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Exerski

Exploration of methods to increase adaptability and usability in rehabilitation games

June 2022

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This creation of this thesis and system would not be possible without the assistance and guidance of others.

I want to thank my supervisor Christopher Frantz for his assistance in creating order out of my chaos. His continued support and aid were crucial for the success of this project.

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Benjamin Skinstad

Abstract

With an increasing aging population, it is assumed the number of people who will require help with assisted living will increase. Data also points to the increase in musculoskeletal disorders in the working population due to low physical activity among the population. This in turn increases the number of people who will require physical rehabilitation.

This thesis explore the usage of games in a rehabilitative manner, with thesis focal point being on the exploration of methods to increase usability and adaptability in rehabilitation game systems. This was done trough literature studies, talks with professionals, and finally the design, development and testing of a game system, utilizing Virtual Reality technology, where players are required to move their body in the real world, to play the game.

The goals of this thesis was to explore methods and technique to improve on adaptability of usability of game systems, as it seems apparent that many of the current rehabilitation games on the market difficult to use, and lack the potential to be adapted for the individual users.

With the finalised system, I conducted a large scale test of the system on a diverse group of 40+ rehabilitation patients, with the goal to observe the usability level of my system, and how the system was able to adapt to each patient.

The results indicate that there are several design and development techniques that can be used to increase the usability and adaptability of rehabilitation games. Some of these are: Taking design inspiration from cultural phenomenons and activities, strong positive feedback loops on wanted user behavior and designing systems in such a way that all variables that affect an player experience can be adjusted easily during play.

This thesis also discussed other topics related to the development and usage of rehabilitation games, like long term usage, design issues, player and healthcare personnel needs.

Sammendrag

Med en økende aldrende befolkning antas det at antallet personer som vil trenge hjelp til med dagligdagse aktiviteter vil øke. Data peker også på økningen i muskel- og skjelettplager i den yrkesaktive befolkningen på grunn av lav fysisk aktivitet. Dette øker igjen antallet personer som vil trenge fysisk rehabilitering.

Denne oppgaven utforsker bruken av spill på en rehabiliterende måte, med oppgavens fokus på utforskning av metoder for å øke brukervennlighet og tilpasningsevne i rehabiliteringsspillsystemer. Dette ble gjort gjennom litteraturstudier, samtaler med fagfolk, og til slutt design, utvikling og testing av et spillsystem, ved bruk av Virtual Reality-teknologi, der spillere må bevege kroppen sin i den virkelige verden for å spille spillet.

Målet med denne oppgaven var å utforske metoder og teknikk for å forbedre tilpasningsevnen og brukervennlighet til spillsystemer, da det ser ut til at mange av dagens rehabiliteringsspill på markedet er vanskelige å bruke, og mangler potensiale for å tilpasses den enkelte bruker.

Med det ferdigstilte systemet gjennomførte jeg en storskala test av systemet på en mangfoldig gruppe på 40+ rehabiliteringspasienter, med mål om å observere brukervennlighetsnivået til systemet mitt, og hvordan systemet var i stand til å tilpasse seg hver pasient.

Resultatene indikerer at det er flere design- og utviklingsteknikker som kan brukes for å øke brukervennligheten og tilpasningsevnen til rehabiliteringsspill. Noen av disse er: Å hente designinspirasjon fra kulturelle fenomener og aktiviteter, sterke positive tilbakemeldinger på ønsket brukeratferd og designe systemer på en slik måte at alle variabler som påvirker en spilleropplevelse enkelt kan justeres under spilling.

Denne oppgaven diskuterte også andre emner relatert til utvikling og bruk av rehabiliteringsspill, som langtidsbruk, designproblemer, spillere og helsepersonellbehov.

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Acronyms

VR Virtual reality. 3, 22

Glossary

GameObject Base class for all entities in Unity Scenes. Unity documentation . 30

Kinect A motion tracking camera which can be used on an Xbox, to enable to possibility to play games using motion controls. Lifespan 2010-2017 . 10

Occulus Facebooks VR headset, it is wireless, and selfcontained. . 10

VIVE Valves VR headset, it require a PC to be used. . 22, 23

Wii An gaming console developed by Nintendo. The console focused on the usage of motion controllers for their games. Lifespan 2006-2013 . 10

Chapter 1

Introduction

Figure 1.1: An image of one of the Beitostølen testers using my game system. Printed here with permission.

1.1 Topic

Regular exercise is essential to maintain a normal and healthy physical life. It improves your physical and mental health, improves your flexibility, and assists in strengthening bones and muscles[1]. Regular exercise is crucial among the elderly, as it makes it easier to maintain a certain level of living. Exercise is essential in the field of physical rehabilitation.

Physical activity and repetitive exercises are staples of physical rehabilitation[2]. When partaking in physical rehabilitation, patients are often given exercises expected to perform over a prolonged period repeatably. The goal is to regain often mobility or control over an area of the body that is currently struggling.

However, having patients partake in these activities for a prolonged period is difficult. The leading factor why patients drop out of physical rehabilitation is quoted to be due to the drop in motivation among patients[3]. This is especially true when the patients are given exercises to perform independently, as compared to supervised sessions.

It is estimated[4] that it will be getting increasingly difficult to arrange one-on-one supervised sessions with patients. It is costly to have patients partake in private sessions with healthcare personnel, and such an endeavour will also put a strain on personnel resources.

The research estimated that over a billion individuals will soon require assistance with everyday living due to various disabilities[4]. For example, in Norway, it is estimated that over a million individuals are affected by back and neck related issues only, costing the society 2019 165 billion NOK. In addition, NAV claimed the same year that 33% of sick leave is related to musculoskeletal disorders. [5] As an alternative to traditional rehabilitation exercises, several groups have looked into alternative fields and methods to help the patients in maintain motivation throughout the rehabilitation program.[6] One such field is the field of games.

Making repetitive actions fun and exciting is a necessary and widely used trait in games[7]. Certain games have players performing menial, repetitive tasks for several hundred hours by using gamification elements. Bodies like the EU[6] have dedicated resources and money to investigate physical rehabilitation alternatives involving game elements, and they are not alone.

Around the world, including in Norway (Gjøvik, Sunnås, Vikersund, Modum bad), rehabilitation centres are trying to incorporate games into their rehabilitation program. Some have even used games in rehabilitation for a decade and more.

Even if using games in rehabilitation seems to have a positive effect, there are still challenges that face the expansion and further usage of these systems. In my opinion, the most pressing challenges that face the usage of games and gamification elements in rehabilitation are:

Usability: *Many rehabilitation patients are elderly, with little to no prior data or gaming experience, which makes it difficult for them to understand and operate complex systems.*

Adaptability: *Commercial games that can be used in a rehabilitation programs often lack the possibility for adaptation on a patient to patient basis, many of which are too complicated for patients to use or are non-compatible with patients' disability*

Long term support: *Commercial hardware and software systems that have practical usages in the healthcare industry often becomes obsolete and legacy systems after some years. As of now, the most popular off the shelf systems (Wii, Kinect) that are used in the healthcare industry are designated as legacy systems which makes it* *challenging to acquire the proper hardware and software support.*

To further investigate the linkage between games and rehabilitation, and to research and test potential solutions to the aforementioned issues, I will design, develop and test a rehabilitation system designed around a game based framework.

1.2 Keywords

Physical rehabilitation, Serious games, Virtual reality rehabilitation, VR, Adaptability, Usability, Exergames

1.3 Target group

This thesis covers game design, system development and healthcare related topics. The thesis does not go deep into technological areas or healthcare-related topics. The language and terminology used in this thesis should be understandable for non-specialists, but it is assumed the readers have some experience or interest in either of these fields.

I believe that individuals interested in gamification, usability design, VR development, or rehabilitation will get the most out of this thesis.

1.4 Authors limitation

The author of this thesis comes from a background in game development and information security. Prior to this thesis, the author had little to no experience in the healthcare field, let alone the rehabilitation field. This means that the author has limited experience regarding rehabilitation methodology, terms and terminology.

My research indicates that the best way of approaching this form of system design is to rely on direct, frequent contact with patients. However, as this was impossible, I had to rely on research papers and secondary and tertiary sources, which impacted my system development process, especially regarding the system requirement gathering process.

1.5 Motivation

This thesis is the culmination of several years of interviews, observation and research. I have keenly followed the gaming scene for 20 years, and I have always wished that the gaming scene could impact the world in a positive sense. I have seen how the EyeToy inspired physical activity back in the day, and how the Wii/Kinect changed how the public viewed games as more than just entertainment systems. In recent years, Pokemon Go made millions want to partake in physical exercise. I nevertheless feel the usage of physical activity in games lacks enough research, and I want to assist in the further progression of this field. Regardless of the outcome of this project, I am sure it will help me become both a better designer and developer.

I personally chose the topic of this thesis. I started working on this topic during the IMT6231 - Serious Games and Gamification course, where I started exploring and researching gaps in the rehabilitation field in regards to the usage of games. I continue refining the topic area over the remanding semesters trough interviews with healthcare personnel, school teachers, and personal research.

I am very interested in the rehabilitation field personally; my family struggles a lot with hereditary bodily issues and is familiar with physical rehabilitation on a personal level. This also extends to other parts of the family and friends. If I can assist in furthering this field if only by a bit, I would be delighted.

1.6 Research questions

I will in this thesis mainly focus on two top level research questions, with linking second order questions.

RQ1: What can be done to increase the usability of rehabilitative games?

Based on my observation and research, it is apparent that rehabilitative games can be difficult to use, and unintuitive for users, I will research methods to increase usability and intuitiveness to improve the user experience. Linked to this research question are three sub questions. These questions are designed to expand on this topic.

SQ1: Can you use cultural embedment to increase intuitiveness and usability?

Based on research and talks with healthcare personnel, it seems to be possible to increase intuitiveness by relying on activities known for the users, during design 1.8. I want to explore the possibility to use known activities as based design for my system to increase intuitiveness and in turn usability.

SQ2: What are some features healthcare personnel likes to have in their system?

I want to further explore what kind of features and modules healthcare personnel wants to be present in such a system.

SQ3: What measures can be taken to avoid the system from turning legacy?

From a technical point of view, I have observed that many systems that are relevant in the healthcare industry require proprietary hardware or software that gets outdated with time, rendering it expensive or impossible to use the systems.

I want to explore methods to extend the shelf life of my system, and in turn increase usability.

RQ2:What are ways to increase adaptability within rehabilitation games?

Commercial games and rehabilitation games seemingly lack the possibility to adapt to disabled users needs, or are relying on super specific which makes their use cases few. I want to explore methods to increase a games adaptability potential. Linked to this research question are two sub questions. These questions are designed to expand on this topic.

SQ1: How do you design such system to improve odds of adaptation and usage?

To ensure that the system will be used, I will look into methods to increase usability, both in regards to users, and potential external helpers.

SQ2: What methods can be used to verify that adoption was successful?

I want to research possible methods to use to verify that the system has been adopted properly from a user to user basis.

1.7 Contribution

The contribution of this thesis will consist of the collection of four main parts. These are:

A literature study *I have in this thesis conducted a literature review that highlights the current gaps in rehabilitation and gamification*

Research and gathering of design requirements *I have structured my method of approaching this problem in regards to the gathering of user requirements based on research and discussions with healthcare personnel*

A working rehabilitation game prototype *To evaluate and test my assumptions and observations, I developed a functional prototype. This is a fully functional system capable of potentially assisting in physical rehabilitation. At the time of development, there were also effectively zero VR biathlon based skiing games on the market, making my contribution novel.*

An large study consisting of qualitative and quantitative results *My final contribution is a large scale practical test of the system, where I tested my system on a large, diverse crowd of patients, with multiple types of disabilities, with varying severity, which I use to document quantitative and qualitative results.*

1.8 Thesis structure

As this thesis contains a more extensive research section, development section and an experiment section, I felt that the more traditional templates were limiting, as they often focus on either research or development but rarely both. My structure follows a hybrid structure, where I combine traditional development structure with traditional research paper structure. Below is a summary of the various chapters and the main points discussed in each chapter.

Chapter 1: This chapter covers the background and goals of the thesis.

Chapter 2: This chapter covers the related work that this thesis builds upon.

Chapter 3: This chapter covers the full development of the rehabilitation system, including the gathering of requirements and how they were implemented.

Chapter 4: This chapter documents the experiment methodology I used during my experiments, focusing on the data collection methods and the justification for said methods.

Chapter 5: This chapter documents the data collected through the various methods documented in chapter 4.

Chapter 6: This chapter covers the interpretation of the data concerning the research questions. Here I try to interpret the data on a macro and micro level. The chapter contains a quantitative analysis of my study.

Chapter 7: This chapter documents the conclusions I drew from the data, ending with recommendations for future work.

Chapter 2

Background

This thesis is the continuation and integration of the work undertaken in a range of university courses as part of my Masters specialisations. Figure 2.1 offers a conceptual visualisation of the individual activities.

To this end, I consider the three reports and interviews with healthcare experts to be a central empirical basis for the work performed as part of this Masters project. Preceding this, I conducted a literature study that explored existing work in the field of serious games and rehabilitation. The central contribution of the thesis itself is the developed prototype, as well as the actual empirical evaluation presented in discussed in the later parts of this thesis.

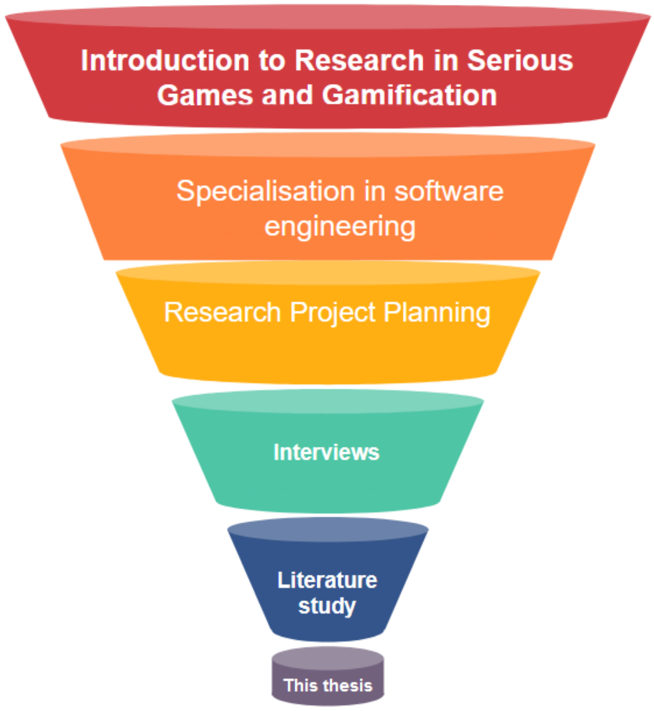


Figure 2.1: A funnel diagram highlighting the schematic integration of the different activities across relevant university courses

The courses this thesis builds upon include:

IMT4307 – Introduction to Research in Serious Games and Gamification

As part of my work in the Serious Games Course, I performed a literature study that helped me identify a range of gaps in the usage of rehabilitation games. The evident need for further investigation in this area was the main motivation for engaging in this domain for my master thesis.

IMT4134 – Specialisation in Software Engineering

Building upon my findings in my initial literature review, I wanted to further explore how different development methods affected the final results, in regards to the development of rehabilitation systems. In this paper I explored the benefits and challenges of using different development methodologies. The goal of this paper was to find the development methodology I would use during my master project.

IMT4205 – Research Project Planning

To get started on my master thesis, I used IMT4205 as course to explore potential preliminary works. This was to ensure a smoother start for my master thesis. During the *literature study in IMT4205, I found research that strongly implied that the usage of familiar and cultural activities improved on the usability and effect of rehabilitation games, which is one of the focus areas of this thesis.*

Talks with Vikersund Kurbad

During the summer of 2021, I came into contact with Vikersund Kurbad (Vikersund). They had shown interest in my Serious Games and Gamification thesis, and was interested in a collaboration in regards to the continued exploration of the rehabilitative gaming field. Even if this collaboration was challenged by the advent of Covid, I still managed to get a lot of domain knowledge and information relevant in this background chapter. A visit to Vikersund Kurbad occurred in November 2021.

2.0.1 Further elaboration of the background theses

I will use this section to further elaborate on the work done in the other courses, with relevance to this paper. I will also elaborate on my talks with Vikersund. The three papers are unpublished, but available by request.

IMT4307 – "Serious games and rehabilitation: a literature review"

In this course I performed a literature study which "aims to research the current state of rehabilitation focused serious games and their effectiveness, with the paper focusing primarily on the possibility of developing a system for the general rehabilitation of disabled individuals". The conclusion of this paper states that it is difficult to develop generalised rehabilitation games. I also conclude that current research papers avoid looking into methods to expand adaptability and usability of their systems, and mostly focusing on developing systems targeting specific groups of disabled individuals.

The paper also documents that using serious games as part of physical rehabilitation programs yields positive results.

This paper is the reason as to why I chose this topic for my thesis.

IMT4134 – "Rehabilitation and User-driven development: a systematic literature review"

One finding from my initial IMT4307 paper, was how several scientists groups who tried to develop rehabilitation games and systems, struggled in ensuring their system was usable for the end user groups. Based on my initial findings, I investigated 2072 research papers from the last decade, which discussed the usage of User-driven development. Further analysis of 212 development papers was performed. The conclusion of this paper was that the usage of User-driven development strongly increased the chance of the development of a usable system. It also states that the involvement of patients is a must during design and development, as developers without a deep understanding of the end users are unable to design systems which fits super specific needs.

This paper is the reason as to why I aimed at a development model which involved end users.

IMT4205 – "MSc Project Plan"

The IMT4205 paper is used as a base for this project. The idea with that course is to get a better understanding of the potential master thesis domain, while also being able to justify the feasibility and scope of the study.

Talks with Vikersund Kurbad expanded

Prior to the start of this project, I was given the opportunity to visit Vikersund Kurbad. At Vikersund Kurbad, I had discussions with their staff about their experience with working within the rehabilitation field, and about their experience in using rehabilitation games as part of their rehabilitation program. As Vikersund uses rehabilitation games as part of their rehabilitation program, I was given the opportunity to observe and test some of the systems they used on their patients.

During this visit, I was able to verify some of the findings and assumptions I had made during my literature review, while also gaining insights in other issues that faced rehabilitation games, according to the staff.

The main issues the staff I talked to brought up were:

Adaptability among commercial systems: They stated that commercial physical sports games sometimes lacked the accessibility options needed to make them work for patients. An concrete example they brought up was how Beat Saber (the fourth most sold VR game on steam as of 2021 [8]) lacked accessibility options which would make it usable for their patients, stating how overstimulation was an issue among users of the system.

Usability among specific rehabilitation systems: Vikersund have bought specific systems designed to let disabled patients be able to play games, with a rehabilitative goal. These games were often complex, poorly designed, and some users, had issues understanding how to play games using these systems, according to Vikersund. A concrete system I tested, was their Armeo arm rehabilitation robot[9]. Vikersund stated that this robot was deigned to let patients play games while partaking in hand rehabilitation programs, but the games offered were too difficult and unintuitive for players, especially elderly, to understand.

Existing systems getting outdated: At Vikersund Kurbad, their gaming room contained systems like: Occulus, Xbox Kinect, and a Wii, with more. Most of the corresponding games to these systems are games that encourage physical activity in the players. The issue here, is that these games all require proprietary hardware systems to be able to be played. As these systems have either reached their end of life stage, or are soon nearing said stage, it is very difficult and expensive to acquire replacement parts, eventually rendering them obsolete. Similarly the systems are also not receiving updates from their respective developers, limiting the long-term applicability.

2.1 Focus

The literature study of this thesis will build upon and extend the aforementioned papers with focus on the top level research questions. A re-review of these papers will be performed with these new focus areas.

This literature study will have two focus areas, corresponding to the two research questions. Long term support of systems has not been added as a focus area as it does not have a corresponding research question.

I will firstly aim at the usage of scholarly papers and journals, but based on experience, I know its common to find valid information within grey literature. This is especially true when it comes to aggregation of information.

Focus area 1: Usability

In this area, the focus lies on investigating how researchers and developers have increased the usability of their games, mainly focusing on rehabilitation games and software. A specific interest lies on development methodology and system verification. This will further extend to non-research papers if I find them during my search and deem them relevant. Based on the feedback from Vikersund, I will also investigate the linkage between usability and intuitiveness.

Focus area 2: Adaptability

I will investigate how researchers and developers have increased the Adaptability of their games, mainly focusing on rehabilitation games and software. I am also here highly interested in development methodology and system verification. I will investigate non-research papers papers if I find them during my search and deem them relevant. I will look after design principles, issues with adaptability, and projects that looks like the one I have planned.

To limit my scope, I will mainly focus on adaptability methods targeting the rehabilitation of the upper body of individuals. I will also mainly focus on physical adaptability, as psychological adaptation would be out of scope for this project.

2.2 Method

For both focus areas identified as part of my work, central methodological features include a structured literature review for both of my focus areas. Parts of this review will be iterative, but will generally follow this structure.

1. Re-review of the aforementioned papers with focus on the new focus areas.
2. Write down keywords.
3. Review sources within the literature if relevant to expand the scope.
4. Generate search queries based on collected keywords and focus areas.
5. Query the queries using Google scholar, expand to other search engines if results are unsatisfactory.
6. Document and group the findings in a form.

These structure will be followed until a sufficient number of papers which discussed the research questions has been located.

2.3 Inclusion and exclusion criteria

Inclusion criteria

- The language is in either Norwegian or English
- The paper is from 2006 or later.[1]
- Describes system development where the focus areas are explicitly mentioned.
- Describes processes or principles that can be followed in relation to the focus areas.
- Focus on physical rehabilitation is a plus.
- **The paper needs to offer new insight or information which was not discussed in the baseline papers**

Exclusion criteria

- The study is not in English or Norwegian.
- The paper has no mention of the focus areas in either their abstract or title.
- The study is a book. The size of the study makes it impractical to use.
- The study is seemingly of poor quality.
- The study is unrelated to the areas: System design, System development, Game design, Game development, rehabilitation
- The study is not easily available using the school resources.
- Systematic literature studies without proper conclusion and synthesis of findings.
- The study covers a very specific implementation or use case.
- The study covers cognitive rehabilitation.

[1] This year was picked as its the release year of the Wii as one of the first off-the-shelf consoles used for rehabilitation purposes.

2.3.1 Re-review

Re-review paper	Paper type	Keywords	Number of relevant papers
MSC project plan	literature study	Serious games and rehabilitation Marginalised design User centred design	18
Rehabilitation and User-driven development	systematic literature review	Agile Requirements Engineering Co-design Co-production End-user development End-user programming End-user software engineering Participatory design User/Patient/Citizen/public Involvement User/Patient/Citizen/public driven design User/Patient/Citizen/public driven development User/Patient/Citizen/public innovation User/Patient/Citizen/public participation	212
Serious games and rehabilitation: a literature review	literature study	technology games physical problems handicapped technology games exergames handicapped exergames wheelchair serious games exergames serious games exergames technology	41

2.3.2 Keywords

The keywords used as part of this study, are based on the keywords located during the re-review. Words deemed irrelevant to the focus areas were removed. I have also added keywords based on the focus area and the related serious games area, expanding on this using synonyms. The keywords were:

Serious games and rehabilitation	technology games physical problems
Agile Requirements Engineering	usability
Marginalised design	intuitiveness
User centred design	Adaptability
Co-design	Universal Design
Co-production	handicapped technology
End-user development	games exergames
Participatory design	handicapped exergames
exergames technology	wheelchair serious games
exergames	

2.3.3 New search queries

I have avoided replicating the search queries found in base literature papers as these papers are still very new.

All of the queries were ran January-February 2022. If Google scholar was used, the five first pages were looked at, due to the sheer voulme of results.

Focus area 1

Table 2.1: Focus area 1 search queries

Serious games and rehabilitation usability
Serious games and rehabilitation intuitiveness
Marginalised design Serious games usability OR intuitiveness
User centred design Serious games usability OR intuitiveness
Participatory design Serious games usability OR intuitiveness
exergames technology design usability OR intuitiveness
technology games physical problems usability OR intuitiveness
Serious games Universal Design usability OR intuitiveness
disabled design Serious games usability OR intuitiveness
disabled development Serious games usability OR intuitiveness

Focus area 2

Table 2.2: Focus area 2 search queries

Serious games and rehabilitation adaptadility
Marginalised design adaptadility
Marginalised design Serious games adaptadility
User centred design Serious games adaptadility
Participatory design Serious games adaptadility
exergames technology design adaptadility
technology games physical problems adaptadility
Serious games Universal Design adaptadility
disabled design Serious games adaptadility
disabled development Serious games adaptadility

2.3.4 Execution

Duplicated papers were not noted down. Many of the queries had quite a large overlap in terms of articles found.

Note: Every words found in the cell "search query" was ran as one line query. They are here separated over two lines to ensure that the table would fit on this page.

Focus area 1

Search query	Filter	Database	Results	Articles included
Serious games and rehabilitation usability	2006-2022	Google scholar	17 000	2
Serious games and rehabilitation intuitiveness	2006-2022	Google scholar	18 100	3
Marginalised design usability OR intuitiveness	2006-2022	Google scholar	17 000	0
Marginalised design Serious gamesusability OR intuitiveness	2006-2022	Google scholar	15 500	2
User centred design Serious games usability OR intuitiveness	2006-2022	Google scholar	20 300	1
Participatory design Serious games usability OR intuitiveness	2006-2022	Google scholar	17 600	0
exergames technology design usability OR intuitiveness	2006-2022	Google scholar	6 670	5
technology games physical problems usability OR intuitiveness	2006-2022	Google scholar	17 900	0
Serious games Universal Design usability OR intuitiveness	2006-2022	Google scholar	20 900	1
disabled design Serious games usability OR intuitiveness	2006-2022	Google scholar	18 100	0
disabled development Serious games usability OR intuitiveness	2006-2022	Google scholar	18 100	0

Focus area 2

Search query	Filter	Database	Results	Articles included
Serious games and rehabilitation adaptability	2006-2022	Google scholar	17 800	1
Marginalised design adaptability	2006-2022	Google scholar	17 100	0
Marginalised design Serious games adaptability	2006-2022	Google scholar	17 900	0
User centred design Serious games adaptability	2006-2022	Google scholar	20 200	0
Participatory design Serious games adaptability	2006-2022	Google scholar	17 600	0
exergames technology design adaptability	2006-2022	Google scholar	1 720	2
technology games physical problems adaptability	2006-2022	Google scholar	17 800	1
Serious games Universal Design adaptability	2006-2022	Google scholar	19 700	1
disabled design Serious games adaptability	2006-2022	Google scholar	18 300	0
disabled development Serious games adaptability	2006-2022	Google scholar	18 300	0

2.4 Results

Evaluation of searches

The resulting papers from the literature studies in focus area 1, were quite good. They expand on the focus areas, while also adhering to the statements gathered during the preliminary work and interviews. This was not as true in regards to the literature review in focus area 2. To expand on this focus area, I conducted searches after grey literature.

The issue in regards to focus area 2 was how the resulting journals were either inaccessible, books whiteout indexing, heavy on the healthcare focus, or within a completely different domain.

Synthesization of information

2.4.1 Focus area 1

Re-review

The literature studies I performed prior to the new study, indicates that some find rehabilitation games difficult to use. The developers who did not regularly test their system on patients, ended up with massive issues in regards to their usability aspect of their system during verification. Implementing cultural links to the design seems to have a positive effect on the usability of the system.

New literature study

The literature study strengthen the findings from the re-review, especially in regards to the usage of familiarity during design. [10] [11] [12] I feel the papers were somewhat limiting in their scope, with many focusing mainly on the development and design towards specific user groups. Many of the papers I was able to located focused on the design towards elderly users (42%), which is problematic for a generalising the design process [10] [11] [12] [13] [14].

The literature strengthens the assumption that designing around familiar actives increase intuitiveness and usability of the system.

The study also pointed out how some researcher has worked towards "Designing Universally Accessible Games"[15], which contains very good design related resources to increase usability and accessibility.

The full results can be found in the Appendix

2.4.2 Focus area 2

Re-review

New literature study

For focus area 2, I only found 4 relevant results out of the 500 I looked at by using Google scholar. So few results indicate an potential gap in the field. The few papers I located expanded on the principle of designing "highly configurable and adaptable games"[16] with the goal of reaching "Universal Design"[17].

Core findings from these papers, indicate that relying on open adaptable design, is key. The papers also discuss the successful usage of Universal Design principles[18] [11] [17]

The full results can be found in the Appendix

Principle	Example of Practice that Applies the Principles
UD 1. Equitable use	*Career services*. Job postings are in formats accessible to people with a great variety of abilities, disabilities, ages, racial/ethnic backgrounds, and technologies.
UD 2. Flexibility in use	*Campus museum*. An exhibit design allows a visitor to choose to read or listen to descriptions of the contents of display cases.
UD 3. Simple and intuitive	*Assessment*. Testing is conducted in a predictable, straightforward manner.
UD 4. Perceptible information	*Dormitory*. An emergency alarm system has visual, aural, and kinesthetic characteristics.
UD 5. Tolerance for error	*Instructional software*. An application provides guidance when a student makes an inappropriate selection.
UD 6. Low physical effort	*Curriculum*. Software includes on-screen control buttons that are large enough for students with limited fine motor skills to select.
UD 7. Size and space for approach and use	*Science lab*. An adjustable table and flexible work area is usable by students who are right- or left-handed and have a wide range of physical characteristics.
UDL 1. Multiple means of engagement	*Courses*. Multiple examples ensure relevance to a diverse student group.
UDL 2. Multiple means of representation	*Promote services*. Multiple forms of accessibly designed media are used to communicate services provided.
UDL3. Multiple means of action and expression	*Course project*. An assigned project optimizes individual choice and autonomy.
WCAG 1. Perceivable	*Student service website*. A person who is blind and using a screen reader can access the content in images because text descriptions are provided.
WCAG 2. Operable	*Learning management system (LMS).* A person who cannot operate a mouse can navigate all content and operate all functions by using a keyboard (or device that emulates a keyboard) alone.
WCAG 3. Understandable	*Instructional materials.* Definitions are provided for unusual words, phrases, idioms, and abbreviations.
WCAG 4. Robust	*Application forms.* Electronic forms can be completed using a wide range of devices, including assistive technologies.

Figure 2.2: An overview of some of the proposed universal design guidelines from Washington edu.

Other relevant findings

An re-review of the Specialisation in software engineering report, still concludes that the reliance on end users, in my case, patients, is vital for the success of the system.

2.5 Limitations

Non standardised field

As thoroughly stated in the "Rehabilitation and User-driven development: a systematic literature review" paper, the field of rehabilitation, design and computer engineering is in dire need of standardisation in regards of the research and development of rehabilitation systems. The lack of standardised makes it very challenging to find all relevant literature, but also to avoid irrelevant literature.

Examples of this is how the physical and cognitive rehabilitation field kept mixing during my queries.

Cross domain issues

The design and development of rehabilitation games, is not just within the field of computer science. It also covers the healthcare domain, design domain, computer science and computer games domains. This makes it highly difficult to navigate the journals.

Confirmation bias

As I already had talked with healthcare personnel prior to this study, and also performed several literature studies in this field in the past, means that I have a certain degree of knowledge of the field. This could make me look for research papers that already aligned with my prior understanding of the field.

2.6 Summary

It is great to observe that the information provided to me by the rehabilitation expertx align with my prior findings. As indicated by the literature, it is optimal to involve patients during development, which is methodology I will try to follow. In terms of designing elements, the new literature study have provided me with some guidelines I can consider during the desing of these elements.

Chapter 3

Exerski - system development

This chapter will describe the research and development of my main application, Exerski. I will discuss how I gathered the requirements for the system, performed the internal and external testing of the system, and how I developed the finalized system prior to the experiments that provide empirical support for the application, as discussed further in the Experiment Methodology chapter.

Many of the features discussed in this chapter were developed as a response to the various tests I performed prior to the main study. The studies are not discussed in this chapter, but can by found in the Pilot test experiment results

3.1 Research and Preliminary work

I have separated the parts into two sections to separate the research and development work explicitly, while recognizing there is overlap since the development and vice versa drove the research. This section is separate from the background chapter because it is conducted closer to the development phase. This initial part of the research specifically involved personnel who were familiar with rehabilitation theory and who had been informed about my plans to develop a ski game with a rehabilitation baseline.

This section tries to explain the features included in the system.

Background

This section builds on the information I gathered during my preliminary research, as documented in the previous chapter.

Before the development phase, I tried to gather as much information about what rehabilitation patients and staff might want to see in a potential rehabilitation game.

In mid-November 2021, I visited Vikersund Kurbad to discuss with expert practitioners in the rehabilitation field. At the same time, I was also allowed to observe and test some of the rehabilitation games and systems they had in place to date.

When we were done with the observational study, I shared with them my idea of a skiing game designed for rehabilitation purposes. We then spent time discussing and highlighting potential features they would like to see in such a system.

Key aspects that Vikersund considered central for a the ski game as as follows (without signalling priority):

Easy to use and highly intuitive.
Use on both traditional and VR screens.
Collection of patient data and statistics.
Rehabilitation of neck, arms, and back.
Discourage fear avoidance.
Encourage leg movement.
Avoid overstimulation of patients.
Contain mini games and other gamification elements.

Requirements

Based on these basic feature, the central requirements below list the core features I intended to include in my system. They are separated into functional and non-functional requirements.

Functional requirements include:

- Ski-Esque movement system.
- Wheelchair accessible
- A working game utilizing the VIVE VR unit.
- An interesting snow map
- The ability to change the game on the fly - control panel
- The possibility to make a predetermined path on a map.
- Possibility to see user statics at run time

Non-Functional requirements include:

- Stable and high frame rate
- Intuitive control system
- Easy to use User interface
- Interesting and familiar landscape

Restrictions and limitations

Due to the various reason below, selected features were omitted in the final system design. Some of omitted features were explicitly mentioned by healthcare personnel, while others were natural features that were omitted due to scope and time limitations. I will, in this section, describe features that were omitted from the system and explain my reasons why they were omitted.

Using the system without VR:
One of the most requested features was using the system without a VR head-

set. This was due to the assumption that some patients would not either not like to use VR headsets, or simply not be able to use those due to physical or cognitive challenges associated with their condition. To make this system operate on traditional screens and VR headsets, which would have effectively required the need to develop two separate systems. Due to time constraints and the focus on central aspects related to the principal usability of the system, I thus decided not to implement this feature.

Oculus capabilities:
Oculus is the most popular VR headset by far. It is a lot easier to use, offers wireless capabilities, and does not require an expensive PC. This is more in depth discussed here That said, I prioritized the usage of the VIVE headset, as it is the headset I have the most experience with, easy to work with VIVE and Unity, and since it offers the ability to perform changes to the game at runtime. It is also worth noting that the usage of Oculus could raise potential privacy challenges due to data collection by Facebook[19] (as the manufacturer of the Oculus ecosystem), often tracking and capturing player data, exposing the system to legal and ethical issues.

Multiple maps:
I created only one map for testing purposes to ensure tester based on a controlled experience that exclusively focuses on usability of the system. While I created other maps to test the flexible use of the system, these were not used during experiments.

No gamification elements:
I purposely avoided implementing gamification elements into the system, as I wanted to test the system in its pure form with focus on basic mechanics. I also assumed that if the system contained game elements, the patient might look at the system as a competitive game, rather than a training exercise. Further testing to explore opportunities to integrate both perspectives is subject to future studies. The choice to avoid implementing other game elements is furthermore related to time constraints. I prioritized the completeness of the basic game experience over adding other elements that could negatively impact the experience.

No audio:
To ensure that both the staff and I could communicate with testers during testing, I avoided using music and audio in the system. This was also done due to security concerns, as unclear communication methods could lead to errors in the tester's understanding, given their diverse abilities to communicate.

No saving of patient data:

Some rehabilitation staff was very interested in saving patient data and using this data to observe patient progression in a data driven sense. However, saving and storing medical data requires explicit protocols and permissions. The initial stage focuses on developing a proof of concept, which would require iterative refinement, making the explicit definition and compliance assessment of potentially introduced changes practically impossible.

No leg movement:
Vikersund specifically requested mechanics that would encourage lateral movement in the player. I avoided this due to my focus on arm/neck/shoulder rehabilitation. This is also in relation to the requests I got from the other centres I interviewed with respect to requirements, since these were in part contradicting. As a compromise, I implemented a method that encouraged players to move their legs to rotate through the map instead. My implementation forces the players to turn physically in the world, to ensure turning inside the game, instead of implementing the a possible lateral movement system. A rotation based system was, based on testing, less prone to bugs than a lateral movement system.

Photorealistic environment:
I experimented with using photorealistic environments in VR in my previous bachelor's. I concluded that the technology is not readily available for the practical application in the devised system, since such an environment makes the frame rate too unstable, exposing the players to additional risk of VR sickness. The headset furthermore has too low of a resolution to display the realistic nature of the environment. I opted to use a low polygon environment to reduce rendering costs (and thus fluid experience) and increase the visual reward.

Free player movement:
Another of the more common observation and requests from players was the ability to move freely around the map. Free movement was not implemented due to several reasons. Again, the main reason was to guarantee that the players would all test and provide feedback on the same map and experience. Allowing players to free roam around the map would have required a far more extensive testing of the map to anticipate errors or usability challenges (e.g., getting lost or stuck). Similarly, as the system is trying to mimic a biathlon course, I opted to control the experience by building a high-quality course rather than giving the players liberty to roam freely.

Hill based speed adjustments:
Another requested feature was to provide context-sensitive speed, i.e., to decrease the player's speed while moving uphill, and to increase their speed while moving downhill. I implemented and tested this feature during pilot

testing, only to observe that some testers started tipping over and losing their balance while moving downhill due to missing corresponding corrections in the physical environment. Due to security concerns, especially given the potentially vulnerable tester group, this feature was removed.

3.2 System development

This section will document the development process of each of the modules in my system. The modules were developed simultaneously in an iterative fashion, with experiments and tests performed regularly. However, I believe dividing this section into module based parts makes this section more readable.

Development methodology

My initial choice of development methodology was to follow an iterative scrum-like structure, where I would develop a module and test, verify, and fine tune said module on patients undergoing physical rehabilitation at a rehabilitation centre. I wanted to utilize this methodology as my prior research strongly indicated that this is the superior method for developing these kinds of systems. However, due to Covid, my ability to perform in-person visits to centres was limited.

During the development of this system, I still followed an agile development methodology with informal sprints. However, as the development of these modules would involve a lot of experimentation and unknown factors, I avoided doing a complete system design at the start. Instead, I aimed to work on a module until it reached a minimum viable product state and then gather some more requirements before starting on a new module.

By always having the system in a working state, I avoided any potential over scoping issues, and it made it possible to send examples of the current state of my system to rehabilitation personnel to get more feedback, which I utilized when choosing what modules I should implement in the future.

Map

This is mainly a development project; I utilized bought 3D assets for my map. I customized these assets to make them usable for my use case. The goals I had in mind during the design phase of the map were:

- Snowy environment
- Interesting environment
- Avoid holes and too steep hills
- Low-performance requirements

After I found an environment that fulfilled all of these goals, I added movement nodes to make traversing possible and other environmental objects clearer for the player as to where it was expected they should move. In addition, the map had its angles adjusted to make traversing possible.

Figure 3.1: An birds eye overview of the path the players would follow, here highlighted. The red dots are representations of the pathing system.

In the case of the test map, I designed it to contain hills, flat stretches, hard and soft turns, and varied environments. Again, this measure how the system and the player reacted to environmental differences.

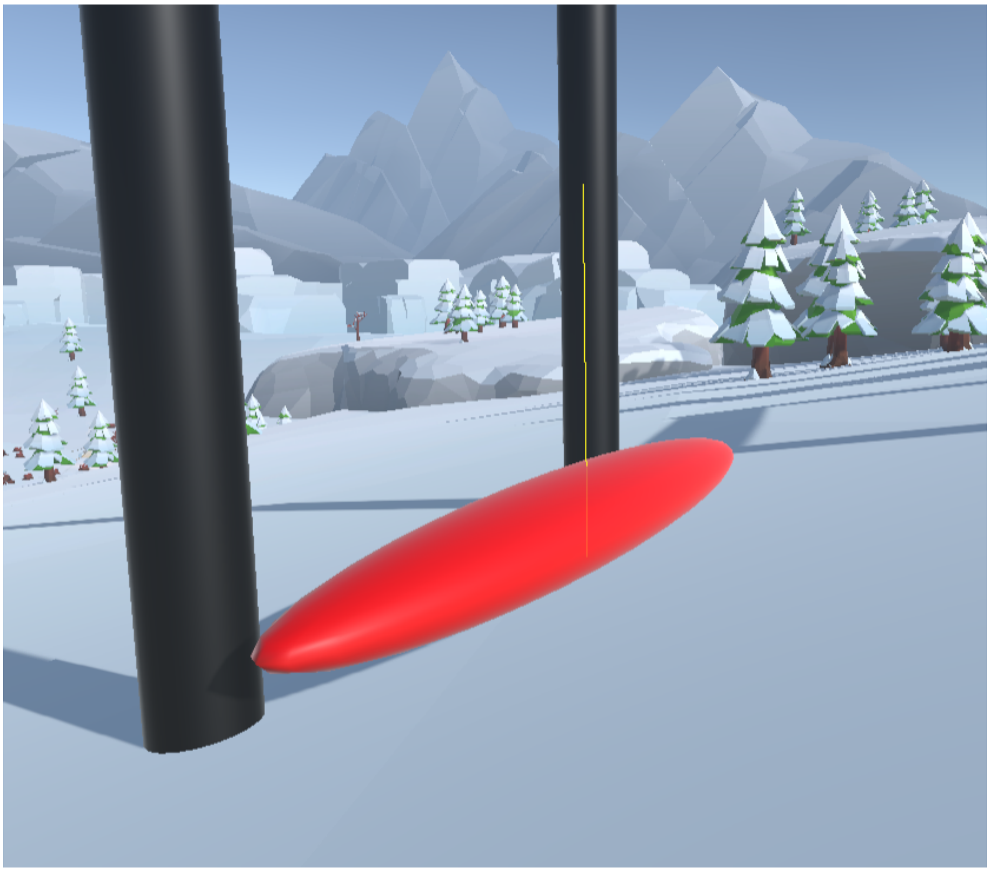


Figure 3.2: An image of a movement node. The yellow line here represents how the nodes has adjusted itself based on the current terrain.

The path system

The path system is an ordered list of 3D positions in the game world. The list is ordered with the first start position at index 0, with the final position saved at the last index. To make it easier to design a map, I record the position of game objects saved as children to a parent object. This makes it possible to perform visual debugging and design the path. The game objects used for path finding purposes will be referred to as nodes in the future.

To simplify the map design progress, it is possible to place the nodes using a top-down view of the map (2D representation). Furthermore, to ensure that the nodes are uniformly placed at the same height off the ground, they will automatically place themselves at a specific offset of the ground at startup.

The nodes contain a "trigger hitbox" to allow the player to move through the list of nodes; the nodes contain a "trigger hitbox". A hitbox of the trigger type provides no collision in physics, but it registers collisions with the player hitbox. When a collision with the player is registered, The current node index increases by one, making the player move towards the next node.

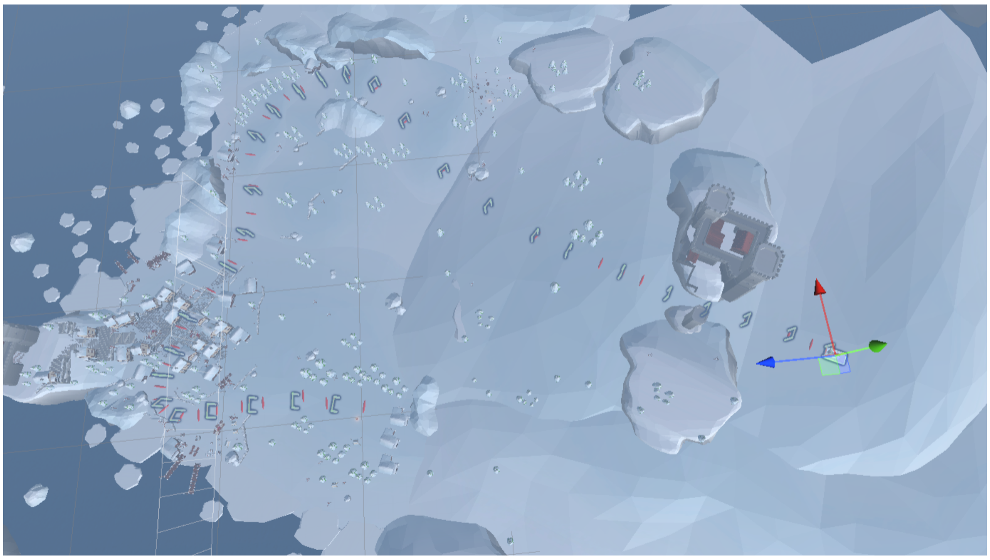


Figure 3.3: An birds eye overview of the path the players would follow, here highlighted. The red dots are representations of the pathing system.

Arrow decal

To make it even more apparent for the player which direction they are currently moving in, I added an arrow that rotates based on where the next node is located. The arrow is a black arrow, which looks like a shadow projected onto the ground in front of the player. I tried to implement this system using the built Unity decal system, but I faced compatibility issues. I used and customized a free asset to add this functionality to my system.

Core movement system

The core movement system is designed to mimic a ski experience. The system is developed to use the VIVE hand controllers as ski staves, which the player needs to move in an L fashion, to move through the world. I performed several experiments and tests to find a functional implementation that worked in regard to the movement system. This implementation makes it, so the controllers and headset are not linked in regards to moving the player, making it possible to look around the world, independent of the directions the player is moving.

The movement system is separated into two parts, one for each hand but identical.

Note: The player will always try to move towards a target node, which corresponds to the next node on the list along the map course.

Figure 3.4: Diagram of how a skiers arms are moving downwards and backwards during biathlon. Photo:Mathias Vindal on Youtube

Testing of various movement systems

The movement system went trough several iterations and different designs before ending on the one described above. The other movement systems showed greater promise in regards to further expansion, and had potentially more freedom in regards to design. However, the other movement systems had massive bugs which I was not able to fix. The bugs induced heavy motion sickness, vertigo, dizziness and headache. I have included an video to demonstrate some of the old bugs here

The general idea of the other movement systems, was that they were going to be more independent, but due to issues with local space - world space issues, I was unable to fix this error.

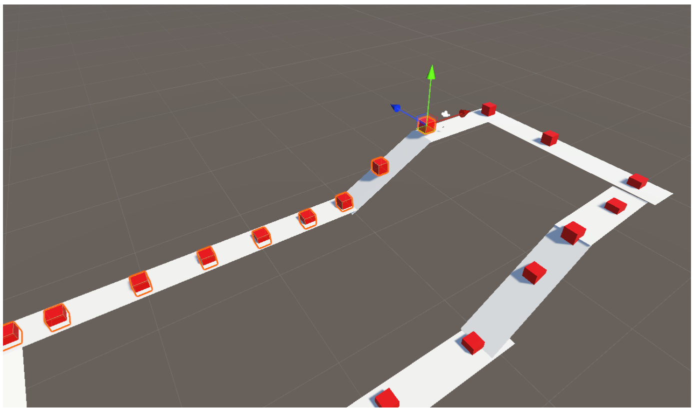


Figure 3.5: Image of an old experimentation map, where the other movement system was tested.

Player character

The final player object is built upon the free Unity VIVE asset, connecting the VIVE headset and controllers to the Unity scene. I added a Unity RigidBody to the player object, making it possible to perform physics calculations within the scene. I conducted little experiments to figure out the physics that worked within the world.

By setting the RigidBody mass and drag to 5 and 0.5, respectively, based on iterative testing a realistic moevement of the player in the world was established. Gravity was enabled, and I froze the RigidBody's rotation, as the physics simulation should not modify the rotation. A capsule collider is also added, making it possible to traverse the environment naturally.

Calculating force

The system adds force to the player character based on how much the player has moved each controller between updates. Utilizing the built in Unity FixedUpdate function, which is called 50 times per second, the system calculates the amount of distance the controllers have been moved since the last update. This calculation is performed twice per hand in parallel. First, the system calculates the distance the controller has moved along the vertical axis in the downward direction. Then it calculates the distance the controller has moved horizontally away from the current target node.

If the controller has been moved further than a certain minimum distance, the calculated distance gets saved away and multiplied with a speed modifier. The modifier will be discussed later in the UI panel section. This number is then multiplied by a 3D vector, corresponding to the angular difference between the player and the target node positions. The angle is calculated by normalizing the result of the target node's position and subtracting the player's current position. I then call the Unitys AddForce function on the player RigidBody, using said calculated 3D vector as input. This call makes it, so the player is moved towards the target node. This function is called on both hands and needs to calculate horizontal and vertical movement; it gets called four times per update cycle. The speed modifier is unique for both the right arm and the left arm's vertical and horizontal function, making it possible for the system to adapt to players' movement impairments.

Rotational mode - wheelchair

During regular play, it is expected that the player rotates their body, and therefore the VR headset, to compensate for the lack of turning. As a sitting player can't rotate their body in turns, automatic rotation functionality had to be developed.

When the sitting mode is enabled, the player GameObject is rotated to align itself with the current target node. Whenever a new target node is selected, the player object is then aligned with the new target node. The player object only rotates along the Y axis, as the other axis is irrelevant for this adjustment. To ensure a smooth transition, the system utilizes linear interpolation over time to ensure a smooth player experience. Based on internal testing, snapping transitions tend to induce motion sickness. This mode is designed for wheelchair users.

Figure 3.6: An image of one of the Beitostølen testers using the wheelchair mode. Printed here with permission.

UI panel

To adjust the system during gameplay, I built a UI control panel, which makes it possible to observe and adjust game variables to improve the player's experience. The toggleable variables have one button, which toggles it on and off, while the other variables have two buttons linked to the variable. One which increases the variable and one which decreases it.

The UI is linked with these game variables:

- Toggle wheelchair mode
- Right arm speed modifier
- Left arm speed modifier
- Rotational speed
- Toggle statistics panel

The PC game window and the VR view are the same by default. Therefore, everything the player observes can be observed on the PC screen and vice versa.

To avoid the VR player observing the control panel, I render two cameras, one used for the VR view and one for the PC view. In addition, the PC view has the UI component, which makes it possible to render the UI out of view for the player.

Figure 3.7: Image of the UI with displayed while a player plays in the background. 1: Statistic panel, 2: Enable/disable UI, 3: buttons to increase/decrease right arm assistance, 4: buttons to increase/decrease left arm strength, 5. buttons to increase/decrease rotation speed of wheelchair, 6: panel to show current speed of variables, 7:arrow decal as discussed earlier in chapter 3, 8: The red cylinders here represent the movement nodes, 9: button to toggle wheelchair mode

Statistics

I register and save the distance the player has moved the controllers between frames in a list during play. The numbers registered in this list are averaged and passed along to a UI graph element at specific intervals. The current interval rate is 1/3 of a second. This was due to performance related issues observed when the Ui was updated in real time. The data is not persistently stored to avoid issues with data storage laws.

The graph system displays the registered speed data from both hands simultaneously. They overlap to make it easier to spot strength differences between the hands, making it easier to make speed adjustments per hand, which improves the player experience. The UI element is a bought Unity asset, which I Incorporated into my system.

Due to performance issues, I chose not to showcase more data elements in the graph overview.

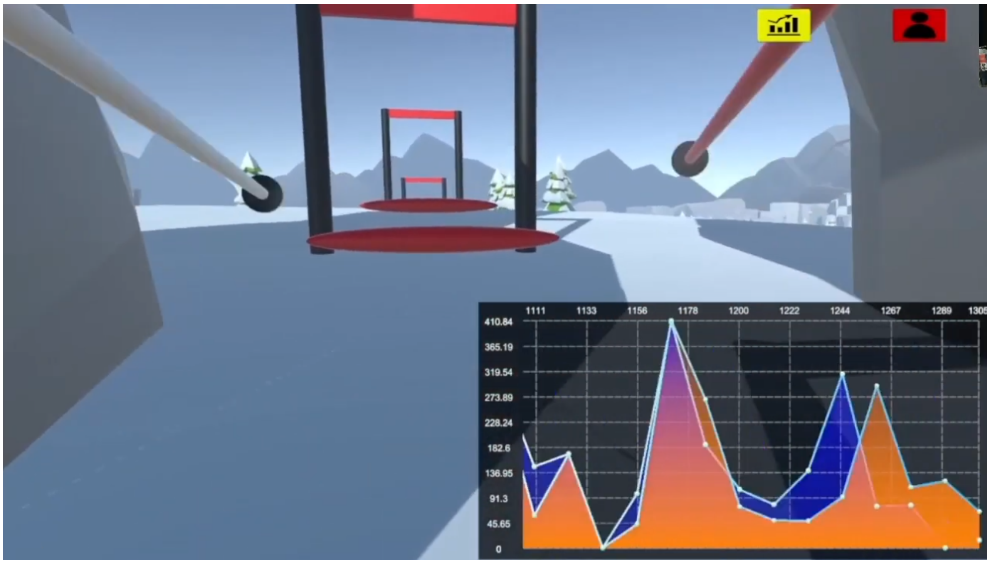


Figure 3.8: The image here showcase the tracking of player hand statistics. The different colors represents different hands.

Chapter 4

Experiment Methodology

In this thesis, three experiments were conducted. The first part was a pilot study to test the performance and usability factors of the system. These pilot tests consisted of several smaller tests spread out over a few months, where I tested on family members, friends and university students. This was a very unstructured observational study using a straightforward feedback approach as I was unsure of what could be relevant prior to testing.

The second part was a smaller study aimed at healthcare personnel and staff. During the design phase, it was unknown how many patients I would be able to work on to ensure that I would get enough feedback on the system. Therefore, I created a smaller semi-structured interview guide targeting healthcare personnel. This interview guide was designed to either support or discredit my assumptions about the rehabilitative gaming field while also shining a light on issues facing the rehabilitating field.

The third and central part of the study was a large scale test of the system on multiple diverse patient groups at Beitostølen Healthcare centre(Beitostølen). A small experiment was also conducted at "Sykehuset Innlandet Gjøvik (Gjøvik)" as an addendum, following the same methodology. The results of this study will be used to determine the effectiveness of my system concerning usability and fun.

4.1 Pilot studies

To observe how users would use my system and discover errors that needed to be fixed. I planned on conducting several small scale system tests. By running these tests, I should understand how patients eventually would use my system, observe how the system reacted to users, and get feedback on missing features.

As these tests were very casual, no proper protocol was followed during these tests. These tests were more about how the users experienced and interacted with the system.

Various research papers indicate that the best method to create rehabilitation systems requires the involvement of end users, aka patients, in an iterative development cycle. However, as this was impossible, I had to rely on the available testers.

Initial pilot test

The initial pilot test was performed on family and friends between the 10. and 13. March. This test involved 4-5 testers who tried the system. Every tester tried the standing mode without rotation assistance. The observations and changes done to the system post test can be found in Chapter 5

Second Pilot test

The second pilot test happened in a more structured manner, on April 20. I had been permitted to run a stand in the school's A-building. I ran this stand between the hours 10 to 15. Between these hours, I had five testers of varying ages and gender. The goal of this test was to finalise the system before taking it to Beitostølen Helsesportsenter (Beitostølen) for the final test. I was especially keen to observe the intuitiveness of the system.

Figure 4.1: Image of a tester testing my system during my pilot tests.

The data collection method for this test was mainly observational, but I prepped some questions for my users to be used in semi-structured interviews with users.

These questions try to cover areas of my system I was insecure about. The questions I had prepared for this test were:

- Do you have prior ski experience?
- Do you like to ski?
- Do you have Vr experience?
- Are you proven to have motion sickness?
- Do you feel like the system works as expected?
- Do you feel there is missing feedback inside the game?
- Staves feedback:

There where the artefacts I had the most interest in observing as well were:

- Mode sitting/standing
- Right arm speed:
- Left arm speed:

The testers were offered to try out standing mode and sitting mode with rotation.

A fundamental test protocol was followed during these tests. The observations and changes done to the system post test can be found in Chapter 5

A small last minute test was also run on April 25 to do some last minute testing and adjustments.

4.2 Healthcare staff talks

I followed the same guidelines and protocols regarding testing the system on healthcare staff as I did on the patients to compare their reactions and behaviour. The talks and observations were informal.

Interview with personnel

During my stay at Beitostølen Healthcare centre, I assumed I would be able to mingle with people who had experience working in the rehabilitation field. I wrote an interview guide to be used while talking with healthcare staff. The interview guide can be found in the Appendix B. Due to various limitations, the interview guide was only used on one rehabilitation personnel, while the rest of my interactions with staff were very informal.

The questions I had prepared were:

- Name:
- Position:
- How long have you been here at Beitostølen?
- Can you tell us about potential problems with rehab?
- Research indicates that motivation and interest, especially when it comes to rehab activities alone. Have you observed this?

- Do you have knowledge/experience with games based rehabilitation? If yes: Have different forms of handicaps reacted differently to game rehab?
- Can you tell us about these games' positive/negative aspects?
- Lack of customisation options in these games?
- Lack of fun in these games?
- Is this something you use actively
- Is this anything you plan to use more of in the future?

Post test
- What do they think of the system? bad/good
- What do you think about the system about the normal exercises you practice and perform?
- Do you think this system could be a potential alternative to normal exercises?
- Do you collect data from the patient? How?
- My system can collect and view data. Do you see any use for this?
- What kind of data could be nice to look at?
- Do you see any utility in such a system in terms of ski based movement
- The movement system can be reused in other 3d lanes; do you see any practical value in investigating other uses / further development of this system about rehab?
- Other comments?

Note:The questions have been translated from Norwegian.

4.3 Main study

I consider the testing of the system on rehabilitation patients the core part of my thesis, as this is as close to a real case scenario as I can get. Therefore, this part is divided into two sections: the more significant test conducted at Beitostølen Healthcare centre and the smaller test conducted at Hospital Innlandet - physical medication and rehabilitation.

4.4 Beitostølen

Beitostølen allowed me to visit them for two days, the 27. and 28. of April, where I would be given access to a section of their current on-site rehabilitation patients. These tests would be facilitated by the head of the department, Viljar Aasan.

Beitostølen study

As I was given no information regarding the age, demographic or disabilities of the patients I would be given access to; I created three supplements I would bring to Beitostølen to assist me during my stay. All of these supplements can be located in the Appendix . As a legal requirement, I also brought several NSD agreements for patients or their guardians to sign, which allowed me to use their collected data in my thesis. A copy of this can be found in the Appendix C.

- Protocol: The protocol is a document outlining how I will introduce myself and the project to patients and staff members. It gives a brief overview of the project, the NSD agreement and various safety warnings. This protocol is to be followed to ensure that every group is given the same amount of base information before testing.
- Information brochure: As a way to provide supplementary information about my project while also advertising for the system, I wrote up a small brochure which contains information about me, the school, and the project, with links to a demo video I created months prior.
- Patient interview guide: As I was given no information about the patients I would be given access to, I wrote up some simple questions with guidelines while testing on patients. The guidelines were written in a way to avoid me getting stuck while talking with patients. The questions were written in an open-ended fashion to encourage patients to give me their unbiased opinion and limit my ignorance's impact. In addition, the document contains follow up questions to encourage reflection and to ensure that the patients would provide some tangible feedback.
  These guidelines and questions were written under these assumptions
  - The patients would mostly be adults.
  - The patients would mostly have the high cognitive ability.
  - That I would be given access to the patient prior to and post to the testing of the system.
  - That I would be relatively alone with the patient during testing.

  In the next chapter, I will detail how the interview process was very different than I assumed, but the guidelines mentioned above were still core in my discussions with the patients during testing.

The information I was aiming to collect or observe during my tests were these:

- Demographic information: To be able to perform any comparative studies, I wanted to document the age and gender of the testing patients. This would make it possible to see how different ages and genders react to the system.
- Medical information: I was curious to see how different disabilities interacted and experienced my system. To be able to do this, I had to document disability information.
- Ski experience: The system tries to copy a ski experience. To understand how a patient can relate to a ski game, it would be interesting to know the level of skiing experience they had, if any.
- VR experience: I wanted to see if prior VR experience impacted how patients experienced and interacted with the system.
- Observational data: Observational data includes all information I can ob-

serve while the patient interacts with the system. This can include but is not limited to: patient enjoyment, system problems, patients understanding of the systems, patient movement patterns, patient speed, patient choice of play method (sitting, standing with and without auto rotation)

Due to data collection restrictions, capturing pictures, video recordings, and audio recordings was complicated. Most of the documentation during the Beitostølen testing was recorded using a dictaphone and some written notes. This collection method was not 100% accurate.

Post test interview with Viljar Aasan

Some days after the tests had taken place, I emailed Viljar Aasan with a few questions, asking about what he and the staff thought about my system now that they had had some days to talk about it and observe the testers post test thoughts.

The questions I sent to Viljar were:

- Have you observed any positive or negative reactions about my system for either patients or staff after I left?
- What did you think about the tests that were conducted?
- Did you observe any issues with the execution of these tests?
- Can you imagine any possibilities for further development and usage of this system or a system like this built on the technology?
- Do you have other feedback?

Hospital innlandet Gjøvik testing (Gjøvik)

On the 10. of May, I was given the opportunity to demonstrate and test the system at the Innlandet Hospital - physical medication and rehabilitation department. As I was given no information about the patients or the test area prior to the test time, I followed the same protocol as I did at Beitostølen. The only information I had was that I had been given a 3-hour time slot where we would try to use their VR equipment.

Arriving there, I was informed the plan was to run individual tests, utilising their newer VR headsets with the assistance of a staff member. Unfortunately, due to unforeseen technical and logistical challenges, we lost two hours of the testing time, and we had to rely on my older VIVE headset when we conducted the tests.

The test area was a secluded larger room. However, it was large enough to conduct VR testing without worrying about hitting walls or the roof. In addition, the room was closed off, making it so there were no onlookers or others who could observe or disturb the tests.

Due to the short time limit, I was informed that I would only be able to conduct tests on two patients, but I would be given more time per patient than the Beitostølen. Tests, I opted to perform a more in-depth qualitative study than the more quantitative study I performed at Beitostølen.

Time was dedicated to conducting pre-test and post-test interviews with the patients. The results of these two tests can be found in chapter 5.

Post test discussion with Jørgen Olsen

I talked with Jørgen prior to and after the various tests to better understand his experience in rehabilitation, especially in regards to his view on the usage of games and VR in rehabilitation.

Chapter 5

Experiment Results

This chapter will document my studies and experiments' quantitative and qualitative data. The experiments and obtained data are presented in order of acquisition.

All of the tests were executed on using this hardware systems:

PC specifications:

- *Acer Predator Helios 300 Laptop*
- *Intel® Core™ i7-12700H-prosessor*
- *Nvidia Geforce RTX 3080-grafikk*
- *32 GB DDR5 RAM*

Original VIVE headset

5.1 Pilot studies

This section will discuss the findings and observations I made during my pilot studies. As I believe it is interesting to point out how these findings affected the development of the system but not enough to warrant a section in the discussion chapter, I will document these changes here.

Initial pilot test

The initial pilot test was purely an observational study.

Main findings:

- **Lack of clarity**: Users found themselves confused at the start of the game, stating the system lacked clarity.
- **Lack of guidance**: Users found themselves confused in regards to where they were moving.
- **Adjusting variables was complex**: I found myself unable to make changes on the fly. The changes had to be done inside the Unity editor; it often required the user to stop playing while I adjusted their variables.

- **Ways of abusing the system**: One of the users discovered a way of abusing the system, which involved him doing short bursts of movements with his hands, moving them up and down in a rapid movement. This movement made the user move super fast through the map, breaking both pathfinding and collision. As this will be relevant again in the future, this bug will forward be referred to as "**The Downward bug**".
- **Works well with one hand**: One user at the time was only able to use one hand. After performing some speed adjustments, the user could complete the course in a typical fashion.
- **Lack of sitting mode**: It was also observed around this time that the system lacked a mode for sitting users, indicating that the system, in its current state, would be inaccessible for wheelchair users.
- **No dizziness or other adverse reactions**: One of the most positive observations was the lack of any adverse physical reactions in my users.

Effects on development

To ensure that the users would better understand what was expected of them, ski staves and skiing objects were added in the player's proximity. As the players were confused about where it was expected of them to move, I also added gates along the course. The wheelchair mode was also researched and implemented after this pilot test.

Second Pilot test

As the number of participants was only five people, I went away from relying on the interview guidelines and instead deep dived into the testers' opinions.

Main findings:

- **VR scare**: Some of the testers displayed uncertainty and scepticism in regards to the system.
- **Path was not clear**: Some of the testers were still unsure where they were supposed to move.
- **Higher speeds increase the likelihood of motion sickness**: Some of the testers were able to move very fast through the map, and some of these testers complained about the early onset of motion sickness.
- **Moving too fast or too slow makes the player move out of bounds**: If the player moved in abrupt motions or moved too slowly in specific paths, the player was unable to make certain turns. They would also occasionally move past gates, which breaks the pathfinding.
- **Sharp turns are tricky**: The system seems to handle sharp turns poorly.
- **Requests to be able to slide more**: Some of the testers who had more ski experience requested the ability to slide more when they reached higher speeds or when going downhill.

- **The system seems to work as hoped, and all modes are operational**: The system seems operational and ready for the upcoming Beitøystølen

Effects on development

A minor adjustment was made to the system. After this test, the main addition to the system was the decal arrow, which points to where the player is expected to go. In addition, I added more objects behind the player and along the course to heavier indicate to the player where it is expected that the player will be moving.

It was nice to know of potential challenges that I will meet during the main experiment, like players being scared of VR initially. No other changes were made to the system to mitigate VR fear. The map was not adjusted to minimize the errors observed concerning players moving too fast or too slow, as I wanted to investigate further if the same issues would be observed during the proper experiment.

I further investigated and implemented a sliding function, but this was removed as the tests indicated people would fall over if this was put in use.

5.2 Healthcare staff talks

Observation and talks with staff and personnel

Interview with personnel

I was only able to interview one member of the staff, who name was Alexander. These results were noted down under a two hour unstructured talk. I have here documented the core findings of our talk.

Results from the talk with this staff member at Beiostølen:

Alexander has worked several years in the rehabilitation field, currnetly working as a Occupational therapist, with prior experience from Sunnås.

He mentions how rehabilitation struggles with boring repetitive tasks, stating how motivation is in his opinion the clear biggest factor when it comes to completing a stay at this facility.

One of the issues he mentions in regards to game based rehabilitation, is stimuli and mental tiredness, stating that even if you design systems to not be as stimulating, the usage of VR in itself will be enough stimuli for many.

He states how the usage of games is beneficial in the younger generation, as many of those might find themself less interested in physical activity, but with a higher interest for video games, in their case, game based rehabilitation can be really good. Games are yet another tool in their toolbox.

Referencing other rehabilitation games, he makes a statement how they often lack the ability to adapt to the patients' needs during usage, making them not as ideal as they could be. He does state that he lacks some experience in the usage of these, but states that usability and intuitive usage are key factors. Adding how these features make it a lot easier to use for children and people with lower cognitive ability, extending how ease of use increases the possibility of the system actually being used in a relevant manner.

His feedback in regards to the importance of doing the exercises well versus doing physical exercise in general is mixed. He states that the quality of the exercise tasks definitely is important, but physical stimuli is also very important, but it's massively on a patient to patient basis.

- Name:
- Position:
- How long have you been here at Beitostølen?
- Can you tell us about potential problems with rehab?
- Research indicates that motivation and interest, especially when it comes to rehab activities alone. Have you observed this?
- Do you have knowledge/experience with games based rehabilitation? If yes: Have different forms of handicaps reacted differently to game rehab?
- Can you tell us about these games' positive/negative aspects?
- Lack of customization options in these games?
- Lack of fun in these games?
- Is this something you use actively
- Is this anything you plan to use more of in the future?

Post test

- What do they think of the system? bad/good
- What do you think about the system in relation to the normal exercises you practice and perform?
- Do you think this system could be a potential alternative to normal exercises?
- Do you collect data from the patient? How?
- My system can collect and view data. Do you see any use for this?
- What kind of data could be nice to look at?
- Do you see any utility in such a system in terms of ski based movement
- The movement system can be reused in other 3d lanes; do you see any practical value in investigating other uses / further development of this system in relation to rehab?
- Other comments?

5.3 Main study

5.4 Beitostølen

Raw data from the Beitostølen patient tests

This section contains the raw data collected from the various patients at Beitostølen.

Notes and assumptions about the data:

- Dashes are added between each group for easier reading
- If the ages of the patients were not rerecorded, I used the age gap range provided to me by Beitostølen.
- Unless otherwise specified, it is assumed that 3000 is the speed used by the user
- Unless otherwise specified, it is assumed that the user has no VR experience
- Unless otherwise specified, it is assumed that the user has ski experience
- Unless otherwise specified, the user's age is given between minimum and maximum interval per group.
- Unless otherwise specified, NA is the default response to "Likes the game." I only note down explicit verbal confirmations in regards to their enjoyment of the game.
- 42 out of 55 possible patients tried the system. Three patients explicitly stated they did not want to participate in VR experiments. I assume that the remaining ten did not partake due to time restrictions or were unavailable for that session. I have been informed post experiments that there were some sick patients that day. With that said, there might be people who did not dare to play with VR that never got to my station, as indicated by "only" 42 out of 55 people showing up. As I saw these patients, I couldn't make any assumptions about them.
- I fill the cognitive field. If the patients displayed physical traits of cognitive issues, like Down Syndrome, they were tagged as Moderate. If the patients required assistance, had issues in talking with me or had a legal guardian to assist them during play, they were tagged with Severe.

Chronological ordered data collected from patient testing at Beitostølen. The table can also be found in Appendix D

Table 5.1: Complete Beitostølen data table

GR	Patient	Gender	Age	Prior VR experience	Speed	Type	Likes the game	Cognitive issues	Comments
1	1	male	8	yes	3000	standing auto rotate	yes	yes	looks down a lot
1	2	female	10	no	3200	standing auto rotate	yes	yes	claims its exercise
1	3	male	10	no	3000	standing auto rotate	yes	yes	looks down a lot,claims its exercise
1	4	-	-	-	-	-	-	yes, heavy	headset too small
1	5	male	7-12	no	4000	sitting	yes	yes, heavy	guided trough
1	6	female	7-12	no	3000	sitting	yes	yes, heavy	guided trough, looks down a lot
1	7	male	7-12	no	3500	sitting	yes	yes, heavy	slight guidance, looks down a lot
	-	-	-	-	-	-	-	-	-
2	1	female	18	no	3000	standing auto rotate	yes	no	-
2	2	female	18-33	no	3000	standing auto rotate	yes	yes	tries to move off track, plays 2 times
2	3	female	18-33	-	-	-	-	yes, heavy	abort
2	4	female	20	no	2700	standing auto rotate	yes	no	-
2	5	male	65	no	3000	wheelchair	yes	no	-
2	6	female	25	no	3000	standing auto rotate	yes	no	slight dizzy
2	7	female	18-33	no	2000	standing auto rotate	yes	no	-
-	-	-	-	-	-	-	-	-	-
3	1	female	11	no	3000	standing auto rotate	yes	no	-
3	2	female	9	no	3000	standing auto rotate	yes	no	claims its exercise
3	3	female	9-14	no	3000	standing auto rotate	yes	no	looks down a lot
3	4	female	9-14	no	3000	standing auto rotate	yes	no	-
3	5	male	9-14	no	3000	standing auto rotate	NA	no	no ski experience
3	6	male	9-14	no	3000	standing auto rotate	NA	no	no ski experience
3	7	male	9-14	no	3000	standing auto rotate	yes	no	-
3	8	male	9-14	no	3000	standing auto rotate	NA	no	-
3	9	-	-	-	-	-	-	-	scared of vr
3	10	male	6	no	3500	standing auto rotate	yes	no	-
3	11	male	9-14	no	3000	standing auto rotate	yes	no	-
-	-	-	-	-	-	-	-	-	-
4	1	male	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	2	female	45-68	no	3000	wheelchair	yes	no	no skii experience
4	3	male	45-68	no	3000	wheelchair	yes	no	-
4	4	male	45-68	no	2500	wheelchair	yes	no	-
4	5	female	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	6	female	45-68	no	3000	standing auto rotate	NA	no	-
4	7	female	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	8	male	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	9	female	45-68	no	3000	wheelchair	NA	no	-
4	10	female	45-68	no	3000	wheelchair	yes	no	quits early
4	11	male	45-68	no	3000	standing auto rotate	yes	no	-
-	-	-	-	-	-	-	-	-	-
5	1	male	14	yes	3000	standing	yes	no	-
5	2	male	11-18	yes	3000	standing auto rotate	yes	yes	-
5	3	male	11-18	yes	3000	standing auto rotate	NA	no	-
5	4	female	11-18	no	3000	standing auto rotate	yes	yes	-
5	5	female	11-18	no	3000	standing	yes	yes	one hand, tries to walk of map
5	6	female	11-18	yes	3000	standing	yes	no	one hand

Observations per group Beitostølen

This section will cover data collected from each one of the groups. Information like "Total number of patients possible", "age range", "Gender separation in total", and "Disability in the group" has been provided to me by Beitostølen.

"Total number of patients possible" indicates how many patients were assigned to each group, not the number of patients present during testing. Unfortunately, Beitostølen could not provide me with the number of present patients at each session.

Group 1

Total number of patients possible:	11
Number of patients I tested on:	6
Age range:	7-12 years
Gender separation in total:	5 female, 6 male
Disability in the group:	Down syndrome

Notes and observations:

- Due to startup issues, and external scheduling reasons, this session ran a bit short, which is why I assume so few patients were able to play.
- All of the patients had a parent or guardian present, who sometimes assisted their child in understanding and playing the system.
- Several of the patients wanted to play again.
- A large section of the patients kept staring down on the floor at the start.
- The initial patients mainly started standing but changed it to sitting during play.
- Several of the patients got very immersed in the world, with one patient wanting to explore the world more, repeatedly asking if there was a princess in the castle.
- Positive feedback from parents as well.
- Some of the patients seemed scared at the start/before starting, potentially indicating that a more smooth start could be nice. It might be good to create an area designated for patients to get familiar with the VR world.

Group 2

Total number of patients possible:	11
Number of patients I tested on:	6
Age range:	18-33 years
Gender separation in total:	9 female , 2 male
Disability in the group:	Autism, Cerebral palsy

Notes and observations:

- It is unknown why there was only 54% participation. I did not observe 11 patients in the hall at the time of testing. My observations would say there were closer to 8 or 9.
- It is observed that some of the patients that come too close or collide with the environment react erratically.
- A few patients came back to play again and one of them changed their mode to a more difficult one time two, indicating that some people might need a warmup to the system.

- One standing patient had issues with turning naturally, potentially indicating that my assumption regarding standing and turning is flawed, as supported by the way the staff members and skiers are unable to naturally understand the turning system.

Group 3

Total number of patients possible:	10
Number of patients I tested on:	11
Age range:	9-14 years
Gender separation in total:	5 female, 5 male
Disability in the group:	mild developmental disorders, behavior issues, autism

Notes and observations:

- The 6-year-old patient seems to not have belonged in this group, but as he claimed to be a patient and managed to successfully play the game, I will count him as a participant.
- Some patients required basic guidance to get started but could easily complete the course after this.
- Some needed a bit of guidance to understand where to look; a few stared at their feet, unsure as to why.
- It is observed that some of the patients that come too close or collide with the environment react erratically
- It largely depends on how much the kids get immersed in the world. It is unknown how many of these patients pretend to be immersed vs actually being immersed. This was observed in 1-2 patients.
- Some of the patients discover the downward bug 5.1, but I ask them to please avoid doing that for an extended time. Another patient performed the downward bug right after the other patient performed the bug , indicating that the patients might observe and learn from each other.

Group 4

Total number of patients possible:	15
Number of patients I tested on:	12
Age range:	45-68 years
Gender separation in total:	7 female, 8 male
Disability in the group:	Spinal cord injuries and various muscle diseases, mostly wheelchair users

Notes and observations:

- Some of the patients state they feel "carsick" while playing my system, but most state that they often get easily carsick/seasick.
- Some patients claim that their chair kept moving back and forth, which might have increased the likelihood of motion sickness.
- A few of the patients (patients 3, 4, 6) tried to steer themself by using one hand at the side. It is unknown if they all figured out this behaviour independently or if they observed each other during playtests. 3 and 4 were wheelchair users, meaning that this is a natural way for them to perform turns, but this would not be the case for patient 6.
- The users in this group seem to not like the transition from uphill/downhill to flat ground.
- The speed at which the patients can move through the system varies greatly. Based on observations and talks with people who have developed wheelchair VR systems before, I believe that if the users are moving too fast, they will get motion sick.

Group 5

Total number of patients possible:	8
Number of patients I tested on:	6
Age range:	11-18 years
Gender separation in total:	3 female, 5 male
Disability in the group:	Cerebral palsy, chromosomal abnormalities, epilepsy

Notes and observations:

- I was requested to not perform the normal intro speech + security talk for the kids as the team leaders stated that the kids were eager to start.
- The kids had been informed about the game by the other kids, and we're hyped to play it based on others' experiences.
- Patients 2 and 3 were given the option to play with or without safety mode and said they wanted safety mode.
- Due to their disability, patients 4 and 6 had reduced ability in one hand. For patient 4, I increased their speed to 6000, double what seems to be the average speed using both hands. They managed to complete the course without issue. Regarding patient 6, I attached the controller to their arm; they managed to move their arm in a skiing motion and completed the course with little issue.
- Patients were randomly given encouragement to do proper skiing movements from trainers and staff, which made some adjust their movement to be more proper.
- It seems like most of the patients in this group had prior experience in skiing. They might have been trained at Beitøystølen based on the encouragement

cries from the staff member. With that in mind, it seemed like the patients all knew what was expected from them inside the game, but they would sometimes not perform the exercise properly until they were informed about this by a staff member. This seems to imply that the patient's mind and body are performing different activities. If this is the case, it implies that it is vital to provide the patients with proper feedback during activities inside the virtual world, as they can not tell how they are doing.

Other Observations I had during testing:

- A few patients have little to no prior skiing experience, but they managed to play through my system with ease, indicating the importance of a good positive feedback loop when the users perform the wanted "moves."
- Some patients started to make weird moves during testing. I assume that if the patients are given complicated instructions without a point of reference, this was especially the case when I tried to explain how they had to rotate the body to play the game.
- Too high or too low speed changes how the patients feel about the system, as they can get stuck or hit walls etc
- Staff talks about expanding the data collection and making it possible to track player progression
- Giving the patients a goal seems to increase their motivation to complete
- Do patients stare at their feet because they are scared of moving?
- Extremely few people requests to change their speed, indicating they do not know or remember its possible
- Downhill to flat ground needs to be a smooth angle
- 2 hands in the parallel movement are faster than interchanging hands
- Patients can use their wheelchair, but it depends on the size and width
- Some patients in wheelchairs experienced a rocking motion, which might have induced motion sickness.
- A few patients try to move one hand at a time to turn; this is not intentional
- The turn speed was always 0.7, no complaints
- One handed mode works nice, but a method to disable staves needs to be done Ignoring the patients with severe cognitive issues, I am unable to observe any difference in the amount of training or explanation of the system needed for the various patients to be able to complete my system. Independent of gender or age

Adjusted table from Beitøsolen

As the results gathered from Beitøsolen contains some errors and are, in certain places, incomplete, I have made some adjustments to the table using external information. **This is the table that will be used in all statistical discussions in regards to the Beitøsolen experiment.**

A copy of the adjusted can be found in the Appendix E

Table 5.2: Adjusted Beitostølen data table, further analysis can be found in 6.2

GR	Patient	Gender	Age	Prior VR experience	Speed	Type	Likes the game	Cognitive issues	Comments
1	1	Male	7-12	Yes	3000	Standing auto rotate	Yes	Moderate	looks down a lot
1	2	Female	7-12	No	3200	Standing auto rotate	Yes	Moderate	claims its exercise
1	3	Male	7-12	No	3000	Standing auto rotate	Yes	Moderate	looks down a lot,claims its exercise
1	5	Male	7-12	No	4000	Sitting	Yes	Severe	guided trough
1	6	Female	7-12	No	3000	Sitting	Yes	Severe	guided trough, looks down a lot
1	7	Male	7-12	No	3500	Sitting	Yes	Severe	slight guidance, looks down a lot
-	-	-	-	-	-	-	-	-	-
2	1	Female	18-33	No	3000	Standing auto rotate	Yes	No	-
2	2	Female	18-33	No	3000	Standing auto rotate	Yes	Moderate	tries to move off track, plays 2 times
2	4	Female	18-33	No	2700	Standing auto rotate	Yes	No	-
2	6	Female	18-33	No	3000	Standing auto rotate	Yes	No	slight dizzy
2	7	Female	18-33	No	2000	Standing auto rotate	Yes	No	-
-	-	-	-	-	-	-	-	-	-
3	1	Female	9-14	No	3000	Standing auto rotate	Yes	No	-
3	2	Female	9-14	No	3000	Standing auto rotate	Yes	No	claims its exercise
3	3	Female	9-14	No	3000	Standing auto rotate	Yes	No	looks down a lot
3	4	Female	9-14	No	3000	Standing auto rotate	Yes	No	-
3	5	Male	9-14	No	3000	Standing auto rotate	NA	No	no ski experience
3	6	Male	9-14	No	3000	Standing auto rotate	NA	No	no ski experience
3	7	Male	9-14	No	3000	Standing auto rotate	Yes	No	-
3	8	Male	9-14	No	3000	Standing auto rotate	NA	No	-
3	11	Male	9-14	No	3000	Standing auto rotate	Yes	No	-
-	-	-	-	-	-	-	-	-	-
4	1	Male	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	2	Female	45-68	No	3000	Wheelchair	Yes	No	no skii experience
4	3	Male	45-68	No	3000	Wheelchair	Yes	No	-
4	4	Male	45-68	No	2500	Wheelchair	Yes	No	-
4	5	Female	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	6	Female	45-68	No	3000	Standing auto rotate	NA	No	-
4	7	Female	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	8	Male	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	9	Female	45-68	No	3000	Wheelchair	NA	No	-
4	10	Female	45-68	No	3000	Wheelchair	Yes	No	quits early
4	11	Male	45-68	No	3000	Standing auto rotate	Yes	No	-
4	12	Male	45-68	No	3000	Wheelchair	Yes	No	-
-	-	-	-	-	-	-	-	-	-
5	1	Male	11-18	Yes	3000	Standing	Yes	No	-
5	2	Male	11-18	Yes	3000	Standing auto rotate	Yes	Moderate	-
5	3	Male	11-18	Yes	3000	Standing auto rotate	NA	No	-
5	4	Male	11-18	No	3000	Standing	Yes	Moderate	-
5	5	Female	11-18	No	3000	Standing	Yes	Moderate	one hand, tries to walk of map
5	6	Female	11-18	Yes	3000	Standing	Yes	No	one hand
-	-	-	-	-	-	-	-	-	-
6	10	Male	6	No	3500	Standing auto rotate	Yes	No	-

Adjustments done to this table:

- All ages have been adjusted to be within their respective age groups based on the information given to be about the various groups. I lacked enough concrete ages to pull any meaningful data.
- Patient 10 group 3 was not a patient who belonged to that group, according to staff members. Since he was a patient but did not belong to this group, I recorded his response but moved him to his group. Patient 10's response will be used in this thesis, but his age or gender will not be used during the statistical analysis of the groups, as he is an outlier.
- Patient 5 group 2 has been moved to group 3 as the group was initially 100% young adult female, and his age and disability were a much better fit for that group.
- Patient 4 group 1, patient 3 group 2, and patient 9 group 3, have been removed from the chart as they did not get far enough to try the system to provide me with tangible feedback.
- For later analysis, I have opted to use Beitostølens grouping of age in regards

to statistical analysis, which means these groups have been merged:

- Group 1,3,5: Children. Count: 21 people.
- Group 2: young adults. Count: 5 people.
- Group 4: elderly. Count: 12
- Gender balance: 50% Male, 50% Female.

Issues with the experiment

This section will cover some of the issues I faced when collecting data. This is done for transparency reasons, as I do not know how all of the listed issues could have affected the observed outcome. Further discussion about what these issues meant and how I mitigate this can be found in the discussion chapter.

- The system was first and foremost designed for mentally able but physically disabled individuals, but a section of the testers had varying cognitive abilities.
- It was difficult to perform structured interviews with the patients for varying reasons:
  - A majority of the patients were children, making some of the questions difficult due to their lack of life experience and comparable experiences.
  - It was challenging to ask the patients some more personal questions as it was a more casual, public environment, meaning that I rarely asked about their prior rehabilitation experience, handicaps, etc.
  - The patients were taken out from their normal social activities to perform testing, and it was clear that they wanted to go back to their group. I did not feel it was my place to hold them.
  - A complete interview and test took around 15 minutes, while system testing while talking with patients was often completed in under 5 minutes. With only one hour sessions and upwards of 15 people, complete interviews were not feasible.
  - My testing place sometimes became a hangout place for patients who wanted to watch their friends play. This adds a social component to my tests, which might make the game more enjoyable due to the company.
  - The speed of testing: I was almost instantly given a new tester when I had conducted my system test, making it difficult to take proper notes and review the test that had just taken place.
  - I was in charge of the patient security and live system adjustments, which means my notes were often made hastily.
- With most of these results being recorded via Dictaphone, it becomes impossible to verify or double check my results. As a lot of my adjustments happened on screen, there is no record of my changes unless I verbally expressed the changes while it was done; while listening to the audio recording, I am sure that this did not happen.

- Rumors about my system had spread between the groups between the days, possibly making it so the 2. Day groups might have received information about the system from other testers.
- The testing section was in a very public place during tests 2-5. I believe that some testers might have "played a bit to the crowd", so to say, making it slightly difficult for them to react naturally to the system.
- Patients who had played earlier and staff would occasionally give feedback to individuals who were currently using the system.
- Group 3 and 5 knew about the experiment through word of mouth; it is unsure how this affected the testing.
- The casual conversation with spectators made it difficult to focus on the testers
- I was the developer and tester of the system, meaning that people might respond nicely to my questions to avoid hurting my feelings. It is impossible in a setting like this to not
- The testing of the staff members happened sporadically. During these times, I did not record the tests of the staff members, making the documentation process more difficult.
- The statistics indicate that I might have been too aggressive to turn on standing auto rotate mode. I found it difficult to judge the patients' physical capabilities in regards to how stable they would be while using my system. To avoid any accidents, I enabled the auto to rotate preventive.
- It is challenging to ensure that the VR headset is in its best position when put on a user's head. This could create blurriness for the users. I am questioning if blurry vision might negatively impact the users and make them experience the speed badly.
- The kids might pretend to be brave and not give too direct feedback about the system.
- Almost all elderly were wheelchair users, making it impossible to test standing mode.
- The young adult group was only female.
- The young adult group is the smaller one, with the kid group being the largest.
- The more ski experience you have, the better you understand the system. For example, some skiers tried to move their bodies in ways I did not anticipate.
- It's challenging to know if the patients were completely aware of what I was testing. An example of this was how no one complained about the turning of the system, even though I have my doubts it was perfect.
- It was up to me when I felt that a patient needed their speed adjusted, as it did not happen automatically, meaning that a patient might not get optimal speed during their testing phase.

Post test interview with Viljar Aasan results

Viljar responded after a few days. His answers have here been translated from Norwegian. My questions are highlighted in bold.

> **Have you observed any positive or negative reactions about my system for either patients or staff, after I left?**
> "*What I have heard, is that they found it entertaining and they wished for more maps*"
> **What did you think about the tests that were conducted?**
> "*What I observed looked good. That there are two modes, where the wheelchair mode also makes it easy for children to complete the game, as an example, is good. The tests were ran in an simple and understandable way, something that made it so everyone were able to master the activity and had a positive experience.*"
> **Did you observe any issues with the execution of these tests?**
> *No, not really*
> **Can you imagine any possibilities for further development and usage of this system or a system like this built on the technology?**
> *It would have been fantastic for us to have some of our trails virtually. Both so that those who do not get out on the slopes can get the experience of it and train coordination in regards to cross-country skiing. This is also an offer we can give to our very weakest patients, who will never otherwise get out into nature. With children and VR in mind, it would still have been desirable to be able to play it on screen without glasses. If that was the case, the mode of movement must be in the handles in some way with regard to steering*
> **Do you have other feedback?**
> *It would have been interesting to connect it to a pull-down device/stake machine. It worked well with the ski mill we tested, but it requires good coordination and technique if you are aiming at hitting the bands every time without being able to see.*

Hospital innlandet Gjøvik testing

In regards to the Gjøvik tests, I was given access to two patients that my contact person, Jørgen Olsen, had selected. These were chosen to test the system's ability to deal with patients with severe physical disabilities. The two patients were also chosen as Jørgen knew they had an interest in technology and exercise. Unfortunately, I can not compare the collected data with the Beitøsolen data.

Patient 1

Patient number:	1
Gender:	Male
Age:	60+
Disability	stroke, balance issues
Ski experience:	High
VR experience:	some
Speed:	3000
Likes the system?:	yes, a lot

Observation of Patient 1: The patient had an assistance belt strapped around his waist at the start before we attached the VR headset and controllers to him. Jørgen was behind the patient, physically supporting him via the belt throughout the run.

Jørgen requested to test out standing mode without assistance mode. As this was their first time, I instructed them how to manually turn in this system, as I wanted Jørgen to be aware of any unexpected situations.

We had a small debate about whether the patient did not understand the turning system or if he was scared about their balance problem. Also worth noting that he, at least in the beginning, was looking a lot down.

He states that he would have liked to use this as a way of arm and or balance exercise if given the opportunity.

The patient improves a lot in confidence in mastering the turning mechanic. It might be worth creating a testing area for patients where they can get better used to the VR world before sending them through the track.

Overall, he was optimistic about the system and had no complaints or requests to change the system. "I found this really good. This system gave me extra challenges in regards to.[omitted]... this was perfect."

Patient 2

Patient number:	2
Gender:	Male
Age:	60+
Disability	wheelchair user + weak strength in arms
Ski experience:	High
VR experience:	none
Speed:	3000-6000
Likes the system?:	yes, a lot

Observation of Patient 2:

Patient 2 started in a wheelchair and was moved over to a chair later on due to the wheelchair construction getting in the way of the player's hands. However, the chair was still problematic as it blocked the player's arm movements.

The patient had no issue understanding the system but was severely limited by the chair's construction. As the patient lacked strength in their arms, they had issues correctly adjusting themself to this problem. As the patient lacked physical strength in their arms, we tied assistance rubber bands to his arms. Jørgen and I then held onto each of our bands, assisting the patient in moving their arms. This made it, so the patient had to move their arms down to move in the game but had an easier time getting back to a resting position that did not collide with the chair.

The patient registered no complaints about dizziness etc., while using the wheelchair, but I do not think the patient was strong enough to physically make the chair wobble. This can strengthen the assumption that the chairs' wobbling is why wheelchair users have higher odds of motion sickness. The wobbling of chairs was observed during the tests at Beitøstølen, but not in a structured manner. It was observed that higher player speeds increased the likelihood of motion sickness. I assume there is a correlation between the player's speed and how wobbly the wheelchair becomes. Proper investigation of the causality between these should be studied in a new study.

One observation we made was that the patient had challenges meeting the minimum movement requirement of the system. Jørgen stated that he believes it would be massively beneficial to decrease the minimum movement requirement for weaker patients.

I had to repeatedly adjust the patient's speed to accommodate his varying level of activity.

The patient was unable to complete the course in one sitting. So we paused at the midway point and continued where we left off a few minutes after. Note that it might be difficult for tired patients to take a break from VR as the headset might be challenging to remove for many.

Notes: The construction of the chair matters a lot.

Post test discussion with Jørgen Olsen

Jørgen was quite satisfied with the system and believes that its simplicity makes it easy for staff members to make accommodations based on the patients, for example, the belt used on the first patient or the rubber bands used on the patient 2.

Keeping the system as simple as possible is great, not just for patients but also for staff, as many are unfamiliar with technology and games. Simple systems increase the odds of the system being used. Vive makes it easy for staff to observe the player while playing while also making possible live adjustments to the system, as this is difficult to do on oculus.

Chapter 6

Discussion

This chapter will interpret and discuss the data collected from the various experiments and tests concerning the research questions. The first section is divided into subsections corresponding to the various experiment results from chapter 5. In these subsections, I will discuss the individual findings and their meaning. I will also, in these sections, try to paint a complete picture of the various tests, which hopefully makes it easier for others to build upon my findings.

In the second section, I will discuss the findings in their entirety, especially in regard to my research questions. I will also discuss the ramifications of these findings on a grander scale.

6.1 Section for section

Interpretation of the Pilot studies

I ran the pilot tests to better understand my system and get some tangible feedback that I could use to make changes to my system. I am confident the results of the pilot tests improved the system in general, as I could observe remnants of the same issues/feedback in the later tests. However, as previously mentioned, I ignored some of the feedback I got during my pilot tests, as I wanted to later verify other testers would make the same observations.

Interpretation of the Interview with personnel

I only had the opportunity to perform one complete interview with healthcare personnel, but it was a fruitful discussion. The interview confirmed many of my assumptions while also shining a light on new information.

Interpretation of the Observation and talks with staff and personnel

The talks and tests conducted with the personnel happened largely sporadically and unstructured. The majority of these tests happened after the tests were conducted on the patient groups, who all had multiple staff members as instructors. I never asked any staff members if they wanted to try, as they ultimately approached me after the patients had tested the system. The testing of the system had the same issues as the patient tests, as the tests were all conducted in the same area, with a majority of the tests being conducted with an audience. While the staff members were testing my system, they asked a professional skier to test it; while he was not a staff member, his response to the system will be discussed here.

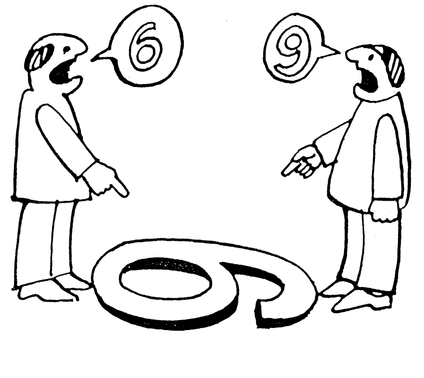
The main difference between the patient and staff tests was how the staff used the Standing mode without rotation assistance. The staff members also stated how they all had a lot of prior skiing experience.

The staff members displayed a lot of the same behaviour as the patients, as they all liked the system and could play through it relatively quickly.

The most exciting difference between the patients and the staff members was how their bodies reacted to the turns. While the patients did what I expected, physically turning their bodies in response to turns, the skiers tried to twist their bodies to accommodate for turns, sometimes turning their bodies upwards of 180 degrees. It was also observed how they tried to shift their weight to the sides to make turns, as this is the usual method of turning while skiing. Some of the staff members also stood on their toes, bobbing up and down in a rhythmic fashion, which, once again, is a standard method used during skiing. *Note: As the staff members were able to observe each other play with the system, there is a risk that some of them mimicked the behaviour of their predecessor, but I do believe that most of them, including the professional skier, approached the system with little intrinsic bias*

The implication here seems to be that what I, as a developer, understand to be core elements of an activity can be something very different than what someone else might think is core concerning the same activity. This once goes back to how different views and opinions must be considered, especially regarding different skill levels.

Figure 6.1: Even while observing the same activity, different people might have different points of view



Interpretation of the Beitostølen tests

As previously stated, I will use the adjusted table during my discussion.

Due to the many sources of information in the Beitostølen experiment, this section will be divided into parts corresponding to the parts found in the Raw data section. This is to increase readability.

Group 1 test result discussion

Group 1 consisted of 6 patients in the age range 7 to 12 years, 4 males and 2 females. The group consisted of patients with different severe levels of Down syndrome 5.4.

Group 1 was the first real group to test my system. The group consisted of children with varying severity of Down syndrome. The system was not designed for individuals with cognitive issues, nor was it designed with children in mind either. Surprisingly, the patients were able to use the system with little to no hassle, and they all appreciated the use, as far as I could tell. One patient was unable to use the system due to hardware limitations. Their head was too small for the headset.

A minor selection of the patients had issues understanding the VR system and was scared of losing their visual senses. As they were scared of the system, they got help from their parent, or me, in guiding their hands, which made them complete the system eventually. As other patients also showed initial scepticism to play the system due to they being scared/sceptic of it, it would be interesting to make them run through the system again, as they then would have been familiar with it. It would also be interesting to see if the patients would stare as much down into the floor on their second try. It might essentially be due to initial fascination with the system, as the floor has the moving arrow during play.

The ability to assist the patients was only made possible due to the observation screen, which made it possible for both myself and the parents to visually confirm their children's status while also providing guidance when needed. The observation screen was also aligned, so the more sceptical children had the opportunity to observe other children playing the system before it was their turn.

It was surprising to observe the positive reaction of the patients with lower cognitive function. They all explicitly commented about how they liked the system; it is unknown if this is due to the game's novelty of the actual game itself.

Overall, the test was very successful, showing the power of adaptability within the system and its ease of use. The patients indicated their fondness for the system, and every tester explicitly stated that they enjoyed the system. The findings are further discussed later on in this chapter 6.1

Group 2 test result discussion

Group 2 consisted of 4 patients, in the age range 18 to 33 years, 5 females. The group consisted of patients with different severity levels of physical and mental disabilities 5.4.

Group 2 was performed in a different area than group 1. The tests performed on this group went more or less flawlessly. Observing the data, it seems that I overused the automatic rotation mode during testing, but this was done based on reactions from the patients during testing. They were all allowed to test the system without assistance mode, but due to balance issues observed in the users, I always ended up enabling the auto turning mode.

Once again, the test was very successful, showing the power of adaptability within the system and its ease of use. It was also good to observe it being fun among an older group, with 100% of the group explicitly stating their enjoyment of the game.

Group 3 test result discussion

Group 3 consisted of 9 patients in the age range 9 to 14 years, 5 male, 4 females. The group consisted of patients with mild cognitive disorders. 5.4.

Group 3 was one of the groups that had the most varied experience regarding my system. The Speed of the testers varied a lot, and their periodic motions made it so they kept going out of the track or colliding with the environment. Their reaction to collisions was surprising, but I assume this is based mainly on how immersed the patients became with my system.

The interesting observation in this group is how some of the patients discovered the downward bug 5.1 while using the system. Based on the observations I did, I assume that the patients are not intentionally breaking my system but rather trying to perform the actions that provide them with the best feedback when performed; using the downward bug is the definitive way to move the fastest through the system, and it is apparent when it happens. This assumption is supported when you observe the patients who had little to no prior skiing experience. These patients were very quickly able to understand and use the system in its intended fashion, which makes me assume that the usage of a clear positive feedback loop is essential. It is worth noting that it is difficult to draw a definitive conclusion due to the system lacking complexity. This makes it difficult to observe if their actions are related to innate intuition due to prior experience or whether the system itself provided a low learning curve.

Group 4 test result discussion

Group 4 consisted of 12 patients in the age range 45 to 68 years, 6 male, 6 female. The group consisted of patients with spinal issues and other muscle diseases. A majority of these patients used a wheelchair 5.4.

Group 4 was the group where I observed the most instances of motion sickness. This group also required quite a lot of speed adjustments during play. Regarding the motion sickness observation, it is highly likely due to the usage of wheelchairs and not age. My data cannot confirm for sure if that is the case as the wheelchair users are also the group with elderly users. I firmly believe that the wheelchair creates a rocking motion inverse to the patient's arm movements, which induces motion sickness. I talked with Øystein Ketilsønn Kjevik, a VR developer from Classic Moose, who has prior experience with developing VR systems for wheelchair users, who supports my observation, stating how they also have observed how wheelchairs were more prone to motion sickness. Stating how they also recommend the usage of a static chair to avoid involuntary movement. Further testing is needed to rule out the other factors.

I observed that some of the patients were trying to move one hand at a time to perform turning actions. This replicates the turning action they are used to when using a wheelchair, again potentially indicating how different individuals make different assumptions when presenting a scenario. It is worth noting that the patients observed each other try the system, which might have made them susceptible to mimicking the patients prior to them.

Group 5 test result discussion

Group 5 consisted of 6 patients in the age range 11 to 18 years, 4 male, 2 female. The group consisted of patients with varying degrees of physical and cognitive disabilities 5.4.

The patients were given the option to play either standing, sitting or standing with automatic rotation mode, and some picked the automatic rotation one. I did not try to convince them otherwise. It is difficult to measure the results of these tests like they were done in a vacuum, as the patients all have trainers and staff around them who will, at random intervals, shout encouragements to the patients during play. They will also occasionally tell them to perform posture checks and technique checks, which, in response, some of the patients adjusted their movements. I assume that during VR play, the player might lose control over their stance and position, making it so they will unintentionally make the wrong moves. This indicates the importance of good in system feedback.

I found it very interesting how the system accommodated the usage of only one hand with minimal issue. I could not disable the unused controller during play, which left a floating controller visible during play, which I fixed by moving the controller out of the field of view during play. I find it very satisfying that the patients who used this one hand mode explicitly said how much they liked the system.

General discussion about the execution of the experiment

In general, the execution of the tests did not align with the design plan due to last minute changes and limitations of the testing arenas. However, I was happy with the results, especially regarding the number of participants. I believe that I did almost the best I could, given the circumstance. It is difficult to provide comments about the accuracy of the results, as I was effectively the single observer handling many tasks at once, let alone accommodating the relatively diverse nature of participants. This concerns player safety is the most significant concern due to the hectic testing environment and participation dynamics.

It is also difficult to generalise the data, as the collected data are unevenly distributed. An example of this is how the largest selection of patients who experienced motion sickness was the elderly group. However, this group also consisted of my testers who used wheelchairs, making it difficult to draw a concrete conclusion. Another example is how the young adult group were all female, making it impossible to state how males in the same age group would react. Further analysis can be located at 6.2

I believe the speed variable provides limited insight from the aggregation of speed data recorded on a patient by patient basis. This is mainly due to the poor documentation method. I avoided saving any data on the machine during testing, and it became difficult to look over the post-test data. Another aspect that was unclear is whether the patients explored the option of adjusting Speed in practice. While I informed patients about the option to increase or decrease the speed modifier, the observed feedback suggests that most patients did not understand this feature. The same applies to the turn speed variable. The patients were informed and asked if they were comfortable with the current settings, but none could provide tangible feedback. Therefore, even though these variables are of utmost importance and were adjusted at intervals based on patient performance, I do not believe the data regarding the speed variable in the table table should be aggregated to draw substantive insights.

General discussion about the issues observed during the experiment

There were many practical issues related to the execution of the tests. I will try to list them here in order of what I assume is their severity and how much they affected the end results. However, I believe my results to be indicative even with the issues mentioned in the list.

Social norms and behaviour: It is hard to accurately judge the impact of social norms and behaviour (e.g., the observed group dynamics across individuals) when testing my system, so I relied extensively on observational data, not just patient interviews. Even if I have extensive experience working with children and VR, I still find it hard to quantitative analyse their responses.

Social aspect: The social aspect was not taken into account during the design phases. I found it much more difficult to question the patients about personal issues and medical history than I assumed. Alternative methods need to be considered regarding data collection for this kind of data, let alone the discussion as to whether such data should be collected in the first place. The original idea was to collect this data and look at how different disabilities reacted to my system. More prominent physical or mental disabilities are worth collecting as it’s fascinating to observe how patients with, for example, one hand use the system compared to a wheelchair user. More substantive insights could be gained by grouping the disability types while avoiding collecting concrete sensitive data, as it will be challenging to get a representative sample size. Even if the sample size of the Beitostølen experiment was large, it was not large enough to draw intricacies of particular subgroups.

Beitostølen test result discussion

Note: This section will discuss everything concerning Beitostølen, including the "Adjusted observation" table

Based on the test results, the tests have been deemed a success. With 84% of users giving explicit positive feedback, and 16% provided no concrete response to the system. Again note that this does not mean they did not like the system, but they did not provide feedback. I find the lack of negative feedback concerning, as I would personally rate my system as adequate and not as good as the responses indicate. The prior research also indicated the need for end users during development to ensure the system would be as usable as possible, which I did not have access to, making this result even stranger. Therefore, I cannot make any assumption as to why I got as many good responses. The most straightforward explanation is that my system is sound, but it could also be that the testers avoided providing me honest feedback as I was both the conductor of the tests and the developer. Another aspect worth mentioning is how the novelty of VR might have impacted the experimental results, as the usage of VR might be fun enough to make the testers provide me with positive feedback about their experience. Further longitudinal studies need to be run to eliminate this possibility. Out of the testers with prior VR experience, 4 out of 5 reported positive experiences with the system.

The execution left things desired, as it happened in a public space, making it difficult to isolate the results. In addition, receiving very little information about the test locale or the test groups made it difficult to properly prepare tests; it was also surprising that that 28% of the testers had a lower cognitive ability, something that had not been taken into account during preparation, even if the results from that group was in general extremely positive, with 100% recorded explicit positive feedback. Also, the different speeds, or rather, how fast the player moved through the system, seem to impact their experience, both regarding potential motion sickness and concerning experiencing collision or other unwanted events.

Concerning the map design, it was expected that the sharper turns would create some problems for the users, as observed during the pilot testing. Their testers complained surprisingly little about these sharp turns, but I observed reluctance among the players to move too fast during the sharper turns. These turned added very little and mainly were a hassle for the players. I would recommend avoiding using extreme sharp turns when designing ski maps. The usage of hills also proved to be a challenge; this is especially the case regarding downhills. If the downhill angle is too steep, the player will feel nausea. Special care needs to be taken regarding the section where the downhill meets the flat mark, as many patients complained about the transition feeling strange and wrong. I assume this is primarily due to the patients imagining they are moving faster downhill, and the imagined deceleration makes the player feel uneasy.

Concerning usability, I can state that almost every tester could efficiently complete the course. There was some initial scepticism by some testers, but they were relatively quick to get used to the system once immersed. I believe that testers like this would benefit from a play area that they were introduced to before entering the natural course, which would allow them to better understand the system in a more quiet environment. I do not believe the reaction of these testers to have anything to do with my system, and instead, an innate fear and scepticism towards VR. Based on my observations, I think that the linkage to a real-world activity that most of the testers have experience with makes it easier for testers to understand how they should use the system; this observation is supported by the papers in chapter 2 [10] [11] [12]. It is still difficult to draw any conclusive argument without having further tested if the system is too simple to make this argument or if the usage of a good feedback loop trumps the need for cultural linkage.

Concerning adaptability and accessibility, it is important to note that the system could adapt to almost all forms of disabilities that I tested on, barring physical limitations based on the hardware (head size). As I had not been able to test the system on disabled individuals before this test session and had to rely on designing the help of research papers and pointers from healthcare personnel, I was happy with the final results. Using guidelines like the Universal design ones discussed at 2.2 seemed to increase the general adaptability and accessibility of the system. Based on the preliminary research, I expected more issues concerning making the system playable for the users, and I find it surprising that there was only one patient who could not use the system. The reason, in this case, was how the patient's head could not fit inside the headset and not concern my system. I attribute the results of these tests to how I designed around potential user disabilities and how I exposed all possible variables that affect the user experience. By doing this, the system could almost painlessly adapt to almost all disabilities. Furthermore, it was straightforward to make these adjustments on the fly by linking these variables to the control panel. With these things said, it is complicated to design for people you do not have access to. Examples of this are how patients 5 and 6, group 5, were the only patients out of the large group where I had to utilise the arm assistance system. Even if the system had never been tested on testers with this condition, the system was able to adapt, making it usable. With that said, even though I had taken this scenario into account during the design phase, flaws in my implementation became clear under testing as it could not disable unused objects when one hand mode was required. Something similar was observed during the tests performed at Gjøvik as well. It is difficult to find a large, diverse group to be used to validate systems, but it seems apparent that it is a must if the goal is to cover as many disabilities as possible.

After the tests had been completed on the patients, we also tested the system using other ski related hardware; this was primarily due to Viljar Aasen's interest in the potential expansion of the system. Surprisingly, connecting the system to a ski based thread mill worked fantastic, indicating that the system can adapt to both software and hardware changes and wishes.

Interpretation of the post test interview with Viljar Aasen

I emailed Viljar Aasen (Beitostølen) some days after the execution of the experiment to give the centre some days to reflect. This was also done as I suspected based on my 2. day experiment, that the groups discuss internally and between each other. His response has been translated to English for easier reading.

His response did not leave much for discussion and reflection; he was happy with the experiments' result and execution but seemed very interested in further development and possible future use cases.

Interpretation of the Innlandet Hospital Gjøvik tests

Due to the late involvement, I only had the time to test the system on two patients at Gjøvik. However, in contrast to group settings at the other centres, I was able to spend a lot of time with both patients and was thus able to document these tests in more detail. These patients were not chosen randomly, as happened at Beitostølen, but by my contact person, who specifically chose patients with a love for exercise. In both cases, the patients suffered from severe physical disabilities. My person of contact at Gjøvik was Jørgen Olsen.

Patient 1 test result discussion

Patient 1 was able, with assistance, to go play through the system. It is interesting to see how much assistance the patient could get from external sources while still being able to play through the system using his arms. Using the external screen, Jørgen, who was standing behind the patient, guided him during turns, etc. Patient 1 was sceptical about the VR headset at first, especially since it removed his ability to observe his feet. This was indicated by how he kept looking down at the start, but not after some time. There is little worth discussing regarding patient 1 that has not been discussed concerning the patients prior at Beitostølen.

Patient 2 test result discussion

Patient 2 was a wheelchair user and lacked strength in his arms. It was complicated to find a position that worked for him as the wheelchairs available were all very wide. During play, Jørgen and I assisted the patient by using training bands to ensure that the patient would avoid hitting his chair during play. The patient seemed frustrated over this obstacle, but he still stated that he enjoyed the system.

The most exciting observation regarding this patient was how he had issues meeting the minimum movement requirement to register movement. The variable that contains the minimum required distance a player needs to move their hands is a hard coded, inaccessible variable. This response indicates how even if I tried to design around adaptability, I could not anticipate everything, and my testing only highlighted this issue after 40 individual testers. These findings align with the findings of "New Approaches to Exciting Exergame-Experiences for People with Motor Function Impairments" [20]

Interpretation of the post-test discussion with Jørgen Olsen

The post test talks share similarities with the Beitostølen discussions. He notes how easy and important it was to use external tools to further assist in expanding potential use cases for the system.

Jørgen also notes how important it is for the system to be easy to use by the patients and person who needs to run and observe the system. His statement fits my anecdotal observations in regards to the usage of commercial games in the rehabilitation context, where games like Beat Saber is sometimes used due to their ease of use for patients, healthcare personnel are not able to properly utilise its potential as many of the settings are difficult to find.

6.2 Quantitative analysis of the Beitostølen result

I will, in this section, perform a quantitative analysis of the results documented during the Beitostølen tests in an effort to debate the findings. I will, through this analysis, use the adjusted table for my discussion 5.4. The adjustments are documented in 5.4

Age and Gender balance: The gender balance of my testers was: 19 female and 19 male. Totalling 38 testers in total for my analysis.

Table 6.1: Age and Gender balance per group

GR	Male	Female
1	4	2
2	0	5
3	5	4
4	6	6
5	4	2

Table 6.2: The number of testers per groups

Age	Total
7-12	6
9-14	5
11-18	9
18-33	12
45-68	6

It is here worth noting that there are no males in group 2, which is the 18-33 age range. Following Beitostølens age grouping, I have grouped groups 1, 3 and 5, into the Kids group, Group 2 is Young adults, while Group 4 is Elders.

Table 6.3: Gender balance per grouped age

GR	Male	Female
Kids	13	8
Young adult	0	5
Elder	6	6

In this grouping, we can see that there are 55% Kids, 13% Young Adults, and 31% Elders. The gender balance is mostly even across the groups, with a slight majority of males in the Kids group. The Young Adult group is a 100% female group. I will continue using grouping when looking at responses in this section.

Table 6.4: Table of all recorded instances of the speed variable

Speed	Total
2000	1
2500	1
2700	1
3000	32
3200	1
4000	1

Speed : Based on these statistics, it is apparent that the speed variable was underutilised, which supports my statement made in 6.1.

Likes the game: *Note: As previously mentioned, I require an explicit verbal positive statement to count a patient's response as Yes to them liking the game.*

Table 6.5: Likes the game: total

Yes	No response
33	6

The patient's responses were overwhelmingly positive response, with 84% stating explicitly that they liked the system. There were no negative responses recorded.

Table 6.6: Likes the game: Kids

Yes	No response
17	4

Table 6.7: Likes the game: Young Adult

Yes	No response
5	0

Table 6.8: Likes the game: Elder

Yes	No response
10	2

Table 6.9: Likes the game: Female

Yes	No response
17	2

Likes the game: Male

Table 6.10: Likes the game: Male

Yes	No response
15	4

Table 6.11: Likes the game: Cognitive Ability

Yes	No response
10	0

Likes the game: Prior VR experience

Table 6.12: Likes the game: Prior VR experience

Yes	No response
4	1

Based on the responses recorded, I see no clear difference between the genders or the age groups. The group with the highest percentage is within the group of lower cognitive testers, with 100% positive responses recorded. Based on these responses, the system is liked by all, across all age groups and genders and cognitive abilities. It is still up for debate if the novelty factor of VR is what makes patients give such and positive response, but 4 out of 5 of individuals with prior VR experience, still had a positive response to my system, which strengthen the assumption that players enjoy my system, and not just the novel factor of VR headsets.

Table 6.13: Motion sickness in total

No motion sickness	Motion sickness
33	5

Motion sickness Motion sickness based age group

Table 6.14: Motion sickness based age group

Age group	Total
Young adult	1
Elder	4

Four out of these five are using wheelchair mode. These two tables overlap with the same patients.

Table 6.15: Motion sickness in: Wheelchair vs standing auto rotate

Mode	Total
Standing auto rotate	1
Wheelchair	4

The number of testers are over-represented with in wheelchair category:

Table 6.16: Motion sickness in: Wheelchair

Wheelchair motion sickness	Total
Yes	4
No	6

Based on these findings, it is clear that either there is an overrepresentation of motion sickness among the elderly or among wheelchair users. My observations, as discussed in 5.4 make me assume that there is a linkage between using a wheelchair and the risk of motion sickness.

6.3 The Larger picture

In this section, I will expand on the previous discussions with relevance to the research questions. I will also here add more of the anecdotal observation I did during testing and talks with various experts and healthcare personnel. Please consider that these data were not collected using proper empirical methods and should be considered as secondary sources and even anecdotal. However, I find these accounts and observations relevant to be able to draw a full picture.

6.3.1 Research question discussion

RQ1: What can be done to increase the usability of rehabilitative games?

In terms of usability, my tests seem to indicate that relying on activities known to the players can increase the intuitiveness of the system. It might also be equally important to rely on a strong feedback loop, which makes it clear what is expected of the users. Every user input action needs a clear feedback response. Discussions with healthcare personnel seem to support this, as they state they often use familiar activities to the patient during training, both to increase motivation but also to increase ease of use, which in turn leads to improved exercise.

SQ1: To what extent does cultural embedding increase intuitive use and hence usability of a rehabilitation system?

Based on observed feedback from various healthcare personnel, it is common to rely on physical activities that are familiar to the patients during rehabilitation. As previously discussed, I do not believe I have enough data to conclude that the usage of cultural embedding improved the intuitiveness and usability of the system. I believe, based on the user observations, that there are signs that indicate that the system ended up being very intuitiveness and had high usability, but further exploration and the removal of other factors need to be done before any conclusive statements can be made. The theory and healthcare personnel I have talked to also share the sentiment that the usage of cultural embedding and known activities increase intuitiveness.

I did not explore this theory in detail, but I have reasons to assume that the usage of cultural embedding could backfire if done poorly. Cultural embedding and culturally familiar activities and behaviour have intrinsic behaviour linked to them. This means that if a system relies on the design characteristics of such activities but does them poorly, users' intuitive behaviour could be misaligned with the system design. This was observed during testing when testers with a high understanding of skiing performed motions counterintuitive to my design. The disconnect between the designer and the user could potentially lead to an "uncanny valley" situation [21].

SQ2: What are features healthcare personnel like to have in their system?

I did not investigate this question in a very structured manner but in a more observational and experimental manner. During discussions with healthcare personnel about features they would like to potentially see in such a system, most of their ideas came from a non-developer mindset. At least in the case of the individuals I talked with, our points of view were very different, making discussion difficult. I would also like to attribute this to my lack of experience in explaining the potential possibilities and limitations of the developed system. Due to this issue, During the development of the system, I developed several modules smaller modules designed around potential use cases, which I described and sent recordings of demonstrations to various centres to get feedback. Tangible examples made it a lot simpler to acquire feedback. An example of such a video can be found here: exerskii master demo 1. Information brochures were also sent to centres to increase the interest in the system. A copy of the brochure can be found in Appendix F.

Based on module feedback, observation, and requirement discussions, it seems that popular wanted features can be put under three groups:

- Adaptation
- Observation and tracking of progression
- Safety

Even if these are not tangible features, they describe some of the features personnel was most excited about during the discussion. I will discuss those in detail in the following.

Adaptation: Many patients require assistance and customisation within a system to be able to use it correctly. A system might, on the surface, be a very good fit for a patient and might lack the necessary options to make the system viable for rehabilitation patients. an example of this, as retold by a healthcare worker, is how the popular VR game, Beat Saber, makes the patient perform a lot of the same exercises that my system does, but it lacks the customisable aspect, which makes it hard to use for many rehabilitation patients. They were, in this instance, referencing the lack of ability to disable extreme stimulation within the game

Observation and tracking of progression: To showcase potential use cases for my system, I developed a live statistics tracker that is able to live to showcase the patient's performance during play. This system was met with very positive reception, with healthcare personnel stating how they would wish for the ability to both observe and track the patient's performance long term, which would move them more into a data-driven approach to rehabilitation. This indicates that there is a want for data-driven approaches within the games system. I avoided implementing such a system due to legal concerns in regards to the storing of patient data.

Safety: There were repeated discussions in regards to the safety of the players. This seems to be mostly related to reluctance to VR headsets. I make this assumption due to the repeated request to have alternate modules made that do not rely on VR headsets. When a patient wears a VR headset with an audio headset, they will lose their ability to observe the world around them, which makes navigation and keeping balance difficult for some. I was unable to properly investigate security alternatives, but I mention the need for them here, as it is clearly a field worth investigating.

SQ3: What measures can be taken to avoid the system from turning legacy?

Naturally, it is difficult to validate the long term potential of my system, but steps were taken to increase the likelihood of long-term usage. During design, I tried to design a very simple application which avoided relying on any proprietary hardware elements, like buttons on hand controllers. In theory, my system can be easily adapted to rely on any form of hand motion tracker and any VR headset. Libraries used in the course of the development are open source, maximising the potential for later adaptation. It also makes it possible to make adjustments in the future if the new hardware systems are incompatible with my current software system.

RQ2: What are ways to increase adaptability within rehabilitation games?

During the development of my system, I designed the system with the goal of exposing all variables that affected the gameplay experience of the player, with the goal of making the system very adaptable based on the player's needs. Based on the data, this seems to be a very effective approach, as I could, on the fly, adapt to almost any disability that I tested on. Ultimately, having one dedicated person to ensure adaption through the usage of the system is not sustainable. Further investigation into the automation of adaptability and user profile storage should be prioritised.

SQ1: How do you design such system to improve odds of adaptation and usage?

Based on observations and discussions with healthcare personnel, the system should not only be designed to be easily used by the players but also by the healthcare personnel or other assistants, who might not be tech savvy. If the system requires a lot of complicated setups, it increases the risk of personnel avoiding using it in their work. It should also be possible to observe the patients within the system to ensure it is possible to guide them. An issue I faced during testing was a tester who was able to access the VR setting menu, but as Unity does not display an exact mirror of what the tester sees, it became difficult to guide the tester without being able to observe exactly what they see. Efforts should be dedicated to ensuring that players stay within the designed system and avoid any accidental system changes or confusion.

SQ2: What methods can be used to verify that adoption was successful?

I found it difficult to verify that the adjustments I made were correct, as the testers were unable to provide me with proper feedback on adjustments. An example of this is how none of the testers requested speed change during play, and none of them registered my adjustments during play either. It is difficult to know if the players are aware and are able to understand possible adaptation adjustments that can be applied to the system, especially during higher stressful situations like during play. I explored the use of visual aids and statistics to make it possible to observe user behaviour in data form, which in turn makes it possible to make adjustments to improve the user experience. I did not explore this method in detail, and further research is required. Future work could turn to explore a more exhaustive collection of user data in order to provide a reliable data basis for assessing adoption quantitatively, in addition, to direct interviewing of testers. This could further be paired with ML techniques to aggregate the collected data effectively and efficiently in order to present the results in a manner accessible both to developers as well as rehabilitation practitioners.

6.3.2 The future of rehabilitative gaming

Based on my work and research, there is some uncertainty in regards to what the future holds for rehabilitative gaming. It is becoming an increasingly popular research topic, with several rehabilitation institutions, globally and inside Norway, dedicating funds to the research and development of such systems. However, in my opinion, some years have passed since the commercial golden age of these systems (Kinect, Wii, PlayStation Move), which makes me question if any system of that type will take their place. There are currently several projects being worked on (Nintendo Switch, VR headsets), which can be used to assist in the development and usage of rehabilitation games, but in my opinion, these kinds of the system seem to lack the ability to reach the masses, and will eventually face the same issues as their predecessors, becoming legacy systems. An example of this is how Nintendo, the developer of Wii, at the 29. April 2022, launched their new sports system, which uses physical controllers to make the players move around in the world, with Nintendo already discussing what they will replace the Switch with, meaning Nintendo is already planning on facing out the system, rendering the game absolute.

On a more positive note, that accessibility is becoming increasingly popular to include in games. The accessibility model of the AAA title, The Last of Us 2, was hailed as the most accessible game on the market [22], with some other high profile games being released around the same time, also with extensive accessibility modes. The issue with these modes is that they require funding and dedicated time to testing and development, something many smaller studies might not have. The customer base that would use these modes is few and seemingly not worth catering to.

On the hardware side, Microsoft released their Xbox Adaptive Controller, which allows individuals to make complex adaptations to their system to allow individuals with severe disabilities to game again.

Having extensive accessibility modes in single player games seems to have no drawbacks for the players as they are optional to the players, but in multiplayer games, adding such accessibility modes can massively impact the game. I have not explored this topic deeply. But I am questioning how competitive games can have complex accessibility modes as such modes can be abused by people who are not disabled. In certain competitive games, there are reports of players abusing accessibility modes to get an edge; examples of this are how colour blind modes can have unintentional effects on normal vision, highlighting things that should be hidden in the game world. [23].

6.3.3 The feeling of mastery

"A Qualitative Study Exploring the Usability of Nintendo Wii Fit among Persons with Multiple Sclerosis"[24] states that usage of properly adapted exercise games can increase the sense of accomplishment and feeling of mastery among patients. This is also stated in the book "Serious Games Foundations, Concepts and Practice"[25]. I assume that, since my game allows everyone, independent of their disability level, to play the game like able-bodied people, I can offer them a feeling of mastery that might be lacking in their day to day life.

6.3.4 Opportunities for future development and research

During the planning, design and development of this project, I made several assumptions, which led to design related choices. In this section, I will discuss if these choices affected my system in a positive or negative manner. Most of the choices reflected upon in this section were previously discussed in Chapter 4. I will not discuss features that were removed due to time or legal constraints.

Multiple maps:

The choice to keep the testing to one map was slightly limiting as I was unable to test multiple scenarios. By keeping it to one map, it made it easy to cross verify the testing on patients due to their shared experience. One extra map was designed to verify the limitations of the system but was never properly tested.

No of gamification elements:

The decision to not implement or use gamification elements inside the system was built on the assumption that players would be incentivised to rush through the system and avoid doing the proper movements. Every player I observed viewed the system as a game to beat. Almost no one took their time with the system and tried to complete it as fast as possible, with some asking if they had today's best time. The design of the system might have had unintended consequences in relation to player expectations. The lack of such elements made it, so I could avoid unintended disturbance, making the player experience shared and easier to compare post experiment.

No audio:

Surprisingly enough, there were no requests for audio. Even if I believe that audio improves the design of the system in terms of immersion, avoiding it made it much easier to talk to players during testing and ensured the security of said players.

No leg movement:

As a compromise, I developed a system that encourages some leg movement during play. I do believe this system ended up being a bit sub-optimal, as I tried to impose my own assumptions on what the players would expect for such a movement system without properly verifying it or gaining enough ski experience to properly implement it. Even so, I think that not offering such a system to the players will make the system boring in the long term.

Environment design:

I chose to go with an artistic simplistic low polygon art style for resource and design reasons. In terms of resource management, my PC had issues running this system at a stable frame rate, and there were clear performance issues. While using the graph panel, the frame rate dropped by more than half. Indicating that relying on anything more realistic could be very challenging due to performance reasons.

I did not receive any negative feedback from any of the testers in regards to the art style; surprisingly, even the elderly testers were okay with this "childlike art style". Among the younger testers, this art style was a hit, with some comparing it to Minecraft. It is also worth noting that the usage of artistic designs over realistic designs might be better due to the lower resolution on VR headsets.

Free player movement:

I chose to limit player movement and force them to follow a preset path. Some players were initially confused about this and tried to move off the track. Later they got used to the set path but still stated how they wished for more free movement.

I do believe that this was the correct choice, and this makes it easy for me to guarantee that the path the players follow will be complete, contain all the relevant design elements, and be bug-free. A free movement system would require extreme amounts of work, and I am certain that the current state of the system would be unable to handle this, as previously discussed in relation to hills and movement.

Choice of data to collect

The choice of data to collect was inspired by the potential variables I could adjust in my system and variables that could be used to group testers. Examples of this were gender, age, disability etc.

I chose to record this data as I wanted to note down all data that could be relevant for further quantitative analysis and to observe if different demographics responded differently to the system.

6.3.5 Players with lower cognitive ability

As I stated earlier in the thesis, the system was designed to be used by patients undertaking physical rehabilitation. The system had undergone no preparation or changes prior to being used to test on testers with lower cognitive ability. I also had neither performed any research on how experiments on individuals with lower cognitive ability should be executed.

These testers managed to use my system without too many issues. They managed to understand what was expected and managed to go through the system. There were some issues in regards to the patients with severe lower cognitive ability as they were scared of the VR headset, but these patients were still able to play through the system with external assistance from their parent or guardian. This group of patience was the group who loved my system the most, with 100% explicit positive feedback.

Even with the results as positive as they were, I still recommend potentially performing more tests on individuals with lower cognitive ability after having performed stronger background work. It could also be beneficial to involve someone with experience working with individuals with lower cognitive ability, as I am unsure how to interpret the data collected from these testers. The usage of these specialists could, in theory, extract information or patterns I overlooked. If they assisted during the testing, they could potentially observe different behaviour than I did.

6.3.6 Core findings and main takeaways

I will, in this section, bring forth and discuss what I think are this thesis's core findings and the main takeaways from this project.

Open adaptable design

In the case of this system, following an open, adaptable design approach seemed to yield excellent results. By exposing all variables at run time, it became possible to adapt and adjust the system to increase how well testers were able to use the system. I do believe this form of system design approach can work outside the field of physical rehabilitation game design. The obvious field would be traditional computer gaming, but I do believe other forms of systems could benefit from following this form of design. Note that following this form of design ideology does open the system up for abuse and unintended behaviour. The trade-off between usability and security needs to be considered.

Cultural linkage can increase the usability of the system ...

Taking inspiration from activities and cultural norms during the design of systems could assist in making the system easier to understand for users, therefore increasing its usability level. However, as previously discussed, I do believe this form of design should be used with care. I assume this form of design is best applied if you are very familiar with your user base but also are able to rely on someone with vast experience within the field you are trying to take design elements from.

... but strong feedback loops can also work wonders

As previously discussed, it is unclear if the usage of cultural links or a strong feedback loop was the reason for the success of this system. Even so, signs point to the effectiveness of using a strong, clear feedback loop to increase usability and clarity of systems.

KISS, Open Source and System Independence

A sub focus of this thesis was the exploration of techniques and methods that can be applied to decrease the likelihood of a system becoming obsolete and legacy. Even if these techniques lack the proper testing compared to the main focus areas of this thesis, I am confident these techniques can be used to decrease the likelihood of obsoleting.

KISS *The KISS design principle, or "Keep it simple stupid" design principle, when followed, makes it easier to offer long term support for a system, makes it easier to port a system, and it makes it easier to make adjustments to the system over time. Games like Beat Saber is a very simple system, which just utilise hand controllers and a VR headset, making it very simple to adapt it for different hardware systems in the future*

Open source: Relying on open source systems makes it possible to continue working on the system, even if the original creators have stopped supporting the system.

System Independence: Relying on specific proprietary systems makes it challenging to provide long term support for the system. This is especially true for hardware systems, as they might have their production discontinued. Optimally, you should follow current industry standards for the needed hardware, which would potentially make it possible to replace the hardware systems in the future. This might be challenging for newer systems, but old hardware systems like PlayStation controllers and Xbox controllers still work today due to their standardised design.

Rehab games can work on all ages, genders and on all cognitive levels

Even if the age distribution of my testers has an over-representation of younger individuals, it seems evident that all age groups had an overwhelmingly positive response to my system. I also recorded an overwhelming positive response to my system across genders, and my system was a clear hit among individuals with lower cognitive ability.

It is challenging to anticipate all needs of disabled individuals - testing is needed

Designing and developing a system aimed at users with delicate needs is challenging. It is difficult to design for a user base that has vastly different user needs than yourself. The result from my testing indicates that there is a need for a diverse group of testers during the design and development of this system. Even so, relying on research and expert opinion during design, seems to greatly improve on the system usability among the targeted end user group, which means less adjustments are needed during testing.

The possibility to capture unbiased data via systems

Some of the healthcare personnel I talked to seemed thrilled about the possibility of gathering concrete data from patients using body trackers and, in turn, using this data to paint a clear progression picture of patients. Further verification and testing are needed, but there seems to be a potential gap in the systems available.

High adaptable design

The design methodology discussed in this paper, when tested, was able to adapt to almost all disability types. The positive positive responses recorded could indicate that this form of system design is very effective when it comes to the development of systems targeting groups with very specific user needs.

Difficult to ensure proper adaptation without proper systems

I found it challenging to ensure that the adjustment of the system during play improved the player's experience. This was largely due to the player's lack of understanding of how the system worked and how the various adjustments affected their experience. It is challenging to rely on players' feedback and observation to ensure that the system has been adapted properly. The statistical view of player movement proved to be helpful in some cases but was not useful in every case. I recommend the further investigation and development of tools capable of ensuring proper adaption of systems.

Chapter 7

Summary and Conclusion

This thesis explored some of the issues I deemed the most pressing when it came to increase the usability of rehabilitation games, and improve their adaptation capabilities. It also investigated other smaller fields related to the usage of rehabilitation games as they become apparent during the experimentation and interviews.

To gain a better understanding of the field, this thesis tried to answer these two first order research questions: **RQ1: What can be done to increase the usability of rehabilitative games?** and **RQ2: What are ways to increase adaptability within games?**

To investigate these questions, I first conducted a literature study and interviews with healthcare personnel to increase my understanding of the field. With this information I designed and developed a game system with the goal to explore and test my assumptions. This system was tested on 40+ patients undergoing rehabilitation programs.

The findings indicate that it is possible to design rehabilitation games that are usable for many different disability groups, when proper care is taken in the design phase. These games have high potential to be enjoyable for all age groups, and genders. If the systems are intuitive, they can also be used by individuals with lower cognitive ability with great success. It is worth noting, how many other development papers, often focus on designing rehabilitation systems with a hyper specific user group in mind. My paper indicates that it is possible to design for a much wider audience.

As a final note, I would say that this thesis should be used as a basis for further research, rather than than a conclusive thesis. Due to time restrictions, I was only limited to a few tests over a short time span, meaning that even if I tested on an large number of individuals, there were too many errors in my main test which needs to be rectified in a different test scenario. Even so, I believe this thesis can offer insights on design and development related challenges, and some of their answers, while also highlighting the human aspect from a developer point of view. I am happy with the results presented in this thesis, but I can't ignore that more tests over a larger time frame, would have made my results and final assumptions more conclusive.

7.1 Limitations

7.1.1 Weak literature study

This paper is built heavily upon prior work and guidance of healthcare workers. With that said, the lack of literature relevant found during the literature study hampered the discussion within this thesis. A stronger fundamental understanding of the field is recommended for further improvements.

Lack of representation with in the testers

The system was tested on over 40 patients undergoing rehabilitation programs, but the grouping of the patients was not evenly distributed. (e.g. no male testers between the age 18 and 45, or almost no non-wheelchair users above the age of 45) Further testing of the system on a more diverse group is recommended.

Only tested once

The main study of this paper was only ran once. The study was ran at a very diverse group of patients, but as it only was ran once, I was unable to make any adjustments and improvements based on my initial observations. Several studies over a time frame is recommended to get a better understanding of the responses.

Lacking access to patients during design

The research states very clearly that not being able to use end users for iterative testing during the design phase, deceases the quality of the final product [26]. With that said, the quality of the finalised system seems to be very high, even if lacking access to testers during the design phase. This could indicate that the usage of experts in their field during development might be a good substitute for the lack of testers.

7.2 Future work

The system described in this thesis is, as far as I can tell, quite novel, both in its approach and in its implementation. However, due to various limitations, as discussed prior, there is definitively the potential to perform further development and research in this area. Some of the areas that I deem require further work are:

Further investigate the usage of cultural linkage in regards to usability

As I discussed in Chapter 5, I can not with certainty make the claim that the usage of cultural linkage improved the usability of my system. Further investigation on this claim is encouraged, as I believe this system is relying on a very simplistic design which could negate any benefits from a cultural embedment.

Further investigate if wheelchairs induce motion sickness

My data is not diverse enough to conclude if there is an increase in motion sickness in the elderly, or if their wheelchairs is the culprit. Further testing is required to verify if its the wheelchairs, and if that is the culprit, alternate development methods needs to be researched.

Perform longitudinal studies to confirm is the system is good

As previously discussed, I feel the response from the testers to be a bit too good. It would be very interesting to perform multiple testers over a period of time, to remove the novelty factor.

Longitudinal studies to research the effect of the system

Further studies to see if people would like to play this game long term, have any long term retention or physical improvements after use, would also be very interesting.

Rework the maps to a better state

The map I used for testing was designed to tests extreme edge cases when it came to terrain. It would be nice to see a test using a more proper map, which takes the design feedback into account from the large scale test.

Test on multiple systems

Even if the system was designed to be used on multiple systems and setups with regards to long term support, I did not have access to other systems during development to verify this claim.

Wider spectrum of testers

As discussed earlier, even if I had access to a large tester base, I continued to find edge cases for my system up until the last day. To further verify and test the adaptability potential of the system, more testers with varying disabilities needs to be tested on.

Check if healthcare personnel are able to operate the system

As mentioned by staff personnel, the ease of use and setup is a massive factor in regards to the likelihood of a system being used in a healthcare facility. During testing I was the sole facilitator and I was in charge of making adjustments to make sure the system was able to adapt to the patients. It would be interesting to observe healthcare personnel facilitate and run patients trough the system, to observe how they interact and adjust the system accordingly, compared to me.

Investigate expansion possibilities

During testing, there was a lot of involvement of external hardware. It would be interesting to investigate the incorporation of external tools to improve on the exercise part, as the VR controllers lack weight. Both Viljar and Jørgen was excited about the potential to extend the design to include exercise apparatus. We confirmed that the system can be used with exercise apparatus without issue, but further testing would be beneficial.

Figure 7.1: Image of Viljar combining my system with external exercise apparatus.

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Appendix A

Additional Material

This appendix entry contains a copy of the protocol I followed when conducting my tests at Beitostølen and at Gjøvik rehabilitation centres.

Gjøvik/Beitøstølen protocol

Personlig introduksjon

Skole introduksjon

Projekt introduksjon

- Hvorfor, hva, ski, master program

Sikkerhets advarsel

- Kan brytes umiddelbart om dere føler no rart
- Lukk øyene, ta av headsettet, og informer meg så jeg kan assistere med å bryte
- Om dere sliter med bilsyke, sjøsyke eller lignende, vennligst si ifra på forhånd
- Vi ungår lyd og musikk via headset under testing for sikkerhets messige grunner

Har mulighet for sittende eller stående modus

NSD gjennomgang i plenum

- Trenger underskrift, spørsmål kan taes meg meg direkte eller via epost
- Ingen identifiser data blir brukt i projektet, eller deles med noen
- Vil spørre hovedsakelig om alder, og tidligere erfaring med rehab+trening
- Stor interesse i å vite hva dere syntes, hva som fungerer/ikke fungere, manglet, var forvirrende, kunne vært anderledes, etc
- Lydopptak vil bli gjort for enklere dokumentering av testene her, men om dere ikke ønsker dette så kan jeg la være og gjøre opptak av testene deres
- Dere har så klart muligheten til å takke nei til data innsamling, og fremdeles få teste systemet, men dette er ikke optimalt for forskning

Appendix B

This appendix entry contains the interview guides used at patients and healthcare personnel.

Master projekt intervjuguide

Rehabilitativ spilling

Dette dokumentet inneholder spørsmål som skal stilles muntlig til pasienten, før og etter de har spilt spillet. Pasienten står fritt til å ikke svare på spm

- Kandidat nr:
- Aldersgruppe:
- Kjønn:
- Hvor lenge har dere vært her på beitostølen og deltatt i deres rehab program?
- Vill dere si dere har tatt del i mye/lite rehabilitative programmer før?
- Om dere tillater meg og spøre, hva er det dere får hjelp med her?
- Har dere kjennskap/erfaring med spill basert rehabilitering?
- Har dere erfaring med ski?
    - Liker dere å gå på ski?

  Etter testing

- Hvordan føler du deg? Kvalm etc
- Hva synes de om systemet?
    - dårlig/bra
        - Dårlig
            - Hva var dårlig?
            - Systemet?
            - Miljøet?
            - Mangel på noe?
            - Ikke realistisk nok/enkelt å forstå?
        - Bra
            - Hva var bra?
            - Hva synes dere om ski systemt?
            - Miljøet?
- Systemet brukte ikke realisistke objekter, hva syntes dere om dette?
- Fungerte systemet som forventet?
    - Var det klart nok hva som var forventet i systemet?
- Systemet følger en fast vei, hvordan føltes dette?
    - Var veien klar nok?
- Det var ingen indikasjon av kropp/ski eller lignende i systemet, var dette et savn?
- Det var mangel på spill aktig systemer, som tidstaker eller likende
    - Var dette et savn?
- Spillet manglet bevegende elementer/intresange elementer
    - Var dette et savn?
- **Om rullestol**: systemet har innebygd rotasjon, hva syntes de om dette?
    - Var høyden okay?
    - Andre savn for å gjøre det bedre for rullestolbrukere?
- Ville dere ha interesse i å bruke dette systemet i større skala/kopi av ski løyper?

- Hva synes dere om systemet, i forhold til de normale øvelsene dere pleier og utføre?
- Tenker dere at dette systemet kunne vært et potensielt alternativ til normale øvelser?
- Andre kommentarer?

Master projekt intervjuguide - personnel

Rehabilitativ spilling

Dette dokumentet inneholder spørsmål som skal stilles muntlig til personen, før og etter de har spilt spillet. Personen står fritt til å ikke svare på spm

- Navn
- Stilling:
- Hvor lenge har dere vært her på beitostølen?
- Kan dere fortelle om potensielle problemer med rehab?
  - Forskning tilsier at motivasjon og interesse spessielt når det kommer til rehab aktiviteter alene, har dere observert dette?
- Har dere kjennskap/erfaring med spill basert rehabilitering?

Hvis ja

- Har forskjellig former for handicaps reagert forskjellig på spill rehab?
- Kan du fortelle om positive/negative sider med disse spillene?
- Mangel på tilpasningsmuligheter i disse spillene?
- Mangel på morro i disse spillene?
- Er det noe dere bruker aktivt
- Er det noe dere har planer om å bruke mere av i fremtiden?

Etter testing

- Hva synes de om systemet?
  - dårlig/bra
- Hva synes dere om systemet, i forhold til de normale øvelsene dere pleier og utføre?
- Tenker dere at dette systemet kunne vært et potensielt alternativ til normale øvelser?
- Tar dere å samler data av pasienten?
  - Hvordan
  - Systemet mitt kan samle inn, vise data, ser dere noen bruksområde for dette?
  - Hva slags data kunne vært fint å se på?
- Ser dere noen nytteverdi i et slikt system med tanke på skii basert bevegelse
- Bevegelsessystemet kan gjenbrukes i andre 3d baner, ser dere noen nytteverdi i å undersøke andre bruksområder/videre utvikling av dette systemt i forhold til rehab?
- Andre kommentarer?

Appendix C

This appendix entry contains a copy of the NSD form I asked all patients, or their legal guaridan to sign prior to testing.

Vil du delta i forskningsprosjektet

NTNU master projekt - rehabilitativ spilling

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å utforske hvordan man kan utvikle et spillsystem for rehabilitering, for norske brukere. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Formålet med prosjektet er å forske på design og utviklingen av rehabilitering spill med Nordiske brukere som målgruppe. Benjamin ved NTNU, har for sitt masterprosjekt, designet og utviklet et trening spill som utnytter virtuell virkelighet. Designet er basert på forskning gjort i andre land, og målet er fortsette denne forskningen, samt verifisere at disse funnene passer Nordiske brukere også.

Deres respons vil kun bli brukt av studenten for å bevise eller motbevise antagelse han har gjort i sitt prosjekt.

Hvem er ansvarlig for forskningsprosjektet?
NTNU er ansvarlig for prosjektet.

Prosjektet er i del gjort i samarbeid med Sykehuset innlandet Gjøvik

Hvorfor får du spørsmål om å delta?

Du har som pasient hos Sykehuset innlandet Gjøvik, tilfeldig fått tilbud om å delta på dette prosjektet.

Hva innebærer det for deg å delta?

Hvis du velger å delta i prosjektet, innebærer det først et kort intervju om din erfaring i relasjon til rehabilitering og spørsmål om du ofte er utsatt for svimmelhet ol.

Det er ingen forpliktelse til å fullføre testen, og testen kan enkelt brytes underveis.

Noe informasjon om systemet er tilbakeholdt ettersom jeg utfører testing av brukervennlighet, men mere utdypende informasjon kan gis om ønskelig.

Du får så information om rehabiliterings spillet, hvordan det fungerer, og potensielle bivirkninger som kan forekomme under bruk. (Hovedsakelig svimmelhet)

Om du så velger å delta, får du muligheten til å prøve et treningsspill.

For å spille spillet, kreves det bruk av VR briller, og 1 eller 2 håndkontrollere. Jeg vil assistere med å tilpasse disse for deg. Jeg har masse erfaring med å assistere personer med å teste VR spill fra før.

Etter dette, vil dere så ha muligheten til å spille et VR ski spill. Spillet er hovedsakelig en 3-4 minutter gå tur, hvor jeg kontinuerlig monitorer deres respons og interaksjoner med systemet. Under testing ønsker jeg også å ha dialog med deg, ettersom jeg kan tilpasse spillet underveis for å prøve å tilpasse spillet for den optimale spill opplevelsen.

Etter du har spilt dette spillet, ønsker jeg å stille noen flere spørsmål i relasjon til din opplevelse av systemet. Dette vil ta i rundt 15 minutter.

Jeg tar lydopptak og notater fra intervjuet. Reservasjoner mot lydopptak kan gjøres.

Lydopptak publiseres ikke og er kun gjort for å simplifisere dokumentering. Opptak vil bli slettet fortløpende etter dokumentering..

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

Opplysningene deres vil hovedsakelig bli behandlet av Benjamin Skinstad.

Dataene vil bli anonymisert og ingen identifiserbar data vil bli publisert i sluttrapporten.

Hva skjer med personopplysningene dine når forskningsprosjektet avsluttes?
Prosjektet vil etter planen avsluttes 1. Juni 2022. All konkret innsamlet data vil bli slettet, men rapporten vil fremdeles inneholde generelle trekk observert av den innsamlet dataen.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra NTNU har Personverntjenester vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- *Student: Benjamin Skinstad, Benjamns@ntnu.no*
- *Veileder: Christopher Frantz, christopher.frantz@ntnu.no*
- Vårt personvernombud: *Thomas Helgesen, thomas.helgesen@ntnu.no*

Hvis du har spørsmål knyttet til Personverntjenester sin vurdering av prosjektet, kan du ta kontakt med:

- Personverntjenester på epost (personverntjenester@sikt.no) eller på telefon: 53 21 15 00.

Med vennlig hilsen
Benjamin Skinstad

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet *NTNU master projekt - rehabilitativ spilling*, og har fått anledning til å stille spørsmål. Jeg samtykker til:

- □ å delta i *intervju*
- □ å delta i *spill prosjektet*

Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet

----
(Signert av prosjektdeltaker, dato)

Appendix D

This appendix entry contains a copy of the data collected during testing at Beitostølen rehabilitation centre. This table contains all the observed data entries, in chronological order of observation.

GR	Patient	Gender	Age	Prior VR experience	Speed	Type	Likes the game	Cognetive issues	Comments
1	1	male	8	yes	3000	standing auto rotate	yes	yes	looks down a lot
1	2	female	10	no	3200	standing auto rotate	yes	yes	claims its exercise
1	3	male	10	no	3000	standing auto rotate	yes	yes	looks down a lot,claims its exercise
1	4							yes, heavy	headset too small
1	5	male	7-12	no	4000	sitting	yes	yes, heavy	guided trough
1	6	female	7-12	no	3000	sitting	yes	yes, heavy	guided trough, looks down a lot
1	7	male	7-12	no	3500	sitting	yes	yes, heavy	slight guidance, looks down a lot
2	1	female	18	no	3000	standing auto rotate	yes	no	
2	2	female	18-33	no	3000	standing auto rotate	yes	yes	tries to move off track, plays 2 times
2	3	female	18-33					yes, heavy	abort
2	4	female	20	no	2700	standing auto rotate	yes	no	
2	5	male	65	no	3000	wheelchair	yes	no	
2	6	female	25	no	3000	standing auto rotate	yes	no	slight dizzy
2	7	female	18-33	no	2000	standing auto rotate	yes	no	
3	1	female	11	no	3000	standing auto rotate	yes	no	
3	2	female	9	no	3000	standing auto rotate	yes	no	claims its exercise
3	3	female	9-14	no	3000	standing auto rotate	yes	no	looks down a lot
3	4	female	9-14	no	3000	standing auto rotate	yes	no	
3	5	male	9-14	no	3000	standing auto rotate	NA	no	no ski experience
3	6	male	9-14	no	3000	standing auto rotate	NA	no	no ski experience
3	7	male	9-14	no	3000	standing auto rotate	yes	no	
3	8	male	9-14	no	3000	standing auto rotate	NA	no	
3	9								scared of vr
3	10	male	6	no	3500	standing auto rotate	yes	no	
3	11	male	9-14	no	3000	standing auto rotate	yes	no	
4	1	male	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	2	female	45-68	no	3000	wheelchair	yes	no	no skii experienc
4	3	male	45-68	no	3000	wheelchair	yes	no	
4	4	male	45-68	no	2500	wheelchair	yes	no	
4	5	female	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	6	female	45-68	no	3000	standing auto rotate	NA	no	
4	7	female	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	8	male	45-68	no	3000	wheelchair	yes	no	slight dizzy
4	9	female	45-68	no	3000	wheelchair	NA	no	
4	10	female	45-68	no	3000	wheelchair	yes	no	quits early
4	11	male	45-68	no	3000	standing auto rotate	yes	no	
5	1	male	14	yes	3000	standing	yes	no	
5	2	male	11-18	yes	3000	standing auto rotate	yes	yes	
5	3	male	11-18	yes	3000	standing auto rotate	NA	no	
5	4	female	11-18	no	3000	standing auto rotate	yes	yes	
5	5	female	11-18	no	3000	standing	yes	yes	one hand, tries to walk of map
5	6	female	11-18	yes	3000	standing	yes	no	one hand

Appendix E

This appendix entry contains a copy of the data collected during testing at Beitostølen rehabilitation centre.**This table has been adjusted for easier reading**

GR	Patient	Gender	Age	Prior VR experience	Speed	Type	Likes the game	Cognitive issues	Comments
1	1	Male	7-12	Yes	3000	Standing auto rotate	Yes	Moderate	looks down a lot
1	2	Female	7-12	No	3200	Standing auto rotate	Yes	Moderate	claims its exercise
1	3	Male	7-12	No	3000	Standing auto rotate	Yes	Moderate	looks down a lot,claims its exercise
1	5	Male	7-12	No	4000	Sitting	Yes	Severe	guided trough
1	6	Female	7-12	No	3000	Sitting	Yes	Severe	guided trough, looks down a lot
1	7	Male	7-12	No	3500	Sitting	Yes	Severe	slight guidance, looks down a lot
2	1	Female	18-33	No	3000	Standing auto rotate	Yes	No	
2	2	Female	18-33	No	3000	Standing auto rotate	Yes	Moderate	tries to move off track, plays 2 times
2	4	Female	18-33	No	2700	Standing auto rotate	Yes	No	
2	6	Female	18-33	No	3000	Standing auto rotate	Yes	No	slight dizzy
2	7	Female	18-33	No	2000	Standing auto rotate	Yes	No	
3	1	Female	9-14	No	3000	Standing auto rotate	Yes	No	
3	2	Female	9-14	No	3000	Standing auto rotate	Yes	No	claims its exercise
3	3	Female	9-14	No	3000	Standing auto rotate	Yes	No	looks down a lot
3	4	Female	9-14	No	3000	Standing auto rotate	Yes	No	
3	5	Male	9-14	No	3000	Standing auto rotate	NA	No	no ski experience
3	6	Male	9-14	No	3000	Standing auto rotate	NA	No	no ski experience
3	7	Male	9-14	No	3000	Standing auto rotate	Yes	No	
3	8	Male	9-14	No	3000	Standing auto rotate	NA	No	
3	11	Male	9-14	No	3000	Standing auto rotate	Yes	No	
4	1	Male	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	2	Female	45-68	No	3000	Wheelchair	Yes	No	no skii experience
4	3	Male	45-68	No	3000	Wheelchair	Yes	No	
4	4	Male	45-68	No	2500	Wheelchair	Yes	No	
4	5	Female	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	6	Female	45-68	No	3000	Standing auto rotate	NA	No	
4	7	Female	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	8	Male	45-68	No	3000	Wheelchair	Yes	No	slight dizzy
4	9	Female	45-68	No	3000	Wheelchair	NA	No	
4	10	Female	45-68	No	3000	Wheelchair	Yes	No	quits early
4	11	Male	45-68	No	3000	Standing auto rotate	Yes	No	
4	12	Male	45-68	No	3000	Wheelchair	Yes	No	
5	1	Male	11-18	Yes	3000	Standing	Yes	No	
5	2	Male	11-18	Yes	3000	Standing auto rotate	Yes	Moderate	
5	3	Male	11-18	Yes	3000	Standing auto rotate	NA	No	
5	4	Male	11-18	No	3000	Standing	Yes	Moderate	
5	5	Female	11-18	No	3000	Standing	Yes	Moderate	one hand, tries to walk of map
5	6	Female	11-18	Yes	3000	Standing	Yes	No	one hand
6	10	Male	6	No	3500	Standing auto rotate	Yes	No	

Appendix F

This appendix entry contains a copy of the information brochure that was sent out to various rehabilitation centres.


EXERSKI
Ski-basert rehablitering i VR
- HØY BRUKERVENNLIGHET
- HØY TILPASNINGSEVNE
- ENKEL TILGANG TIL PASIENT STATISTIKK
- RULLESTOLVENNLIG
- MULIGHETER FOR EKSPANSJON
- VIVE ONLY (FOR ØYEBLIKKET)
VR
Exerski er et VR system, som gir brukere med nedsatt bevegelsesevne, muligheten til å gå på skitur i enhvert VR miljø
Systemet er åpent for tilpasning under bruk, noe som gjør at brukere med forskjellig mobilitet nivå kan få samme spillopplevelse.
Systemet er generalisert så det kan legges oppå enhver 3D bane i Unity.
OM MEG
Jeg er siste års masterstudent på NTNU Gjøvik. Jeg har brukt de siste årene på å spesialisere meg i rehabiliterings basert spilling. Basert på mine observasjoner og forskning, så føler jeg sterkt at det er mangel på gode rehabiliteringsspill og jeg har lyst å utvikle gode spill systemer som kan brukes i rehabilitering.
For mer information om systemet, og visuel demo av projektet, følg QR koden under.
DEMO VIDEO


KONTAKT MEG
Privat: Benski@live.no
Skole: Benjamns@stud.ntnu.no
KJERNEFUNKSJONALITET
Høy tilpassingingevne
Systemet har høy tilpasning evne og kan justeres live av terapauter etter behov. Systemet kan vise statistikk for hver bruker, som kan brukes for direkte tilpasning.
Designet for rullestol brukere
Systemet har innebygd funksjonalitet som gir rullestol brukere muligheten til å bruke systemet fullt ut.
Kan brukes i egne projekter
Systemet kan inkorporeres med andre projektor, eller kan brukes som base for andre ski prosjekter. Kontakt meg for mer informasjon og diskusjon om fremtidig bruk.
OM EXERSKI
Exerski er et svært tilpasselig bevegelsesystem i VR, som har som mål og la personer med forskjellig bevegelsesproblemer kunne utforske virtuelle miljøer med mest mulig mestringsevne. Det er en mangel på brukervennlige og gode rehabiliterings spill på markedet. Exerski håper å fikse noe av dette problemet.
Exerskis design er basert på flere år med forskning, interjuver med terapauter og observasjoner av terapi spill. Jeg håper at resultatene fra dette systemet kan brukes for å forbedre rehabiliteringsspill i fremtiden.
Exerski er sluttprosjektet til min masteroppgave ved studiet:"NTNU Master in applied computer science"

Appendix G

This appendix entry contains a copy of literature study for focus area 1.

Name	Link
Designing a Serious Game for Myoelectric Prosthesis Control	https://ieeexplore.ieee.org/abstract/document/9201812
Games for the Rehabilitation of Disabled People	https://dl.acm.org/doi/pdf/10.1145/3051488.3051496
Natural user interfaces in serious games for rehabilitation	https://ieeexplore.ieee.org/abstract/document/5974331
Adaptation in serious games for upper-limb rehabilitation: an approach to improve training outcomes	https://link.springer.com/article/10.1007/s11257-015-9154-6
A Virtual Reality Serious Game for Hand Rehabilitation Therapy	https://ieeexplore.ieee.org/abstract/document/9201789
Playmancer: Games for Health with Accessibility in Mind	https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1427332
Activation and rehabilitation games for people with special needs	https://elibris.pikakirjakauppa.fi/images/kurkkaa/49/9789516331594/9789516331594.pdf#page=27
Serious games to improve the physical health of the elderly: a categorization scheme	https://www.researchgate.net/profile/Jaime-Garcia-39/publication/244993334_Serious_games_to_improve_the_physical_health_of_the_elderly_a_categorization_scheme/links/0f31753b4bbf73b9ae000000/Serious-games-to-improve-the-physical-health-of-the-elderly-a-categorization-scheme.pdf
Usability and acceptability of balance exergames in older adults: A scoping review	https://journals.sagepub.com/doi/full/10.1177/1460458215598638
Assessing Older Adults' Usability Challenges Using Kinect-Based Exergames	https://link.springer.com/chapter/10.1007/978-3-319-20913-5_45
Design, Implementation, and Wide Pilot Deployment of FitForAll: An Easy to use Exergaming Platform Improving Physical Fitness and Life Quality of Senior Citizens	https://ieeexplore.ieee.org/abstract/document/6980053
A Qualitative Study Exploring the Usability of Nintendo Wii Fit among Persons with Multiple Sclerosis	https://onlinelibrary.wiley.com/doi/full/10.1002/oti.1345
Familiarity Design in Exercise Games for Elderly	https://www.researchgate.net/profile/Hao-Zhang-196/publication/325735164_Familiarity_Design_in_Exercise_Games_for_Elderly/links/606286cb458515e8347d8794/Familiarity-Design-in-Exercise-Games-for-Elderly.pdf
Designing universally accessible games	https://dl.acm.org/doi/abs/10.1145/1486508.1486516

Appendix H

This appendix entry contains a copy of literature study for focus area 1.

Name	Link
Universal Design and Its Applications in Educational Environments	https://journals.sagepub.com/doi/abs/10.1177/07419325060270030501
Digital Game Design for Elderly Users	https://dl.acm.org/doi/pdf/10.1145/1328202.1328206
Exergaming Platform for Older Adults Residing in Long-Term Care Homes: User-Centered Design, Development, and Usability Study	https://games.jmir.org/2021/1/e22370/
Serious Games for Health – Personalized Exergames	https://dl.acm.org/doi/pdf/10.1145/1873951.1874316
Serious games for physical rehabilitation: designing highly configurable and adaptable games	https://isvr.org/ICDArchive2021/2012/P/2012_S06N5_Omelina_etal.pdf