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Location Invaders

Creation and Evaluation of an Endurance
Focused Exergame

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Abstract

A sedentary and inactive lifestyle is quickly becoming the norm and in combination with the ever growing obesity epidemic is causing a wide range of detrimental effects on the human body. Exergames has risen from the gaming industry as a way to mitigate this issue by combining the traditional gaming experience with physical exercise, in the hopes of cultivating an active lifestyle and adherence to exercise. Exergames are still in a relatively early stage, and this thesis aims to make a contribution in this domain, focusing on an endurance game with elements of high-intensity interval training.

A theoretical introduction to the aforementioned inactive lifestyle and obesity epidemic, alongside a presentation of our research methodology, exercise theory, exergames in general, game mechanisms, and suitable technologies, lay the foundation for implementing an exergame prototype based on endurance training.

The implemented prototype is presented, alongside a discussion of the rationale behind decisions taken in regard to the technological choices, as well as the exercise design. The prototype was then user tested (n=11), in the aims of uncovering the users perception of the games enjoyment, engagement, and motivation, as well as providing insights into the degree of physical activity the game supported. The user testing was conducted using heart rate monitors to track the physical exertion during a game, GPS to track distance traveled and speed, and a questionnaire to provide the necessary insights in the users perception of the game.

The results indicate that the implemented prototype is motivating, enjoyable, and engaging, and provide some degree of endurance training. The provided exercise is currently not at a satisfactory intensity level to be categorized as high-intensity interval training. The tracking of the user location through the use of GPS proved to be too inaccurate, and this had a detrimental effect of the user enjoyment of the game.

Sammendrag

En stillesittende og inaktiv livsstil blir stadig mer vanlig, og i kombinasjon med den voksende fedmeepidemien, foresaker det en rekke skadelige effekter på menneskekroppen. Exergames har vokst fra spillindustrien som en måte for å dempe dette problemet. Ved å kombinere den tradisjonelle spillopplevelsen med fysisk trening, i et håp om å kultivere en aktiv livsstil og overholdelse av trening. Exergames er fortsatt i et relativt tidlig stadie, og denne avhandlingen har som mål å gi et bidrag i dette domenet, med et fokus på et utholdenhetsspill med elementer av høy intensitet intervalltrening.

En teoretisk introduksjon til den tidligere nevnte inaktive livsstilen og fedmeepidemien, sammen med en presentasjon av vår forskningsmetodikk, treningsteori, generelt om exergames, spillmekanismer, og passende teknologier, legger et grunnlag for en implementasjon av en exergame-prototype basert på utholdenhetstrening.

Den implementerte protoypen er presentert, sammen med en diskusjon om begrunnelsene bak valgene som er gjort i forhold til teknologi, og treningsdesign. Prototypen ble så brukertestet (n=11), med mål om å avdekke brukeroppfattelsen av spillets fornøyelse, engasjement og motivasjon, samt å gi innsikt i graden av fysisk aktivetet spillet støttet. Brukertestingen ble gjennomført med bruk av pulsmålere for å måle fysisk anstrengelse, GPS ble brukt for å måle distansen spillerne hadde flyttet seg og hastighet.
En spørreundersøkelse ble brukt får å gi nødvendig innsikt i brukeroppfattelsen av spillet.

Resultatene indikerer at den implementerte prototypen er motiverende, fornøyelig, engasjerende, og gir en viss grad av utholdenhetstrening. Graden av fysisk anstrengelse har for øyeblikket ikke en tilstrekkelig intensitet for å bli kategorisert som høy intensitet intervaltrening. Sporingen av brukerens posisjon med bruk av GPS viste seg å være for unøyaktig, og dette hadde en skadelig effekt på brukernes fornøyelse.

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Part I

Introduction and Research Methodology

In this part, the project and project context will be introduced. We discuss the motivation behind the project, as well as the project goal and research questions used for guiding this thesis. Finally, the research methodology is presented.

Chapter 1

Introduction

This chapter will introduce the project, its context and the motivation behind it. The research goal, research questions, and a short introduction to the research methodology are also presented.

1.1 Project and Context

This project came to life as a master thesis in Computer Science at the Norwegian University of Science and Technology, with the following project description:

> **[Exergames] Play to get fit**
> "In this project, the goal is to come up with new game concepts and game technologies for exergames - games where the player carry out physical exercise at the same time. There are several approaches for exergames, and the challenge is to find the balance between something that is fun to play as well as you get a real physical exercise from playing the game.
>
> The first phase of the project will consist of a theoretical study of exergames and mechanisms for how games can be used as a motivator. The second phase focus on implementing a prototype using various technologies. In third and final phase, the prototype will be evaluated and tested."

The thesis follows the project description, where a prestudy is conducted, then a design for our own exergame is presented based on these findings, implemented, then finally evaluated.

1.2 Motivation

Urbanization, globalization, and technological progress has freed the average western worker from the physical struggles of everyday life. The energy-intense manual labor typical of a rural areas have been replaced by sedentary desk jobs and work that requires little physical labor [1]. Adults spend on average 60% of the day seated and the car has become the most common mode of transportation, even on short distances [2].

Obesity and higher body weight, which comes with a wide range of detrimental effects on the human body, is strongly correlated with a sedentary lifestyle [3]. 7.7 % of deaths in high-income countries were caused by illnesses traced back to insufficient physical activity, and can cause cancer, diabetes, and heart disease [4]. According to Helsedirektoratet 1 in 8 deaths can be attributed to physical inactivity, and world wide it is defined as the fourth biggest cause of death from noncommunicable diseases [2], while sufficient physical activity can help mitigate or even treat several illnesses. For more information about physical activity see Part II, Section 3.

Exergames has emerged from the gaming community as a way to mitigate this issue, and does so by combining the traditional gaming experience with physical activity in the hopes of cultivating a more active lifestyle. It uses various technologies, such as GPS, motion tracking, and accelerometers, to track body movement and reaction. Exergames has been found to be a suitable alternative to traditional fitness activities, or as a part of an exercise program [5, 6], and that they can improve fitness and improve the adherence to exercise [7].

The authors of this thesis have an interest in physical activity and exercise, and work out several times a week. The idea of creating something that may aid others increase their physical activity and motivate exercise is very intriguing. With both having played various games since childhood, there is also a deep-rooted enthusiasm in computer games. Therefore with our interest in both gaming and exercise, and seeing the importance of physical activity for human health and well-being, we wish to make a contribution in this domain. By creating an exergame that can be enjoyable for a wide audience, while helping to motivate and increase physical activity for the players, we hope to make a valuable contribution.

1.3 Goal, Research Questions, and Methodology

The main research goal of this thesis is to create a game that promotes physical activity in a positive way, and measuring the effect of that. To aid the creation of this we have created the following research questions to guide this thesis.

Research Questions

RQ1: How can exergames motivate/promote physical activity?

This research question looks at what game mechanics can be used in exergames to increase the player's motivation and promote physical activity. This will be answered based on results from the prestudy and from user testing.

RQ2: What technologies are suitable for use in exergames?

This research questions investigates suitable platforms for exergames, as well as technologies for tracking player movement. It will be answered based on results from the prestudy, and from user testing. The user tests will measure the chosen technologies for our exergame.

RQ3: What degree of physical activity does our game support?

This research question investigates the level of activity the game supports, which we will determine by monitoring the participants heart rate during the user tests.

RQ4: How well does the chosen game mechanics and genre allow for high-intensity interval training?

This research question investigates how well or if the game facilities high-intensity interval training by having periods of high intensity physical activity and periods of low intensity.

RQ3 and RQ4 will be answered based on results from user tests where we evaluate the physical activity by measuring the heart rate, distance moved, average speed, and maximum speed in each game.

RQ5: How does our game affect the players motivation?

This research question looks at how motivated the players are to play this exergame, and how the motivation to play compares to conventional exercise.

RQ6: How does our game affect the players engagement?

This research question looks at how engaged the players are in the game, and how well they are able to focus on the goals and tasks of the game.

RQ7: How does our game affect the players enjoyment?

This questions investigates how enjoyable the players find the game, and whether the game achieves some sense of flow in the players.

RQ3 - RQ7 looks at how the chosen game mechanics affect the player's experience. It is based on results from the user test. The player's motivation towards playing the game and exercising.

To answer these questions we first performed a theoretical study of exergames and mechanisms for how games can be used as a motivator for physical activity, see Part II, as well as general game mechanics and exercise theory.

We used the theoretical study as a basis for the design of the game, see Chapter 7. After the development phase we started a testing phase were we tested the game with fellow students. During testing we gathered both *quantitative* and *qualitative* data, using a questionnaire to get feedback on the playing experience, and a heart rate monitor to measure physical exertion. The testing was done over two days where we tested eleven fellow students.

After testing we analyzed the data gathered to answer the research questions and evaluate our game. We looked at how the game affected the players motivation, enjoyment, engagement, and the amount physical activity. The data was also used to discuss if the genre and mechanics used were suitable for an exergame, and how it allowed for high-intensity interval training. For a more in-depth description of the research methodology, see Chapter 2.

1.4 Report Outline

This thesis is separated into five parts:
Part I contains the introduction to the thesis, project description and the research methodology.
Part II contains the prestudy, where physical activity and obesity, existing exergames and technologies, game mechanisms, and exercise theory is presented.
Part III contains the game development and game design.
Part IV contains the testing and evaluation of the game.
Part V contains the discussion of the results found.
Part VI contains the conclusion for this thesis, contributions, suggestion for further work, and a project evaluation.

Chapter 2

Research Methodology

This chapter introduces the research strategy and methods used in this project, as well as the data generation methods, planned execution of testing, and sampling.

2.1 Research Strategy

The project description presented in Section 1.1 describes the phases of our thesis. The first phase consist of a theoretical study of exergames, mechanisms for how games can be used as motivation, and exiting technologies that is used in exergames. It also contains a study on physical activity and exercise theory. This phase consists of a literature review of the field, and is presented in Part II. The second phase consists of designing and implementing a prototype using knowledge gained from the first phase of the project, see Part III, and Part IV is testing and evaluating the prototype developed. The phases of this project coincides with the research strategy *Design and creation* described in the book Researching Information Systems and Computing [8]. The research strategy and methods presented in this chapter is in accord with the strategies and methods presented in this book.

2.1.1 Design and Creation

Design and creation is a strategy that focuses on the creation of new information technology (IT) artifacts. The artifacts include [8]:

Constructs:	Concepts or vocabulary used in IT-related domain.
Models:	Combinations of constructs representing a situation and to aid problem understanding and solution development.
Methods:	Guidance on the models that are to be produced and process stages to be followed to solve problems using IT.
Instantiations:	A system that demonstrates that constructs, models, methods, ideas, genres, or theories can be implemented in a computer-bases system.

The contribution from this thesis is an instantiation, in this case as an application prototype that demonstrates that using exergames combined with the technology of smart phones, can motivate and aid physical activity, and increase engagement and enjoyment. The prototype will be tested and evaluated in the final phase to help answer the research questions presented in Section 1.3.

When using design and creation as a research strategy it is important to demonstrate academic qualities such as analysis, explanation, argument, justification, and critical evaluation as well as technical skill. This is to prevent it from being solely design and creation. It also has to have some contribution to knowledge.

Design and creation typically uses an iterative process involving awareness, suggestion, development, evaluation, and conclusion:

Awareness is the recognition and articulation of the problem. This is found through studying the literature, finding areas authors have identified for further research, findings in other disciplines, from practitioners/clients expressing the need for something, field research, or from new developments in technology. In the prestudy, presented in Part II, we performed a literature review to achieve an awareness about the problem area.

Suggestion involves a creative leap from curiosity about the problem to offering an idea of how the problem might be addressed. The idea of creating an exergame as a solution to the problem is part of the project description. However, the leap to creating an exergame seems logical by seeing the decrease in physical activity and the increase in gaming, see Section 1.2 for a more detailed look.

Development is where the idea is designed and implemented. Here we used the knowledge gained in the prestudy. The development is presented in Part III.

Evaluation examines the developed artifact and assess its worth and deviations from expectations. This is presented in Part IV.

Conclusion is where the result from the design process are combined and written up. The knowledge gained through the process is identified, together with any loose ends, unexpected or anomalous results that can be explained and could be the basis of further research. The conclusion is presented in Part VI.

There are several advantages and disadvantages to the design and creation research strategy. Advantages include that you have something tangible, and not just abstract theories or knowledge, and appeals to people who enjoy technical and creative development work. This suited the authors perfectly.

The disadvantages include the challenge of justifying why it is research and not just regular development. It can also be difficult to generalize the findings from the use of an IT artifact in a single situation. A possible successful IT artifact may depend on the presence of the researchers, and the method/system developed may not be effective once they are gone. The research produced can also be perishable, as rapid advances in technology may invalidate results. This is something that needs to be considered when using design and creation.

The book Researching Information Systems and Computing [8] presents a guide on how to evaluate design and creation, and this helped us review our own project throughout the process.

2.1.2 Literature Review

The purpose of a literature review generally falls into two parts. Initially the researchers explore literature to identify a suitable research idea and discover relevant material about topics. This helps give the researchers a sense of the area and define a research problem. Once a topic is chosen, the second part begins, and continues throughout the remainder of the research time. The goal is to gather evidence to support the claim that the researchers has created some new knowledge.

Researching Information Systems and Computing book [8, p. 72] presents several objectives for a literature review, and a successful review will meet most of these objectives:

- Show that the researcher is aware of existing work in the chosen area.
- Place the researcher's work in the context of what has already been published.
- Point to strengths, weaknesses, omissions or bias in the previous work.
- Identify key issues or crucial questions that are troubling the research community.
- Point to gaps that have not previously been identified or addressed by researchers.
- Identify theories that might explain data the researcher will test or explore by gathering data from the field.
- Suggest theories that might explain data the researcher has gathered from the field.
- Identify theories, genres, methods, algorithms that will be incorporated in the development of a computer application.
- Identify research methods or strategies that the researchers will use in the research.
- Enable subsequent researchers to understand the field and the researcher's work in the field.

In this project the main literature resource was the Internet. When using the Internet as a resource it is crucial to look at the authorship, credibility, and authenticity of the material. The Internet also has an incredible amount of material, making it is easy to become overwhelmed or sidetracked when following hyperlinks online. This requires discipline when using the Internet.

The book presents steps on how to carry out a literature review:

1. **Searching:** Identify relevant concepts and search terms to use, and consider whether there are to many results, or too few, and if the results are relevant. It may be required to change and work on the concepts and search terms to get optimal results.
2. **Obtaining:** After gathering a list of possible useful references, they now have to be obtained.
3. **Assessing:** After obtaining the text it is important to assess its credibility. The book includes questions that should be asked about the specific material found.
4. **Reading:** When reading the text found, it is not always necessary to read the entire text from beginning to end, it is instead important to extract the important information before moving to the next item. When reading a article or conference paper, the reader can get an overview of the text from the abstract, and then look at the introduction and conclusion, and get further detail by looking at section headers. In books the reader can get an overview of what is written an in what detail by looking at the index. After getting an overview of the material, it can be decided whether it is necessary to read the entire text.

5. **Critically evaluating:** The text and its relevance to the readers research should be critically evaluated. What the text offers, if it is useful and why, should be considered. It is also important to examine if the paper has flaws or omissions. Such as if the conclusions are justified, or if there is some flawed logic or unfounded assumptions.

2.2 Sampling

Sampling is selecting participants for testing. The sampling frame is a collection of the population that could be included in testing. The target demographic of this project is mainly children and young adults, making the sampling frame of this project large. Having acquired a sampling frame, one has to decide which sampling technique to use. There are two presented in the book Researching Information Systems and Computing: *probability* and *non-probability*.

Probability sampling means the sample chosen is believed to have a high probability of being representative of the population studied. This allows for stronger generalization.

Non-probability sampling means that there is uncertainty about whether or not the sample is representative. This allows for weaker generalization.

In this project non-probability sampling was used, applying the convenience sampling technique. Using the convenience sampling technique solely because of convenience is not regarded as good research. However our sampling frame consists of children and young adults, and the sample was chosen from fellow students. Thus our sample is young adults, which is part of our sampling frame.

Having a large enough sample size is a very important. It makes the statistical analysis more reliable, and gives a higher confidence level and accuracy range on the results. This thesis does not have a large sample size, and this makes it difficult to make strong generalizations, but may be able to identify trends within the sample.

2.3 Data generation and Analysis

Data generation methods are methods for producing empirical data or evidence that is relevant to the research questions and objective [8]. In the book Researching Information Systems and Computing, four data generation methods are presented: interview, observations, questionnaire, and documents. The data generated can be either quantitative or qualitative. Quantitative data is numeric, such as speed, number of inhabitants, distance traveled, and qualitative is all the other types of data, such as words, sounds, images.

In this thesis two methods are used to gather data: observation and questionnaire. We are also using *method triangulation*. This is the use of more than one data generation method, and allows us to corroborate our findings and enhance their validity.

Observations involve paying attention to what people do and what happens, instead of people reporting it. We used various technologies to observe the physical demand the game had, and how the game allowed for high-intensity interval training. GPS was used to gather data on how far the players moved during the game, their average speed, and max speed. A heart rate monitor was used to observe how the game affected the heart rate.

This data is ratio data, which is data where there exists a true zero. During testing how participants played the game and how they spoke of the game was observed.

Questionnaires are a set of predefined questions in a specific order, where people give answers that can be analyzed and interpreted by the researcher. This was used to gather information about the player's motivation, enjoyment, and engagement, as well as the player's relationship with video games, exergames, and physical activity. See Appendix B for our full questionnaire and Section 13.3 for the development.

The questionnaire will gather qualitative data using comment fields, and quantitative data using Likert scale-based statements [9]. These statements have the possible answers: strongly disagree, disagree, neutral, agree, and strongly agree. Here we get ordinal data by allocating a value to the possible answers. Strongly disagree has the value 1, while strongly agree has the value 5. With ordinal data there is an order to the assigned values, however there is no possible way to know how much stronger strongly disagree is than disagree.

2.3.1 Prestudy

The prestudy was done as a literature review, by studying existing work to the in the relevant fields, found using Google Scholar, a web search engine for scholarly literature [10]. Relevant literature was also found by using the curriculum and relevant articles from the course TDT71 (`http://www.idi.ntnu.no/emner/tdt71/`). Data from Statistics Norway (SSB), World Health Organization (WHO), and reports from Helsedirektoratet was also used in the prestudy.

2.3.2 Questionnaire

A questionnaire was used after the user testing as it suited our need to collect standardized data. It gives us brief and uncontroversial information from the test subjects. It is not just an assembly of multiple choice questions, but must be carefully designed and constructed to ensure valid and reliable data can be generated. During the development of the questionnaire the questionnaire's *content validity*, *construct validity*, and *reliability* was considered.

Content validity: is the extent the questions are a well-balanced sample of the domain covered. Addressing the content validity can be done by using the literature, previous questionnaires, or a panel of experts.

Construct validity: is how the questions measure what is intended and claimed to measure. To test construct validity of a questionnaire, it may be necessary to compare the responses to different responses in the questionnaire or other information.

Reliability: is how reliable the questionnaire is over time, if the questionnaire would produce the same results if given several times to the same respondents. This can be difficult to assess, as respondent may change their views, remember the previous answers and repeat, or deliberately give opposite answers.

2.3.3 Ethical Issues

When doing research, research ethics is important to consider and abide by. The researchers has to have knowledge about laws concerning research, such as the data protection rights of individuals, intellectual property rights, legal liability of software developers and so forth. The rights of the participants in testing is very important, they include [8]:

- Right not to participate
- Right to withdraw
- Right to give informed consent
- Right to anonymity
- Right to confidentiality

Therefore we gave all the test participants a test participant agreement, see Appendix A, where we informed them about the purpose of the research, their rights to withdraw at any point, what data would be gathered and that it would be anonymous.

Before the participants signed up for the user testing, we informed them about what the game was about, how the testing would be completed, and what data would be collected, see Appendix E.

2.4 Summary

In this chapter we introduced our chosen research strategy, design and creation, methods used in this thesis, and how we implemented them. Our prestudy consists of a literature review of exergames and exergame technologies, game mechanisms, and physical activity and exercise theory.

Then an exergame will be designed, developed, and finally evaluated with user testing. The test participants will be gathered with convenience sampling, and a prototype test and questionnaire will be executed. Both quantitative and qualitative data will be collected during testing, about physical exertion and the user experience. Finally, the results will be presented and discussed before a final conclusion is given.

Part II

Prestudy

In this part, our findings from the prestudy will be presented. The obesity epidemic and effects from physical inactivity will be introduced, as well as different forms of exercise. Technologies used in exergames and game mechanisms are presented before the history of exergames and existing exergames are explored.

Chapter 3

Physical Activity

This chapter introduces the obesity epidemic, physical inactivity in our current society, and the impact these have on the human health. Basic concepts of strength and endurance training are introduced, as well as the effects exercise has on the human body.

3.1 The Obesity Epidemic

The alarm bells for the increasing obesity epidemic has been rung since the early 1990's, when the World Health Organization reported an estimated 200 million obese adults worldwide [11], as per 2014 this estimate has risen to 600 million. The detrimental effects on health caused by obesity are well documented [12] [13], and is linked to a wide range of illnesses including diabetes, coronary artery disease and stroke, cancers, liver and gall bladder disease, and osteoarthritis.

Obesity is, on a fundamental level, an energy-imbalance between calories consumed and calories expended. The obesity epidemic is naturally rooted in this equation, and globally there has been an increased intake of energy-dense food, and a decrease in physical activity [11]. See Section 3.2 for a more comprehensive discussion on physical inactivity. To reduce the amount of excess calories consumed there are really only two options. First, either reduce the amount of calories consumed by eating less or changing to less energy-dense diet. Second, one can increase the daily expended calories. The human body needs a certain number of calories to maintain its basic function, called the resting metabolic rate, and calories consumed in addition to the resting metabolic rate are stored in the body as glycogen, a complex carbohydrate, or as fat when the glycogen stores are full.

3.2 Physical Inactivity

In today's society fewer and fewer people are physically active enough in everyday life. The car is most common transportation method, even on distances as short as 1-3 km and adults spend on average 60% of their day seated [2]. The share of gainfully employed

adults who have a job which is predominately seated has increased considerable the last decades; from 1970-1990 it increased from 20% to 30-40% among men, and from 10% to 30% among women [2].

The World Health Organization (WHO) [14] and Helsedirektoratet [15] have similar guidelines for recommended minimum physical activity, see Table 3.1.

Children: 5-17
• 60 minutes of moderate to vigorous intensity physical activity daily. • More will provide additional health benefits. • Should include activities that strengthen muscle and bone, at least 3 times per week.
Adults: 18-64
• 150 minutes of moderate intensity physical activity throughout the week, or 75 minutes of vigorous-intensity physical activity, or an equivalent combination of these. • An increase to 300 minutes of moderate or 150 of vigorous intensity will have additional benefits. • Muscle-strengthening activities involving major muscle groups should be done 2 or more days a week.
Adults: 65+
• 150 minutes of moderate intensity physical activity throughout the week, or 75 minutes of vigorous-intensity physical activity, or an equivalent combination of these. • An increase to 300 minutes of moderate or 150 of vigorous intensity will have additional benefits. • Muscle-strengthening activities involving major muscle groups should be done 2 or more days a week. • Should incorporate additional exercises to improve balance.

Table 3.1: Recommended Physical Activity [15, 14].

According to Helsedirektoratet, around 90% of Norway's 6-year-olds reach the recommended minimum of physical activity, but this is reduced to 50% at the age of 15 [16, 2]. See Table 3.2.

Age	Girls	Boys
6	87%	96%
9	70%	86%
15	43%	58%

Table 3.2: Children and young who fulfilled minimum recommended activity levels [16].

The amount of time spent seated each day increase by age, with 6-year-olds being seated for 50% of the day, and 15-year-olds 70% [16, 2].

In adults, only 32% achieve the minimum requirement of at least 150 minutes of moderate intensity physical activity or 75 minutes of vigorous intensity weekly [16, 2, 17].

In 2010, 81% of adolescents between the ages of 11 and 17 had less than 60 minutes of physical activity daily [14, 17]. Only 18% of women and 20% of men have two muscle-strengthening activities twice a week, while 15% of the elderly achieved these two sessions. A large reduction in activity levels can be seen as people age [18, 16, 17]. Globally, in children, boys are on average more active than girls [14, 18], however in Norway from age 20 women are more active [16]. Education is related to activity, with activity increasing with education level in adults and children with parents with higher education.

Around 23% of adults aged 18 and over were not active enough in 2010, 20% of men and 27% of women. In high-income countries 26% of men and 35% of women were insufficiently physically active, as compared to 12% and 24% in low income countries. The drop in physical activity in high-income countries can be partly attributed to inaction during leisure time, sedentary behaviour on the job and at home, and passive modes of transportation [14]. Physical activity happens at different times depending on the country. In high income countries physical activity generally happens during leisure time, while in low income countries it happens during work, transport and chores [4]. Trend data has shown that physical activity is decreasing during work, but there is an increase in leisure-time physical activity [17].

Many countries are trying to address the insufficient physical activity, and policies are operational in 56% of WHO member states [14]. However several factors can discourage physical activity, such as: Fear of violence and crime in outdoor areas, high-density traffic, low air quality/pollution, and lack of parks, sidewalks and sports/recreation facilities.

3.2.1 Health Risks

The obesity epidemic and the lack of physical activity poses a major health risk, with 65% of the world's population living in countries where obesity and overweight is the cause of more deaths than underweight [4]. In 2004, 5.5% of deaths world wide and 7.7% in high income countries, were caused by diseases traced back to physical inactivity. It is the fourth greatest risk for death of non-communicable diseases, and is estimated to cause 21-25% of the breast and colon cancer burden, 27% of diabetes, and about 30% of ischaemic heart disease burden [4, 14]. People who are not sufficiently active have a 20-30% increased risk of death, compared to those who are sufficiently active. According to Helsedirektoratet, 1 in 8 deaths can be attributed to inactivity, as well as a decrease in quality of life [2].

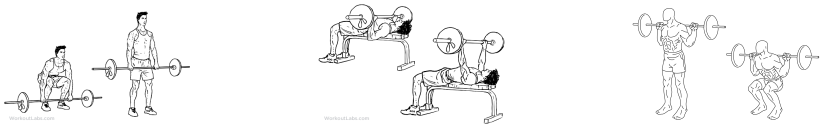
Physical activity has many health benefits, such as reducing the risk of cardiovascular disease, some forms of cancer, and type 2 diabetes. It can also improve musculoskeletal health, reduce symptoms of depression, and control body weight [4, 14]. It can be used preventatively or as a treatment for up to 30 different diagnosis and illnesses [2]. Physical activity improves muscular and cardiorespiratory fitness, bones and functional health, reduce the risk of falls as well as hip or vertebral fractures [14]. Socioeconomic calculations have shown that Norwegian residents could gain 400 000 extra quality adjusted life years every year if the recommended levels of physical activity were met [2]. Which means more healthy inhabitants and more people living longer without disease.

3.3 Strength Training

Strength training is an activity that introduce resistance, either in the form of free weights, the body itself, or training machines, to induce muscular contraction that builds strength, anaerobic endurance, and size of skeletal muscles. Strength training is a rather broad term and catches most training forms that aims to increase physical strength, which includes weight training, circuit training, isometric exercise, gymnastics, yoga, and Pilates to name a few. In the rest of this section we will focus on weight training and body weight training.

3.3.1 Weight Training

In weight training the subject uses equipment such as dumbbells, kettle-bells, barbells, certain training racks, and stacks in the form of training machines to generate resistance on a particular muscle group or groups. During training, small rifts are made in the muscle fiber, and after the workout the body starts to fuse these broken muscle fibers to make new muscle protein strands. The repaired protein strands increase in both numbers and size. This creates muscle growth and increases muscle strength [19].



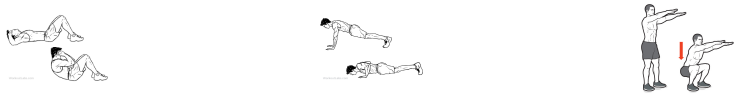
(a) Deadlift [20]. **(b)** Bench press [21]. **(c)** Squat [22].

Figure 3.1: Weight training exercise examples.

Weight training has been shown to have a positive impact on several aspects of physical and mental health, including increase in lean weight and metabolic rate, decrease in fat weights, improved physical performance, enhanced movement control, improved glucose and insulin homeostasis, reduced resting blood pressure, enhanced vascular condition, increased bone mineral density, decreased symptoms of depression, increased self esteem, and has been shown to reverse aging factors in skeletal muscle [23].

3.3.2 Body Weight Training

Body weight training is similar to weight training, except for the equipment used. In body weight training the subject only uses their own body to induce resistance on a muscle or muscle group. A great part of body weight training can be done with no or little equipment besides your own body, making it highly accessible.



(a) Sit-up [24]. **(b)** Push-up [25]. **(c)** Squat [26].

Figure 3.2: Body weight training exercise examples.

3.4 Endurance Training

This section introduces activities that aims to increase physical endurance, focusing on the aerobic system. All of the training activities presented in this chapter requires little equipment other than a pair of running shoes, and is therefore easily accessible.

3.4.1 Running

Running is a method of terrestrial locomotion allowing humans to move quickly on foot. Running consists of a phase where both feet is in the air at the same time, differentiating it from walking, where one foot is always in contact with the ground.

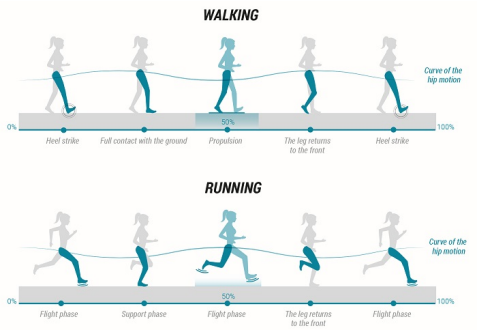


Figure 3.3: Comparison between running and walking [27].

The potential for injury is present while running, just as with any form of physical activity, but there are several benefits. Running can lead to potential weight loss, improved cardiovascular and respiratory health (reducing the risk of cardiovascular and respiratory diseases), improved cardiovascular fitness, reduced total blood cholesterol, strengthening of bones, possible strengthening of the immune system and an improved self-esteem and emotional state [28].

3.4.2 Jogging

Jogging is defined as the activity of running at a steady, gentle pace as a form of physical exercise [29]. Jogging is therefore subset of running, with a lower intensity. The intention is to increase physical fitness with less stress on the body than from faster running, or to maintain a steady speed for longer periods of time. Jogging performed over longer distances, is a form of aerobic endurance training.

3.4.3 High-Intensity Interval Training

High-Intensity Interval Training (HIIT) is a form of cardiovascular exercise with short periods of high intensity anaerobic exercise and periods with lower intensity for recovering.

Evidence that support the idea that even low volume HIIT may be a solution to induce both cardiovascular and peripheral adaptions that are linked to improvement of health outcomes [30].

Low-volume HIIT can also improve glucose control and induce adaptions in skeletal muscle (peripheral) that are linked to improved metabolic health in patients with type 2 diabetes.

3.4.4 Heart Rate

Measuring heart rate can be used to estimate the intensity of exercise, and Olympiatoppen [31] has developed a intensity scale based on maximum oxygen consumption (VO_{2MAX}), max heart rate (HR_{MAX}), and lactate concentration. In this thesis we will focus on heart rate, see Table 3.3.

Zone	% of $\mathbf{HR_{MAX}}$	Intensity	Duration
1	60-72%	Low	30-180 min
2	72.5-82.5%	Low-moderate	30-180 min
3	82.5-87.5%	Moderate	30-120 min
4	87.5-92.5%	Moderate-high	30-90 min
5	92.5 - 97.5%	High	20-30 min
6	-	High	30-120 sec
7	-	High	15 - 30 sec
8	-	High	3 - 15 sec

Table 3.3: Heart rate zones [31].

Zone 1 is all aerobic exercise with low intensity. This is mild exercise that increases the speed of restitution. Zone 2 is the intensity where fat burning is on it's peak. This is low to moderate exercise intensity and is generally achieved through moderate long distance running. Zone 3 is aerobic exercise with moderate intensity. This zone is below the anaerobic threshold (AT). AT is where the production and the elimination of lactic acid is equal. Zone 4 is all aerobic exercise with moderate to high intensity exercise. Training in this zone is on or slightly above AT. Zone 5 is well above the AT close to the maximum oxygen consumption. Zone 6-8 is anaerobic exercise close to or up to maximum intensity. Here the heart rate is not used as a measure, as the main purpose of this training is to increase the amount of lactate a person can handle. It's done using interval training with 3 - 120 seconds periods of maximum intensity.

Exercise intensity is often measured based on maximum heart rate HR_{max}. Measuring HR_{max} manually is the most accurate way to obtain a persons max heart rate, but there are several ways to calculate it. A well know way to calculate HR_{max} is 220 - age, this however is often questioned. Some studies have shown that it overestimates HR_{max} in young individuals, is consistent with actual HR_{max} around 40 years, and increasingly underestimates HR_{max} [32]. Therefore in this thesis we will use 211 - 0.64*age, presented in the paper "Age-predicted maximal heart rate in healthy subjects: The HUNT Fitness Study" [32]. Using this formula we must take a standard error of 10.8 beats/minute into

account.

3.5 Summary

In this chapter we have seen how lack of physical activity, and obesity are a global phenomenon, with over 600 million obese worldwide, and adults spending on average 60% of their day seated. We have seen how obesity and physical inactivity is linked to a wide range of detrimental health effects.

Fundamental exercise concepts has been presented along with the health benefits associated with an active lifestyle. We have seen that body weight training, running, jogging, and High Intensity Interval Training can suitable options for our game, based on the little equipment required, making them accessible exercises for a wide target group.

Chapter 4

Technologies

As mention in Chapter 6, exergames relies on technology to register a users physical movement or reactions during gameplay. This information can be captured in several ways, and the goal of this chapter is to introduce technologies that have previously been used for such purposes, or technologies that might be suitable in this domain.

4.1 Location

Location-aware games can utilize the whole world we live in as an element of the game. This relies on the ability to identify and measure a players location and movement in the real world. There exists several way of achieving this, and the most used techniques will be presented in this section.

4.1.1 Global Positioning System

The global positioning system (GPS) is a network of at least 24 operational satellites that transmit one-way signals containing information about the satellites position and time [33]. The GPS-receivers at the ground can then utilize the transmitted information to calculate a three dimensional position for the user. The global positioning system is free and open for everyone to use, and is operated and maintained by the U.S Air Force.

In modern smart phones an inboard GPS receiver has become then norm, making this technology accessible for a broad audience. In Norway, as of 2017, 80 percent of the population owns a smart phone [34], and similar numbers can be found in most developed countries.

The accuracy of GPS is dependent on the hardware and software of the GPS-receiver. Smart phones are typically only accurate withing a 4.9 m radius under open sky [35, 33], and the accuracy declines in the presence of buildings, tree, bridges, and other physical objects. However, a new chip developed by Broadcom will be accurate to 30 cm and may be available in smart phones in late 2018 [36, 37].

GPS signals do not penetrate solid materials well, making it unsuitable of indoor use [38], however, it is accessible on the entire planet making the entire globe a potential playing field.

Figure 4.1 shows Google Maps. This uses GPS to track location, and is shown with the blue dot in the center of the screen.

Figure 4.1: Google Maps on Android [39].

4.1.2 WiFi Positioning

WiFi positioning uses terrestrial based WiFi access points to determine the devices position. Every WiFi access point broadcasts a signal to announce their existence. In urban areas several such access points are accessible, creating natural reference points the WiFi positioning software can use to determine the device location.

WiFi access points are deployed both for private and public consumption, mainly for indoors use. This enables WiFi positioning to be used with great coverage and performance indoors [40]. WiFi positioning does not require a connection to be established between the access points and the device, but only uses the unique MAC-address and sig-

nal strength at a given position to determine a location. This enables WiFi positioning to take advantage of weak and encrypted signals, which would otherwise be useless.

WiFi positioning has been found to have a positioning error of 13-40 meters [41]. While this positioning error is higher than traditional positioning systems such as GPS, WiFi has less of a calibration overhead, and is easily deployed and provides coverage across large metropolitan areas.

4.1.3 LTE Positioning

Long-Term Evolution (LTE) is best known as 4G and is a standard for high-speed telecommunications. LTE ships with the LTE Positioning Protocol (LPP), which supports positioning on the LTE network [42]. There exists several techniques utilizing this protocol, but the most relevant is the LTE Observed Time Difference of Arrival (OTDOA). The devices measures differences in time of arrival from the signals in one or more base stations, and from this information calculates the user position [42]. the OTDOA technique can be used both outdoors and indoors, and has an accuracy of about 50-200 m.

4.2 Motion Capture

Some exergames has the need to capture the player's body motion and movement. There is a wide variety of ways this can be done, and the most relevant of these technologies are presented in the following section.

4.2.1 Gyroscope

A gyroscope contains a disc or wheel mounted in a way that it can spin about an axis which is itself free to alter in direction [43]. This leaves the orientation of the axis unaffected by tilting of the mounting, so gyroscopes can be used to maintain a reference direction. A gyroscope can in the context of exergaming be used to track angular velocity for a specific user movement or gesture.

The gyroscope has been digitized and is now included in a wide range of electrical equipment, such as smartphones, tablets and controllers for video game consoles, such as the Nintendo Switch and Playstation 4.

4.2.2 Accelerometer

An accelerometer is a device that can measure proper acceleration. An accelerometer can be used to handle axis-based motion sensing, and has become an integral part of the smart phone [44].

The accelerometer can be used for detecting motion for a wide range of movements such as jumping, boxing, doing push ups so forth. Figure 4.2 shows the three axis where the smart phones measures acceleration.

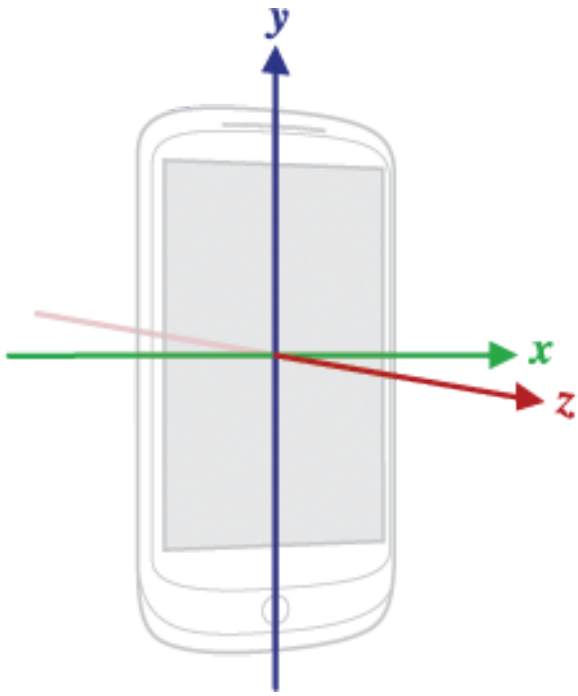


Figure 4.2: Accelerometer [45].

4.2.3 Pedometer

A pedometer is a device that measures physical motion by counting steps. A pedometer can be worn as a stand alone equipment, but pedometer functions are present in most smartphones and smartwatches. Early pedometers were entirely mechanical, however in smartphones and watches the pedometers are electronic and based on accelerometers.

4.2.4 Optical Sensor

Body movement can be tracked by using a camera, such as the Kinect developed for Xbox and Microsoft Windows PCs. The kinect removes the need for a controller by using gestures and voice commands. The Kinect is a movement sensor that has the possibility to interact with all body movements: legs, arms, head, feet, waist. [46]. Microsoft has discontinued Kinect and it will no longer be supported in the future, but there exist other similar cameras developed by other providers. Proximity sensors can also be used, eg for seeing if a person takes a push up.

4.3 Physical Monitoring

Many exergames use traditional exercise equipment with video games. This was an early idea, as seen with VR Bike and Prop Cycle, See Section 6.2, however, using traditional exercise equipment can be very expensive and is not necessarily easily available.

4.3.1 Heart Rate Monitor

A heart rate monitor can be used to measure the intensity of an exercise. The more physical challenging the higher the heart rate, see Section 3.4.4 for a more in depth explanation of heart rate. The heart rate can be monitored continuously throughout the exercise with the use of smartwatches, Fitbits, or heart rate monitors worn around the chest.

4.3.2 Physical Exercise Equipment

Using traditional exercise equipment is also a possibility to track physical exercise. Machines such as treadmill, exercise bike, rowing machines, and stair climbers can track how fast the person is moving, what resistance is used, how far the person has moved, and this can be used as input for an exergame. Virtuix has created an omnidirectional treadmill that can be used with virtual reality [47]. It is a platform that can track movement in any direction that in turn can be used to move characters in game, as seen in Figure 4.3.

Figure 4.3: Virtuix Omnidirectional Treadmill [47].

Pressure sensitive surfaces can also be used to track body movement. Such as the

Wii Balance Board that consist of a board with four pressure sensors to track the user's center of balance, or Dance Dance Revolution that uses four pressure activated switches that users have to step on.

4.4 Summary

In this chapter we have researched and presented various technologies that can be incorporated with an exergame, and discussed what form of activity tracking or monitoring they are suitable for. While there exists several technologies, this chapter has illuminated each technologies practical applications, and this will be a valuable contribution when choosing technology for our own prototype.

There exists several suitable technologies for exergames, but considering that we want to create a game that is available without the need for additional gear, it is clear that the GPS stands out as a preferable choice. It is accurate, and has become a de facto standard smart phone equipment.

Chapter 5

Game Mechanisms

This chapter introduces several game mechanisms and how these affect a users enjoyment of games.

5.1 Challenge, Fantasy, and Curiosity

According to Malone, the essential characteristics of a good computer game can be organized into three categories: challenge, fantasy, and curiosity [48]. Malone put forth a set of heuristics for designing a game to meet these criteria, which is presented in this section.

In order for a game to be **challenging** it must provide a goal whose attainment is uncertain [48]. If the user does not feel challenged, boredom is inevitable. Malone presents several techniques to ensure the uncertainty of a goal. First, *variable difficulty level*. A game should have the option to be played on different difficulty level. This could be manually selected by the player, automatically adjusted by the game itself, or by the opponents skill level in multiplayer game. Secondly, we have *multiple level goals*. Here the game ensures that players who are certain to achieve one of the goals may still be challenged. Examples of this can be seen in score-keeping and time-tracking. Even though the player beats a certain level, they can still be motivated to finish the level as fast as possible, or with the highest overall score. Third, *hidden information* helps make the game outcome uncertain. This information can be selectively presented to the user, and could potentially lead to increased curiosity as well. Finally we have *randomness*, which is a method for avoiding predefined outcomes by introducing an element of luck and chance.

Fantasy is an element found in nearly every game, and makes a game able to present, or evoke, images of situations or objects that is not bound to reality. The objects or situations can be anything from the physically impossible, to games where it reflects the possibilities in the real world. Malone distinguishes between extrinsic and intrinsic fantasy.

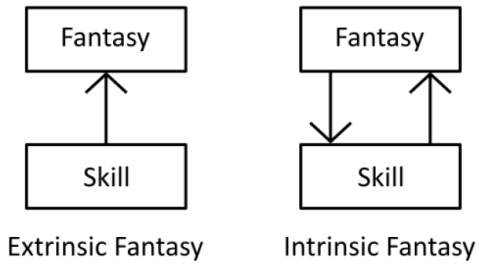


Figure 5.1: Logical relations in extrinsic and intrinsic fantasy [48].

Extrinsic fantasy is fantasy where the fantasy depends on the use of skill, for instance if an answer is right or wrong in a math game, whereas intrinsic fantasy the skill also depends on the fantasy. Malone notes that ”in general, intrinsic fantasies are both more interesting and more instructional then extrinsic fantasies”.

Curiosity is, according to Malone, the motivation to learn, independent of any goal seeking or fantasy-fulfillment. Games that have an *optimal level of informational complexity* can evoke a players curiosity. This means that the game must find the right balance between complexity and simplicity in regards to the players existing knowledge. Malone distinguishes between *sensory* and *cognitive* curiosity. Sensory curiosity is achieved by attention attraction through visual, audio, or other changes in sensory stimuli of an environment. Cognitive curiosity is a players desire to bring a better ”form” to their knowledge structures. This can be utilized by presenting just enough information so that the players information feels incomplete, inconsistent, or unparsimonious, which leads the players to desire more information to make sense of the knowledge presented.

5.2 Flow

The term flow was coined by psychologist Mihály Csíkszentmihályi [49], where he describes a mental state where a person is fully immersed in a feeling of energized focus, full involvement, and enjoyment in the process of an activity. This state leads to a loss in one selves sense of time and space, and is often refereed to as ”being in the zone”.

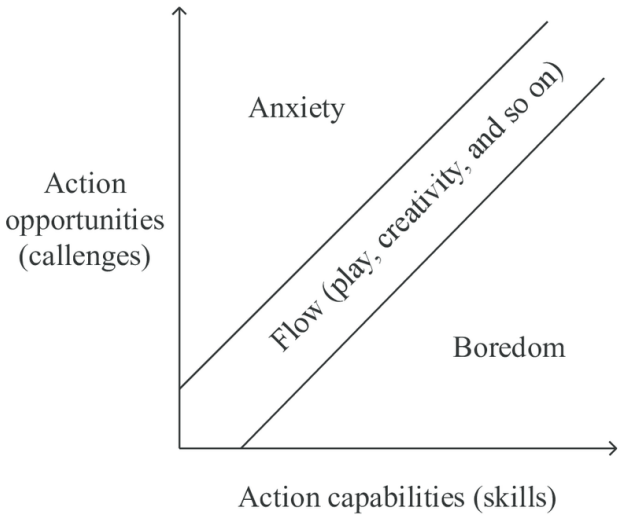


Figure 5.2: The concept of flow [49].

As illustrated in Figure 5.2, a sense of flow is dependent on two main factors, skills and challenges. If a task is too challenging for a persons skill set, anxiety ensues. If the challenge is too easy, boredom and apathy is inevitable. The state of flow is achieved when these two factors are proportional. Flow can be achieved through a wide range of activities, but eight generalizable traits in an activity can be found for achieving flow:

- a task that can be completed
- the ability to concentrate on the task
- that concentration is possible because the task has clear goals
- that concentration is possible because the task provides immediate feedback
- the ability to exercise a sense of control over actions
- a deep but effortless involvement that removes awareness of the frustrations of everyday life
- concern for self disappears, but sense of self emerges stronger afterwards
- the sense of the duration of time altered

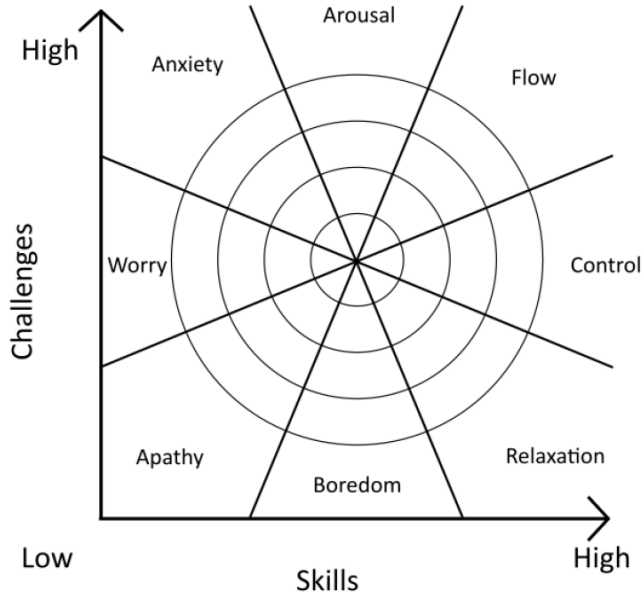


Figure 5.3: A finer differentiation of the flow state [50].

Later research indicated that the flow state could be further differentiated, and that the flow state is achieved when the perceived challenges and skills are above the persons average. The intensity of the sensation increases with the distance from a persons average, as shown in Figure 5.3.

5.3 GameFlow

It is clear that games that manages to induce a state of flow has come a long way in achieving the most fundamental quality of a game, enjoyment. In order to build and understanding of enjoyment in games Sweetser and Wyeth introduced GameFlow [51], a model for evaluating player enjoyment in games. The model is based on heuristics put forth in the flow concept, and mapped these to fit a game setting. The GameFlow model consists of the following eight elements:

Concentration: a game should require concentration, and the player should be able to concentrate on the game. This is done by providing stimuli from different sources, and making the stimuli worth attending to. The game should quickly grab the players attention and focus, and maintain this throughout the game. It is important that the tasks feel important, and not feel distracted from tasks they want or need to concentrate on. The game should have a high work load, but this should be balanced by the players perceptual, cognitive, and memory limits.

Challenge: games should be challenging, and meet a players skill level. To achieve

challenge, the games must match a players skill level, while providing different levels of challenge for different players. The challenge should also increase as the player progresses through the game, and their skill level increases.

Player Skills: game must support a players skill development, and adjust difficulty accordingly. To support this, the game would be able to be played without reading a manual, and rather introduce the player to the game through tutorials or initial levels that are easy and gives an overview of the game. The players skill level should increase in an appropriate pace as they progress, and the players should be rewarded for their effort and skill development. It is important that the game interfaces and mechanics should be easy to learn and use.

Control: players should feel a sense of control over their actions. It is emphasized in regards to their characters movements and interactions in the game, the game interface, and control over the game shell (starting, stopping, saving, etc.). It should not be able to make errors that are detrimental to the game, and the game should therefore support the player in recovering from errors. Finally, the players should feel a sense of control over the actions the take and the strategies they use, in other words free to play the way they want.

Clear Goals: games should provide the player with clear goals. The overall goals should be clear and presented at an early stage. Should the game introduce intermediate goals, these should be clear and presented at fitting times.

Feedback: players must receive appropriate feedback at appropriate times. The players progress should be presented to the user, and the player should always know their status or score. It is also important to give immediate feedback on player actions.

Immersion: players should experience deep but effortless involvement in the game. Optimally we want players to become less aware of their surroundings, and less worried about everyday life and self. This also includes an altered sense of time, while feeling emotionally and viscerally involved in the game.

Social Interaction: games should support and create opportunities for social interaction, through competition and/or cooperation between players. Social interaction between the players should be enabled, for instance through a chat. The game should also support social communities inside and outside the game.

5.4 Dual Flow

What separates exergames from traditional computer games is the added dimension of exercise as part of the gameplay. This sets further constraints when it comes to game balancing. The dual flow concept aims to join the traditional flow concept with an added dimension that considers the physiological/exercise.

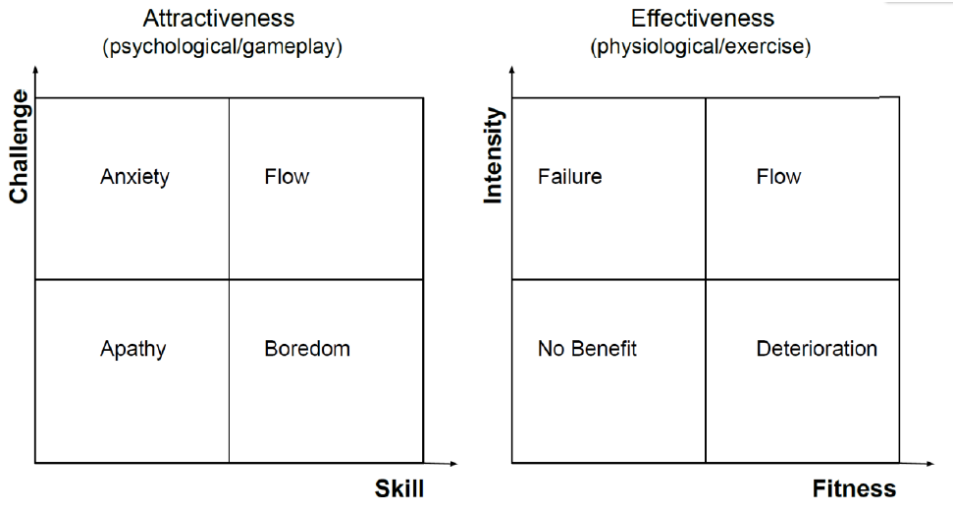


Figure 5.4: Dual Flow [52].

The model, see Figure 5.4, separates the game experience into two parts, *attractiveness*, which can be modelled by the traditional flow concept, and *effectiveness*, which models the physical balance between fitness and exercise [52].

If the perceived intensity is higher then the perceived fitness, the body's "skill" in tolerating exercise, the player will at some point fail. If the fitness level is higher than the intensity leads to deterioration of the subjects fitness level. If the fitness level and intensity level is to low, say playing a computer game using a keyboard and mouse, no benefit is achieved. The flow state is reached when the intensity and fitness levels is matched at a high enough level, leading to increased fitness levels in the subject with continued exercise.

5.5 Summary

This chapter has reviewed game mechanisms, and provided insights in what elements and concepts that should be included in a video game to help facilitate a fun, challenging, and engaging game.

The essential characteristics of a good computer game can, according to Malone, be organized in three categories, *challenge*, *fantasy*, and *curiosity*, and this chapter have presented heuristics for how each of these characteristics can be included in a game.

The *flow* state has been introduced, where a person can feel a sense of loss in on selves and of time and space, and the *GameFlow* and *DualFlow* models have presented guidelines for how this state can be induced in an exergame context.

All mechanisms presented in this chapter are important to the development of a successful game, and these insights will help guide the design of our prototype.

Chapter 6

Exergames

This chapter introduces what an exergame is, and gives a short overview of the history behind exergames. We also present several existing exergames, how they combine physical activity with video games, the various technologies used, and the success of the game.

6.1 What is exergames?

Exergames, also called fitness games or active games, are games that provide some form of physical exercise through it's gameplay [52]. The amount and type of physical activity varies from game to game, from running outdoors with Zombies Run!, to dancing at home with a pressure sensitive pad and Dance Dance Revolution. These games typically rely on different technology to track the movements or reactions of the player, such as using GPS to track running or other outdoors movement, or a Kinect to track body movement and gestures.

There is evidence that exergames may improve fitness and adherence to exercise [7]. Exergames have the potential to increase physical activity [5, 53], and may be a possible alternative to traditional activities for children. Depending on the game it can produce a similar effect as light, moderate and vigorous physical activity, as well as being fun. Although it cannot be stated that it is enough to meet the recommended amount of daily physical activity. Exergames can be an effective tool for weight loss among youth [54], and may improve the energy expenditure in college students [6]. It can also be an innovative way to do high-intensity interval training [55].

There exist research that have shown that exergames produce neutral results, but most research show that exergames can have a positive effect [56].

6.2 History of exergames

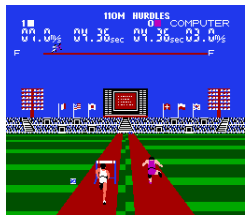
Exergames have existed since the 1980s, with the release of the Atari Joyboard in 1982 seen as the start of exergames [46, 56]. It was a balance board gaming peripheral released for the Atari 2600, with the game Mogul Maniac, which was a slalom skiing game. Other games were in development but were not released because of Atari's bankruptcy. Atari was also working on a project called the Atari Puffer, where a stationary bike would be used to control the speed of avatar on screen. But this was also not released. Atari recognized that many children and adults were not interested in sports and physical activity, and that there was a possibility to for children to become addicted to video games. They wanted children adopt a healthy lifestyle. They saw video games and fitness as two of the most important markets of this era [46].

(a) The Atari Joyboard [57].

(b) The Nintendo Power Pad [58].

Figure 6.1: Early exergaming peripherals.

In 1988, Nintendo released the Power Pad, which was a plastic mat with 12 pressure sensors made for the Nintendo Entertainment System (NES). The Power pad allowed players to compete in games that required them to step on colored circles to interact with the game. Several games were compatible with the Power Pad, such as World Class Track Meet (also known as Stadium Events), a sports game, and Dance Aerobics. Dance Aerobics paved the way for dance games in the 90s such as Dance Dance Revolution (DDR) [46, 56, 58].



(a) World Class Track Meet [59].

(b) Dance Aerobics [60].

Figure 6.2: Games released for the Nintendo Power Pad.

Nintendo also released the Nintendo Power Glove [52, 58], a glove worn by the players

containing a motion sensor and could register the position of the fingers. It was a short lived, and considered difficult to use properly, with only two games developed specifically for the Power Glove before it was discontinued.

The stationary bike is a widely known exercise machine, and is used by many exergames when joining fitness and gaming. It was seen in the Atari 'Puffer project', Tectrix's VR Bike, Namco's Prop Cycle, and many more [46, 56, 58]. VR Bike was released in 1992 to supply the emerging fitness market in the 90s. They also released VR Climbing. These games were offered to fitness centers, but were not especially successful as they were very expensive. VR Bike had several games, where one game was based on moving a war tank with the pedals. In this game the users could play with others allowing for multiplayer. Figure 6.3 shows the game VR Bike. Alpine Racer was developed by Namco in 1996, and was a ski simulator. It used a balance platform that allowed the players to use body movements to control the game.

Figure 6.3: Tectrix's VR Bike [46].

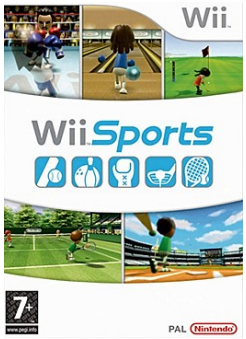
DDR was released in 1998 by Konami and became a big success [46, 56, 58]. DDR is a rhythm and dance based game, where the players step on buttons to control the game. It was released both in video arcades and for home game consoles. By the end of 2003, Konami stated that they had sold 6.5 million copies of the game [52].

Sony released the EyeToy in 2002, which was a camera that was connected to the PlayStation 2 [52]. It could track movement, detect color, and had a microphone for sound detection.

Nintendo released a new console in 2006 called the Nintendo Wii, which had a controller containing motion sensors [52]. It originally came with a game called called Wii Sports, a game that consisted of five different sports. Later, in 2008, Nintendo released the Wii Fit which was geared towards active living [46], and used a balance board. Active living is about health improvement and fitness by incorporating physical activity in every day life.

In 2010, Microsoft launched the Kinect. And while the Wii, Wii Fit, and DDR existed, they were limited by their controllers, while the Kinect used a movement sensors that allowed the player to interact using a large variety of movements [56, 46]. This new input device allowed for a huge variety of games, from sports, and dancing, to action games

such as Kinect Star Wars.



(a) Wii Sports cover.

(b) People playing boxing on Wii Sports.

Figure 6.4: Wii Sports [61].

With the emergence of smart phones and GPS allowed the games to be taken outside [62]. Games such as Zombies, Run!, released in 2012, and Pokémon Go, released in 2016, has been very successful, and uses GPS to track their players in the real world.

Exergames has its roots in different gaming technologies that have some things in common: (1) Evolved from other popular games, (2) dependent on advances in technology, (3) are entertaining, (4) simple to play, and (5) utilize new input devices [56].

6.3 Existing Exergames

This section goes into depth about some chosen exergames, and the technologies used.

6.3.1 Pokemon Go

Pokémon Go, released 2016, is an augmented reality video game, where the objective is to catch Pokemon with your smart phone in ”the real world”. Pokemon Go is location based, meaning that Pokemon appear at certain locations around the globe. To get to the Pokémon each player has to physically travel to the destination the Pokémon is located. The game also contains eggs, that hatch when the player has walked a certain distance. According to Venture Beat, the game had 752 million downloads by 30.05.2017 [63]. Pokémon Go also has a social aspect of the game, where PokeStops ans Pokémon gyms are distributed all over the map, and is a natural gathering place for players, creating a social experience.

Figure 6.5: Augmented Reality in Pokémon Go [64].

Pokemon also uses a relatively new technology called augmented reality, where objects from the game is presented to be part of the real world through the smart phone. Pokemon Go is the most played mobile video game of all time, and has ensured that players have walked a staggering 4.6 billion kilometers in search of various Pokemon [65].

One 30 day study showed that Pokémon Go increased the activity of engaged students by 26% [66]. Another study showed that daily number of steps increased by approximately 23% during the first week, but gradually decreased over the next weeks, and was back to the same amount of steps as prior to installing Pokémon Go within 6 weeks [67]. There is little research on the long term effects.

6.3.2 Dance Dance Revolution

Dance Dance Revolution (DDR) a rhythm based game launched in 1998 by Konami. The game has four arrow switches that need to be stepped on in accord with what is shown on screen. It was originally released as an arcade machine, but was later released for home systems such as the Playstation 2 and the original Xbox. Here the game was controlled using a plastic mat with the four arrows.

(a) A DDR arcade machine [68].

(b) DDR mat for the PlayStation [69].

Figure 6.6: Dance Dance Revolution variants.

DDR has been shown to allow for both the development and maintenance of cardiorespiratory condition following the recommendation of the American College of Sport and Medicine (ACSM) [46]. It can also aid the player reach a good fitness condition and a caloric expenditure close to the ones recommended by ACSM, while being more enjoyable than a treadmill. It help increase physical activity and can be beneficial when treating obesity [70].

6.3.3 Digivice Toy

The Digivice Toy is a small plastic toy that the user attaches to their belt [71]. The Digivice game is based on the Digimon universe, where the player chooses their Digimon character at the start of the game. As the game goes on, their character grows in strength, and eventually evolves to their more powerful form. The player encounters other Digimon on their journey, and must also defeat bosses to progress to other areas.

The game uses a pedometer to count the number of steps taken by the player, and to progress in the game the player has to reach a certain number of steps. As the game only uses a pedometer it is easy to cheat the game, and only shake the toy to generate steps, and thus decreasing the necessary physical activity.

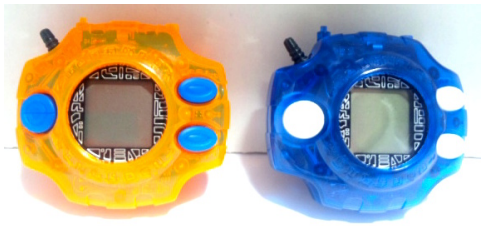


Figure 6.7: Digivice toy [71].

6.3.4 Wii Fit

Wii Fit developed by Nintendo for the Nintendo Wii is a collection of games geared towards active living. It contains four different categories: yoga, strength training, aerobics and balance. Yoga and strength training uses a personal trainer and gamification to motivate the user, while aerobics and balance has several minigames that the users can play. Wii Fit uses a very sensitive balance board to track the users movement. The game has been found to increase physical activity, and can be a beneficial tool when treating obesity [70], providing light-to-moderate intensity activity while being enjoyable for players of all ages [72]. It can help the older adults improve balance [73, 74] and lower body strength [75]. It is not as effective as traditional physical therapy, but can be used as an aid in addition to physical therapy.

Figure 6.8: Wii Fit [76].

6.3.5 Kinect Dance Central

Kinect Dance Central is a dancing and rhythm game developed by Harmonix Music Systems for the Xbox 360, using the Kinect to track player movement. The game shows avatars on screen dancing and the players have to mimic the movements shown. This requires full body movement from the player. The game has different game modes, including one workout mode where the number of calories and duration is tracked. Dance Central provides moderate intensity physical exertion during play [77, 78], and has been shown to increase energy expenditure by 150% in children [79].

6.3.6 Pedal Tanks

Pedal Tanks is a stationary bicycle exergame for four players. The game was developed by two students for a master thesis at The Norwegian University of Science and Technology, and is now the focus of a PhD dissertation. Pedal Tanks is an online multiplayer capture the flag arena game, where each player controls a tank in 3rd person view using the pedals on the bike, and six buttons on the handlebar. The teams consist of two players who have to work together to beat the opposing team. To incentivize movement, in addition to the main goal of the game, the players regenerate ammunition when they move. The game have been shown to give players high exercise intensity, creating a similar heart rate response as traditional HIIT [55, 80].

(a) Gameplay from Pedal Tanks.

(b) Stationary bikes used in game.

Figure 6.9: Images from Pedal Tanks [55].

6.3.7 Exermon

Exermon is an exergame developed as a master thesis at the Norwegian University of Science and Technology, where the player chooses a personal monster to train called an "exermon". The game incorporates strength training as a part of the gameplay, by letting the players increase the exermons stats by performing various strength training exercises such as sit ups and push ups. The exermons stats are increased based on the chosen exercise and repetitions [81].

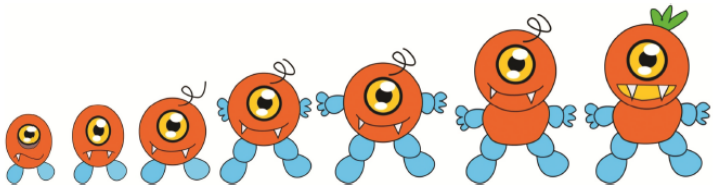


Figure 6.10: Exermon Appearance [81].

The exermons live on an island where they can fight other monsters or fight bosses in an arena. The player can connect with friends to compare their monsters and fight them. To get a monster that fights well, the player needs to keep exercising to boost the monster's

health points, power, and speed. The exermons physical appearance also changes as the exermon gets stronger, as shown in Figure 6.10.

6.3.8 Zombies, Run!

Zombies Run! is a smart phone application for both iOS and Android, where the player is emerged in a zombie epidemic. The story is presented to the user via audio while the user is jogging or running anywhere in the world. The user is presented with a mission through their headphones, and if the user is chased by zombies, they have to speed up. During the game you automatically collect supplies and resources that can be used to upgrade the players base in the application [82]. The game uses GPS to track movement outdoors, but can also be played using indoor equipment such as a treadmill or an exercise bike.

6.4 Summary

In this chapter we looked at and presented exergames, their history, as well as several existing games. There are a good deal of existing exergames available, and many have been shown to have a positive influence on health, allowing varying levels of physical activity and enjoyment.

By reviewing existing games we have acquired knowledge about how technologies and game mechanics are used in games to promote physical activity. For most games presented the main form of physical activity and exercise is focused on endurance, using GPS or physical exercise equipment to track player movement. Increasing physical activity with the use of exergames and GPS has been successful with both Zombies, Run! and Pokémon Go is something we are interested on focusing on in this thesis.

Part III

Design and Implementation

In this part, the design of Location Invaders and the implementation is presented. The design of the game and the chosen game mechanisms will be described, as well as the rationale behind the choices of technology and exercise. Finally, we discuss the development process and the software architecture.

Chapter 7

Location Invaders

This chapter presents the implemented game Location Invaders, the game concept, the implemented features, and how the gameplay itself unfolds.

7.1 Game Concept

The game is inspired by the classic arcade game Space Invaders, see Figure 7.1, a 2D fixed shooter where the player has to protect their world from invading aliens. This is done by controlling a laser cannon and shooting the aliens before they can reach the ground.

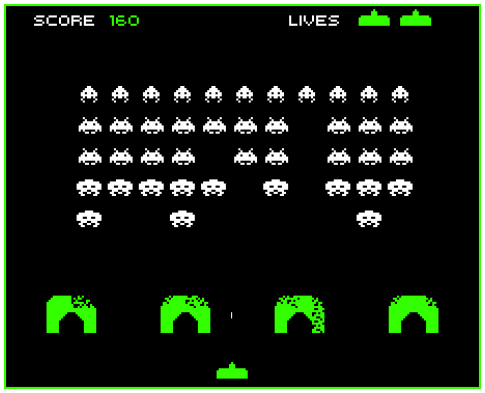


Figure 7.1: Gameplay from Space Invaders.

In Location Invaders this concept is taken a step further by introducing multiplayer, and making use of the players physical location as a part of the game experience itself. The players will compete against each other by sending waves of space ships towards their opponents physical base, and simultaneously defending their own base against the waves of hostile space ships sent by the opponent. This means that the players have to move

around in the real world in order to both defend their base from incoming space ships, as well as attacking their opponent, as seen in Figure 7.2.

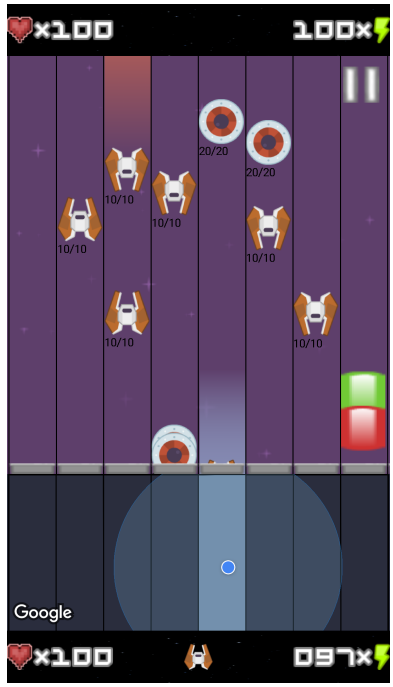
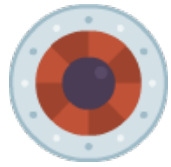


Figure 7.2: Gameplay from Location Invaders.

The objective of the game is to destroy your opponents base by getting their health points down to zero, before they destroy your own base. To inflict damage on your opponent you have to get your units to reach the opponents base without being destroyed by the opponents units. Each player can only send units in the lane they are located in, and in order to defend or attack a specific lane they have to move in the physical world. Here we utilize GPS to keep track of where the players are located.

(a) Normal unit.



(b) Slow unit.

(c) Fast unit.

Figure 7.3: Units in the game.

Figure 7.3 shows the different units in the game, normal, fast, and slow unit. Each of these units have their strengths and weaknesses, as presented in Table 7.1. The speed

presented in the table is not a unit of speed, by relative to the other space ships, and changes throughout the game.

Unit	Health	Damage	Speed	Energy Cost
Fast	5	5	4	5
Normal	10	10	2	10
Slow	20	20	1	20

Table 7.1: Comparison of unit stats.

When units from the opposing players meet a lane, they will attack each other, and deal damage and take damage according to the stats from Table 7.1. If both ships survive the first blow, they are moved slightly backwards, and then deal damage to each other again. This is done until one, or both of the ships are destroyed. If one of the ships survives it continues on its path to the opponents base, or until it meets another enemy ship.

(a) Health.

(b) Energy.

(c) Faster units.

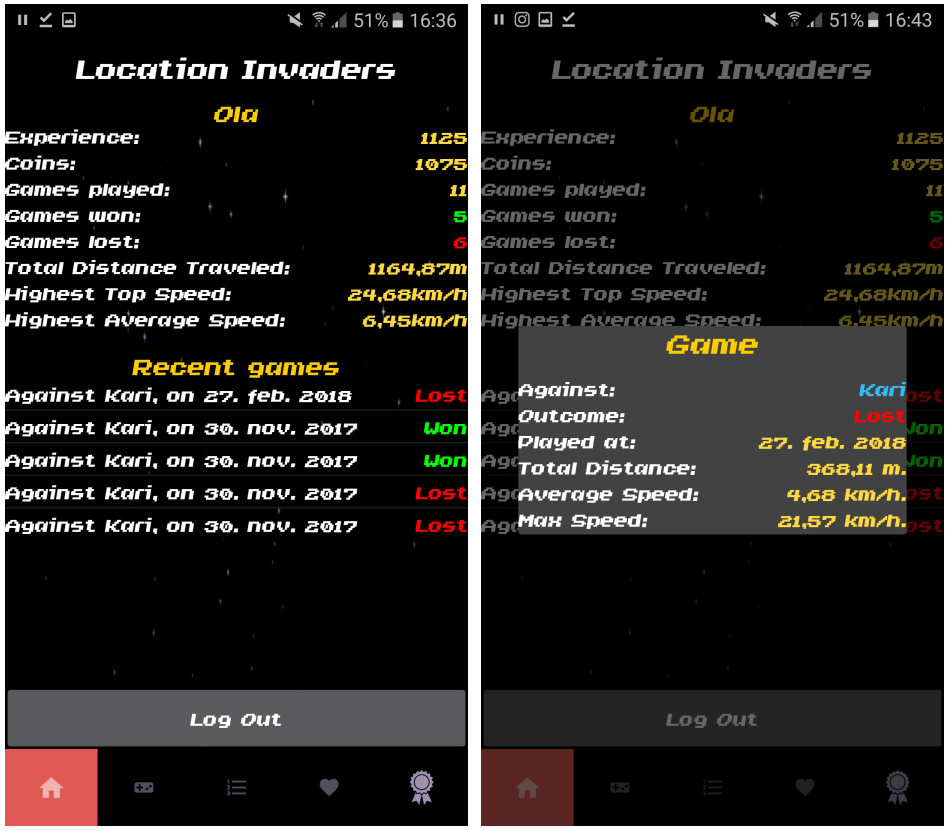
Figure 7.4: Power-ups in the game.

Figure 7.4 shows the power-ups that will appear in the far left and far right lanes of the game, these lanes are exclusively for power-ups, and can not be used for attacking your opponent. The purpose of this is to encourage the players sprint to a given side to pick up a power-up, introducing some high intensity physical activity.

The health and energy power-ups awards the player with 20 health or 20 energy, whereas the faster units power-up gives a speed boost for the units the player have sent, lasting a total of 4 seconds.

7.2 Home

The first thing a user sees when he opens Location Invaders is the home screen, see Figure 7.5. Here the user is presented with various data about their performance so far, such as number of games played, distance traveled, their experience count and so forth.



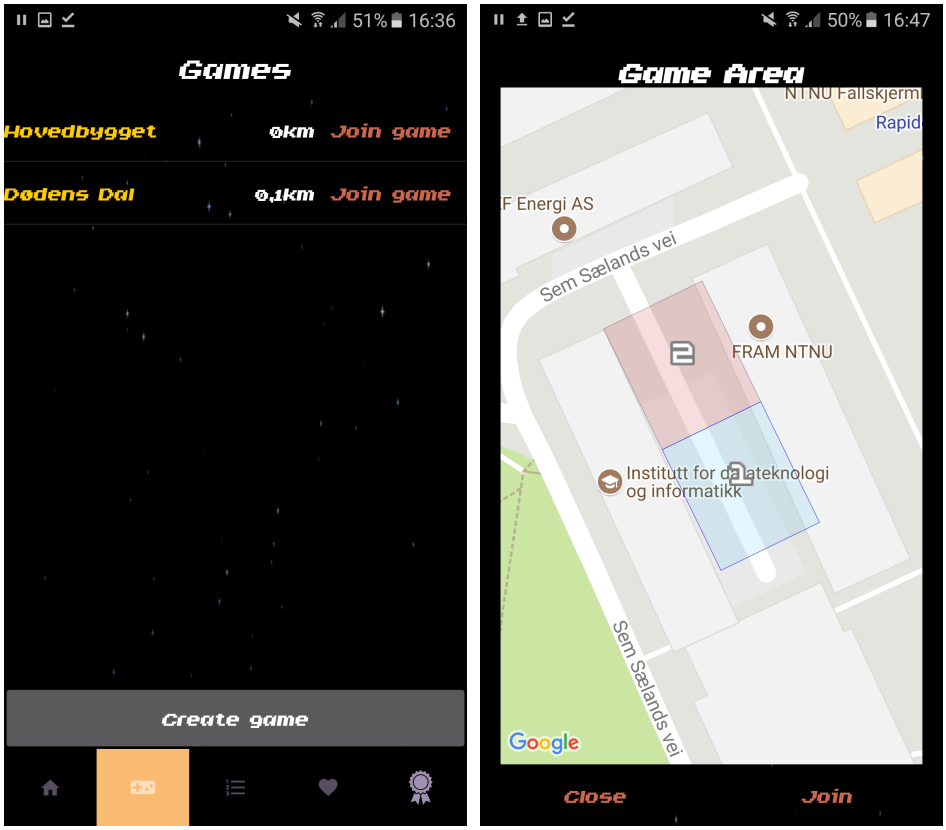
(a) Home view. **(b)** Information about a recent game.

Figure 7.5: Home.

The home screen also includes a list of the players recent games, with information of who the opponent was, the date it was played on, and the outcome. The user can open these recent games to get information about the total distance moved, their average speed over the game period, and their maximum recorded speed in that particular game.

7.3 Games

For a user to join or create a game, she or he navigates to the games tab where a list of active games is presented, which is presented in Figure 7.6. The available games are ordered by their proximity to the user, making it easy to find the nearest game. When a user decides to join a game they are presented with an overview of the game area and each players playing field.

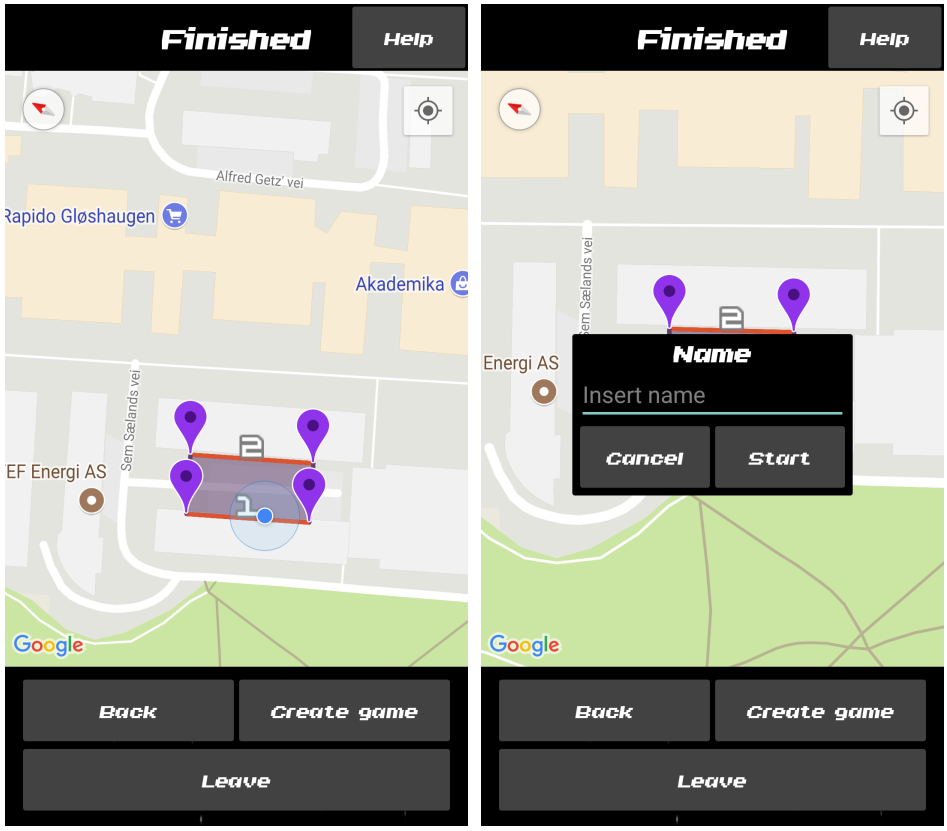


(a) Available games list.

(b) Joining a game.

Figure 7.6: Games.

The user also has the possibility of creating a game, which opens up a area selector where the player selects where the game area should be located, and the direction of the gameplay, see Figure 7.7.

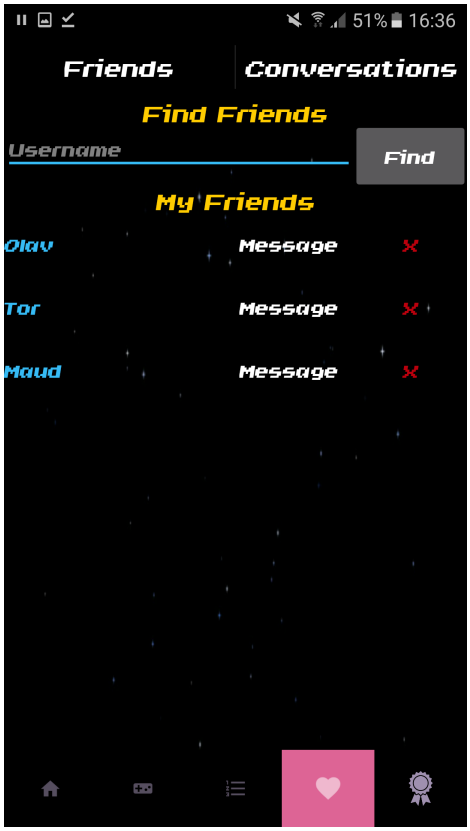


(a) Selecting game area. **(b)** Setting game name.

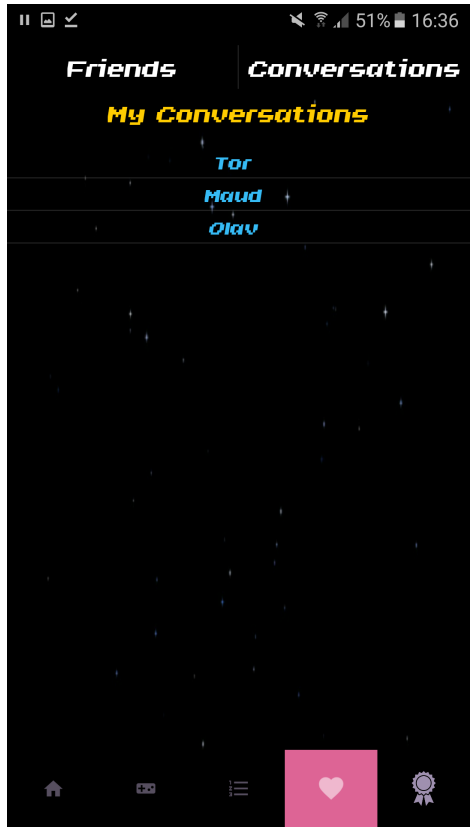
Figure 7.7: Creating a game.

7.4 Friends & Conversations

Each users has the ability to add friends in the game, enabling them to quickly fire up a conversation through the built in chat function, as shown in Figure 7.9. Figure 7.8 presents the users friends and ongoing conversations. Friends are added by searching for the friends user name.



(a) Friends list.



(b) Conversation list.

Figure 7.8: Friends and conversations.

The chat is open up by pressing the ”Message” button from the friends list, or by opening a specific conversation from the conversation list. This allows for player to use the game to organize matches.

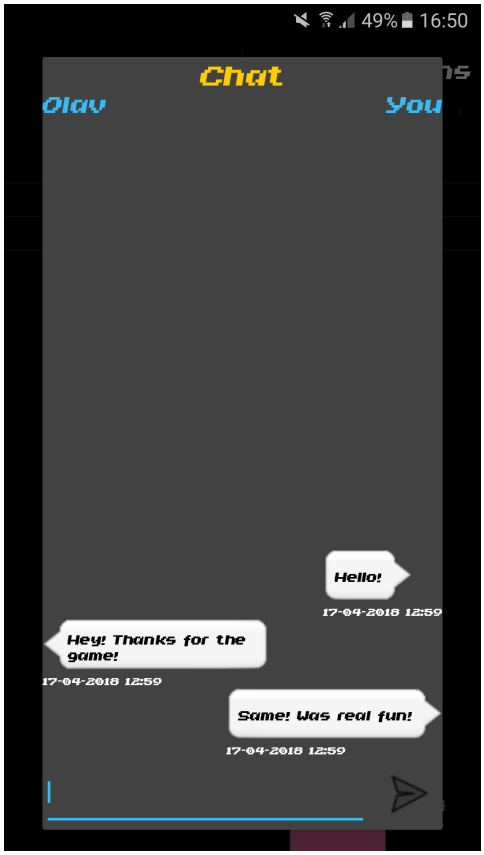


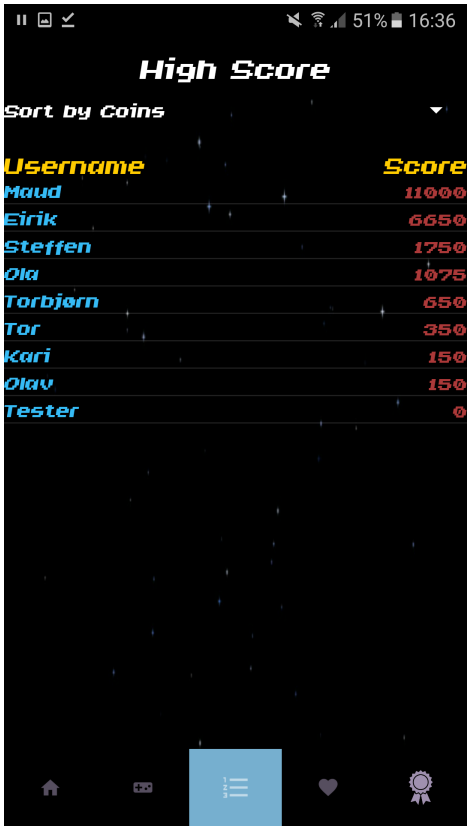
Figure 7.9: A conversation.

7.5 High Score

As seen in Figure 7.10a, we have also implemented a high score feature, which can be organized by several dimensions; coins, experience, total distance traveled, average speed, maximum speed, and win/loss ratio. This gives each player with multiple goals to strive for during the game.

7.6 Badges

The players are rewarded various badges for achieving different milestones. As of now there exists badges for coins earned, experience earned, distance traveled, average speed in game, and maximum speed in game, and is presented to the user as shown in Figure 7.10b.



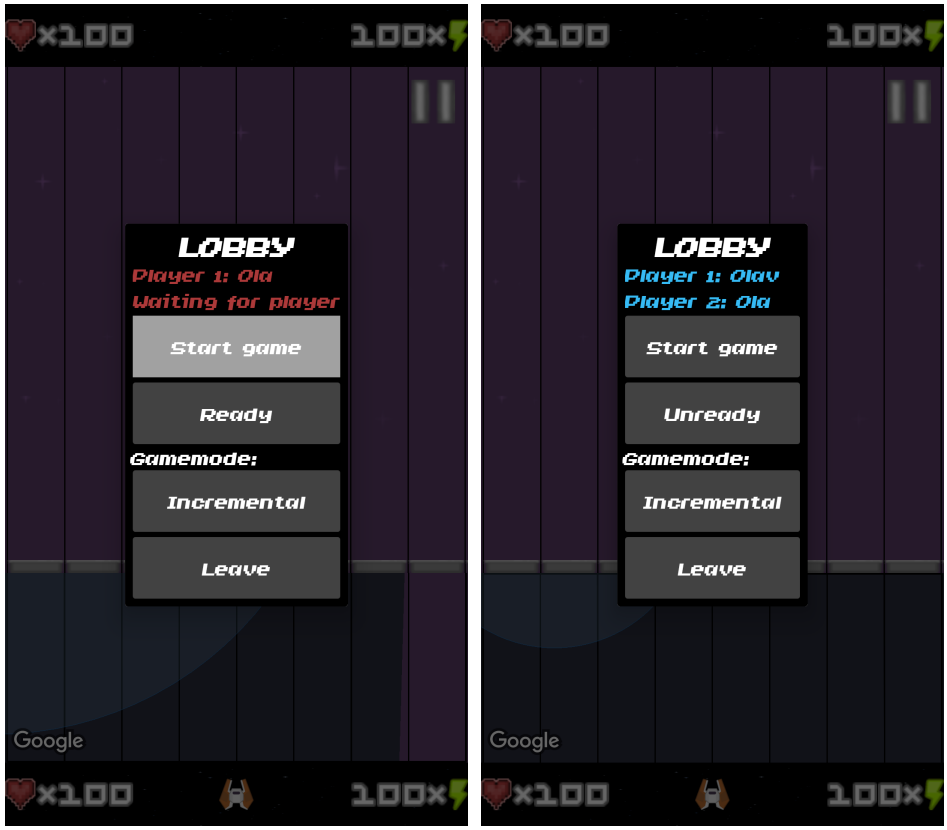
(a) High score.

(b) Badge list.

Figure 7.10: High score list and Badges.

7.7 Gameplay

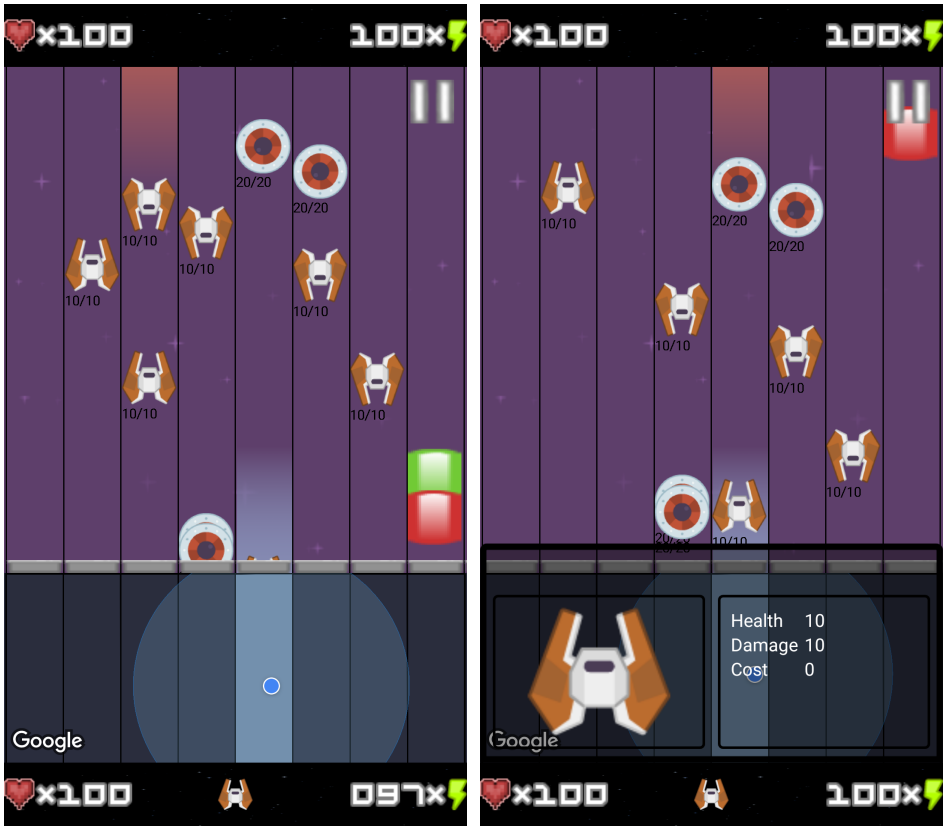
Once the player has created or joined a game, he or she is taken to the game lobby, where he awaits an opponent to join the game. The game lobby can be seen in Figure 7.11.



(a) Awaiting an opponent. **(b)** Both players ready.

Figure 7.11: Game lobby.

When both players confirm their status as ready the game can be started, triggering a countdown until the game starts.

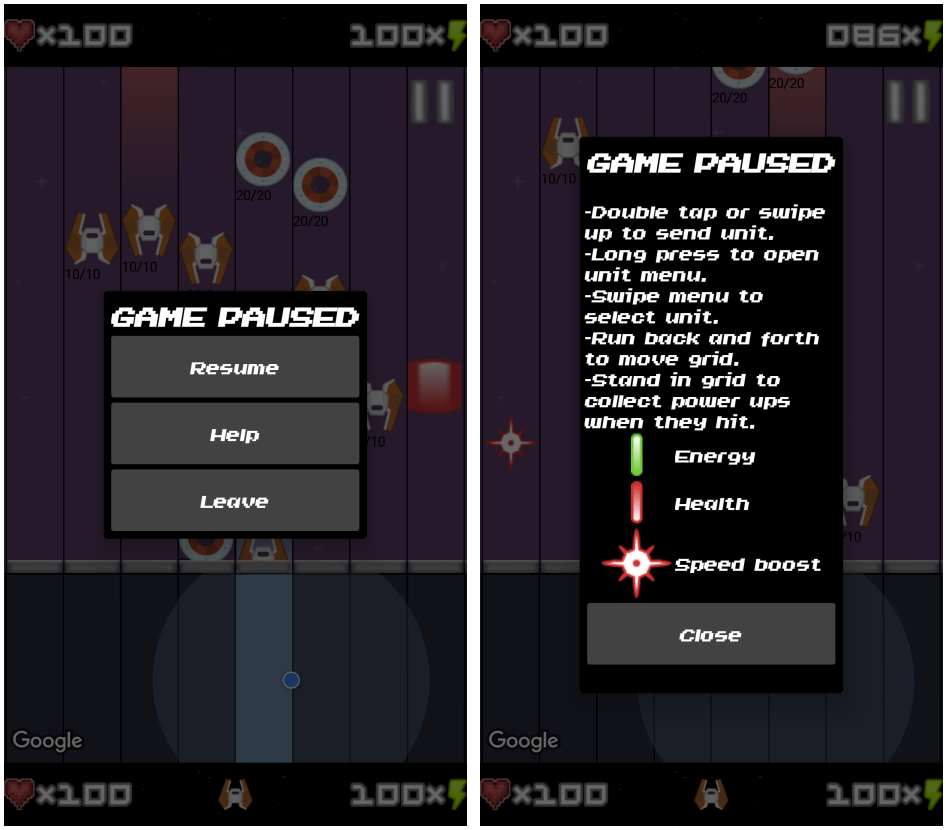


(a) Player view. **(b)** Unit selector.

Figure 7.12: Game in action.

When the game has started, the player is shown their physical position on the map, along with incoming and outgoing units and power-ups, as seen in Figure 7.12. The far left and far right columns are restricted to power-ups only, and can not be used for sending units. The player selects which unit to send by swiping left or right, or by a using the unit selector which is opened by a long-click. With the unit selector the user gets information about the available units, and can browse these by swiping left or right. The unit is then selected by a click. When a user has selected a unit, there is a visual feedback by showing the selected unit with a little icon at the middle bottom of the screen, along with audio stating what unit has been selected. The player can send the unit by swiping upward on the screen, or with a double click. When a unit is sent, the user is given feedback both through audio and a vibration on the phone. If the user does not have enough energy to send the selected unit, feedback of this is given through audio.

During a game the players can pause the game if needed, see Figure 7.13. From the pause menu the players can open up a help dialog, which gives a quick overview of how the game is played, and a description of the available power-ups.



(a) Pause menu. **(b)** Help dialog.

Figure 7.13: Game paused.

When the game is over, each player is presented with an overview of the game. Here stats like average speed, maximum speed, distance traveled, number of units sent, and rewards are shown for both players, as seen in Figure 7.14.

Figure 7.14: Game Over.

7.8 Login, Register and Forgot Password

The game requires each player to register an personal account, where the player registers with a user name, a password and an email address, which can be seen in Figure 7.15. The email is required in order for the players to reset their password should this be forgotten at some point.

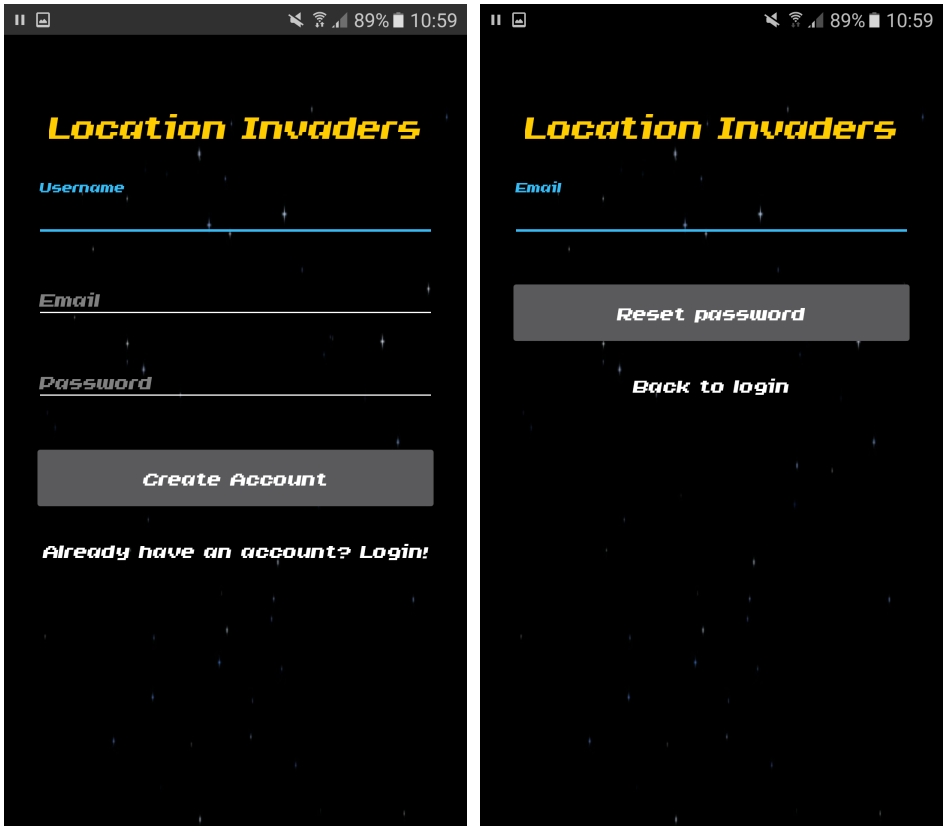


Figure 7.15: Register and Forgot Password.

When a user have created an account they can login using their credentials through the login screen, as presented in Figure 7.16.

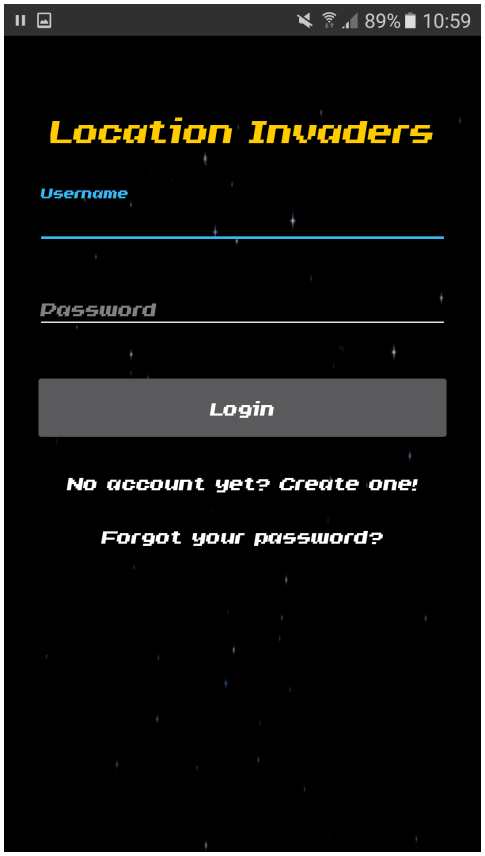


Figure 7.16: Login Screen.

Chapter 8

Game Mechanisms

The following chapter discusses how Location Invaders has implemented the various game mechanisms presented in Chapter 5.

8.1 Challenge, Fantasy, and Curiosity

Challenge. The game consists of a two-fold inherent challenge, on one hand you have the physical challenge of moving between the game squares in time to defend your base from the incoming enemy space ships. This is both physically challenging, but also consists of a strategic element where you have to plan ahead the pattern you must move in order to be able to defend your base successfully. On the other hand each player has to apply a strategy on how to successfully destroy the enemy base.

There exists several types of space ships the players can send towards their enemy, each with unique characteristics such as speed, damage, and health, making it possible to adjust your space ship type to fit with a strategy the player has chosen. For instance, if the player sees that the opponent is located on one end of the map, he can utilize fast space ships to apply pressure on the opposite end.

Variable difficult level: since the difficulty level is mainly a factor of the opponents skill level, both physical and strategical, there could potentially be a problem of players meeting opponents where the skill level gap is too wide, making the game boring for each player, breaking any sense of flow. There is two obvious ways to mitigate this.

First, to match players against opponents with similar skill level. This could be done through a match making system where players will be paired with opponents that can show a similar win/loss ratio, or perhaps introduce a ranking system like you have in chess. This does require enough players to be in the match making queue at the same time, making it impossible to implement before the player base has grown to a certain mass. The game will also require players to meet in person, which means they will probably only play with friends, making this system ill-suited.

Therefore we have chosen to go with a second strategy, namely to give advantages to the player that is losing to compensate for the skill difference. The way we resolved

this issue was inspired by the classical game Mario Cart, where the losing players have an increased chance of picking up powerful items during the race. In Location Invaders we have chosen to reward the losing player by increasing their probability of getting power-ups. The players have a base probability of 50% for receiving a power-up at each power-up interval, which is every seven seconds, and this can be increased by 5 to 25% depending on the difference in health between the two players.

Hidden information: since the opponents strategy and attack plan exists solely within the mind of the opponent, this could be considered a form of hidden information. Each player has to anticipate and plan for various strategies and attack variations formed from the different units each player has at their disposal.

Randomness is introduced through power-ups. Each player has a certain percent chance of receiving a power-up during the gameplay, ensuring that even though physical condition and strategy should be the main forces between the two players, this introduced randomness ensures some uncertainty in the game outcome.

Multiple level goals: as a part of making sure the game is enjoyable on more levels than just beating your opponent, we have introduced several goals within the game. First, we track the total distance traveled, the average speed, and the maximum speed of each game. This is then stored for the user as personal bests.

Another feature is the concept of badges. Here a user can earn badges for special behaviour in a game, for example sending 10 consecutive space ships of the same type, or not sending any space ships for some specified time interval.

Finally we have implemented the high score features, which can be sorted by coins, experience, total distance traveled, average speed, maximum speed, and win/loss ratio.

The goals mentioned here ensures that even though a player is obviously winning or losing, the user can still be find motivation beyond the game goal itself.

Fantasy is an integral part of Location Invaders, and manifests itself in the form of invading space ships that threatens the players base. The game plays on *intrinsic* fantasy, where the fantasy depends on the use of skill, by navigating the player both utilizing physical abilities, as well as a strategic battle plan.

Curiosity is driven by the right balance between complexity and simplicity in regards to the players existing knowledge. Even though the game itself is fairly simple to comprehend, the strategies and tactics that can be applied by the opponent is fairly complex, and can only be understood by paying close attention to the opponents movements and actions. This will hopefully trigger a *cognitive* curiosity. *Sensory* curiosity is sparked by audio, physical vibrations, and visual effects when the players perform actions in the game.

8.2 Flow, GameFlow and DualFlow

Since flow obviously is a state that we would want to induce while playing Location Invaders, we have tried to incorporate some of the key insights that Mihly Cskszentmihlyi presented for achieving the flow state. The GameFlow and DualFow models have mapped these findings to an exergame context, and, as you will soon see, these models have heav-

ily influenced the design of Location Invaders. The game offer a clear *goal*, to destroy the enemy base before they destroy you. Immediate *feedback* is provided to the player both when actions are performed by oneself, in the form of visual and audio feedback, and by the opposing player. Each player is able to quickly determine the health points of the opposing player, and locate incoming enemy space ships shown by the visual feedback. *A sense of control* is achieved by making each action by the player does a decision by the player itself, no interference is done by the game. The game requires the player to *concentrate* on where the current enemy is located, where incoming space ships are headed, how their own space ships are doing, and be ready to grab a power-up if it should appear. We have tried making the tasks feel important, and every action the player performs is either to defend against incoming enemy ships, attack the opponent, or fetch a power-up which will aid in either. Since Location Invaders is a multiplayer game, the *challenge* will come from playing against real opponents, in contrast to an artifical intelligence. Therefore, the opposing players *skill level* decides how challenging the game is. As previously mentioned we have tried to balance the game if it is obvious that one player is better than the other to ensure a sense of *challenge* for both players. Another feature we have introduced to ensure Location Invaders to be challenging is something we have named Incremental Mode, where the game starts out relatively slow, and then the speed of space ships increase incrementally throughout the game. This is especially useful for new players, where the challenge increases as the *player skill level* increases.

The player has clear *control* over their own actions, since the player is free to chose any strategy or action within the game rules by them selves. The game introduces a clear *goal* of destroying the opponents base, and instant *feedback* is provided both visually and trough audio, both on the *goal* and the players *actions*. The player is always presented with their health and energy scores, as well as the opponents. The game supports *social interaction*, both in the form of meeting in person to play against each other, as well as an in-game chat, a friends list, and high score features. Location Invaders is indeed special in that we both have to consider the ever lasting question of how to make a game enjoyable, but also consider how the physical aspect of the game should be balanced between fitness and intensity. The game does indeed reward physical fitness simply by the requirement that a player should be able to move quickly from location to location in order to both defend their own base, and attack their opponents. While this could lead to unbalanced games, where one player simply would not be able to match their opponents physical fitness, leading to *failure* we have tried to counter this by including a strategical aspect, as well as the power-ups favoring the losing player. While this in it self can not ensure a high enough intensity for a given fitness, it at least gives some leeway when it comes to matching players based on their fitness levels.

Chapter 9

Technological Rationale

The following chapter will discuss the rationale behind the technological decisions taken during the design and implementation of Location Invaders.

9.1 Platform

As we wanted to make the game available for a wide audience, it was clear from the very start that we wanted to implement the game as an mobile application, for no other reason than reaching the broadest possible audience. The mobile application market is dominated by three competing operating systems. The biggest is Android, which in 2017 had a market share of 85.0%. Following Android is Apples iOS with a market share of 14.7%, and finally there is Windows Phone with a market share of about 0.1% [83].

We can see that the smart phone market is dominated by Android and iOS, and the choice really stood on choosing which of these platforms to create the application for. Here we had three options:

- developing both an Android and iOS application
- develop an application using a cross-platform tool
- develop an application for either Android or iOS

There exists several cross-platform tools, such as Xamarin, React Native, and PhoneGap to name a few, where you write code which is then compiled to native Android and iOS code, ensuring that developers only have to work on a single code base which then can be distributed to both platforms, and this option was thoroughly considered at the start of this thesis.

The option of developing both an Android and an iOS application in parallel was quickly ruled out simply by the time constraints, as this task would not be feasible in the scope of this thesis.

The option to go for Android over iOS or a cross-platform can be broken down to the following reasons:

- the Android dominance in the smart phone market
- the authors having Android phones, easing development and debugging
- the authors were familiar with java development, which is the language used for the Android sdk.
- learning a cross-platform tool would be time consuming, adding further time constraints

We therefore ended up developing a fully native Android application, utilizing the authors familiarity with java, as well as providing easy testing and debugging with our own smart phones during the development and testing process.

9.2 Location Tracking

Location Invaders relies on being able to track the players physical movement in the real world accurately, and as we have seen in Chapter 4, GPS is present in practically all smart phones, and provides more accurate tracking than both LTE and WiFi positioning, making it an obvious technological choice for our needs.

GPS integration on the Android platform is also available through the Google Maps API, which is thoroughly documented and tested, making it easy to work with using Google Maps and Google Location and Activity Recognition.

9.3 Backend

In order to support a multiplayer game, it was clear that we needed a way for the application to both communicate with the opponent during a live game, and a way to retrieve and store data that would be presented in the application, such as user stats, high scores, recent games and so forth. This was solved by implementing a centralized server, which offered an REST-API for basic CRUD-operations (create, retrieve, update, and delete). The communication between each application was done through socket-connections that was handled by the server, which redistributed the data sent from a player to the corresponding opponent.

There are several technologies that could have been used implementing this solution, but one of the authors had in-depth knowledge and familiarity with REST-API development using the Node.js and Express.js environment, alongside MongoDB as a database solution. Using a familiar language, environment, and database solution enabled us to rapidly start development, and wasting little time on learning new technologies and languages.

Chapter 10

Exercise Design

The following chapter discusses the decisions taken in regard to choice of exercise the game should support, and how this was implemented.

10.1 Exercise Rationale

As we wanted to create a game that was available to a wide audience it was important for us to choose an exercise form that accessible, and requiring little or no equipment. We saw in Chapter 3 that body weight training, running, jogging, and high intensity interval training all were suitable candidates.

We started our game concept brainstorming with these candidates in mind, but as the concept of Location Invaders came to light it became clear that a form of jogging with elements of high intensity interval training was the best match for our game concept, and was also easy and accurate to track with the technological capabilities of the smart phone, see Chapter 4.

10.2 Implementation

As we have seen in Chapter 7, Location Invaders relies on the players physical location as an integral part of the gameplay, and it is on this aspect the exercise part of the game is introduced. The user has to quickly move across the game area to both attack the opponent and defend against incoming units, ideally encouraging players to move around at an relatively high intensity.

To further encourage and reward high intensity activity, we came up with the concept of placing the power-ups in the far left and right lanes of the game area, forcing the players to sprint to one of the sides to pick up power-ups that gives them an advantage in the game.

As discussed in Chapter 8, we have introduced several sub-goals and high score features that are measurements of the players physical performance in a game, intended to motivate the players to perform their best in regard to the exercise part of the game.

Chapter 11

Development

This chapter presents our development approach, the methodology used and how the game was tested during the implementation.

11.1 Development methodology

The development started with a initial progress plan, with rough estimates to the different phases of the project, see Appendix G. We were able to follow the plan almost to the day, and it also gave us milestones, providing us with intermediate goals throughout the project. The development started with a rough concept and design sketches. Figure 11.1 and 11.2 shows the earliest sketches of the home, game, and create game screen.

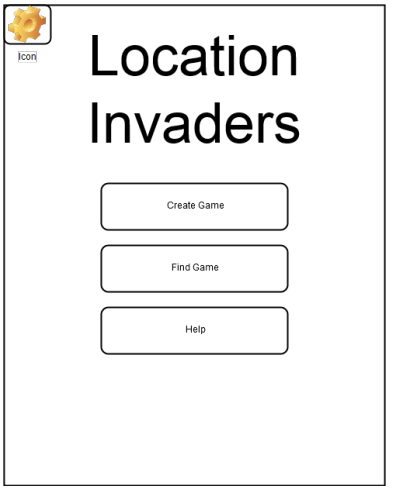
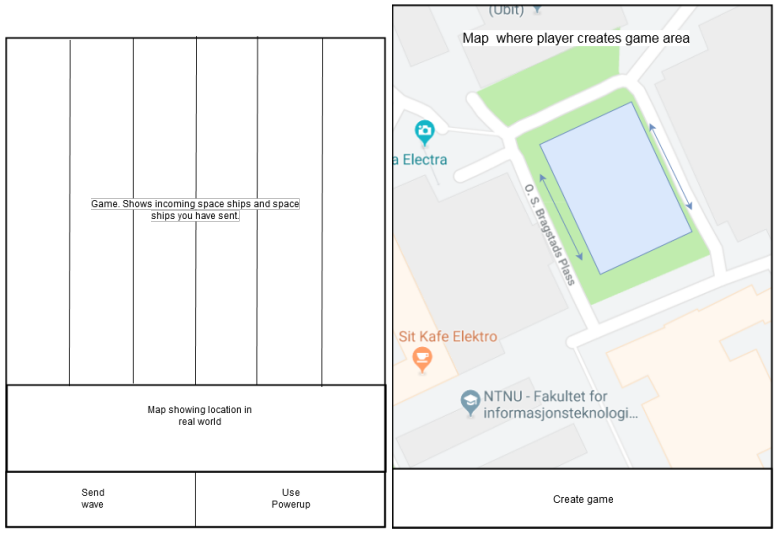


Figure 11.1: Home screen.



(a) Concept drawing of game screen. **(b)** Create game.

Figure 11.2: Concept drawing of game.

We worked in an iterative manner, using a lightweight scrum-like methodology, and after the concept was formalized and we had created the sketches, we broke the game down in use cases and ordered these in three categories: Must have, nice to have, and extra, see Figure 11.3b. Table 11.1 shows the use cases developed. All of the mentioned use cases except one have been implemented in the final product.

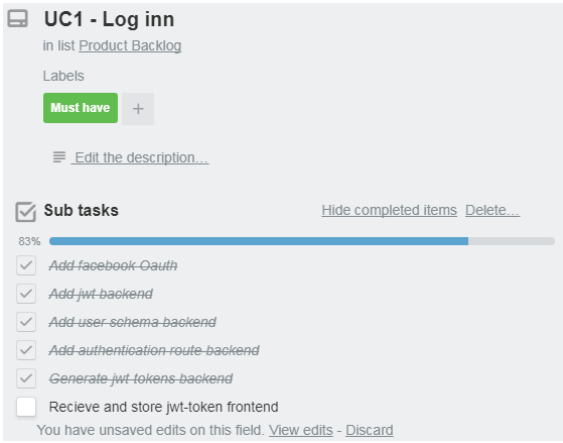
We organized our scrum board using the collaborative tool Trello, which is a web-based project management application. Here we put the initial use cases to our product backlog, and had a clear overview of what we were working on, what was still unfinished and the different stages each use case was currently in.

The scrum board was divided into four distinct stages; product backlog, in progress, quality assurance, and done, as seen in Figure 11.3c. This enabled us to both get fast feedback on our own progress, and making the collaborative development run smoothly. During quality assurance a code review was performed and the use case tested.

The use cases was then further broken down into logical coherent sub tasks which could be implemented in parallel, an example of this can bee seen in Figure 11.3a.

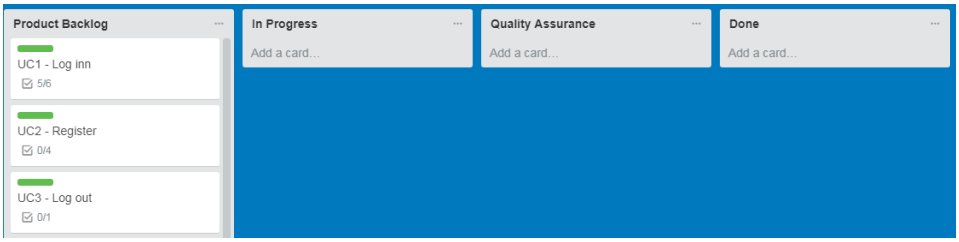
ID	Description	Priority
UC1	Log in	Must have
UC2	Register	Must have
UC3	Log out	Must have
UC4	Create game	Must have
UC5	Select play area	Must have
UC6	See player location	Must have
UC7	Find games	Must have
UC8	Join Game	Must have
UC9	Play game	Must have
UC10	Send space ship	Must have
UC11	Collect power-up	Must have
UC12	Use power-up	Must have
UC13	Control wave location	Must have
UC14	Shoot gun	Removed
UC15	Leave game	Must have
UC16	Pause Game	Nice to have
UC17	Change settings	Nice to have
UC18	See tutorial	Nice to have
UC19	See highscore	Must have
UC20	Add friend	Extra
UC21	See friend	Extra
UC22	Challenge friend to game	Extra
UC23	Remove friend	Extra
UC24	Chat with friend	Extra
UC25	Delete user	Extra
UC26	Change space ship	Must have
UC27	Reset password	Nice to have
UC28	Navigate main menu	Must have
UC29	See game history	Must have
UC30	See user statistics	Nice to have
UC31	Get badges	Nice to have
UC32	See badges	Nice to have

Table 11.1: Use cases.



(a) Use case sub tasks

(b) Use case labels.



(c) Scrum board organization.

Figure 11.3: Trello board.

11.2 Testing and Quality Assurance

Working in an iterative manner enabled us to test features as they were implemented, making sure that new features did not break or alter the intended behaviour of earlier builds. The testing of new features was done by both authors, by manually trying out the new feature. If a new feature was added to the gameplay itself, the authors would play games against each-other.

The quality of the new code was also assured by code reviews, where the authors would review each others commits before they were merged with the master branch.

To ensure that the game would be playable by the end of the development process we included two dedicated testing phases during the development. We conducted an alpha test after about two months of development, where we got friends and family to try out the game, to test both that the game was playable, but also get early feedback on the user experience, and discover previously undetected bugs. The tests were informal, and relaxed.

The alpha test uncovered several minor bugs in the code, as well as providing valuable feedback on the user experience. The area selector for the game proved to be somewhat counter-intuitive, and this was improved upon after the alpha testing.

A beta test was conducted after four months of development. Friends and family got to try there game here as well, and we had an emphasis on testing the new features that had been implemented since the alpha test. The beta test also discovered some bugs, but most notably gave valuable feedback in the balancing of units and power-ups.

Chapter 12

Software Architecture

Location Invaders is implemented in what can be distinguished in two separate systems interacting over a defined interface. The architecture will be discussed both on an overall sense, how the two systems communicate and integrate, as well as the architecture of each sub-system.

12.1 Client-Server

The client-server pattern comes as a result of the networked gameplay. It keeps a clear and distinct line between the front- and back-end components, and gives us a centralized access point for the application data, and opening up for communication flow between two clients during a live game.

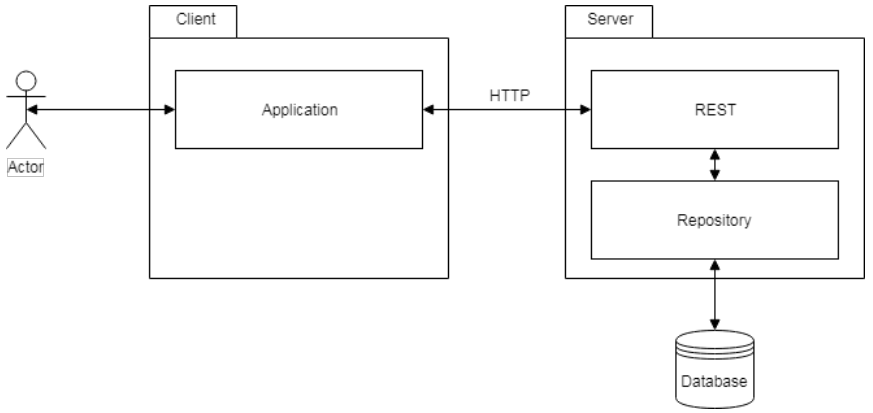


Figure 12.1: API Structure Diagram.

The structure diagram, see Figure 12.1, illustrates the data flow when the application

consumes resources form the server, which offers its resources over the HTTP-protocol, using representational state transfer, see Section 12.2.1. For database operations the communication goes through a repository, see Section 12.2.2.

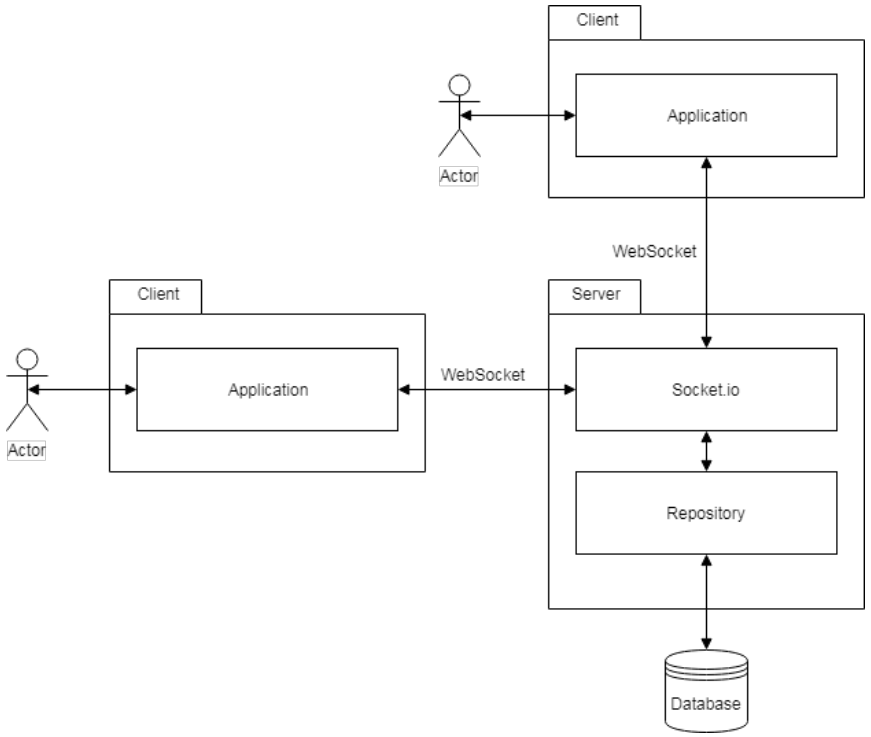


Figure 12.2: Socket Structure Diagram.

The communication between two players during a game is done using WebSocket, which enables full-duplex communication over a single TCP (Transmission Control Protocol) connection. As illustrated in Figure 12.2, when either of the players emits an event, the event is first transmitted to the server, which then redistributes the event to the corresponding opponent. Each of the players have their own socket connection to the server. The clients can send and listen for various events, for instance **`creatureSent()`** and **`playerJoined()`**, triggering various updates and representations on the applications GUI's, updating the game state and so forth.

12.2 Server

The following section describes architectural decisions taken specifically for the server side.

12.2.1 Representational State Transfer

Representational State Transfer (REST) is a architectural style providing a set of recognizable standards between systems on the web, easing communication with each other. In the context of this thesis it manifests itself in how resources hosted on the server are made available to the client consuming them. The REST-api implemented offers its resources over the HTTP-protocol, where the HTTP verbs GET, POST, PUT, DELETE represent traditional CRUD (create, read, update, delete) operations. An example of data flow could be **`GET /user/`**{**`id`**}, and **`POST /games`**, where the former would return a specific user, and the latter create a new game.

12.2.2 Repository Pattern

The repository pattern provides an abstraction of data, providing an easy and intuitive layer between the server application and the database system, offering straightforward methods without the need to deal with database concerns like connections, commands, query languages and so forth. The repository pattern aims to introduce a loose coupling and keep the domain objects independent from the database system used.

12.2.3 Middleware Pattern

The middleware pattern an essential part of the Express.js environment and consists of a set of functions defined as

> ... functions that have access to the request object (req), the response object (res), and the next middleware function in the application's request-response cycle. The next middleware function is commonly denoted by a variable named next [84].

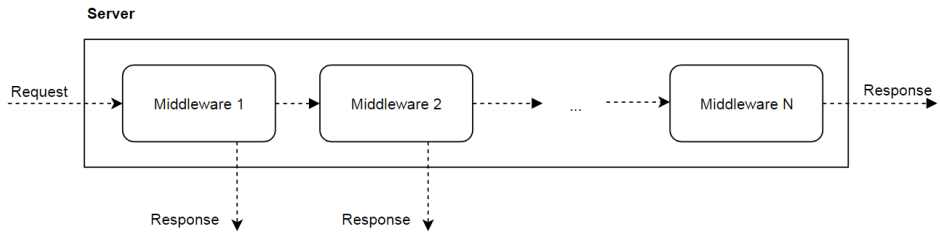


Figure 12.3: Middleware request life cycle.

Figure 12.3 illustrates a middleware function stack, and when a request is sent to the server, it goes through a stack of defined middleware functions. The stack can be the likes of authentication, body validation, database operations and so forth. Each function performs their logic before the next function is called from the middleware itself. If there are errors during on of the middlewares they can abort the stack, and returning an error message to the request sender, or pass along error messages to be handled further down

the middleware stack. The middleware pattern avoids coupling of the request sender and the request receiver by enabling several objects to handle the request. This also enables us to modify the chain of responsibilities of each request which ensures modifiability and separation of concerns.

12.3 Client

The following section describes architectural decisions taken specifically for the client side.

12.3.1 Class Diagrams

This sections presents a class diagrams from the client side of Location Invaders. The diagrams shows parts of the system, and are simplified for clarity. They are based on a diagram exported by Code Iris from Android Studio.

Figure 12.4 shows the classes related to the actual game activity of Location Invaders. GameFullScreenActivity holds the main game loop, the Google map, and two PlayerFragments. The PlayerFragments holds information about the current state of the players. The GameCanvasView draws the game grid, power-ups, and space ships, and checks whether power-ups are picked up, or if space ships have hit anything. UnitcollectionPagerAdapter contains the unit selector, where players chose the active space ship. PauseGameFragment and WaitingForPlayersFragmet are dialog fragments displayed by GameFullScreenActivity. WaitingForPlayersFragment functions as the game lobby.

UnitCollectionPagerAdapter holds a list of all possible space ships, and when a player chooses a space ship, this is used by the GameFullScreenActivity. GameFullScreenActivity holds the current selected unit of the player, as well as a list of all possible space ships. This allows GameFullScreenActivity to send and receive space ships. When GameFullScreenActivity receives a new space ship, this is communicated to the GameCanvasView.

GameCanvasView holds all current objects, and is responsible for drawing objects on the game canvas, checking for collisions, and whether power-ups have been picked up. GameCanvasViews uses PlayerFragment to draw the current location of the players on the game canvas. When GameCanvasViews registers a power-up has been picked up or a space ship has hit a player or another space ship, it communicates this to the object. The power-up or space ship then uses PlayerFragment to execute the effects of the object. The different objects holds a reference to the ”owner” and target of the object.

Figure 12.5 shows how the power-ups and space ships were implemented, which are object drawn on the game canvas. The power-ups and different space ships inherit from BasicPowerUp and BasicUnit, which in turn inherits from BasicObject. Basic object controls all common functions for the different objects, while the other classes are more specified. This was done to minimize the amount of code duplication, and makes it easier to add and remove space ships and power-ups.

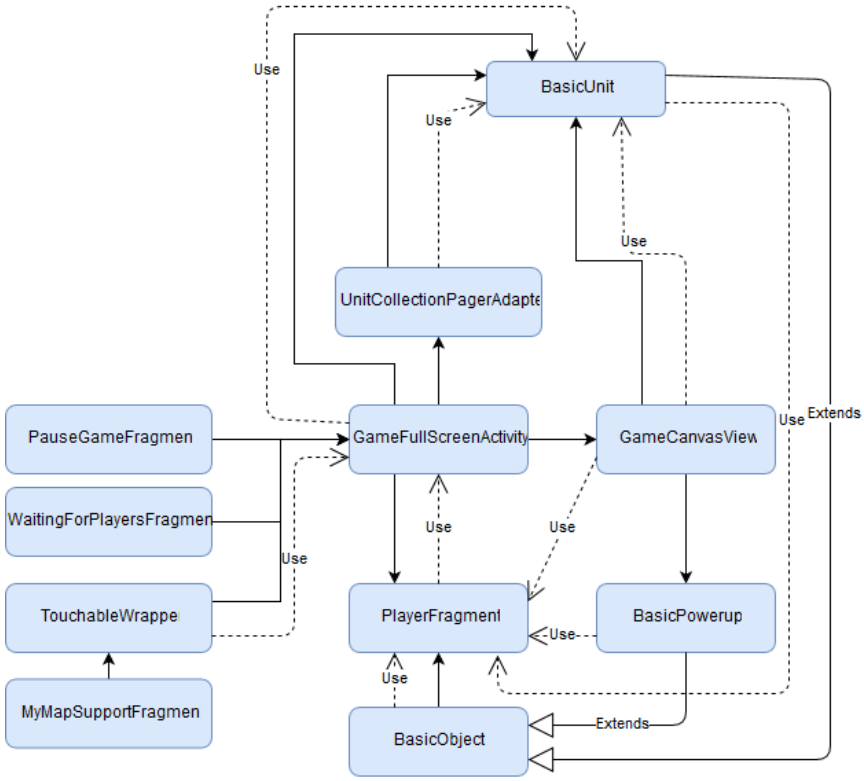


Figure 12.4: Classes related to the game part of the system.

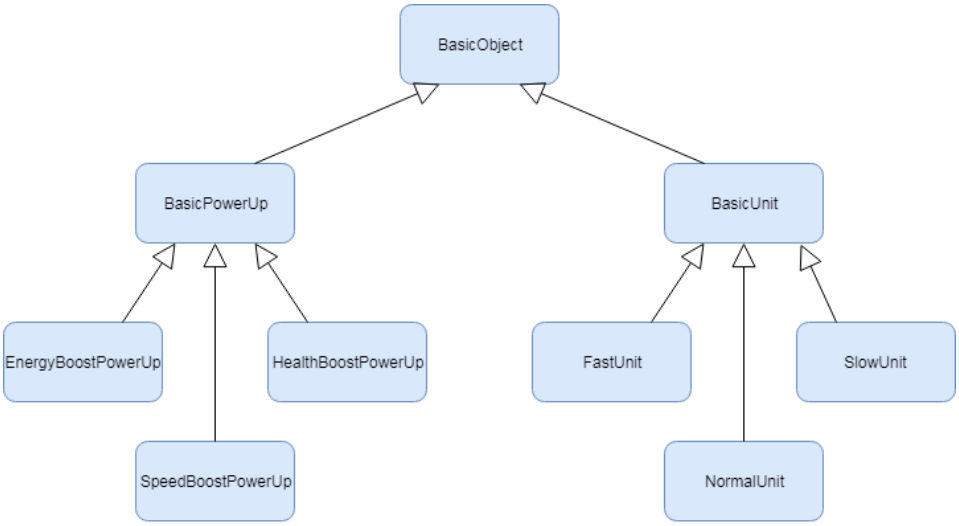


Figure 12.5: Implementation of power-up and space ship classes.

12.3.2 Model-View-Controller Pattern

The Model-View-Controller (MVC) is a pattern which separates an application in three parts, the data (model), the view, and a controller, as seen in Figure 12.6. The purpose it to make the view completely decoupled from the model, such that changes in the view will not have an impact on how the data is handled, and vice versa. The controller is responsible for tracking user input and actions, and updating the data and/or view accordingly.

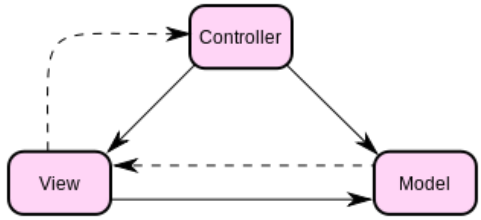


Figure 12.6: Model-View-Controller Concept [85].

In the android application this pattern is introduced by XML layout files, representing the *view*, with the activity or fragment Java classes representing the *controller*, and finally the *model* is represented trough dedicated model Java classes.

12.3.3 Singleton Pattern

Singleton pattern is used to ensure only one instance of an object can exist at once, and is useful when ensuring a single object is available to the system as a whole, an example can bee seen in the following illustrative code snippet

```
private static Retrofit retrofit = null;

   public static Retrofit getClient(Context context) {
      if (retrofit==null) {
         retrofit = new Retrofit(context);
      }
      return retrofit;
   }
```

Part IV

Evaluation

In this part the results from user testing will be presented. The execution and development of user testing will also be described, and the validity and reliability of the generated data will be discussed.

Chapter 13

Data Generation

This chapter presents the sampling and execution of the user testing and data generation, as well as the development of the questionnaire.

13.1 Sampling

The sampling method chosen for gathering participants was convenience sampling. We recruited friends and fellow students through social media. We had a sign up form online where we informed the participants about the game and the research before they signed up, and they could choose which day was best suited for them. The information presented to the participants can be seen in Appendix E

Before the testing began we had 13 participants signed up, however only 11 turned up on the days we performed the test. Before the testing began we repeated what the game was, the intention of the research, and what data would be collected, and they signed a participant agreement form, as seen in Appendix A.

As the sample size is very small, the participants gender and specific age are withheld for the sake of anonymity. The sample consisted of both men and women, ranging from 22 to 26 years of age.

13.2 Prototype Testing

The user testing was split into two days with 4 participants the first day, and 7 the second. Every participant played 4 matches, where 2 were consecutive matches against the same player, before a break, and 2 more matches against a different player. During the break the players were offered food and drink.

The playing area was setup before the testing began and was the same for each game. The playing area was approximately 25 meters wide, and we used physical markers to indicate the ends of the running area.

During the user testing we gathered the participant's heart rate using a Fitbit Charge 2 (FC). The Fitbit does not have a perfect accuracy, and can show a difference of more than 5 BPM compared to Electrocardiography (ECG) [86]. The FC generally underestimates the heart rate [87], and the underestimation may increase as exercise intensity increases.

The accuracy is also affected by the location of the FC on the wrist. With the FC located 2-3 fingers above the wrist bone the mean bias BPM at 6mph is -0.3 ± 7.3, and if it's located on the wrist bone it has a mean bias of -6.7 ± 14.3 [88]. Another study showed a mean bias of -5.9 BPM (95% CI: -6.1 to -5.6), but that an individual measure could possibly underestimate by as much as -28.5 BPM [89].

The accuracy of the Fitbit is not ideal, but we mostly want to show that there is some tangible increase in physical activity. We also had several Fitbits available to us, and it allows us to export the heart rate data easily from Fitbit's official site.

During the testing we also payed specific attention and observed the players. We noted how they played, their enthusiasm and engagement, and got insight through conversations during the breaks.

Figure 13.1: Picture of users testing the prototype.

13.3 Questionnaire

After the participants had completed the testing of the prototype we sent them the questionnaire, which they did on their own time. The questionnaire was distributed and answered online instead of paper, as we wanted to make it easier for the participants give comprehensive and in depth answers in the comment sections.

The questionnaire was developed to gather information about the player's enjoyment, engagement, motivation, and to get insight into how the chosen game mechanics and genre worked. The questionnaire was split into three parts: *Part 1* gathered demographic information. The participants were asked about gender, age, time spent on exercise and video games, and about their experience with exergames. *Part 2* was about their experience

with playing Location Invaders. It contained 21 statements where the participants could answer strongly disagree, disagree, neutral, agree, or strongly agree. It also contained a field where the participants could provide additional feedback on the statements. *Part 3* contained three fields where the participants could provide additional written feedback on their experience with Location Invaders.

For the full questionnaire, see Appendix B.

We presented four statements regarding motivation to help us answer RQ5:

- I was motivated to play the game before each match
- Playing against a human opponent motivated me to perform my best
- I feel more motivated to workout by playing the game than doing interval training
- I feel more motivated to workout by playing the game than going for a jog

We were interested in data about motivation before each match, how the competitive and social aspect affects motivation, and how the motivation compared to motivation for conventional exercise.

Statements regarding engagements were presented to answer RQ6:

- I was engaged while playing the game
- I was completely focused on the tasks of the game
- I was able to concentrate on what was happening during the game
- I was so engaged in the game that I became less aware of my surroundings
- I was so engaged in the game that I became less aware of the physical activity

The statements helped us ascertain whether the players felt engaged, and were able to focus on the game and became less aware of the surroundings and themselves.

To gather data about the player's enjoyment of the game we gave them six statements regarding enjoyment:

- I enjoyed playing the game
- I enjoyed the fantasy of the game
- I can see myself playing this game also after the test
- The genre of the game was appealing to me
- Playing against a human opponent made the game more enjoyable
- I enjoyed comparing stats against my opponent after the game

They included statements concerning their general enjoyment of Location Invaders, statements that allowed us to discern their enjoyment of the genre and fantasy, as well as the social and competitive aspect of the game. The statements allowed us to answer RQ7.

We wanted to assess if the game achieved a sense of flow, an important part of enjoyment, and how the games challenge, fantasy, and curiosity were perceived by the participants. To do this we, in addition to some of the previous statements, presented these statements:

- The game difficulty was appropriate to my skill level
- The goal of the game was clear
- I got sufficient feedback on my actions
- I found the controls of the game was easy to use

- I found this game easy to learn
- I felt in control of what I was doing

A comment field concluded Part 2, where the participants were asked: *Do you have any additional feedback on the statements you have answered?*. The purpose here was to enable the participants to clarify certain answers on the statements, if they needed too.

Part 3 contained three comment fields aimed to give us insight into their thoughts and experience with Location Invaders, and how the game may be improved.

- Any comments regarding your playing experience with Location Invaders?
- Any comments regarding the Location Invaders game itself?
- Any general comments?

Chapter 14

Results

This chapter presents the results from the user testing of Location Invaders. The results presented are the heart rate measured using a Fitbit Charge 2, distance and speed measured using GPS, observations during the prototype test, and the results from the questionnaire.

14.1 Prototype Testing

This section presents the findings from the prototype testing, where we measured heart rate, distance moved, speed, and observed the players during the game. The matches had an average duration of $03:06 \pm 01:05$ minutes, with games as short as 01:38 and as long as 06:05.

We calculated average HR_{MAX} for the participants using the formula presented in Section 3.4.4, and found $HR_{MAX} = 196.6 \pm 10.8BPM$. (This is measured using the average age, is this correct?) This section will present a selection of graphs depicting HR from various matches, to see full results see Appendix C.

14.1.1 Heart Rate, Distance and Speed

The results presented here are in the form $mean \pm SD$. Where the standard deviation is calculated using the excel formula STDEVPA, which uses $\sqrt{\frac{\sum(x-\overline{x})^2}{n}}$.

The players had an average HR of $107.1 \pm 17.7BPM$ and $54.5\% \pm 17.4\%$ of HR_{MAX} during play. The average max heart rate reached during each match was $123.1 \pm 16.1BPM$ and $62.1\% \pm 14.2\%$ of HR_{MAX}.

The average distance ran for each match was 146.96 ± 51.93 meters. The average speed was $3.87 \pm 0.96km/h$, and the average max speed reached was $22.61 \pm 7.49km/h$

In Table 14.1 and Table 14.2 the results from each day are presented. For each match and player it shows the average and max heart rate, average and max speed in km/h, the distance ran in meters, duration of the game in minutes and seconds, and the winner of the game.

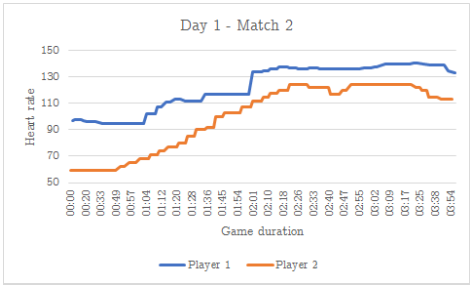
Match	Player	Heart rate		Speed		Meters	Minutes	Winner
		Avg.	Max	Avg.	Max			
1	1	104.86	116	2.81	13.36	144.89	04:58	Player 2
	2	79.21	94	2.84	32.68	154.07		
2	1	122.68	141	4.62	27.68	216.04	03:58	Player 1
	2	100.65	124	4.63	27.62	208.86		
3	1	97.84	119	3.63	29.94	135.34	02:57	Player 2
	2	102.18	115	3.80	31.26	145.96		
4	1	112.00	148	4.11	31.68	133.45	02:58	Player 2
	2	107.68	134	4.71	26.38	162.22		
5	1	111.83	133	3.53	19.80	77.60	02:56	Player 2
	2	103.66	127	4.47	34.07	86.53		
6	1	113.78	120	4.76	22.41	124.22	01:59	Player 2
	2	112.82	124	6.10	29.57	156.41		
7	1	116.39	131	3.50	25.16	109.56	02:55	Player 1
	2	111.51	120	1.62	14.91	54.01		
8	1	122.19	141	5.24	32.30	188.19	04:16	Player 1
	2	83.37	117	3.84	24.47	144.99		

Table 14.1: Results day 1.

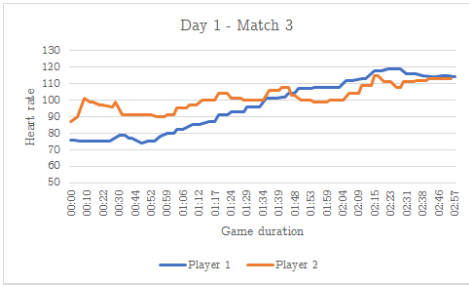
Match	Player	Heart rate		Speed		Meters	Minutes	Winner
		Avg.	Max	Avg.	Max			
1	1	93.37	111	4.30	17.10	142.65	03:11	Player 2
	2	107.71	136	3.08	16.76	100.61		
2	1	96.41	102	3.46	13.42	84.86	01:38	Player 1
	2	120.70	144	5.43	29.56	133.06		
3	1	110.54	137	2.89	19.17	145.71	04:18	Player 1
	2	103.54	112	3.81	21.74	205.67		
4	1	104.82	130	3.07	9.36	152.63	03:23	Player 2
	2	112.69	117	4.40	28.18	201.33		
5	1	94.26	121	3.24	28.95	86.15	03:27	Player 2
	2	100.97	116	2.94	8.13	77.32		
6	1	116.25	127	3.92	30.10	178.99	01:59	Player 2
	2	116.49	127	1.99	12.40	125.92		
7	1	98.86	119	5.76	33.11	159.33	01:55	Player 1
	2	98.43	115	3.27	10.29	84.81		
8	1	135	170	5.06	19.26	154.46	01:51	Player 1
	2	116.75	134	4.38	21.26	120.50		
9	1	151.9	153	3.76	33.24	94.25	01:42	Player 1
	2	92.24	94	3.85	28.31	101.74		
10	1	99.60	113	4.24	15.05	302.19	05:02	Player 1
	2	135.51	149	4.09	20.20	281.92		
11	1	109.31	127	4.37	16.49	241.83	03:29	Player 1
	2	95.78	107	2.55	18.30	139.01		
12	1	105.36	112	5.62	12.77	194.13	01:20	Player 2
	2	94.25	98	3.72	24.19	125.63		
13	1	99.14	111	3.49	16.12	153.34	01:57	Player 1
	2	90.63	97	2.84	28.39	115.14		
14	1	117.80	131	3.78	12.93	181.67	06:05	Player 1
	2	96.84	104	2.88	26.77	139.26		

Table 14.2: Results day 2.

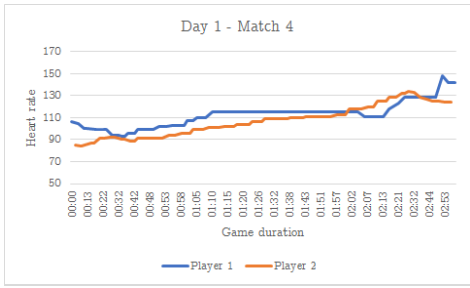
Figure 14.1 and Figure 14.2 shows a selection of the graphs from the matches. They show the heart rate of player 1 and player 2 as the game goes on.



(a) Day 1, Match 2.

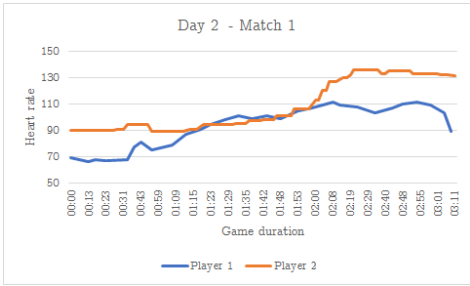


(b) Day 1, Match 3.

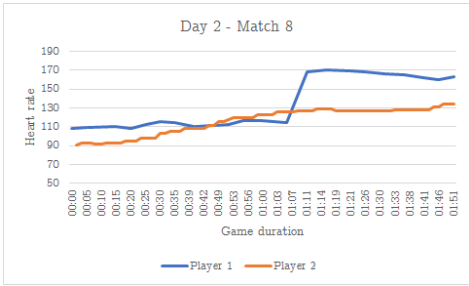


(c) Day 1, Match 4.

Figure 14.1: Results from day 1.



(a) Day 2, Match 1.



(b) Day 2, Match 8.

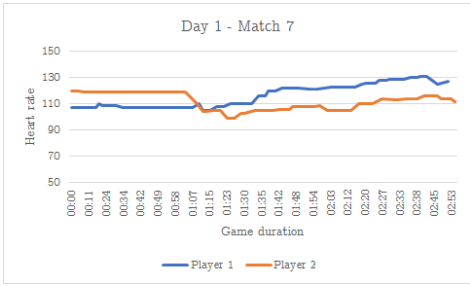
Figure 14.2: Results from day 2.

The results presented here show a great potential for the physical effects of Location Invaders. We had players who reached heart rates of over 150 BPM, which correlates to moderate intensity exercise, despite the short match duration.

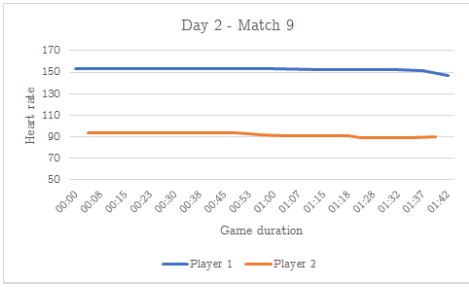
The graphs do not show any tendency towards interval training, but do show a general increase over the duration of the game, often ending or plateauing over 120 BPM, as seen in Figures 14.1 and 14.2.

As can be seen in Tables 14.1 and 14.2, generally the person with the higher intensity, higher heart rate and speed, won. However there are instances where this is not the case, indicating that the balance introduced by giving the losing player more power ups may have been successful.

Using the Fitbit Charge 2 to monitor HR did cause some issues. There were instances where the HR took several minutes before registering the HR and the matches could start.During day 2 there were problems with the Fitbit for player 1, which meant we fewer readings of the heart rate. This can be seen on the graphs as several small flat sections, such as Figure 14.2a. There also were several instances where the heart rate did not change for extended periods of time, as can be seen in Figure 14.3 and in Figure 14.1c. For the heart rate to stay this consistent, in some cases up to 1 minute, is very unlikely, and can be the results of the Fitbit not reading the HR correctly.



(a) Results from day 1 match 7.



(b) Results from day 2 match 9.

Figure 14.3: Poor heart rates from Fitbit.

14.1.2 Observations

The participants were all able to play the game, but we noticed that all players had issues with the accuracy of the GPS at some point during the matches, where several players expressed frustration about GPS both during the game and in conversations afterwards.

There were differences between how the players played the game, and different tactics were applied. Most players stood still for short periods of time while looking at the screen, before looking up and running fast towards where they needed to be, and slowing down and looking at the phone when they were close to their destination, while others were interacting with the application while running. Several participants expressed that you felt completely absorbed in the game, and there were numerous instances where players almost ran into the food station or ran past the end markers. The participants stated that the game reduced their attention to their physical surroundings, and these anecdotes support this.

The speed of the players changed throughout the matches and depended on the player. Some players had speeds ranging from sprinting to casual jogging, while some rarely speed up. Several players were out of breath and sweaty after the matches.

Most players sent space ships when running without looking at the phone or glancing at the screen. Others stood still while sending space ships and continued running, or stood

still for extended periods of time looking at the phone while sending the cheapest space ship.

During matches and the breaks the players showed enjoyment and engagement, cheering when they reached power ups in time or winning the game.

None of the players seemed to have issues with the phone or drop the phone. It was, however, expressed as a concern during conversations with players.

14.2 Questionnaire

The questionnaire was distributed to the participants via email, and every participant in the prototype testing answered. Due to the small sample size the participants age and gender has been withheld to ensure anonymity.

14.2.1 Part 1

Table 14.3 presents the findings from part 1. It shows the participants estimated weekly exercise hours and gaming hours, and whether they have experience with exergames. The participants worked out on average 3.5 hours in a week, and spent on average 6.3 hours a week playing games. Only one participant stated that they had experience with exergames, however, it is believed that there is a lack of understanding of what an exergames is. And therefore several players wrote no.

Participant	Exercise hours	Gaming hours	Exergame experience
1	1	2	No
2	0	28	Yes
3	6	5	No
4	7	10	No
5	4	1	No
6	3	1	No
7	0	10	No
8	4	2	No
9	5	2	No
10	3	6	No
11	6	2	No

Table 14.3: Results from Part 1 of questionnaire.

14.2.2 Part 2

For the presentation of the results in this section we have merged strongly disagree and disagree, and agree and strongly agree, to make the graphs clearer, and easier to spot trends in the data. For the full results see Appendix D.

Table 14.4 shows the median and mean response to statements, where strongly disagree, disagree, neutral, agree, and strongly agree has been assigned the values 1-5. The

Figures 14.4, 14.5, 14.6, and 14.7 show graphs of statements regarding enjoyment, motivation, engagement, and general statements. Finally Table 14.5 shows comments from the participants on the statements they have answered.

Statement	Mean	Median
I enjoyed playing the game	4.18	4
I was motivated to play the game before each match	4.55	5
I was engaged while playing the game	4.64	5
I was completely focused on the tasks of the game	4.45	4
I was so engaged in the game that I became less aware of my surroundings	4.45	4
The game difficulty was appropriate to my skill level	3.45	4
I was so engaged in the game that I became less aware of the physical activity	4.27	4
I was able to concentrate on what was happening during the game	4.55	5
The goal of the game was clear	4.45	5
I felt in control of what I was doing	2.73	3
I got sufficient feedback on my actions	3.00	3
I enjoyed the fantasy of the game	3.73	4
The genre of the game was appealing to me	4.09	4
Playing against a human opponent made the game more enjoyable	4.91	5
Playing against a human opponent motivated me to perform my best	4.64	5
I enjoyed comparing stats against my opponent after the game	3.64	4
I feel more motivated to workout by playing the game than doing interval training	4.27	5
I feel more motivated to workout by playing the game than going for a jog	3.64	3
I can see myself playing this game also after the test	3.91	4
I found the controls of the game was easy to use	3.55	4
I found this game easy to learn	4.27	4

Table 14.4: Mean and median results from statements.

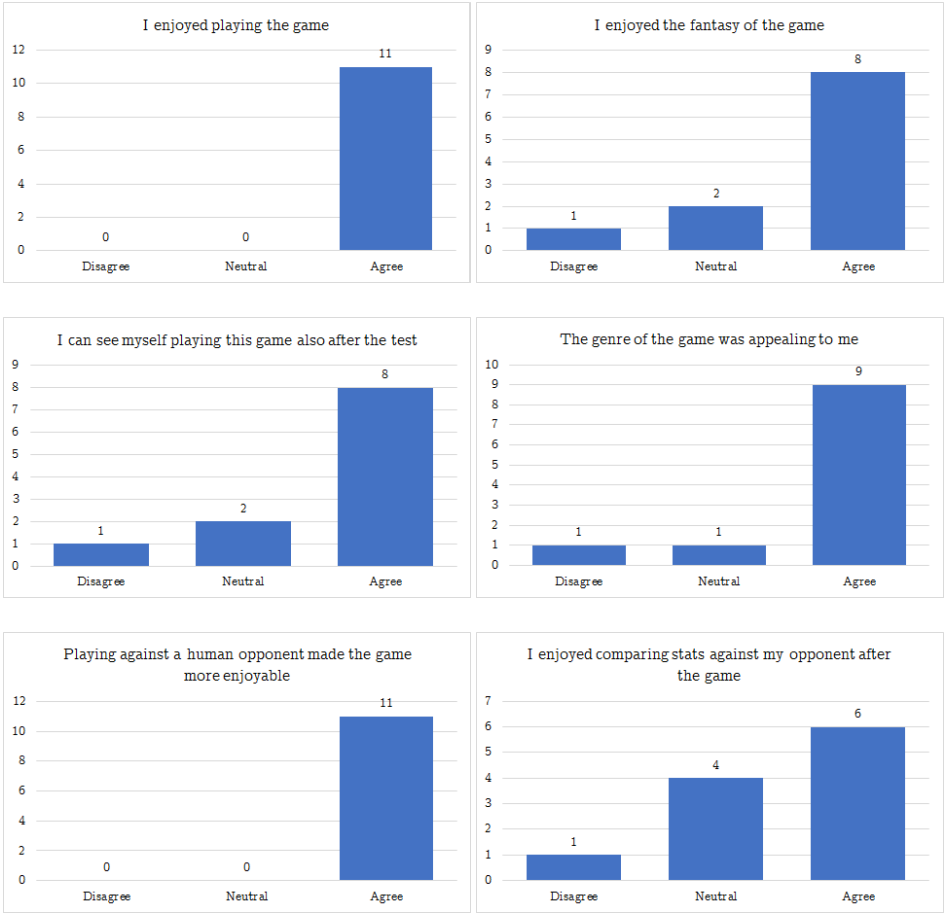


Figure 14.4: Statements regarding enjoyment.

Figure 14.4 shows the results from statements regarding enjoyment. The results show that the participants found the game enjoyable, with every player stating they enjoyed playing the game, and playing against a human opponent made it more enjoyable. The majority of player enjoyed both the fantasy of the game and the genre, and could see themselves play the game also after testing. Comparing stats with the opponent was enjoyed the least by players, however, the majority still enjoyed comparing stats.

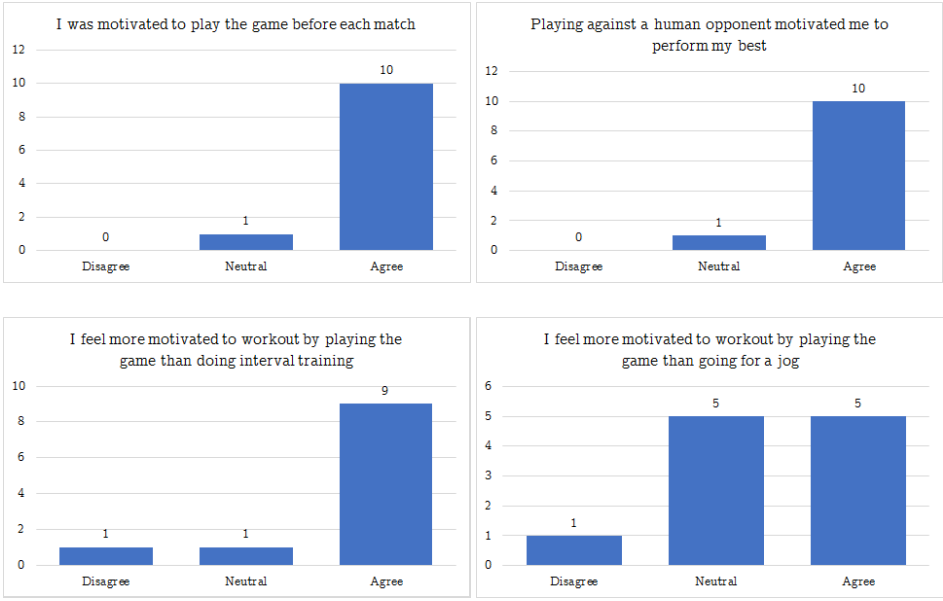


Figure 14.5: Statements regarding motivation.

Figure 14.5 presents the results from statements regarding motivation. The results are positive, with over 90% of the players stating that they were motivated to play the game before each match. Playing against an human opponent appears to be a motivator, with over 90% of the players stating that they felt motivated to perform their best because of this. Two statements looked at the motivation to play the game instead of going for a jog, or performing interval training. 81.8% of the participants stating that they were more motivated by playing the game than doing interval training, while 45.5% stating that they felt more motivated than going for a jog. Overall, we see that the players were motivated to a great degree.

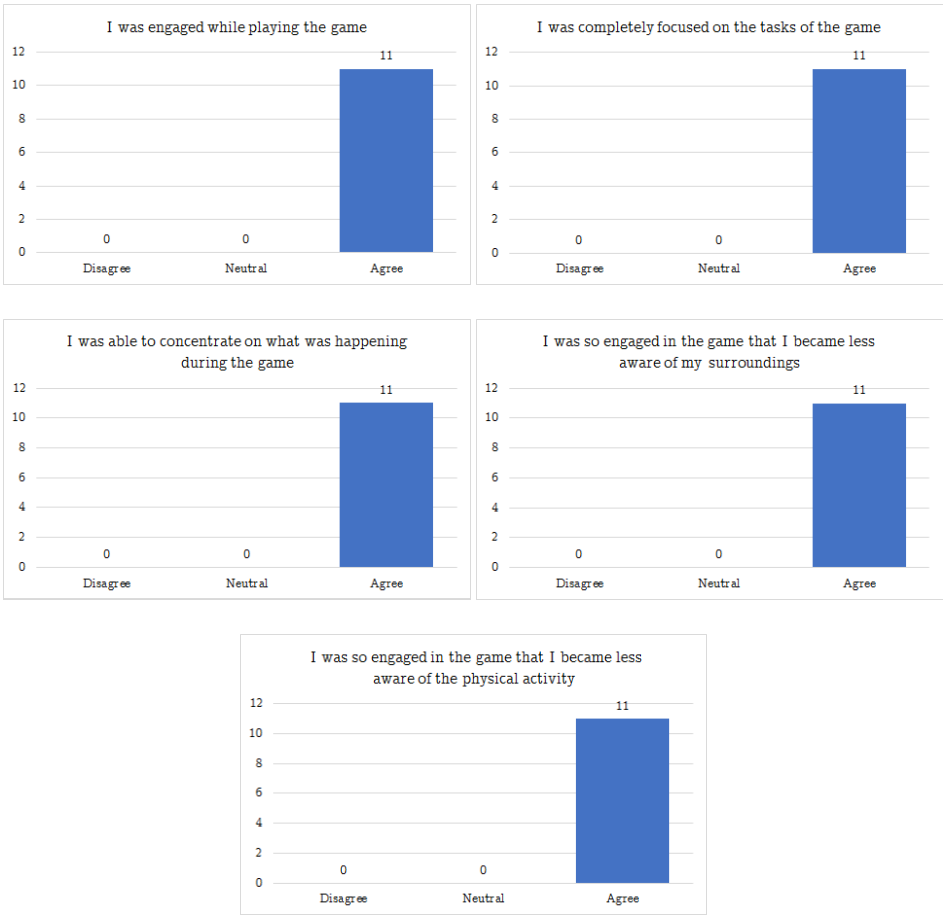


Figure 14.6: Statements regarding engagement.

Figure 14.6, shows the results from the statements regarding engagement. The results show that the game was immensely successful in engaging players, with all test participant agreeing with every single statement.

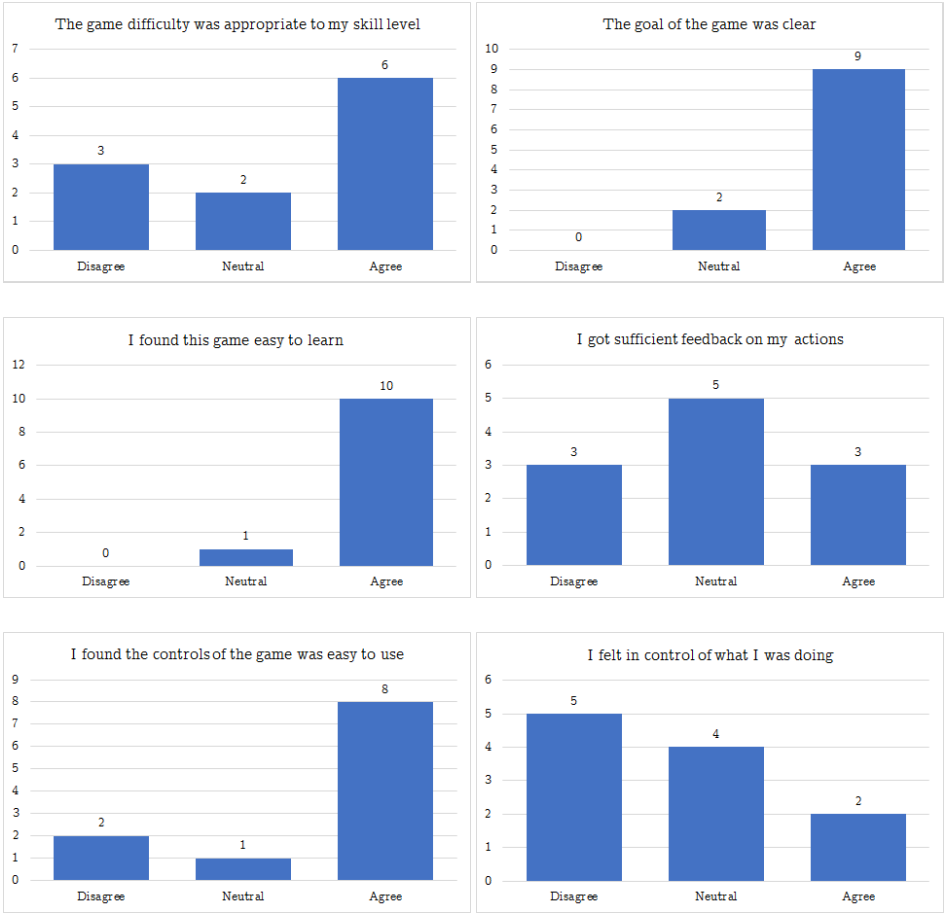


Figure 14.7: General statements.

Figure 14.7, shows the results from statements that were used to assess whether the player achieved a sense of flow while playing the game. The majority of players found the goal of the game clear, easy to learn, and found the controls easy to use. The games difficulty depends on the opponent, and while the majority of players found the difficulty appropriate to their skill level, several players disagreed. The statements regarding feedback and control were the two statements with the worst results. The majority of players did not have a sense on control while playing the game, and the players were mixed when it came to receiving sufficient feedback.

Only two participants wrote additional feedback in part 2.

Do you have any additional feedback on the statements you have answered?
Difficult because of slow and inaccurate GPS. (Translated)
Very interesting game 10/10.

Table 14.5: Comments from part 2.

14.2.3 Part 3

There were few responses in part 3 of the questionnaire, where we received 7 responses on ”Any comments regarding your playing experience with Location Invaders?”, 4 responses on ”Any comments regarding the Location Invaders game itself”, and 2 on ”Any general comments?”. This sections will present a selection of the comments we found valuable. For all the comments see Appendix D.

Any comments regarding your playing experience with Location Invaders?
The game was very engaging and fun to play. I really enjoyed it. There was however some issues with the GPS-tracking during testing. The accuracy was not as good as it should be. I think the game would be even more fun if the location tracking was smoother and more accurate. One thing that was somewhat frustrating was when trying to catch a power-up from the outer lanes, the GPS would continue to move after I stopped, causing me to be outside the playing field and miss the power-up. One should not be able to go outside the outer lanes to catch power-ups more easily. Perhaps making the power-up lanes infinitely wide outside of the game field would help?
The GPS was a bit annoying, but except from that the game was fun.
Sadly the bad GPS ruined some of the playing experience.

Table 14.6: Selection from question 1.

As presented in Table 14.6, several answers to question 1 mentioned the inaccuracy and speed of the GPS. It is clear that this caused trouble for several of the participants, affecting the enjoyment on the game. However, they still state that the game was enjoyable.

Any comments regarding the Location Invaders game itself?
Fun and engaging. Good idea and great implementation of an old classic to bring it back to life and fit today’s trends.
Fun game, if the GPS works. I can see people playing this game if the GPS works perfectly.
Awesome game, maybe some better feedback (vibration) when launching ships. Also, use additional inputs for distance measuring to mitigate lag

Table 14.7: Selection from question 2.

Table 14.7 present a selection of answers from question 2, where problems with the monitoring of physical location was mentioned yet again. The answers were positive to

the game itself. A participant also mentioned the need for better feedback when launching ships.

Any general comments?
Good test session. Great work. Wish we could play more so I could have revenge.
It was neat.

Table 14.8: Question 3.

The general trend on the questions in part 3 was that the game was enjoyable, but that the GPS caused frustration and a reduced enjoyment. Table 14.8 presents answers to the third question.

Chapter 15

Validity & Reliability

This chapter will discuss potential weaknesses for the validity and reliability of the data generated in this thesis.

15.1 Convenience Sampling

The test participants were recruited through convenience sampling, and came from the researchers own social circle. The use of convenience sampling means the results cannot be used for generalization for the target group, by the potential under representation of sub-groups in the sample compared to the target group as a whole, and the inferences drawn from the data collected should only be made for the sample itself.

15.1.1 Group Homogeneity

The test group consisted of 91% males, and 9% women, their age spanning from 22-26 years, making it a rather small subset of the target group, and a clear under-representation of women. Here the weakness of convenience sampling really manifests itself, and the data can obviously not be used for generalizations over the target group as a whole. Another thing to note is that every subject were fellow students at the Norwegian University of Science and Technology, making them quite tech-savvy, and above average in this respect. While the game itself is fairly simple and intuitive to grasp, this may have had an impact on the questionnaire responses.

15.2 Personal Familiarity

The fact that the test subjects personally knew the authors may have influenced the participants to answer the questionnaire favorably, and thus affecting the validity of the questionnaire. Mitigating this issue is not an easy task, but we explicitly encouraged the participants to answer as honestly as they could, explaining the importance of this for the validity

of the data collected. Furthermore, the questionnaire was answered anonymously, making it easier for the participants to answer truthfully. While these measures were taken to encourage objective feedback, the test participants familiarity with the authors may have had an impact on the data collected.

15.3 The Hawthorne Effect

The Hawthorne Effect, or Observer Effect, is an observed adjustment of a test participants behavior due to the mere fact the participant is being observed [90]. Since the participants knew they were being observed playing the game, they might have altered their behaviour as a result, for instance performing at a higher level than they would while playing unobserved. We have no way of correcting for this in the scope of this thesis, and this effect could have had an impact on the results.

Part V

Discussion

This part contains a discussion of the design and implementation of Location Invaders, the results from our user testing, and how this connects to our research questions.

Chapter 16

Game Design

A goal of this thesis was to research what game mechanics can be used in exergames to increase motivation, and promote physical activity, as presented by:
RQ1: How can exergames motivate/promote physical activity?

The prestudy uncovered several mechanisms and characteristics for what constitutes a rewarding activity and how this relates to games and exergames more specifically, which is discussed in Chapter 5. These mechanisms include challenge, fantasy, curiosity, flow, GameFlow, and DualFlow.

In order to develop an exergame that could help promote an active lifestyle and adherence to exercise, as well as being enjoying, motivating, and engaging, these mechanism heavily influenced the game design of Location Invaders, as presented in Chapter 8.

While the aforementioned mechanisms ensured that the game consisted of elements that previously have shown to positively affect the users enjoyment of games, exergames are still an relatively early stage, and it is therefore quite possible that several insights in regard to the design of such games are waiting to be discovered, and was therefore not available to us. How the chosen mechanics affected the player experience is discussed in Chapter 19

The scope of this thesis also set restrictions on the amount of feedback that was available to us as the game was implemented, and as features was added they were mostly tested by the authors, these features may have been perceived differently by the target group.

Chapter 17

Technology

One of the goals of this thesis was to identify suitable technologies for exergames, as presented by:
RQ2: What technologies are suitable for use in exergames?

This was done by studying existing exergames and technologies used. Based on our findings and what was available to us, we chose what technologies to use for our game. These technologies were one of the aspects of the developed game we evaluated during testing.

Location Invaders was developed for Android, and used GPS to track player movement. Using a smartphone as a platform for exergames proved appropriate. They are widely available, fairly easy to develop for, as well as having powerful computational power. They also contain several sensors, such as GPS, accelerometers and proximity sensors, that can be used to track physical movement.

Developing an exergame using the chosen technologies was generally uncomplicated. Android and Google Maps API are well documented and as they are widespread there exits several resources online containing examples, guides, and tutorials. Google Maps also contains several built in tools that were useful for the game, for example we used polygons to create the physical game area and determine where the player was located in the real world, and in turn used this to translate this into the game.

Developing a game where the players had to hold the phone in their hand while running raised some concerns. There were concerns of the players dropping the phone while playing, and whether the players could get a good overview of the current game state and press the correct buttons with such a small screen. Getting an overview and pressing the correct buttons also had to be done while minimizing the amount of time required looking at the screen.

Concerns of dropping the phone were also expressed by the players during testing. However, there were no instances where players dropped the phone, and playing the game on grass did minimize the chance of damaging the phone if it were to be dropped. The likelihood of dropping the phone can also be minimized by using phone case that gives more grip, which also will give protection to the phone if it were dropped.

To decrease the time needed to look at the screen we designed the game to only show crucial information on-screen and exchange buttons with gestures. Despite the small screen, the players were able to get an overview of the game state, with a 100% of players stating that they were able to focus on the tasks of the game and concentrate on what was happening during the game. Exchanging buttons with gestures was successful, but can be improved. 90% of the players found the game easy to learn 70% found the controls easy to use, while 18% found them difficult to use.

A critical part of exergames is tracking player movement, and using the GPS for Location Invaders did not work optimally. In Location Invaders the GPS accuracy, speed, and consistency are crucial, and for most matches this caused issues. 46% of players did not feel in control of the what they were doing, 36% were neutral, and only 18% felt in control. The accuracy and lag of the location tracking was also one of the main concerns mentioned in the comments in the questionnaire, being mentioned in 10 out of the 15 comments received. Several stated this had a detrimental effect on the enjoyment of the game.

It is possible the inaccuracy and speed problems of the GPS can be omitted by increasing the width of the playing area or decreasing the number of game grids. Doing so will in turn increase the width of each game grid, which during testing was too small. It is also possible to make assumptions when using the GPS, such as looking at the speed and direction of the current GPS-location to predict where the player is moving, but this is not something we were able to implement at this time.

We did not measure the game area before we started testing, and it only had a width of about 25 meters. The game was setup to have 8 game grids, and therefore the width of each game grid was approximately 3.1 meters. GPS in smart phones is typically only accurate to a 4.9 meter radius, as discussed in Section 4.1.1, making the width of the grid too small.

Without further testing with a larger game area, it is not possible to make a definitive conclusion whether the GPS is unsuitable for Location Invaders.

Chapter 18

Physical Effects

Another goal of this thesis was to determine the physical effects of playing the game, formulated as RQ3 and RQ4:

RQ3: What degree of physical activity does our game support?

RQ4: How well does the chosen game mechanics and genre allow for high-intensity interval training?

To ascertain the physical effects we used method triangulation, and measured the test participants' heart rate, distance moved, and speed.

The heart rate was measured using Fitbit Charge 2 (FC2), and did pose several issues. As discussed in Section 13.2, the FC2 has a tendency to underestimate the actual heart rate. There were also several instances where the FC2 did not seem to register a change in heart rate leading to long periods of time where the heart rate stayed the same.

We measured an average heart rate of $107.1 \pm 17.7BPM$, and the average max heart rate for each match was $62.1\% \pm 14.2\%$ of HR_{MAX}. This means the physical activity reached a low exercise intensity. However, some participants did reach heart rates of over 140 BPM. The results are promising, as the duration of the matches was short and the heart rate was generally rising throughout the game.

The distance moved during the game was logged by calculating the distance between the newest GPS location and the previous, and adding it to the running total. This distance is most likely an underestimation as the game required the players to run back and forth. For example if a player runs from point A to point B, and back to point A, but the GPS only updates when the player is on point A. If this happens the game registers that the player did not move.

The speed was calculated by measuring the distance from the newest GPS point with the second newest, and using the time difference between them to calculate speed. However, as the GPS is inaccurate, is can cause the GPS point to "jump around" creating sections of high speeds that does not correspond with real life. Because of time limitations, we were not able to correct for this issue and makes the speed results somewhat unreliable.

During the prototype testing we observed the play style of the participants, noting that most of the time the players were jogging slowly or standing still while sending space

ships. There was shorter burst of sprinting when the players wanted to pick up power-ups or to stop the opponents space ships from hitting their base. Although a strategy we saw a couple of times were players continuously spamming the cheapest unit, standing still in a lane while regenerating energy. We also observed that players were out of breath after each match, and many had broke a sweat.

From the results we can see that the game support a varying degree of physical activity, based on how the game is played. The heart rate generally had a steady increase during matches, and as the players played two sets of two consecutive matches, the heart rate data shows that the heart rate in most cases was higher during the second game. This indicates that if the matches were longer or more consecutive matches were played, the heart rate may have been higher. There were 30 instances where players ended a match with a heart rate over 110, and 19 where player ended the game over with a heart rate over 120.

Whether or not the game suits high-intensity interval training is dependent on how the players play the game. As we can see from the achieved heart rate the players did not achieve a high exercise intensity at any point in the games. We also see from the graphs that the heart rate increases as the game goes on, and does not allow for periods of restitution. However, it is possible if the matches had an increased intensity, the down-time between matches could be used for restitution.

It is clear that the game did not induce a high enough physical demand in itself, and the physical toll was mostly based on the players willingness to extort them selves. This is also the case when it comes to regular exercise, but in hindsight we can see that there are some ways of enforcing a higher physical demand, for instance by increasing the size of the playing area, forcing the players to run larger distances. The issue of players spamming units could have been mitigated by rewarding the players with new energy if they moved around, or only enabling them to send a fixed number of unites in a lane at the same time, forcing them to move between lanes in order to be efficient. We could also have made the units move faster, so that the players had less time to move from lane to lane in order to defend their base. Finding the right balance here is tricky, but improvements here are probably possible.

DualFlow splits the game experience in two parts, attractiveness and effectiveness. Attractiveness can be modelled by flow, and effectiveness models the balance between fitness and exercise. Having an imbalance between intensity and the players fitness can cause the player to fail if the intensity is to high, or to have no effect if the intensity is too low. We did not have any statements regarding perceived intensity and exercise, but we had statements about becoming less aware of the physical toll of the game and the game difficulty.

100% of players became less aware of the physical toll of the game, 55% of players found the game difficulty appropriate to their skill level, while 37% disagreed. The difficulty of the game is dependent on the skill of the opponent, and their physical fitness. This means that the intensity of the game may change depending on the opponent and the players drive to win, which may affect DualFlow.

Based on the results, the game may achieve some degree of DualFlow. However some more testing may be required to find out how balanced it is, and whether the intensity is high enough to have some benefit.

Chapter 19

User Experience

One goal of this thesis was to evaluate the users' experience with the developed exergame, and if the game achieved some form of flow. The 3 related RQs are:

RQ5: How does the game affect the players motivation?
RQ6: How does the game affect the players engagement?
RQ7: How does the game affect the players enjoyment?

19.1 Motivation

The questionnaire included five statements regarding motivation, and encompassed the motivation for playing the game, how this motivation compared to conventional exercise, and how competition affected motivation. The results show that the motivation of the players was high. 91% of participants were motivated to play before each match, and were motivated to perform their best because of the human opponent. One participants stating in the comments that he wish he could have played more to get "revenge". 73% of players could also see themselves play this game after testing.

Compared to conventional exercise, the results were mixed. 80% of participants found playing the game more motivating compared to conventional interval training. 9% were more motivated to workout with jogging, while the remaining participants were split between neutral or finding the game more motivating.

This bodes well for using this game for exercise, as a replacement or as a accessory in a regular exercise routine. We lack deep insight into what the players found motivating, except that the players found competing motivating. The general motivation to play may also come from solely the enjoyment of the game.

The prototype testing did not include interaction with the high score list or the badges functionality of the game. This is something that should be included in further work.

19.2 Engagement

To examine the participants engagement we presented five statements regarding engagement, focus, and concentration in the questionnaire. The results show a high degree of engagement from the players, with a 100% of players stating that they felt engaged, were able to focus on the tasks of the game, and concentrate on what was happening in the game.

All the player also stated that they became less aware of their surroundings, and this was also corroborated by observations during testing as there were several instances of players almost running into the food setup, or a nearby tree. They also became less aware of the physical activity required of the game. This is an important aspect of GameFlow, which is discussed in Section 19.3.

Having players be less aware of their physical exertion is important in exergames, as it allows for higher intensity physical activity without diminishing the enjoyment of the game.

19.3 Enjoyment

Enjoyment is arguably the most important part of playing games, and we had several statements measuring the players enjoyment of Location Invaders. GameFlow is a model to evaluate player enjoyment, and we included statements to assess whether the players achieved a sense of GameFlow. The GameFlow model consists of eight parts: concentration, challenge, control, clear goals, feedback, immersion, and social interaction.

The participants all stated that they enjoyed playing the game, and 73% of players stated that they could see themselves play the game on a later date. The enjoyment of the participants were high, as all players stated that they enjoyed playing the game and found that playing against a human made it more enjoyable. Over 80% of the players found the genre appealing, and over 70% enjoyed the fantasy of the game and could see themselves play the game on a later date. Only 50% of players enjoyed comparing stats with the opponent after the game. The statistics presented after the game were not always highly accurate, and this may have affected the enjoyment.

In the comments in the questionnaire several players stated that the GPS affected the enjoyment of the game, however this was not reflected in the statement *I enjoyed playing the game*. This may be because the participants knew the researchers and answered more positively on the questionnaire, or that the game experience was enjoyable nonetheless. This may also be an explanation in the discrepancy between players enjoying the game and players seeing themselves play the game on a later date. That all players stated that they enjoyed the game may also have been different if the players were playing a finished product and not a prototype.

Immersion and concentration are discussed in-depth in Section 19.2 and are both important parts of GameFlow. 100% of players agreed that they were able to focus on the tasks of the game, and concentrate on what was happening during the game. 100% of players were immersed, becoming less aware of their surroundings and the physical exertion. This is also shown by the players almost running down the food station.

The results for whether the game had an appropriate skill level was mixed, with 27%

of players feeling the skill level was inappropriate while 55% felt it appropriate. As this is a multiplayer game, the challenge of the game is dependent on the opponent, and thus is not easily controlled. We did however try to make strategy an important part as well, but physical fitness is very important and one should probably play against someone with a somewhat similar level of physical fitness. We did not have any statements regarding supporting skill development, as this requires testing over a longer period of time. But 91% of players found the game easy to learn.

Control is an important part of GameFlow, and while 73% of players found the controls easy to use, only 18% felt in control of what they were doing, and 46% did not. The lack of control can most likely be attributed to the inaccuracy and speed of the GPS, as this was mentioned by most in the comments. This lack of control has a negative effect on the flow achieved, while playing the game.

Receiving appropriate feedback is important, and the results from the questionnaire shows the feedback was insufficient. 27% of players did not feel they received sufficient feedback, and 46% were neutral. Part of this can be explained by a bug in the game, where one of the phones used during testing would randomly stop giving feedback during games. In addition to visual feedback, such as seeing units being sent on the screen, the game also used audio and tactile feedback in the form of sound effects and vibration. It is likely this feedback was to weak, as hearing the sounds from the phone and feeling the vibration while running may be hard.

Clear goals is another aspect of GameFlow. This requires that the game has a goal, or goals, that are clear to the players. In our game 82% of players found the goals of the game clear, and 18% were neutral. No players found the goals unclear, which is beneficial to the achievement of GameFlow.

The game provides social interaction through competition, chat, and high score lists, however we only tested the competition aspect, and a 100% of players enjoyed the social interaction, and 91% became more motivated because of their opponent. The game is very social, as it requires the players to meet in person to play, and i contains an in-game chat where they can arrange meetings to play the game.

Based on the results we can see that the players did achieve some sense of flow, although it is difficult to say to what degree. There are also several weaknesses in the game that diminishes the sense of flow, where the biggest detriment is the lack of control caused by the inaccurate GPS.

Part VI

Conclusion

This part will presents our conclusions drawn from the discussion in Part V. We also present a project evaluation, discuss the contribution this thesis has made, before finally an giving an overview of potential further work.

Chapter 20

Conclusion

In this thesis, the main goal was to create an accessible game that promotes physical activity, and measure the effects of the activity induced, as well as how the game affected the users enjoyment, engagement, and motivation. We also investigated what technologies and game mechanisms that were suitable for exergames. To aid in this process we developed seven research questions that we wished to answer. In order to do this, we first performed a prestudy where we looked into the effects of physical inactivity, exercise theory, existing technologies used for exergames, game mechanics, as well as the history of exergames and existing exergames. We then developed an exergame based on the findings from the prestudy, and finally evaluated the implemented prototype. The findings from both the prestudy and the tested prototype enabled us to answer the formulated research questions.

RQ1: How can exergames motivate/promote physical activity?

In the theoretical foundation put forth in the prestudy, see Chapter 5, we identified several mechanisms that had been shown to have an effect on the players enjoyment in games. For an exergame to be able to motivate and promote physical activity it is clear that the game must actually be something the players would want to play, and to achieve this the game must be fun and enjoyable. According to Malone, the characteristics of an enjoyable game can be divided in three categories, *challenge*, *fantasy*, and *curiosity.* An activity that induces a sense of *flow*, a loss of a sense of self,sense of time and space, leads to full involvement and enjoyment in the activity. The flow state has been mapped to fit in an exergame setting through the *GameFlow* and *DualFlow* models, which introduces several heuristics in the creation and balancing of an exergame in order for it induce a sense of flow. An important insight here is the added dimension of effectiveness, which models the physical balance between fitness and exercise. Therefore, in order for an exergame to motivate/promote physical activity it should provide the user with a challenge, through the use of fantasy and by inducing the players curiosity. The game should also induce a sense of flow, by incorporating the insights presented in the GameFlow and DualFlow models.

RQ2: What technologies are suitable for use in exergames?

To answer this question we reviewed existing exergames and technologies, chose technologies to use in our exergame, and evaluated the chosen technologies with user testing.

Smartphones are a technology well suited for use with exergames. they are widespread, lightweight and portable, as well as having great computational power. They also contain several sensors that can be used for motion tracking, such as GPS, accelerometers, and proximity sensors.

GPS is a very suitable technology for use in exergames, and has been used in successful games such as Zombies, Run! and Pokémon Go. It allows for tracking player movement everywhere, making the entire world a potential playing field.

The GPS in smartphones does have some limitations. The accuracy and speed is lacking, making it unsuitable for games where this is key. For use in Location Invaders, more testing is required to make definite conclusions, as the game area can be made larger and in this manner downplay the importance of the GPS accuracy. It is also possible to use the speed and direction of the player to predict where the player will be next. However it does appear unsuitable at this time.

RQ3: What degree of physical activity does our game support?

The results indicate that in its current state the game supports low intensity physical activity. There were instances were the heart rate of the participants reached heart rates corresponding to moderate intensity. While the results show that the intensity of the physical activity was low, this physical activity is still more beneficial than compared to regular games.

More testing should be performed to investigate higher intensities, as the intensity is affected by how the player plays the game and the player's drive to win. Modifications to the game design can also be done to increase the incentives to perform at a higher intensity, as well as enforcing this through various methods, as presented in Chapter 23.

RQ4: How well does the chosen game mechanics and genre allow for high-intensity interval training?

We wanted the game to allow for high-intensity interval training (HIIT), and strove to implement that in the game design. To answer this question we measured the participants heart rate during the prototype testing, and compared this to their calculated HR_{MAX} to estimate the exercise intensity. We could also see if their heart rate followed a interval pattern with periods of high intensity and periods of low intensity.

The game in its current state does not seem to allow for high-intensity interval training. The main reason of this is that the results from the testing show that the intensity reached during play corresponds to low-intensity exercise. There were also no interval patterns to be seen in the heart rate results.

During testing we did observe several changes in pace, ranging from standing still to a full on sprint, but these periods were for short periods of time and randomly dispersed throughout the matches. This may indicate that it is possible the genre and game mechanics can allow for HIIT, provided some changes in the game design. The Fitbit measurements have been shown to somewhat underestimate the readings, and tests with more accurate heart rate monitors may provide somewhat different results.

However, if the game was played at a high enough intensity level, it is possible to allow for HIIT as the game is now. Players could play several matches in a row, and use the time between matches as a recovery period.

RQ5: How does our game affect the players motivation?

We found that the game had a positive effect on the players motivation. The players were motivated to play and perform their best, and could see themselves playing the game in the future. Players were also more motivated to play this game compared to traditional high-intensity interval exercise, while the results were mixed when comparing the game with conventional jogging.

The social aspect of the game had a positive effect on the participants' motivation, however further research should be done to investigate the effect of other aspects of the game.

RQ6: How does our game affect the players engagement?

The game was immensely successful in affecting the players engagement in a positive way, with all the players stating that they felt engaged during the game. All the participants also answered that they were able to focus and concentrate on the tasks of the game. This is further cemented by every participant stating that the game made them less aware of their surroundings.

RQ7: How does our game affect the players enjoyment?

The results from the user testing show that the game was enjoyable to all players, and they enjoyed the social aspect of the game. The majority of players could also see themselves play the game on a later date. The choice of genre was successful, as most players enjoyed it. This indicates that arcade-like games may be a suitable genre for exergames.

The game was also successful in creating a sense of flow in the players, despite factors such as a lack of control and feedback diminishing it.

Summary

The results from the user testing show that we have been able to create a game that is enjoyable, engaging, and motivating, while allowing for physical activity. Although there are several ways to improve both the user experience and the physical activity, the game has great potential and we are pleased with the results.

Chapter 21

Project Evaluation

In this thesis, we used the research strategy design and creation presented in the book Researching Information Systems and Computing [8]. The project started with a prestudy where we acquired valuable knowledge about the current state of the fields of exergames, exergame technologies, game mechanics, and physical activity. This knowledge was used in the design and development of Location Invaders.

Using design and creation worked well for this project, as it fit the project description and one of the advantages of design and creation is that it produces something tangible. In this case the game Location Invader, and this suited the authors perfectly.

However, there are several disadvantages with using this strategy, such as justifying why it is research and not regular development. It is also required to have the necessary technical skills, however this was not a problem for the authors. Other disadvantages are that it can be difficult to generalize the results from the use of an IT artifact, in this instance Location Invaders, in a single situation to different settings, and the success of the artifact may depend on the researchers being present. Generalizing the results from the user testing is not possible because of the small sample size, but they can uncover trends.

To assess whether the results from the user tests was affected by the presence of the researchers, the game should be tested without them present. To minimize the effect of this, the questionnaire was answered without the researchers present, and completely anonymous.

After analyzing and discussing the results from the questionnaire, we have discovered that there are statements that could have been formulated better, replaced, or added. This could include getting insight into what aspects the players enjoyed the most, what motivated them the most, their perceived physical exertion and how they would compare playing the game and conventional exercise with regards to physical effect.

The development phase of the project went well. The use of Trello allowed us to have an overview of the different tasks and their progress, and distribute the different tasks between the authors, where one had responsibility of the back-end, and the other the main game function. Throughout the development we performed code reviews and continuously tested new functionality.

We have also had several meetings with our supervisor throughout the process, providing us with invaluable feedback and good ideas.

Chapter 22

Contribution

This thesis has presented the design and implementation of the exergame Location Invaders, with the goal of creating a motivating, enjoyable, and engaging exergame accessible to a broad audience. Location Invaders has been heavily influenced by the game mechanics found in the prestudy, and it has been shown how these game mechanics have been incorporated in the game design.

The game has been tested and evaluated both in regard to the players motivation, enjoyment, and engagement, as well as the physical activity Location Invaders was able to induce. We have identified strengths and weaknesses in regard to the game itself, the technologies it is based upon, and the amount of physical exertion it enables. The most notable contribution is an exergame which is enjoyable, engaging, and motivating, and capable of inducing some form of endurance training.

Further, the thesis has uncovered several suitable technologies that can be used in an exergame setting. The thesis has also shown that the GPS chips in an average smart phone does not support an exergame focusing on rapid changes in location, as the chips does not detect movements fast enough, or track the location with the accuracy needed.

While the game still has room for improvement in regard to the physical activity it supports, we have presented a solid groundwork for an exergame that can be used as a as a replacement or as a accessory in a regular exercise routine, and help motivate the players to a more active lifestyle.

Chapter 23

Further Work

From the user testing we uncovered several areas in need of improvement, most notably is the inaccuracy in the location tracking, as this lead to a severe decline in the user perception of the game, causing frustration among the participants. New GPS chips are soon available with an accuracy of about 30cm, we are therefore confident that this issue will be resolved solely by technological progress, with no needed changes to the code.

A natural next step is also to test the game on a greater sample size, in order to validate the findings we have seen so far. This will also provide data that can be extrapolated for a wider group, providing vital data for the user experience among a more representative selection of players. This could also allow testing different aspects of the game, such as the high score lists and badges, and the long term effects of the game.

The subsequent tests should use a more accurate and responsive heart rate monitor, which will give an improved insight into the physical effects and exercise intensity provided by the game. Performing tests with different game area sizes can show how this affects the physical effects, and how it can be tailored for players of different physical skill levels. A more extensive questionnaire and using interviews can give deeper insight into the different aspects of the game. More specifically what the players found motivating, enjoyable, and engaging.

Another possibility for future testing, is doing experiments where Location Invaders is tested alongside other exergames. This enables us to compare the effects of the game with other exergames, how the physical effects differ, and how the aspects of the different games affect the playing experience.

As for the game itself there are several areas we would like to improve:

- Refactor game activity. Allowing for more modifiability and readability.
- add more units, enabling the players to utilize a greater range of strategies.
- improved graphics and sound effects.
- adding user levels, where they gain new levels by earning experience.
- enabling players to challenge friends to a game.
- adding push notifications for actions in the game, such as receiving a message, or being challenged to a game

- add in-game shop, where the players can buy units, skins, game modes and so forth with the in-game currency they earn.
- adding a cooperation mode, where two or more players can play together against an artificial intelligence.
- adding a team mode, where two teams play against each other.

The iOS market is also of interest, and developing an application for the iPhone would make the game available to a greater user base.

The work mentioned here is extensive, but we consider it vital for creating a game users would actually play, and being able to produce a commercial product. Substantial work is therefore required before this can be achieved.

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Appendix

Appendix A

Test Participant Agreement

Purpose
The purpose of this research is to evaluate an exergame prototype as part of a master's thesis at the Department of Computer and Information Science at the Norwegian University of Science and Technology.

Test Process
The study will consist of a playthrough of our exergame, during which the participant will be wearing a Fitbit Charge 2, which will be collecting data about the participants heart rate, distance, floors climbed, calories burned, and exercise stats. After the playthrough the participants will be asked to answer a survey which will be sent out per email.

Test Data
The data collected in the study will be anonymous, with no way of tracing the data back to the test participant. A summary of the data gathered will be presented in our master's thesis.

Voluntary Participation
It is completely voluntary to participate in the study. You can choose to withdraw from the study at any time without a need to provide a reason for doing so.

I have read the information contained in this document, and I agree to participate in the study.

. . . . . .
Signature, Location, Date

Appendix B

Questionnaire

Location Invaders feedback

The purpose of this questionnaire is to get feedback on your experience playing Location Invaders during the user testing you participated in on the 14th or 15th of April for our masters thesis at NTNU.

The questionnaire starts with some basic demographic questions and general questions about your relationship with exercise and games. Then it moves on to more specific questions and statements on your experience playing Location Invaders.

Please answer the questions/statements as truthfully as you can, as this is essential to the validity of the data collected. Your answers are completely anonymous, and can not be tracked back to you.
The completion of this questionnaire is voluntary and you may withdraw at any time.

Thank you for your time!

*Må fylles ut

Gender *

- ○ Male
- ○ Female

Age *

Svaret ditt

Figure B.1: Questionnaire part 1.

Approximately, how many hours do you exercise on an average week?

Svaret ditt

Approximately, how many hours do you spend on games on an average week?

This includes video games, computer games, mobile games, and browser games.

Svaret ditt

Do you have any experience with exergames?

Exergames are games that incorporate physical movement/exercise as part of the game experience.

- ○ Yes
- ○ No

If yes, which ones?

Svaret ditt

NESTE

Figure B.2: Questionnaire part 1.2.

Location Invaders feedback

*Må fylles ut

Experience playing Location Invaders

Answer these statements based on your own experience playing Location Invaders *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I enjoyed playing the game	○	○	○	○	○
I was motivated to play the game before each match	○	○	○	○	○
I was engaged while playing the game	○	○	○	○	○
I was completely focused on the tasks of the game	○	○	○	○	○
I was so engaged in the game that I became less aware of my surroundings	○	○	○	○	○
The game difficulty was appropriate to my skill level	○	○	○	○	○
I was so engaged in the game that I became less aware of the physical activity	○	○	○	○	○
I was able to concentrate on what was happening during the game	○	○	○	○	○

Figure B.3: Questionnaire part 2.1.

The goal of the game was clear	○	○	○	○	○
I felt in control of what I was doing	○	○	○	○	○
I got sufficient feedback on my actions	○	○	○	○	○
I enjoyed the fantasy of the game	○	○	○	○	○
The genre of the game was appealing to me	○	○	○	○	○
Playing against a human opponent made the game more enjoyable	○	○	○	○	○
Playing against a human opponent motivated me to perform my best	○	○	○	○	○
I enjoyed comparing stats against my opponent after the game	○	○	○	○	○
I feel more motivated to workout by playing the game than doing interval training	○	○	○	○	○
I feel more motivated to workout by playing the game than going for a jog	○	○	○	○	○
I can see myself playing this game also after the test	○	○	○	○	○

Figure B.4: Questionnaire part 2.2.

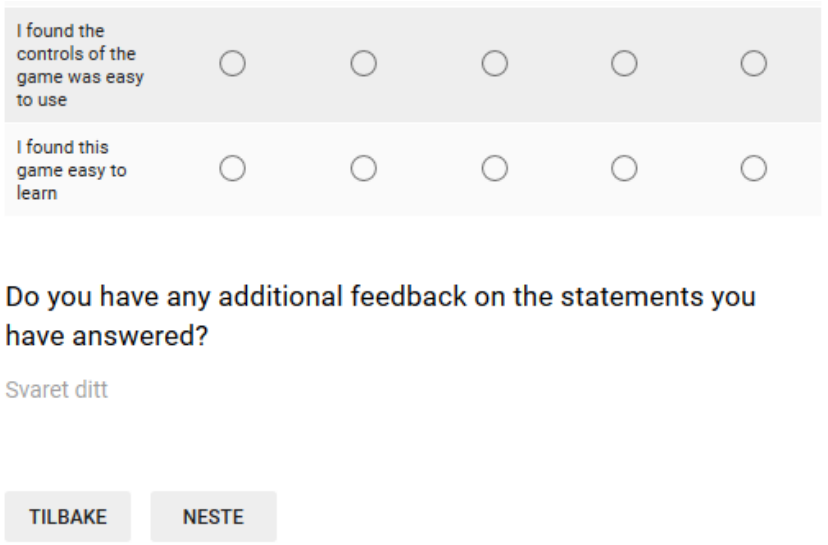


Figure B.5: Questionnaire Part 2.3.

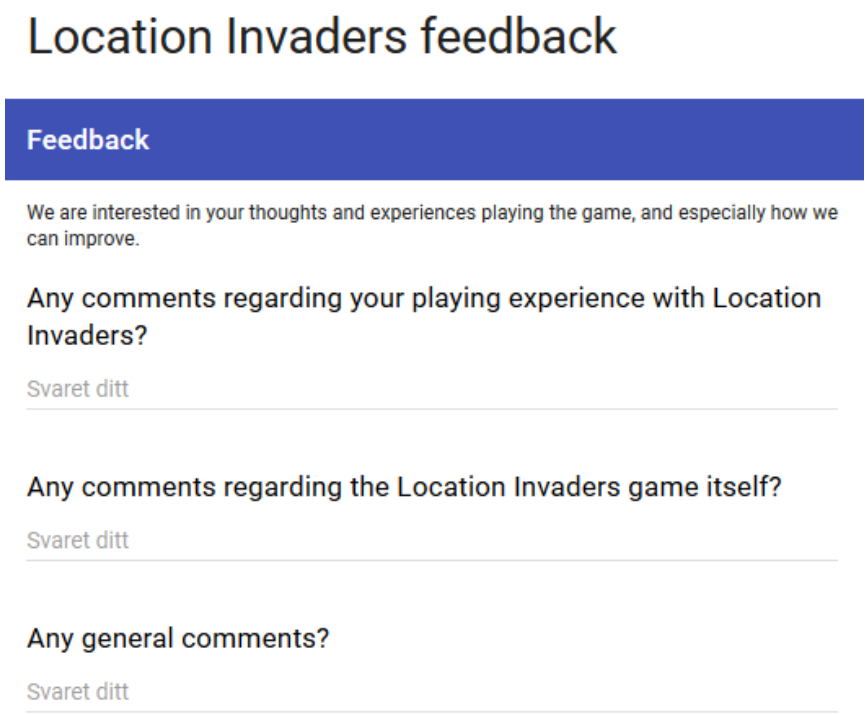


Figure B.6: Questionnaire Part 3.

Appendix C

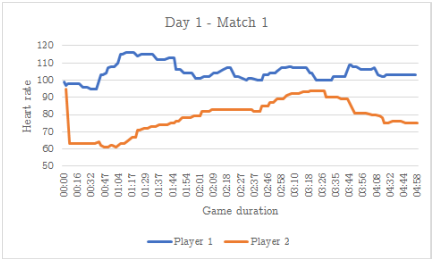
Heart Rate

Match	Player	Min HR	Max HR	Avg HR	Median HR	Duration
1	1	95	116	104.86	104	04:58
	2	61	94	79.21	81.5	
2	1	95	141	122.68	135	03:58
	2	59	124	100.65	112	
3	1	74	119	97.84	101.5	02:57
	2	87	115	102.18	100	
4	1	93	148	112	115	02:58
	2	84	134	107.68	109	
5	1	96	133	111.83	109.5	02:56
	2	77	127	103.66	106	
6	1	105	120	113.78	114	01:59
	2	103	124	112.82	112.5	
7	1	105	131	116.39	116	02:55
	2	99	120	111.51	111	
8	1	97	141	122.19	122.5	04:16
	2	76	117	83.37	78	

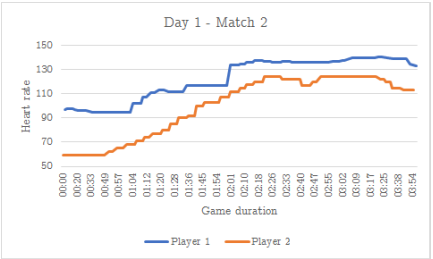
Table C.1: Results from Day 1.

Match	Player	Min HR	Max HR	Avg HR	Median HR	Duration
1	1	66	111	93.37	99	03:11
	2	89	136	107.71	97.5	
2	1	90	102	96.41	96	01:38
	2	106	144	120.70	120	
3	1	87	137	110.54	107	04:18
	2	94	112	103.54	103	
4	1	85	130	104.82	102	03:23
	2	105	117	112.69	114	
5	1	74	121	94.26	90.5	03:27
	2	85	116	100.97	101	
6	1	99	127	116.25	120	01:59
	2	108	127	116.49	117	
7	1	83	119	98.86	100	01:55
	2	88	115	98.43	98	
8	1	108	170	135	116	01:51
	2	91	134	116.75	123	
9	1	147	153	151.9	152.5	01:42
	2	89	94	92.24	93	
10	1	89	113	99.6	99	05:02
	2	117	149	135.51	140	
11	1	88	127	109.31	111.5	03:29
	2	85	107	95.78	97	
12	1	101	112	105.36	105	01:20
	2	88	98	94.25	94	
13	1	91	111	99.14	97	01:57
	2	82	97	90.63	93	
14	1	70	131	117.80	121	06:05
	2	88	104	96.84	96	

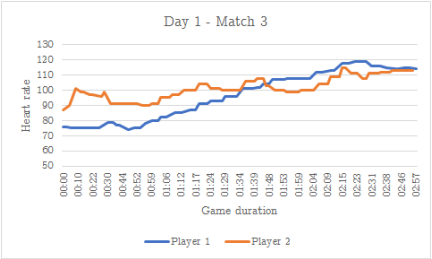
Table C.2: Results from day 2.



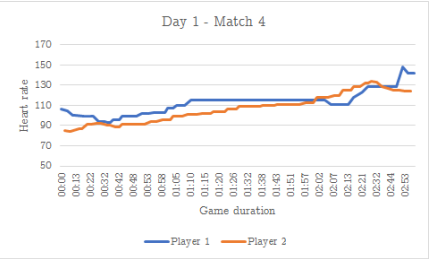
(a) Match 1.



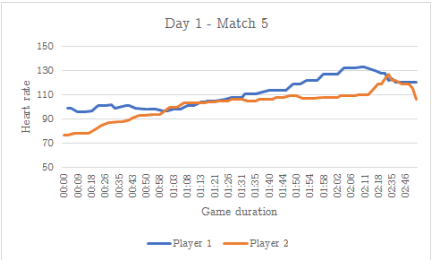
(b) Match 2.



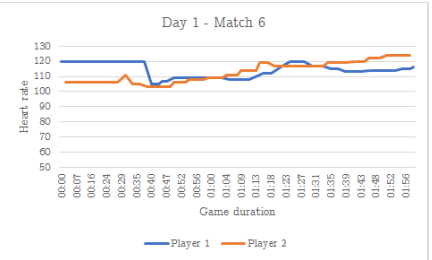
(c) Match 3.



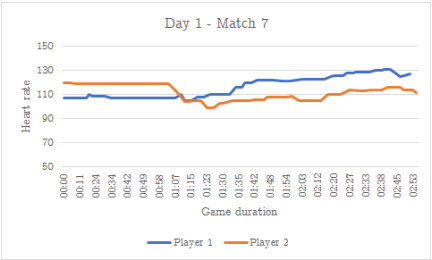
(d) Match 4.



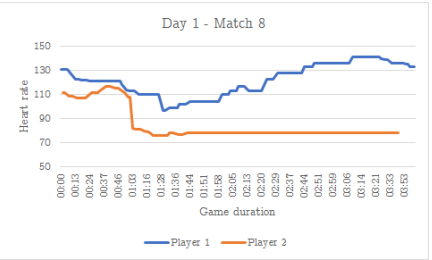
(e) Match 5.



(f) Match 6.

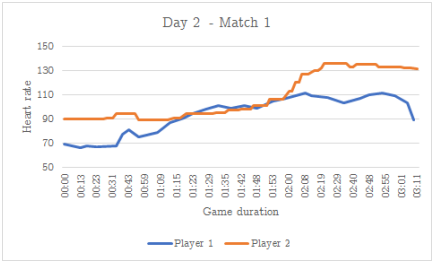


(g) Match 7.

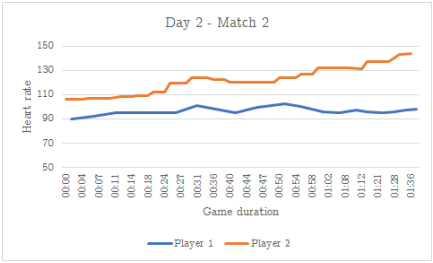


(h) Match 8.

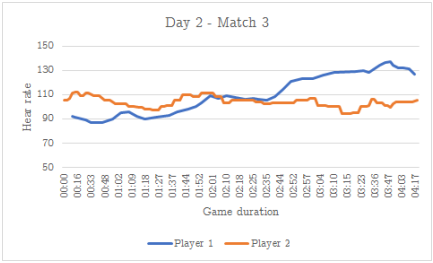
Figure C.1: Results from day 1.



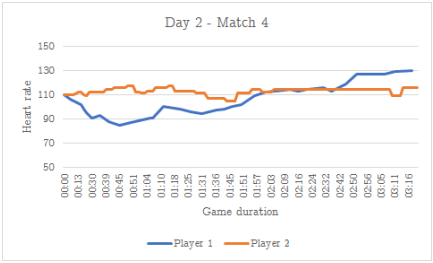
(a) Match 1.



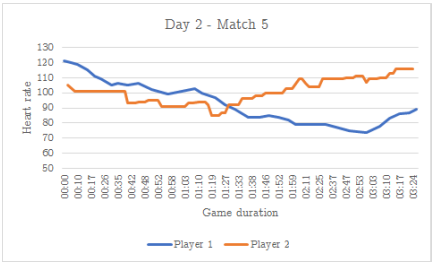
(b) Match 2.



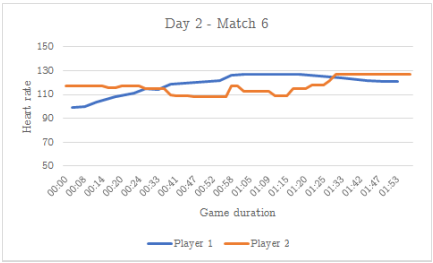
(c) Match 3.



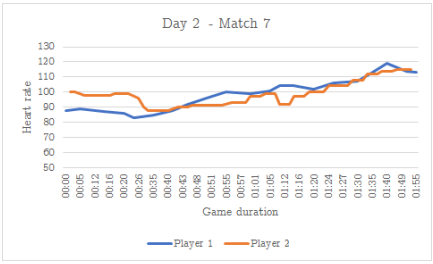
(d) Match 4.



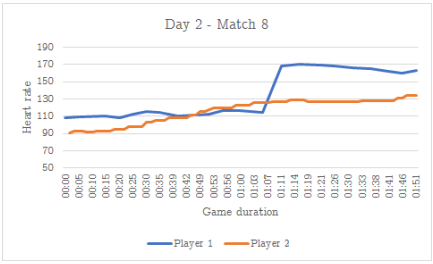
(e) Match 5.



(f) Match 6.

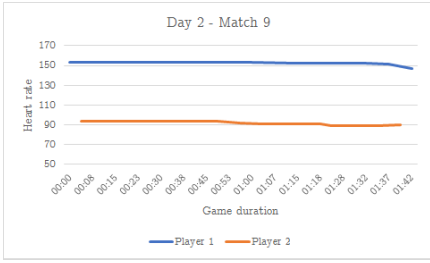


(g) Match 7.

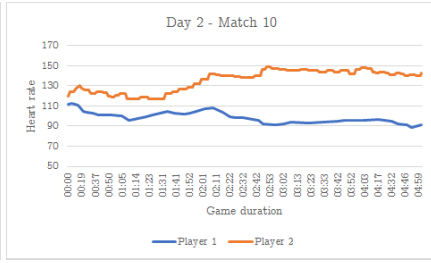


(h) Match 8.

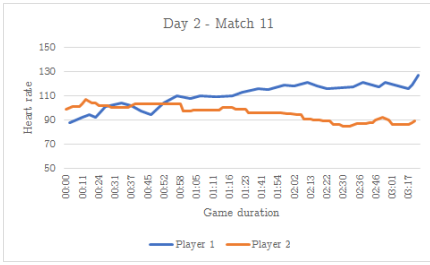
Figure C.2: Results from day 2.



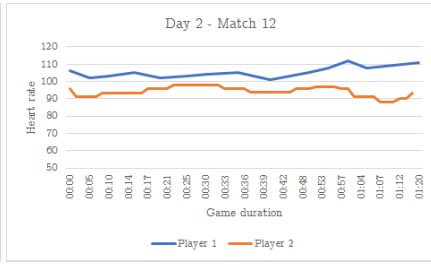
(a) Match 9.



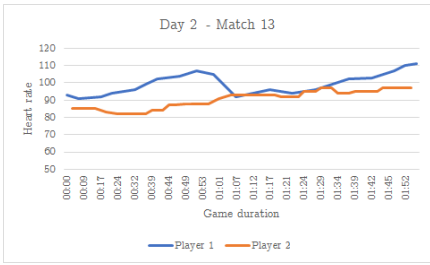
(b) Match 10.



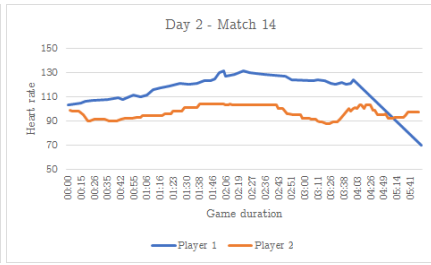
(c) Match 11.



(d) Match 12.



(e) Match 13.



(f) Match 14.

Figure C.3: Results from day 2.

Appendix D

Results From Questionnaire

Table D.1 contains the result from the questionnaire with total of each answer. SD = strongly disagree, D = disagree, N = neutral, A = agree, and SA = strongly Agree. Table D.2 contains the answers to *Do you have any additional feedback on the statements you have answered?* in part 2. Table D.3 contains the answers from part 3 of the questionnaire.

Question	SD	D	N	A	SA
I enjoyed playing the game	0	0	0	9	2
I was motivated to play the game before each match	0	0	1	3	7
I was engaged while playing the game	0	0	0	4	7
I was completely focused on the tasks of the game	0	0	0	6	5
I was so engaged in the game that I became less aware of my surroundings	0	0	0	6	5
The game difficulty was appropriate to my skill level	1	2	2	3	3
I was so engaged in the game that I became less aware of the physical activity	0	0	0	8	3
I was able to concentrate on what was happening during the game	0	0	0	5	6
The goal of the game was clear	0	0	2	2	7
I felt in control of what I was doing	1	4	4	1	1
I got sufficient feedback on my actions	1	2	5	2	1
I enjoyed the fantasy of the game	1	0	2	6	2
The genre of the game was appealing to me	0	1	1	5	4
Playing against a human opponent made the game more enjoyable	0	0	0	1	10
Playing against a human opponent motivated me to perform my best	0	0	1	2	8
I enjoyed comparing stats against my opponent after the game	1	0	4	3	3
I feel more motivated to workout by playing the game than doing interval training	0	1	1	3	6
I feel more motivated to workout by playing the game than going for a jog	1	0	5	1	4
I can see myself playing this game also after the test	0	1	2	5	3
I found the controls of the game was easy to use	1	1	1	7	1
I found this game easy to learn	0	0	1	6	4

Table D.1: Full results from statements in Part 2 of questionnaire.

Do you have any additional feedback on the statements you have answered?
Difficult because of slow and inaccurate GPS
Very interesting game, 10/10

Table D.2: Results from comments in Part 2 of questionnaire.

Any comments regarding your playing experience with Location Invaders?
Would probably have been a better gaming experience if the GPS was more precise
The game experience had been much better if the GPS had worked perfectly.
The game was very engaging and fun to play. I really enjoyed it. There was however some issues,with the GPS-tracking during testing. The accuracy was not as good as it should be. I think the game would be even more fun if the location tracking was smoother and more accurate. One thing that was somewhat frustrating was when trying to catch a power-up from the outer lanes the gps would continue to move after I stopped, causing me to be outside the playing field and miss,the power-up. One should not be able to go outside the outer lanes to catch power-ups more easily. Perhaps making the power-up lanes infinitely wide outside of the game field would help?
Some problems with gps
The GPS was a bit annoying, but except from that the game was fun
Sadly the bad gps ruined some of the playing exper
A more accurate and responsive position would have improved the user experience
Any comments regarding the Location Invaders game itself?
Very good! Can't wait for it to be released.
Fun and engaging. Good idea and great implementation of an old classic to bring it back to life and fit today's trends
Fun game, if the gps works. I can see people playing this game if the gps works perfectly.
Awesome game, maybe some better feedback (vibration) when launching ships. Also use additional inputs for distance measuring to mitigate lag
Any general comments?
Good test session. Great work. Wish we could play more so I could have revenge.
It was neat.

Table D.3: Results from comments in Part 3 of the questionnaire.

Appendix E

Participant Registration

The information that were presented to the participants when they signed up. The text has been translated from Norwegian.

User Testing Location Invaders

In our master thesis we are investigating how games and exercise can be combined, and used as a motivator for a active lifestyle. We have implemented such a game, and need your help to evaluate the final product. The user testing will happen one time and will last approximately 1.5 hours. After the testing a questionnaire will be distributed via e-mail, and will take approximately 10 minutes to answer. We will provide a lot of of fun and free food.

The game is inspired by the classic arcade game Space Invaders, where the player has to protect their base against invading aliens. In our version we have taken the game on step further, and made a multiplayer game where you play against a opponent and send different space ships against their base, while protecting your self from incoming hostiles sent by your opponent.

The game uses your physical position as a part of the game experience, and moving fast from place the place to defend your base or attack your opponent is an advantage. Therefore you should dress in clothes you can move around in. The game is suitable for everyone and there is no requirement of being physical fit to participate.

During the testing we will use Fitbits to collect data about heart rate, speed and location during testing. This data will be anonymous and can't be tracked back to you.

We hope to see you there!

Appendix F

User Manual

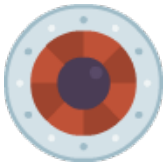
The following user manual was handed out to the test participants. This user manual have been translated from Norwegian to English.

How to play:

- Move in the game area to change your column
- Double click or swipe your finger upwards to send a unit in the column your stationed in
- Swipe left or right to change units
- A long press on the screen will open up the unit selector. Here you can swipe to view the different units and their stats.
- To pickup power ups you must be stationed in the column they arrive at, which is either far left or far right
- You can not send units if you are out of energy, or stationed in the power up columns

Units:

(a) Normal unit.



(b) Slow unit.

(c) Fast unit.

Figure F.1: Units in the game.

The stats of the units are presented in the following table:

Unit	Health	Damage	Speed	Energy Cost
Fast	5	5	4	5
Normal	10	10	2	10
Slow	20	20	1	20

Table F.1: Comparison of unit stats.

Powerups:

(a) Health.

(b) Energy.

(c) Faster units.

The **health** power up rewards +20 health, the **energy** rewards +20 energy, while the **faster unit** increase the speed of your units for four seconds.

Appendix G

Tentative Progress Plan

The following progress plan was written at the start of the project. It has been translated from Norwegian to English.

Tentative Progress Plan

- **Aug 21 - Sept 14 -** Literature Review
- **Sept 16 - Sept 23 -** Brain Storming / Concept Development - (Rapport Writing)
- **Sept 24 - Oct 1 -** Requirement Specification, start to think about Design (Prototyping etc). - (Report Writing)
- **Oct 2 - Oct 9 -** Design Development
- **Oct 10 - Dec 10 -** Implementation
- **Dec 10 - Dec 17 -** "Alpha"-testing. Fast user tests among friends and family. Get most important feedback. Continuous development.
- **Dec 17 - Jan 4 -** CHRISTMAS HOLIDAY
- **Jan 4 - Feb 15 -** Development, implement feedback.
- **Feb 16 - Feb 20 -** "Beta"-testing. Fast user tests. Get feedback on new features. Here the product should be mostly complete.
- **Feb 21 - Mar 28 -** Development. Last finish. Here everything should be completed.
- **Mar 29 - Apr 4 -** Planning the user tests/questionnaires/interviews. Assemble a test group.
- **Apr 5 - Apr 19 -** User Testing.

- **Apr 20 - May 5 -** Collection data from the user tests. Questionnaires, observations etc.
- **May 4 - May 17 -** All the work is completed. Visualize and use collected data. Final touches on the report.
- **May 18 - May 31 -** Fix everything we thought we should have already completed.
- **June 1 -** Deadline