but based on the will of the opponent. The opponent has the ability, as does the user, to pick up items that are spread throughout the map. On the map, the items look like rotating boxes with question marks. If the user picks up this item, they have a chance to pick up one of the 9 available distraction items. This includes
the multiplayer specific item, launch, which primarily shoots the opponent in the air if they are on a flag point. When a user picks up a distraction item, the GUI item box element displays the name icon of the distraction and stores the current distraction (see Figure 31). The user can utilize an item whenever the opponent is on a flag point which is signified in the flag map UI. This way, the user can activate an item strategically based on the status of the flag map. The distraction items can also be used when engaged in a cogni-clash. Similar to single player, every event is recorded, collected and logged in the same XML format. The data log is then exported to the user's computer and opponents. The event tracking, such as flag point entry and distractions, has been altered appropriately to the changes to multiplayer.

Figure 30: Multiplayer Battle "Cogni-Clash"
4.8. Mind Tactics: Multiplayer Game Strategy

In the multiplayer mode of Mind Tactics, the elements of strategy and human competition are introduced. With this introduction, the game not only tests the user’s proficiency at the device, but also how they can adapt to other users while achieving the overall goal. This goal, as in single player, is to capture all three flag points.

Unlike single player mode, the environment is not as straightforward as it is arranged in arena format. The arena has a total of five flags that the user can capture, though they only need three to win the game. As seen in Figure 29, the flags are arranged and named based on their direction (i.e. north flag, south flag, etc). On the first floor where the users begin, there are two flag points; east and west. The other flag points are located on the second floor which includes the center flag point. The level design was created with the notion that a user must capture a flag point on the second floor to win leaving

Figure 31: User with inverse distraction item
room for multiple strategies. An example strategy is, a user can capture all the points on top but have a risk of falling as there are multiple ledges that are a danger to the user. The center flag point is the most hazardous as the only way to reach the center point is to traverse a narrow walkway with no railings, which also takes the most time to reach. Though a user can become accustomed to a personal strategy, the pathing strategy will change based on the opponent that they face.

In terms of general strategy, the user must be aware of the opponent’s actions. These actions are tracked based on the Flag Map UI on the top right of the screen (see Figure 28). The user will utilize the flag map UI to assess the status of each flag point, and then task themselves with a path that is most efficient based on their analysis. There are two ways to challenge an opponent. The first way is using distraction items against the opponent. The opponent is only affected by the item used if they are on a flag point so the user must be careful not to waste the item. The item effectiveness is also different for each user in terms of reaction. Through experimentation, the user can assess which item works best against an opponent. The other way to challenge an opponent is to initiate a cogni-clash battle. In this battle, the user can assess the concentration proficiency of the opponent and assess if direct combat or items are best for slowing opponent progress.

The concept of adaptive and tactical strategy is the most important concept in multiplayer mode. This mode was built to continuously challenge an adept BCI device user. When a user becomes proficient, multiplayer introduces new game play experiences with each opponent. Each new or familiar opponent demonstrates a varying strategy and play styles with each session [7]. The variations in general, keep the adept user engaged through diversity of game play and opponent types.
4.9. Options Menu

Within the option menu (see Figure 32), which can be accessed from the main menu, there is a multitude of options to change the single and multiplayer game settings. A settings file is created and used as a container for variables so that they persist between sessions.

- **Timer** allows researchers to select from three different time modes: decrement, increment, and disabled. The decrement option allows researchers to designate a time in which the user must capture all the points in the environment. This designated time is in the format of minutes and seconds. The increment option is a timer that continuously counts upwards which tracks how long it takes the user to complete the session. Lastly, there is an option to disable the timer.

- **Concentration Bar** allows the researchers to have the concentration bar always displayed, only displayed when on a flag point, or not displayed at all. The concentration bar represents the current BCI index, or concentration level, of the user and designates the speed of capture.
- **UI Flags** allows the researchers to have the map UI either be displayed or not displayed in a game session. The map UI informs the user which points they are capturing, have captured, or need to capture.

- **Choose Device** allows the researchers to choose the BCI device that is currently connected. The current device choices are oscillating script for testing without a device, fNIR, and Neurosky. This device list will increase as more BCI devices become available and integrated in the thesis.

- **Cognitive Assessment** is as self report prompt after a player captures a flag point (see figure 2.7). This prompt allows the user to assess the difficulty of raising the flag with a numerical slider ranging from 0 to 10, 10 being the most difficult. This option can be toggled off or on.

- **Markers Enabled** is a fNIR specific function, which uses a port to send out marker data representing when events occur in the game session. This can be toggled off or on.

- **Difficulty** is the difficulty slider of the BCI index, fNIR specific. It modifies the general difficulty of increasing the BCI index or concentration.

- **COM port to use** is used to specify which port is used to connect to the Neurosky device, or any other BCI device that uses a com port. This can also be used to specify which port should be used to send out marker data for the fNIR.

- **fNIR IP Address** is the IP address that is used for fNIR connection.

- **Distraction** is the option to set what types of distraction occur at specific flag points. The researcher can set specific types of distraction, 10 in total which will be detailed later, and have it occur based on two methods; percentage or time. If the researcher inputs a percentage, representing the percentage of capture completion, then the distraction will be initiated when the user reaches that amount. If the researcher inputs a time, the distraction will be delayed by that time amount based on the arrival of the player at the flag point.

- **Distraction Length** is the amount of time that a distraction will occur on a flag point. The time format is measured in seconds.

- **Save/Save custom/Load custom** allows the researcher to save the options they currently have selected to an editable file type (.ini). The save as command allows researchers to save multiple configurations, instead of just saving over their current settings. The load option is there to load the researcher’s previous option configurations.

- **Back** button is used when the researcher is all done with the configurations and wants to go back to the main menu.
Chapter 5: Methods

To develop the BCI game Mind Tactics, it was important to choose a game engine that could be accessible, powerful, and support networking. Networking support was an important factor in choosing the engine, as building a new network framework was beyond the scope of this thesis. The initial game engine, Blade3D, was still being developed and didn't include network support. The game engine Unity3D was chosen as the main development platform.

5.1. Game Engine Platform: Unity3D

Unity3D was used to develop the 3D BCI game for this thesis. Unity3D was chosen due to its robust support of programming languages, multiple platform deployment, built in networking support, and general ease of use. The game's mechanics and custom drivers were developed primarily using the programming language C#. A major reason for using C# as the programming language was that previous project, Lazy Brains, was developed using this language. This way previously written code could be leveraged for the thesis and updated according to the latest research, specifically regarding the fNIR device. Though Lazy Brains used a different game engine called Blade3D, Blade3D did not support any kind of networking. The networking support offered in Unity made it much easier to focus on specific network game mechanics needed, rather than having to develop both networking framework code and the network game code. Along with easier implementation of code structure, the importation system of 3D assets and animation made development much quicker. With these benefits, it was a logical step to choose Unity3D as the platform to develop on, as opposed to Blade3D which was still in development. With the game engine chosen, the format and language could be determined to develop extensible BCI device scripts for developing proper game mechanics.
5.2. BCI protocol scripts

Before developing BCI game mechanics for this thesis, there must be scripts developed to interpret the raw data from the BCI devices into usable information. The end result is a standardized output between zero and one hundred that can be interpreted as a user's attention or concentration; this data can then be utilized for game mechanics within a game environment. Though these devices are all different, they share similar properties to one another. By creating a public interface, called IBCIDevice, the BCI device scripts can all share the same structure by inheriting the properties of this script (see Figure 33). This allows future BCI devices with similar functions to be implemented along with future expandability of the game and game functions.

![Figure 33: Example of IBCIDevice class inheritance](image)

Within the game environment, a game object called BCI contains each of the BCI device scripts, the XML logger script, and the GlobalOci script. The GlobalOci script determines what kind of BCI device is connected and used within the game; this is initialized by the options menu.
5.2.1. fNIR device script

The fNIR class is encapsulated by the IBCIDevice interface; meaning it never has to be called directly, just placed on the BCI game object. The fNIR script also inherits the IBCIDevice functions including connection, baseline, start, and stop functions. These functions are called internally by the interface using provided fNIR drivers. These drivers are where the script derives its data from. This includes the raw data and device value that is used within the game environment.

Before the game begins, the user is introduced to a black screen with a plus sign in the middle for visual focus (see Figure 34). This black screen is used for the initial baseline calibration that is necessary for concentration tasks. The black screen last for ten seconds in which the user must relax and meditate to get an accurate baseline reading. When the calibration is complete, the user is able to then navigate the game environment. If the researcher or user wants to recalibrate their baseline, the “F3” key is used to acquire the new baseline. When the user presses the "F3" key, the device will recalibrate in the same fashion as the initial calibration. This recalibration function can be done at any time within the game; however the option to do so is left to the researcher.
5.2.2. Neurosky device script

The Neurosky class methods are similar to the methods used in the fNIR class, except for the necessity of the baseline. The baseline isn’t needed as the device is always taking a current reading. The device readings and methods are determined by the Neurosky device driver (thinkgear.dll). There are multiple types of BCI data output streams that are filtered from the device, such attention and meditation. For this thesis, only the attention data is referenced and used within the game environment.

When there is no device connected, the game references an oscillating value that is within the range of the other BCI devices. This is used primarily for testing game mechanics when no device is at hand. These scripts are necessary to determine the cerebral data of the user to be used within the game. Using two types of BCI devices, EEG and fNIR, shows how similar device protocols can be used as universal BCI game mechanic possibilities.

Figure 34: fNIR calibration screen
5.3. Game Mechanic: Concentration Based Capture

When the user enters a flag point, they trigger an invisible collider that signifies capture activation. This activation is handled by the FlagRaise or FlagRaiseMP script depending on what game mode is chosen. Based on the chosen BCI device from the options menu, the current device value to be used in the environment is obtained. In the environment, the flag is either raised or lowered based on this device value and the concentration bar is shown. By default, the concentration bar is shown; however the bar can be toggled in the options menu. When the physical flag has reached the apex of the flag pole, the flag point has then been captured.

The availability of a flag point is dependent on the point's current status. There are three statuses for flag points: CaptureStatus.Neither, which means the point is open, CaptureStatus.HalfRed, meaning capturing, and CaptureStatus.Red, which means captured. The flag point statuses update the flag map UI, the glowing ring at the base of the flag, and the color of the flag. In single player, if a flag point has been captured no more actions may occur on that flag point. In multiplayer, if an opponent has captured the flag point beforehand the user can recapture that point.

5.4. Game Mechanic: Distraction Implementation

In single player, distractions can be set by researchers in the options menu. In options, they can define what type of distraction is used, time or percentage of capture threshold for activation, and on what flag point the distraction will occur on. This mechanic is handled by the FlagRaise scripts and the GUI scripts. The FlagRaise scripts create the calls and the GUI scripts create the visual effects, if valid. Within the FlagRaise scripts, when a user steps on a flag point the script checks to see if a distraction has been set. If a distraction has been set, it will use the shared vars script to deduce how it is activated, either by time or percentage. Based on the activation type, it then uses the shared vars script to activate
the correct distraction, if applicable. The distractions are stored numerically in an array where each number represents a type of distraction. The actual effects of the distractions are functions within either the FlagScript scripts or the GUI scripts, depending on if the distraction is a game environment effect or a 2D screen effect.

In multiplayer mode, the distractions are not preset. The distractions are turned into elements of the game where users can activate distractions as weapons against the opponent. The user gathers these distractions by running over an item box. This item box contains an ItemBox script which detects the collision with a game character. When the ItemBox script detects a collision, it randomly chooses a distraction item for the user. The user has a different script, called ItemScript, attached to their character which allows them to use an item on an opponent.

5.5. *Research Mechanic: Data Acquisition and XML Data Logging*

When the XMLLogger writes out game data into a XML format, it uses tags to signify different sections. This makes it much easier to parse through the data visually. It is also a format that is supported by many spreadsheet programs such as Microsoft Excel (see Figure 26) which then can create visual graphics of the game session data. The game data logs contain not only user information but game settings. The game settings of each session are placed in the logs for researchers to know the setup of the session in post analysis.

When the user is capturing a flag point an entry is created in the XML data log which is written approximately every 500 ms. By default, the entry contains the time, player position, player orientation, and device value.

```xml
<Entry>
  <Time>500</Time>
  <PlayerPosition>(31.3, 16.0, 25.2)</PlayerPosition>
</Entry>
```
The entry format can be modified when events occur in the session. These events can be when users enter/exit the flag point, have a distraction occur, or use the cognitive assessment screen.

The XMLLogger script is attached to the BCI game object in the scene. By having the script attached to a game object, the exposed properties and methods of the script can be referenced globally from any other script. This is important because when an event occurs on a foreign script, the logger needs to be able to be accessed.

Not only is a log created for each session, a raw data log is created for each session specifically for researchers. This is specific to the fNIR device. The fNIR drivers contains a similar function as the XMLLogger where markers can be sent to signify an event in the scene. In this thesis, the marker and the XMLLogger calls are done at the same time to ensure consistency for post analysis.

5.6. Multiplayer: Networking Overview

In this thesis, the networking code was used to create the multiplayer mode of the game. The actual implementation of the low level networking is entirely internal, so an overview of the code will be discussed. In terms of overview, the most important concepts are serialization, instantiation, and RPC messaging. The serialization is the synchronization of the code and game objects. This makes sure that
the users both see the same environment, the same animations, and have the same controls across a network. This is mostly handled by the system.

Instantiation is the creation of the object via server. Within Unity3D, there are game objects called Prefabs. Prefabs are simply game objects that are predefined by users (ie. object with user scripts attached). In the multiplayer scene, the flags, for example, are created as prefabs. This is done because objects cannot be synched unless they are created by the server. The server makes sure that the prefab objects are different to avoid conflict with the system. The SpawnFlags and SpawnPrefab scripts handle the creation of the multiplayer prefabs. The SpawnFlags script specifies where the flags will be placed and how many flags will be created. In SpawnPrefabs script is where the user and opponent game character are specified.

RPC Messaging is used when calling functions from other scripts. RPC, or remote procedural call, is used for network based calls specifically.

```csharp
void SendDistraction(int distChoice)
{
    networkView.RPC("DistractionAttack", RPCMode.Others, distChoice);
}
```

In this example, the RPC message is sending Distraction attack on an opponent, which is specified by RPCMode.Others. The term networkView is a unity class which handles RPC messaging and serialization, so when the user attacks the opponent they receive the attack on time. These three concepts are important in the foundation of the network code structure of this thesis.

5.7. Multiplayer: Cogni-Clash Battle System

Within the FlagRaiseMP script, there is a function that handles two users on the same capture point. When creating this battle system, the code must be able to decipher between the user and the opponent, since identical scripts are being run on both machines. When two users step on the same flag
point, the host user is defined as red and the connected client is defined as blue. These definitions are used when determining the concentration of each user. The host user maintains the current device value while the client receives the remote value. This can also be reversed, where the client is the current device value and the host is the remote value. When the user is in battle, their concentration values are then compared and subtracted from one another. This value is then used to raise the flag upwards. So if one user has a higher concentration then the other, they will have the advantage and the flag will raise upwards with their affiliated color, or fall downwards against their opposing color. Based on the affiliated color and if the user is host or client, the loser of the battle is then pushed off the flag point.

The multiplayer mode of MindTactics is an important feature in both adaptive challenge and how research can be integrated into game design. This integrated design is the right step in the progression of these devices into mainstream audiences either being for games or other entertainment. However, non-invasive BCI devices are still fairly new with limited control and research. Current research is important to assure that proposed BCI game play developed has a foundational standing. For this thesis, a small pre-pilot study was created for MindTactics using the fNIR device.

6. Pre-Pilot Study

To help validate the thesis in both terms of research and game design, a pre-pilot study was done with the single player version of Mind Tactics. The pre-pilot study was modeled around the observation of user concentration control without distraction elements vs. user concentration control with distraction elements. Through game play and post data analysis, the game mechanic of distractions can be tested in terms of observation of the difference in user concentration and the validity of the
distraction mechanic itself. By having a pre-pilot study, a foundation can be created for future studies using BCI game platforms like Mind Tactics.

6.1. Experiment Setup

Similar to the other fNIR studies, the experiment setup as shown in Figure 6 and consists of the Drexel fNIR equipment, a data-acquisition computer, and a Protocol-Computer. The Protocol-Computer is the computer that runs the MindTactics game software. The game software was initialized when the user is sits in front of the Protocol-Computer and has the fNIR sensor placed appropriately on the forehead. As described earlier, the fNIR sensor and control box provides information to the Data-Acquisition computer containing the COBI Studio software which then transmits data back to the Protocol-Computer. The protocol computer then calculates the oxygenation and modifies visual feedback within the game, which then modifies the fNIR signals and closes the loop.

The time synchronization marker data are recorded for later analysis. In this experiment, the marker data was recorded along with a separate XML formatted data log that also contains game information such as device value, player position, orientation, and events.

6.2. Participant

The pre-pilot study contained a single subject. The subject was male, 29 years of age, with no history of neurological or psychiatric disorders. The subject volunteered to test the MindTactics game software for the study over two days. The subject had authorization to use the device.

6.3. Experimental Protocol and Tasks

The game, Mind Tactics, integrates the elements of the Bar-Size control protocol into its user tasks. These tasks are the capture points, or flag points, that represent the territory on the map. The
single player map used in the experiment has three flag points in total. Before the user begins capturing flag points, they must define their baseline. The baseline is initialized at the start of the game where the user is asked to focus on a black screen (see Figure 34) which defines the user baseline.

At this point, the user is then asked to capture all three flag points to win the game. When the user begins capturing the flag point, a vertical bar will appear that represents user's oxygenation data calculations or BCI index. The current index will be used as a rate of capture, where 50 or above raises the flag and 49 or below lowers the flag. The user has no time limit on flag capture and can define when they want to capture the flag based on their character's vicinity to the flag point. When the user captures a flag point, they then are given an assessment screen on which they must rank the difficulty of the task. The difficulty is ranked from 0-10; where 0 is the easiest and 10 is the most difficult. If the user steps off the flag point, without capturing the point, the assessment screen will still appear asking them to rank the task. If this occurs, the user assessment number will be averaged for each attempt.

Included in the pre-pilot study were 10 sessions, with 3 flag point tasks in each session. The sessions were separated into two equal groups of 5 sessions. The first group was the single player mode of Mind Tactics without distractive elements. The second group was the single player mode of Mind Tactics with the addition type distraction.

6.4. Results and Discussion

There were two logs created for each session of the pre-pilot study. The first log was the raw FNIR logs which contained marker data. The second log was the XML formatted data logs that contained game information and events.

Using these data logs, the maker data and self-assessment values were extracted for analysis. As expected, with-distraction trials are on average higher than the non-distraction trials (paired-t(14)=1.74, p=0.05). Figure 35 below displays the comparison.
Figure 35: Average self-reported values for both non-distraction (none) and with-distraction (distraction) cases. (n=15 for both). Error bars are standard error of mean (SEM)

Average oxygenation changes during all 30 trials were calculated for both non-distraction and with-distraction trials. Figure 36 displays the comparison of rest and task period oxygenations. In both conditions, task periods indicate higher oxygenation as opposed to rest periods. These results are in line with previous results of pilot study reported by Ayaz [12]. For non-distraction trials paired-t(14)=1.35, p=0.09. For with-distraction trials, paired-t(14)=1.41, p=0.09.

Moreover, comparisons of average oxygenation during with-distraction and no-distraction periods are displayed in Figure 37. Although the with-distraction trials somewhat higher mean oxygenation, the difference is not significant. (paired-t(14)=1.11, p=0.47).
Figure 36. Average oxygenation changes during rest and task periods. Left graph shows with-distraction trials and right graph shows non-distraction trials.

Figure 37. Comparison of average oxygenation changes for trials with distraction and without distraction.

The distraction tasks created were in line with the oxygenation data collected in this small study; distractions would require a higher amount of oxygenation to complete a task. The task used the
addition type distraction "trick bar" for the trials. In theory, the user would have to delineate each concentration bar that would appear and find the correct bar to utilize as feedback. Hence, the user would have to provide extra attention and concentration to accomplish this goal. However, the mere appearance of additional visual stimuli could also be the reasoning behind the increased oxygenation due to general stimulation. By creating an environment that is non-stimulating, any additional visuals could either distract or encourage users during a concentration task. There is much variability within data and the user, which is why more research needs to be done then this preliminary pilot to define a true connection between distractions and higher oxygenation in a user. This preliminary pilot study was merely done to formulate a methodology for testing the thesis platform and how future experiments can be set up based on the game software developed.

7. Discussion and Conclusions

With the creation of *Mind Tactics*, a game platform was developed that supports research within the field of BCI. Current BCI protocols, specifically the fNIR Bar-Size control task, were integrated as a foundational game mechanic. This game mechanic then lead to the creation of a universal BCI game design based on the multiplayer "capture point" game type, which could be used for any BCI device that measured concentration. The game design also included the same guidelines as research protocols, so with each session of play the user concentration and spatial data was recorded for later analysis. By basing the game design on the "capture point" game type, the game platform created two modes of play; single-player which focused on research and multiplayer which focused more on the "gamer".

With the development of non-invasive and cheaper BCI devices, game companies in the future will start to experiment with this type of controller. Similar to the history of Guitar Hero and Dance Dance Revolution, the only game developers that will create games for these devices will be the BCI
companies themselves with only a few third party developer support (e.g. The Adventure of Neuro Boy for Neurosky)[1]. Also, there will be multiple BCI devices that will come to the consumer market (e.g. Neurosky, Emotiv), but only when one prominent device emerges will true game development occur on that platform. Through future BCI research, the controls available will be more self sufficient meaning that the device will not have to be multimodal. This is where the true evolution of the game controller will occur, where the industry shifts from controllers that require motion to a controller that relies solely on thought. As seen in the evolution of controllers, a company such as Nintendo must adopt the controller platform to be successful [1]. The only way a company like Nintendo will accept this controller is when the research has become defined enough to make it look like a sound investment for the gaming future. This is why, as in Mind Tactics, that the combination of BCI research and game development is important.

Through the development of games for BCI devices, the demand for BCI based games will increase. The demand will give rise to many new games which will lead to the development of a better BCI device. This will drive the market towards new research into better BCI devices hence; the gaming industry can support researchers. The researchers then support developers by defining new methods of control for the BCI devices and the creation of better BCI devices in general.

Though the BCI technology will always be changing, the foundations of game theory laid out by MindTactics will still be valid well into the future. The core aspects of games will always be the balance of skill and challenge. MindTactics was built with that concept in mind to be an adaptive game platform with room for expansion. As new BCI devices come to market, MindTactics will remain a valid game design for concentration based game play.
7.1. Contributions to the Field

In the thesis, *MindTactics* discusses methods in developing a game design that facilitates BCI research. The design utilizes current BCI protocol and guidelines while maintaining the core aspects of game theory. By maintaining these two aspects, *MindTactics* can be used as a valid testing platform but also as an engaging game that the main stream populous can play. This concept of main stream play is the step in the direction in which BCI controllers could have a real progression into the field of entertainment.

This work furthers the field of BCI gaming by contributing the following:

- *Universal concentration based BCI game design*
- *First multiplayer concentration based BCI game*
  - Developed method of user to user concentration based battles
- *Defined rules for BCI game design*
  - Environment should be non distracting or non stimulating
  - Concentration feedback is necessary for users; specifically new users
  - Cognitive challenges (e.g. distraction elements) developed must be possible
  - BCI based goals for the user must be clear
- *Methodology for testing BCI game platforms in a research environment*
- *Expandable software format for future protocol development via BCI attachment*
7.2. Future Work

In terms of future research, this thesis could incorporate a larger amount of users with emphasis on teamwork. User information can then be gathered and analyzed on not just the individual but a group dynamic. This can include players on the same team, on opposing teams, or based on certain moments within the game in which two specific users interacted. The game’s potential lies in its expandability; meaning additional BCI devices and the introduction of online capabilities. These game sessions can be in a local environment (e.g. offline) for practice purposes, but is most effective in an online environment. By using an online environment, researchers have the ability to test a much larger amount of users than within a lab setting. Unlike the previous studies with few participants, using an online game environment makes it easier to have a much larger sample size of users from various backgrounds. This includes gender, nationalities, and religion. MindTactics uses the unique properties of games such as immersion, but also uses protocols as game mechanics which researchers can alter and augment based data acquisition and user feedback.
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