Smart phone based virtual reality as tool for physical therapy

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Så lenge det er liv

er det håp

om en slutt.

Nils-Fredrik Nielsen – Det er aldri for sent å gi opp.

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Abstract

This thesis explores the advantages and challenges of using a phone-based virtual reality solution when creating a system intended for the therapy of patients with non-specific chronic neck pain. It also explores the suitability of popular design principles of the Human-Computer Interaction as specifically applied to the field of smartphone-based VR using a cardboard head mount display. Besides, it also explores what gamification techniques are suitable for VR assisted treatment. To answer these questions a high-fidelity prototype, the Virtual Neck Application (VNA), was produced over five iterations utilizing the user-centered design method and within the framework of the design science research methodology. Conceptual design and cognitive walkthroughs were used to ensure that any design element reflected the envisioned patients' needs.

Data was gathered firstly to understand and formulate user requirements and secondly during evaluation by conducting semi-structured expert interviews with two medical experts and one design expert. Two rounds of usability testing including System Usability Scale (SUS) were performed by a total of 16 asymptomatic participants. The SUS results showed overall good usability facilitated by the VNA design solutions. The first evaluation round scored 87.25 and the second round 90, out of a possible 100. A thematic analysis of the expert interviews identified pain, pain management, movement complexity and variation, general movement principles, and recall being important themes in any application focusing on assisting physical therapy.

Development revealed the limited amount of possible movement variations as a disadvantage during exercise design for phone-based VR, compared to more complex virtual reality solutions. However, usability testing highlighted that the limited amount of movements improved to overall usability. Fewer possible actions from the users reduced the chance for user errors during play.

These findings indicate distinct advantages of a phone-based VR solution, especially in the affordance resulting from reduced costs and design of low complexity, that both practitioners and patients could use to their advantage. The findings also suggest that using a subjective scoring system combined with user friendly feedback can be used as a tool to motivate further play, i.e. therapy.

Along with the VNA, a set of design principles was proposed as a tool for design research in search of a novel and innovative solutions for medical therapy and rehabilitation. The principle focuses on user-centered management in three phases: *The Many*; Early phases of development should focus on rapid and low-cost development as a tool to explore the relevant problem space *The Few*; If a proposed solution requires a manifold of design solutions it should be considered for exclusion. Any such design

problems should be documented and treated as valuable data. *The One by One*; When exploring a singular design solution keep future production in mind and aim for a common and reusable design.

Abbreviations

CW-Cognitive Walkthrough

HCI-Human Computer Interaction

HMD- Head Mounted Display

NSCNP-Non-specific chronic neck pain

SUS-System Usability Scale

VR-Virtual Reality

VNA-Virtual Neck Artefact

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Chapter 1

Introduction

Virtual reality (VR) technology is increasingly being utilized the health sectors and has shown to offer real benefits. As such, VR technology has been broadly explored in areas such as rehabilitation and therapy of patients, medical education and training, patient education, visualization of medical databases, and surgical procedures (Moline, 1997). Given the broad areas in which VR technology can be applied, this research focuses on VR technology in the area of rehabilitation and therapy.

Rehabilitation is a loaded word for many. The idea that one has to spend hours upon hours working in an effort to get back to what was once their normal is a daunting task. When you add pain, anxiety and boredom into the mix, we have the recipe for a truly miserable time. Leveraging of VR technology in rehabilitation has continued to grow dramatically in recent years. Some of the areas explored within the health sector include: stroke rehabilitation (Henderson, Korner-Bitensky and Levin, 2007), brain damage rehabilitation(Rose, Brooks and Rizzo, 2005), exposure therapy for posttraumatic stress disorder (PTSD) (Powers and Emmelkamp, 2008), pain management therapy for burned victims (Morris, Louw and Grimmer-Somers, 2009)(Miller *et al.*, 2008), exposure therapy for anxiety disorders (Powers and Emmelkamp, 2008) and pain management neck exercises (Chen *et al.*, 2014)(Treleaven *et al.*, 2015).

In this research, we explore possibilities to create new and safe tools for treating neck problems given that they are among the most reported musculoskeletal conditions, with pain being the main reason for primary care physician consultation (Borenstein, 2007). In addition, patients are met with challenges such as loss in productivity, and costs for medical treatments and rehabilitation (Baldwin, 2004). It is therefore imperative that solutions developed are cost effective and able to promote pain management and resumption of productive lives.

Therefore, we will also explore what design patterns are suited for phone based virtual reality when creating a support tool for physical rehabilitation. The motivation is to use available technology to develop low-cost implementations in the form of phone-based VR, which will allow users to use the artefact outside of hours spent with a therapist. This will also reduce visits to the physician. This research will also focus on the possible benefits and drawbacks of multimodal immersion on the user's perception of the treatment. Lastly, we will explore possible uses of gamification to motivate users to adhere to a rehabilitation scheme.

As such, design science research approach will be utilized as it provides methods for designing relevant solutions that can be applied in the context of real-world environments with the aim of contributing to

the already existing knowledge. Based on the novelty of the approach used, strong emphasis will involve consulting experts to evaluate tools in order to make them safe and effective.

1.1 Research Questions

The following are Research Questions (RQ) that will be answered during this research project:

RQ1: *What design principles are suited for phone-based virtual reality when creating a support tool for physical therapy?*

RQ2: *What are the advantages and disadvantages of phone-based virtual reality as a tool for use during neck therapy.*

RQ3: *What gamification techniques are suitable for use in VR supported therapy?*

1.2 Outline of Research Project

The following is an outline of the research project:

Chapter 2: Literature Review summarizes the literature and related work during this project.

Chapter 3: Methodologies and Methods explains the methodologies and methods used in this project and their contributions.

Chapter 4: Requirements displays ethical considerations, the target group, and participants of this project and the requirements gathered from users.

Chapter 5: Artifact Development displays the different tools used and the design iterations achieved.

Chapter 6: VNA Features displays the final functionalities of the high-fidelity prototype.

Chapter 7: Results summarizes the results from evaluations during iterations.

Chapter 8: Discussion describes and explains the methodologies, methods, and development process used and answers the research questions.

Chapter 9: Conclusion and Future Work provides a summary of the projects, and recommendations about future work.

Chapter 2

Literature Review

This chapter presents a literature review of several research articles relevant for research for this project. They informed and inspired development of the artifact.

2.1 Relevant Literature

2.1.1 Application of VR in pain management in burn-injured patients
(Miller et al., 2008)

This paper from 2008 looks into the usage of virtual reality as a tool for pain management in burn wound treatment. While my own thesis does not have a main focus on pain management, I can still make use of the findings in the paper. In the paper they explore the idea of VR altering the user's perception due to the attention that VR experiences demand. This attention can be used as a distraction from sources of anxiety and pain while also having analgesic (pain relieving) effects in and of itself. They stipulate that the magnitude of this effect is based on the persons "presence" or immersion in the virtual environment. This could have had both good and bad impact on my own work. It hints at possible relaxing effects from using my artefact, but at the same time forces me to take extra care in designing experiences which promote the correct motions as I could not depend on the users to remember what they should do, or avoid, while immersed.

The paper brings forth the problem that most studies with VR lack which is testing over an extended period of time to test whether the novelty of the technology used adds something significant to the experience. They also point out key "issues" which I have kept in mind while developing my artefact. They are as follows:

1. Immersive virtual reality (VR) is a cognitive–behavioral therapy, ideally suited for short-term pain relief in the procedural pain setting.
2. The psychological and neurophysiologic mechanisms of VR analgesia are undefined, but likely involve cognitive distraction and/or enhancement of affect or mood.
3. Immersive VR appears to be most effective when users feel highly 'present' in the computer-generated virtual environment; therefore, specialized hardware/software and user interaction with the virtual environment are key elements of VR analgesia systems.
4. Immersive VR analgesia does not appear to carry significant safety risks or unpleasant side effects.

2.1.2 Astrojumper: Motivating Exercise with an immersive virtual reality exergame (Finkelstein et al., 2011)

The Astrojumper article has tighter focus on the design principles, which are relevant to game systems which primary focus is something other than entertainment. It also introduced me to the term exergame, which can be defined as: a game where the primary or secondary goal is to facilitate exercise. The paper explores problems like:

- Reward hacking, when a player misuses quirks in the games design to gain points without participating in the intended manner.
- The balance between engagement and exercise
- Warmup and cool down periods in sessions.
- Need for an intuitive control scheme.
- Hardware cost and availability.
- The link between immersion and motivation.
- Game flow models.

Their findings indicate a relationship between gameplay attractiveness and exercise effectiveness. They found the same to be true of motivation influencing workout intensity. They also found correlations between immersion and enjoyment/fun, especially in children who often reported, "getting lost" in the virtual environment.

2.1.3 Motor control using cranio-cervical flexion exercises versus other treatments for non-specific chronic neck pain: A systematic review and meta-analysis (Martin-Gomez et al., 2019)

This meta-analysis concludes that that intervention based on motor control exercises using cranio-cervical flexion shows statistically significant results regarding diminution of pain and disability in a population experiencing non-specific chronic neck pain. This is in comparison with other treatments such as: strengthening and endurance exercises tailoring cervical flexion, mobilizations or other treatments – proprioceptive exercises or 'wait and see'.

2.1.4 Designing informed game-based rehabilitation tasks leveraging advances in virtual reality (Suma *et al.*, 2012)

Lang et al explore different VR technologies that can be used in physical rehabilitation of patients. One of the aspects they investigate the juxtaposition between cost and utility. 2012 the identified that VR technology had come to the point where massive, expensive, and bespoke machinery were no longer the only way to use VR in rehabilitation. They also point to one of the main problems within VR assisted rehabilitation being tracking of the user. Tracking here is recording sampling sufficient amount of

movement from the user to assist the evaluation of the given treatment. The article is a good roadmap of the progress, problems, and challenges discovered in the first twenty years of VR therapy research.

2.1.5 Immersion of virtual reality for rehabilitation – Review
(Rose, Nam and Chen, 2018)

In this literary review, the authors explore the literature written around three topics of VR. These three topics are as follows:

- RQ1: How does the level of VR immersion affect the user performance and/or health outcome?
- RQ2: What facets of VR enjoyment have been researched relative to the improved patient adherence?
- RQ3: What influences do haptic feedback have on individual performance in VR?

They found no significant link between user performance/motor recovery with higher immersion, but at the same time they found that immersion increases task performance accuracy. They also found a correlation between increased fun and likelihood of patient adherence to rehabilitation plans. While these findings cannot be seen as conclusive due to the small sample size of articles featured in the review, it's still outlines certain trends that merit further research.

2.1.6 Rethinking Design Principles for VR
(Hines, 2019)

Rethinking design principles for VR is an article that outlines experiences, which the author Hiens has gathered when creating 3d worlds for virtual reality. The paper focuses on the special cases, which come from designing a virtual environment. He puts forth the following observations:

The finer details, due to the close proximity of the screen to a user's eyes, demands that any detail must be sharp. The goal is to avoid jagged and pixelated edges for which antialiasing is a critical. Avoiding small type fonts when using typography is key in readability. The same goes for user interface elements.

Less is more, the concept that even if VR gives a user access to a 360 scope, it is not necessarily the best idea to use it fully. Considering head movements and peripheral vision when designing a virtual space well help create the interaction. By using leading lines and visual clues one can keep the player concentrated on the correct areas.

Keep it grounded, this point is all about avoiding infinite white voids. By adding gradients to the horizon, one can avoid a floaty and vertigo inducing feeling.

Play around, mockup ideas before making them. Consider what limitations and possibilities VR offers the experience.

Think outside the box, design for the experience you want the use to have. Is the experience linear or branching? Test if the initial ideas work and focus heavily on any user interface, which could be used.

2.1.7 When is virtual reality "therapy"?

(Levac and Galvin, 2013)

This paper brings up a point which I had taken as a given, but which is important to illustrate the value of VR for therapeutic purposes. Levac and Galvin have collected articles about the use and effect of VR in therapy. Their main focus was to underpin that VR as it is today cannot be treated as therapy alone. VR could and should be used as a tool wielded by a therapist and cannot replace the role of the expert. The therapist is the one who decides when and if VR should be used during treatment. The authors highlight that VR can "serve a therapist's traditional role of motivating patients to participate in therapy". They also mention the therapist's role in setting the initial parameters of the task. In their conclusion they point to the following problem: "Anyone who has observed a child fascinated by the buttons, noises, and lights of a new toy knows unless the child can integrate the toy into play in a meaningful way, it will quickly be discarded, regardless of its initial visual or sensory appeal."

2.1.8 Neck motion kinematics: an inter-tester reliability study using an interactive neck VR assessment in asymptomatic individuals.

(Bahat *et al.*, 2016)

The article explores how we can use Virtual Reality to measure dynamic neck movements. By monitoring mean and peak velocity, they found that their system can accurately track user neck movement. Of specific interest is their finding that different HMD hardware products produce different levels of motion sickness in the participants, speculated to be caused by tracking issues. They also found that using a wired HMD restricted neck motion during locomotion. This indicates that a phone-based VR solution should come with a baseline hardware requirement to avoid motion sickness in participants.

2.1.9 Zombification?: Gamification, Motivation, and the User
(Conway, 2018)

"By incorporating a diverse suite of theoretical frameworks that accounts for the social, cultural, and psychological effect of design features, this article argues that gamification too often invokes organization-centered design, treating users as zombies: senseless mechanisms urged onwards by a desire for extrinsic rewards. Gamification still often fails to acknowledge the user's context and innate psychological needs. This can be accomplished in practice through an incorporation of motivational psychology and a concurrent shift toward user-centered design, accounting for the situatedness of the participant. Further, this article claims that for gamification to reach its full, radical potential, it must not only transform the way the user is evaluated and rewarded but also the activity the subject is tasked with performing."

The article explores how the usage of user-centered design can help designers create gamification systems that only focuses on enjoyment of progression. Conway suggests modifying the proposed definition of gamification: "The use of game design elements in non-game contexts" to "the use of

game-like features in non-game contexts" (Deterding *et al.*, 2011). This is a significant change of perspective which allows for the inclusion of actual game components as part of the gamification process.

2.1.10 Research context

As shown the literature is varied and plentiful in the chosen field. The usage of virtual reality, and virtual environment as a supplemental tool to rehabilitation has been speculated on for over 30 years and been actively tested in the last twenty. However, these papers usually focus on the specific effects achieved by VR, and not in its implementation. There is also a heavy focus on specialized tools and setups which are both expensive and highly specialized. This paper focus on phones as it provides a more available and easier to acquire tool. The focus is on testing the proposed design principles and if their implementation can be used as guidelines on future projects even if they use specialized tools. The goal is to find techniques which has yet to be proposed or to affirm the ones already used in the field. There is also a general lack of research regarding the longevity of interest in VR as a therapeutic tool. The burn victim study only expected short term use with it's users, but general rehabilitation and preventative measures are actions which must be repeated over a long period of time to be effective. Because of this there will also be a focus on meta game design in the form of gamification techniques which can help hinder burnout and reduced exercise due to disinterest. Lastly there is a theme of immersion or "feeling like you are there" in many of the papers examined. Through testing it might be possible to find a correlation between extended use and immersion.

2.2 Related Work

VR Neck Applications

2.2.1 VRFysio

The VRFysio application focuses on mimicking neck-stretching. When evaluating the VRFysio application, the main questions to be answered were whether VR could contribute to treating neck problems, and what issues can be solved using the VRFysio application. (Kloster and Babic, 2019)

FIGURE 1 NECK EXERCISES WHERE THE VRFYSIO APPLICATION SUGGESTS TILTING THE HEAD.

2.2.2 NeckVR

The results from the evaluation of the VRFysio application enabled the development of the NeckVR application. This application consists of a VR-game whereby the player observes a black square (the background), and boxes coming towards the square. The goal is to move the reticle pointer over the boxes in order to destroy them before they hit the background. (Kloster, 2019)
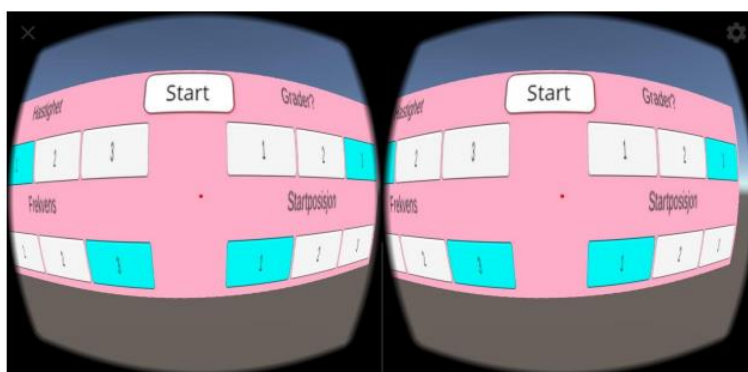
FIGURE 2: EXAMPLE OF NECKVR USER-INTERFACE

2.2.3 VR Physio

VR Physio provides providers medical providers such as clinicians or physical therapists with a piece of VR hardware, optional biofeedback sensors, optional weights. The combination of VR hardware and software enables a gamified physical therapy experience, which shift mindshare away from boring, repetitive tasks towards entertaining and rewarding physical + virtual experience. (Boris, Digital Innovation and Transformation, 2017)

2.2.4 Butterfly chasing

A system that motivates the users to perform neck exercises by engaging them in a serious exergame within virtual reality (VR) environment. The system measures the users' neck movements via a few static and dynamic kinematic tests and a novel VR serious game, tailored to the neck range of motion of each individual user. The game is designed to make the users perform rehabilitative neck movements according to the prescribed exercise regimen while playing. (Mihajlovic *et al.*, 2018)

The analysis of acquired data from VR hardware provides insight into flexibility of the neck during head movements and overall neck kinematics, which is valuable for assessment of pain-related stiffness, as well as for progress monitoring.
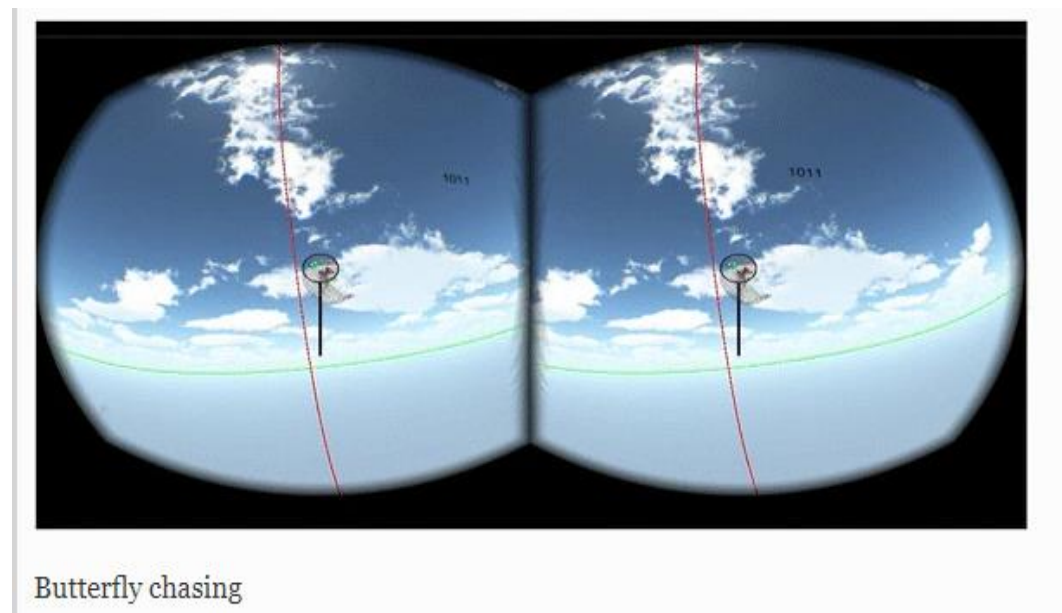
Butterfly chasing

FIGURE 3: BUTTERFLY CHASING MODULE

Chapter 3

Methodologies and Methods

3.1 Design Science and design research

(Dresch, Lacerda and Antunes, 2015) define design science as a "science that seeks to consolidate knowledge about the design and development of solutions, to improve existing systems, solve problems and create new artifacts". (March and Smith, 1995) have the following to say about design science: "design science attempts to create things that serve human purposes. It is technology-oriented- Its products are assessed against criteria of value or utility… Rather than producing general theoretical knowledge, design scientists produce and apply knowledge of tasks or situations in order to create effective artifacts."

Design science lends itself well to my topic of research. By not only focusing on the data gathered from virtual reality applications, but also designing and producing a discreet artefact for the task, any feedback and uncertainties can be iterated upon to further test their influence. A key part of design science comes in the form of relevance and rigor. At its core design science goes in an iteration cycle between design/development of a theory or artefact, and justification in form of evaluation. These iterations are influenced by the existing knowledge base and the specific problem area.
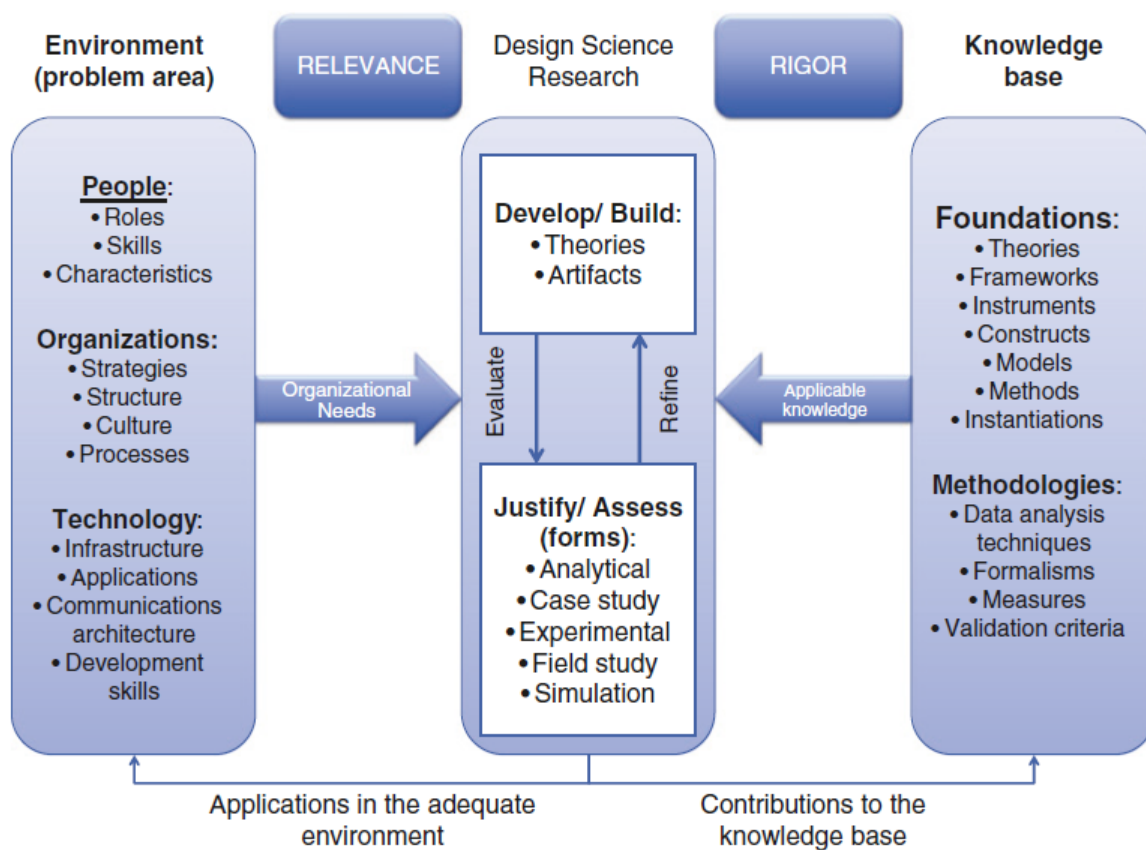
FIGURE 4: DRESCH ET AL. AN ADAPTED GRAPHIC REPRESENTATION OF DESIGN SCIENCE RESEARCH BASED ON HEVNER ET AL

(Hevner *et al.*, 2004) defined seven guidelines for researchers doing design science research (see table 1). While these guidelines have more business focus than the thesis, they are still useful in structuring workflow in the project. Especially when it comes to outlining the role played by the artefact produced. Design of the artefact should act as "innovations that define the ideas, practices, technical capabilities, and products through which the analysis, design, implementation, and the use of information systems can be effectively and efficiently accomplished." The artefact does not have to be a complete information system, it only needs to satisfy the needs of the researcher. The artefact produced for this paper allowed for research of varied gamification methods, depths of immersion and their effectiveness in physical rehabilitation.

Guidelines	Description
Guideline 1: Design as an artefact	Design science research must produce a viable artefact in the form of a construct, a model, a method or an instantiation.
Guideline 2: Problem relevance	The objective of design science research is to develop technology-based solutions to important and relevant business problems.

Guideline 3: Design evaluation	The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well-executed evaluation methods.
Guideline 4: Research contributions	Effective design science research must provide clear and verifiable contributions in the areas of the design artifact, design foundations, and/or design methodologies.
Guideline 5: Research rigor	Design science research relies upon the application of rigorous methods in both the construction and evaluation of the design artifact.
Guideline 6: Design as a search process	The search for an effective artifact requires utilizing available means to reach desired end the satisfying laws in the problem environment.
Guideline 7: Communication of process	Design science research must be presented effectively both to technology-oriented as well as management-oriented audiences

TABLE 1: HEVNER ET AL. GUIDELINES FOR DESIGN SCIENCE RESEARCH.

In the paper A three cycle view of design science research, (Henver, 2007) outlines the iterative process of artefact design. He puts emphasis on the third cycle which is the design cycle. This is where one outlines the design and evaluation process of an artefact.

"…artifacts must be rigorously and thoroughly tested in laboratory and experimental situations before releasing the artifact into field testing along the relevance cycle. This calls for multiple iterations of the design cycle in design science research before contributions are output into the relevance cycle and the rigor cycle".

Thorough each iteration the artefact will be evaluated using different methods detailed further under the evaluation header in this text.

3.2 Agile development

Atlassian is one of the leading businesses when it comes to agile development methods and frameworks. Their article Kanban vs. Scrum (Rehkopf, 2019) will provide definitions of agile methods used in this thesis. Rehkopf defines agile development as "a structured and iterative approach to project management and product development. It recognizes the volatility of product development, and provides a methodology for self-organizing teams to respond to change". Using a system development style based on iterative workflow lends itself well to the cyclical workflow expected in design science research. When deciding upon what style of agile development should be utilized, there were three styles to choose from.

3.2.1 Scrum

Firstly, Scrum provides a very firm loop structure by utilizing "*sprints*" which are short intervals with specific goals of what to develop. The sprints should be rigid once started and mid sprint modification of goals should be avoided. The goal of every sprint should function as learning loops where missed

deadlines will be evaluated to improve work allotment in later sprints. Scrum also firm roles such as the scrum master, product owner and development team. In-between each sprint there is time set of for evaluation work-flow and progress.

3.2.2 Kanban

The second approach is Kanban, which has a much leaner approach than Scrum. In Kanban there are no specific roles allotted to different members of the project. Key features of the Kanban framework is limiting "work in progress" (WIP), visualizing work and workflow, and maximizing efficiency. The visualization aspect is steered by the kanban board where different elements of the product are categorized by work type and current work commitment.

3.2.3 Hybrid

The last approach, which was the one chosen for tis research is the hybrid approach. As (Al-Baik and Miller, 2015) outlined in their paper The Kanban approach, between agility and leanness: a systematic review, "Kanban and Scrum are individual concepts as Kanban acts as a change agent and the principles in Scrum can be used to optimize the Kanban workflow". Their findings highlight that using Kanban as a part in a hybrid method is both popular and efficient as Kanban often lacks definition when used on its own. Al-Baik and Miller also highlight the that "the Kanban board, as reported by almost 46 percent of the studies, is an efficient visualization tool and should be used effectively to ensure that the development process takes place as expected." When choosing what elements of the two approaches to adopt focus was set on visualizing workflow, evaluating the work produced, solo developer practices and flexible timelines.

3.3 Structure and visualization

The timeline divided into sprints cycles. The goal here is to have specific goals for every sprint. Using sprints will make spotting problem areas easier and faster while also segmenting work into manageable tasks. Using the "limiting work in progress" principle will help keep work focused on the sprint goal while also deterring a split focus work method. Tasks will be sorted and built into *"User stories"*. All user stories will be categorized based on the nature of the work, a user story named "implement camera controls" would be tagged as development while a story named "Set up meeting with design experts" would be tagged as managerial. All user stories will be displayed at a digital kanban board where progress will be split up in the following stages: To-do, in progress, review, done, *cryo*, removed. User stories will only be added to To-do at the start of a sprint or if is emptied before a sprint is officially over. In progress and review will both have a WIP lock on them meaning that no new stories can be added to that stage if it would make the amount exceed the limit.

3.4 Roles and key metrics

There will be no formal roles used in the hybrid method. While these can be very helpful when working with a team, they are only a hindrance when there is only one developer. There will however be a focus on inviting input from the collaborating experts on current and close to current sprints. Production will be evaluated using velocity and cycle time. Velocity is calculated based on how many user stories completed per sprint. Any one user story should not be expected to take more than 16 hours to avoid clogging the timeline. Its also prudent to schedule smaller tasks as it makes observing problem areas easier. Cycle time is how long any one task takes to traverse one part of the board to another. If certain tasks constantly take longer than other they should be broken up if feasible. Cycle time might also enlighten if certain tasks are to dependent on outside influences.

3.5 Conceptual Design

"Conceptual design is concerned with transforming requirements into a conceptual model … conceptual models take many different forms and it is not possible to provide a definitive detailed characterization of one. Instead conceptual design is best understood by exploring and experiencing different approaches… A conceptual model is an outline of what people can do with a product and what concepts are needed to understand how to interact with it. The former will emerge from the current functional requirements; possibly it will be a subset of them, possibly all of them, and possibly an extended version of them." (Preece, Rogers and Sharpe, 2015)

3.6 Prototyping

Prototyping a process where a design concept can be explored without overcommitting resources in its production. Prototypes are often ranked by their fidelity, such as low-fidelity paper prototypes or high-fidelity software versions. These less refined versions can be used to explore, evaluate, and communicate ideas. As such a prototyped can be called a communication aid and as such it will often emphasize one set of ideas or characteristics while de-emphasizing others. (Preece, Rogers and Sharpe, 2015)

3.7 Evaluation

3.7.1 Usability Testing

"Usability testing includes three key components: representative participants, representative tasks, and representative environments, with participants' activities monitored by one or more observers, Within this framework, however, usability tests have a wide variation in method and motivation. They can be formal or informal, think-aloud or not, use low-fidelity prototypes or working systems. They can have a primary focus on task-level measurements (summative testing) or problem discovery (formative

testing). This latter distinction is very important, as it determines the appropriate general approach to sample-size estimation for usability tests" (Lewis, 2006). The form of usability testing performed in this thesis is a think-aloud, informal summative tests in conjunction with a system usability scale survey.

3.7.2 System Usability Scale

System usability scale (SUS) offers a quick way to get feedback on an artefacts usability. The goal when testing usability is no to see how well designed something is, but rather to see how well it fits it's proposed function. (Brooke, 1996) defines usability as: "a general quality of the *appropriateness to a purpose* of any particular artefact… the usability of any tool or system has to be viewed in terms of the context in which it is used, and its appropriateness to that context."

SUS serves as a simple scale to be used for quick evaluation where there are no requirements of familiarity and expertise from the participant. SUS is built op of ten different statements where the participant indicates agreement or disagreement based on a Likert scale response. The statements chosen for the SUS should be extreme to avoid uncertain answers. "I thought the system was easy to use" is a better question than "I thought the system was easy to use for someone with my technical knowledge". Statements should also be split evenly between negative and positive questions. As an example Brooke presented the following table to use for SUS:

	Strongly disagree				Strongly agree
1. I think that I would like to use this system frequently	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system were well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

TABLE 2: DEFAULT SYSTEM USABILITY SCALE

The SUS score is calculated using the following rules. Odd rows: 1,3,5,7,9 all contribute their value minus one and the even number contribute five minus the value given in their range. If someone answers 4 in row 1 the score would be three. A 4 in row 2 would give a score of 1. All scores are summed up and multiplied by 2.5. This means that the scale ranges from 0-100 where 100 is the best possible score possible. All answers should be filled in quickly, a participant should not spend too long on any one question. If the participant does not understand or know their answer to a particular question, they should fill in the middle number. Answers given to specific points in the survey should not be treated as meaningful on their own as there is no explanation given for the scores.

In their paper Determining what individual SUS scores mean: adding an adjective rating scale, (Bangor, Kortum and Miller, 2008) proposes that the numerical score produced by a SUS correlates with a typical letter grading scale. They propose that using a lettering system might help in readers when evaluating SUS scores. Therefore results from any SUS performed will also be give a letter grade based on the scale shown in Figure 5.
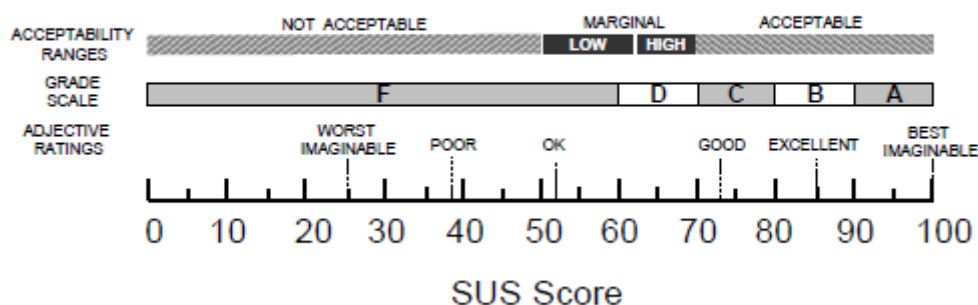
FIGURE 5: A COMPARISON OF THE ADJECTIVE RATINGS, ACCEPTABILITY SCORES, AND SCHOOL GRADING SCALES, IN RELATION TO THE AVERAGE SUS SCORE.

3.7.4 Expert interviews

Experts on both game design and physical therapy will be consulted throughout the project. Initial interviews will be held with game designers to help design and sketch out least viable versions of the artefacts. These meetings will be more unstructured than later interviews. Based on feedback and feasibility evaluations given by the designers a questioner will be constructed for later use when interviewing the physical therapist expert. Interviews with the physical therapist will be focused on safety of the artefact as well as its utility. The therapist has valuable knowledge about what tools are needed and what requirements a therapy tool has. They will also function as stand in user during early development.

3.7.5 Cognitive Walkthrough

The Cognitive walkthrough method is meant to be used in early development stages without any other users other than the analyst. There are many variations, but the one utilized in this paper is based on Martin G. Helander and Örjan Skinnars's paper, Use of cognitive walkthrough for evaluation of cockpit design (Helander and Skinnars, 2000). Both this project and the project done in the paper has a very specific userbase where a certain amount of previous knowledge and guidance can be expected. This allows for certain assumptions during the analysis. CW is split into three stages:

- Preparation for analysis
  "The background of the user, choice of important and realistic tasks, specification of correct action sequence for tasks and determination of interface states along the sequence."

- Analysis

  "Will the pilot try to achieve the right effect?", "Will the pilot notice that the correct action is available?", "Will the pilot associate the correct action with the desired effect?", "If the correct action is performed will the pilot see that progress is being made?"

- Follow-up

  "Record success, problems, reasons and assumptions"

CW expects there to be errors in the analyst's assumptions but reconcile this with the speed of which the analysis can be performed. By specifying specific steps that must be followed to obtain a desired effect the analysts can discover unexpected problems or challenges with the design interface. By recording every assumption and action taken the CW provides early feedback to a project which can later be confirmed or debunked by user-tests.

3.7.6 Thematic analysis

All interview data will be subjected to a thematic analysis to identify patterns in expert responses. Braun and Clarke suggest the following definition of the thematic analysis method along with six phases of analysis which should be used by researchers:

"Thematic analysis is a method for identifying, analysing, and reporting patterns (themes) within data. It minimally organises and describes your data set in (rich) detail. However, it also often goes further than this and interprets various aspects of the research topic. … a 'theoretical' thematic analysis would tend to be driven by the researcher's theoretical or analytic interest in the area and is thus more explicitly analyst driven. This form of thematic analysis tends to provide less a rich description of the data overall, and more a detailed analysis of some aspect of the data." (Braun and Clarke, 2006)

Chapter 4

Requirements

During this chapter the ethical and practical requirements of the artefact will be defined. What functions will it provide the user and what ethical considerations must be observed to ensure participant safety and privacy. The ethical requirements are based on the Norwegian centre for Research Data's (Norsk senter for forskningsdata, NSD) requirements and the Hippocratic oath. The functional requirements were created based on the literature review, observed needs based on testing, and expert feedback.

4.1 Ethical Considerations

The interview procedure and storage of personal information has been approved by NSD. All research participants were required to sign a consent waiver, and all taped interviews has audible consent to their usage. The consent waiver and NSD feedback can be found in appendix A. The chief concern here was the spread of personal information and misrepresentation of the participant's views.

Health and user security were also a concern. Due to the projects scope and timeline, it was decided not to test the VNA on any people experiencing NSCNP. During expert interviews with health professionals this point is brought up and discussed and will be mentioned during the discussion.

4.2 Target Group

For this project it was decided to focus on people with non-specific chronic neck pain on the recommendation of one of the interviewed experts. The reason for this is twofold. On one side the chances for injuries are minor as compared to injuries that could happen for people with more severe neck problems. Moreover, opting for unspecific indications suggests using the therapeutic methods which are less specific than exercise meant to treat specially targeted areas of the neck.

Anyone can experience non-specific chronic neck pain (NSCNP), (Martin-Gomez *et al.*, 2019) proposes that between 12-71% of the world's population is affected by neck pain. Most of the neck pain is categorized as NSCNP where there is no certain cause of pain, but it has been constant for three months or longer. Neck pain is mostly prevalent in in the adult population. The following target group for this study was decided to cover an adult population with enduring pain (Table 3):

Gender	Any
Age	18 or older
Duration of pain	3 months or longer
Required equipment	Smartphone

TABLE 3: TARGET GROUP SPECIFICATION

4.3 Research Participants

4.3.1 Users

Users are volunteers who tested the VNA and filled in the SUS questionnaire who require no knowledge of design or usability. Due to challenges during testing period, most users ended up being master students at UiB. Two kinds of master students participated, information science and media studies, which seems to have affected results which will be taken up in the discussion part of this thesis.

4.3.2 Medical Experts

Two medical experts were consulted during the runtime of the project. One expert regarding the usage of virtual reality as therapeutic tool and one physiotherapist in the evaluation, both of whom participated separately in semi-structured expert interviews.

4.3.3 Usability Experts

One game developer with gameplay and design experience gave a semi-structured expert interview.

4.4 Establishing Requirements

4.4.1 Functional Requirements and Non-Functional requirements

Specific requirements for VNA were defined based on two user experience and HCI books. Functional requirements that are needed to secure a fully functioning and non-functional requirements that enhance the functionality and improve the performance of the system (Preece, Rogers and Sharpe, 2015). Garrett gives the following suggestion for constructing requirements: *Be positive, focus on what the system should do instead of describing what could go wrong. Be specific, avoid requirements that need interpretation. Avoid subjective language, requirements must be falsifiable* (Garrett, 2011).

4.4.2 Functional Requirements

VNA needs

- full 3d movement in VR
- an interactive menu
- good readability while using a HMD

- to save user settings
- have at least two playable modules
- a consistent framerate
- to be usable by people with decreased motor functions

4.4.3 Non-Functional Requirements

VNA needs

- to run on older phones
- a consistent visual design
- a low skill celling
- to be inexpensive

The primary challenges to tackle are usability and motion sickness. The hope is that limiting the amount of time a user is given to use the HMD and keeping framerates constant will help with motion sickness. The VNA is designed to be first used with a physiotherapist so some usability problems might be tolerable. Menus and modules should be easy to use regardless of help.

Chapter 5

Artifact Development

This chapter will present the development tools used when designing and creating the artefact. It will go in depth about preproduction, prototyping, iterations, and methods used during development. Each iteration will be presented with its goal, what was done, and evaluation of the results achieved withing the iteration. Throughout development the Scrum/Kanban hybrid method was used. While sprints did not always go as planned, the Kanban board was used to good effect during the different stages of development. In between each iteration the board was cleaned and work in progress tasks were evaluated. Some of the ideas got permanently removed before completion.

5.1 Development Tools

All the main tools used in the development are commonly available and adequate for prototyping, here they briefly presented.

5.1.1 Unity3d

Unity3d is a functional game development engine (Unity Technologies, 2020), which allows for quick deployment of builds. This was the main tool used during development of the NVA. Unity was chosen due to its compatibility with GoogleVR, and its collection of free to use assets.

5.1.2 GoogleVr/Google Cardboard

GoogleVR is a VR API which allows for easy creation of VR application which can be used by any phone-based HMDs (Google, 2020). This was chosen to ensure compatibility with the cheapest available HMD while also allowing users to experience the VNA with higher end products. The API also has a ready to go version for Unity3d which made development significantly faster.

5.1.3 Windows and Android OS

Development was done on Windows computer this removed the possibility for easy deployment on Apple OS based phones. Because of this the VNA can only run on phones using Android OS. By using a virtual machine or buying an Apple computer this could be avoided, but due to the project scope this was not done.

5.1.4 Visual studio

Visual studio was chosen as the integrated development environment (IDE) for the project. It is compatible with Unity3d which allows for quick and efficient testing of code (Microsoft, 2020).

5.2 Early Prototyping

Early development was focused on exploring different possible game modes for VNA and defining limitations and challenges when using phone-based VR. Unity3d, Visual Studio and the GoogleVR API needed to be set up and tested. Outline the user base and expected steps during the cognitive walkthrough.

5.2.1 Design limitations

GoogleVR comes with a host of tutorials and an extensive documentation. The first limitation was the possible input provided by the HMD. Google cardboard does not allow any input other than head rotation. Because of this limitation, no module could involve gameplay involving moving the body from side to side or up and down. It also created a challenge when deciding how a user could exit any chosen module. Using the HMD along with a headset also proved to be a limiting factor. Faster head movements and looking up presented the risk of the headset falling off and first time use of the VNA is designed to be done while in the company of a physiotherapist giving instructions, so music or sound effects could become a barrier for communication.

The second limitation was the intended target group. The expected user suffers from some form of neck pain and thus no essential task should require extreme head movements both in range and precision. Essential tasks were deemed any action taken outside of the exercise environment.

The final limitation was graphical fidelity and memory. The NVA is intended to run on legacy software and older phone models cannot be expected to run GPU heavy applications without suffering any loss of framerate. The expert interviews in Kloster's thesis (Kloster, 2019) also indicated that users experiencing pain would not either require more than basic visuals.

5.2.2 Low fidelity prototypes

The earlier prototypes produced were all low fidelity paper prototypes. Play was tested by taping a stick to a hat to simulate the pointer. All prototype production was given four hours to be completed, with the expectation that design problems and challenges in scope would be handled during evaluation. The project limitations, findings from the AstroJumper paper (Finkelstein *et al.*, 2011), similar applications, and the recommendations found in (Hines, 2019)'s paper were used as guidelines for the early design. The kind of neck movement was also influential when considering ideas. Examples of designs produced in this step were*: Moving targets, Labyrinth, Bird flight, Rolling ball, Watering can.*

Moving targets:

When flying towards a large screen, the goal is to look at the moving targets before they touch the screen (Kloster, 2019). Unlike the original, the boxes are destroyed immediately instead of requiring holding the gaze. The games end when the timer runs out. Dynamic and quick movements is required by the user.

Labyrinth:

The user tracks a marker through a maze. Points are scored by how much of the path is traversed. Contact with wall is penalized by reducing point gain afterwards. Game ends when the user exit the maze. Dynamic movements and precision control are needed from the user.

Bird flight:

The users tilt their head to guide a sea gull through rings while avoiding obstacles like clouds. Points are gained by avoiding obstacles and entering rings. Rings adds a score multiplier akin to the golden sun bonus objectives found in Astro Jumper. Game ends after the timer reaches zero. Static head movements and stretches are required.

Rolling ball:

A ball rolls from side to side and the user must track it with their head. Points are gained for every second the user is within the ball perimeter. Longer periods will slowly add a higher multiplier to points scored. Loosing focus on the ball reduces this multiplier. The game is on a timer and when the timer runs out the game ends. Static head movements and stretches are required.

Watering can:

The users must look at flowers and tilt their head forward to pour water. The flower grows while being watered. Points are scored by holding the position without looking up or to the sides. The game ends when a certain number of flowers have bloomed. Static movements and neck tilting are required.

5.2.3 Preparing the Cognitive Walkthrough

The originally intended target group were people with neck pain, the chronic and unspecific addition were added later the recommendation from the first medical expert interview. This rather large target group considered in this project which also brings consideration regarding neck and head movements to secure the users' health and safety. When preparing for the CW certain assumptions had to be made such as:

- the user is being guided by a medical professional when first interacting with the VNA.
- The user is familiar with how a smart phone operates.
- The user is experiencing some form of neck pain which hinders movement.
- The user is inexperienced with virtual reality and HMDs.

Task 1. Moving Targets	Task 2. Change settings
1. Set up HMD.	**1. Set up HMD.**
1.1 Launch application.	1.1 Launch application.
1.2 Put phone in HMD.	1.2 Put phone in HMD.
2. Start the game	**2. Change Options**
2.1 Look at the "choose module" button	2.1 Look at options button
2.2 Look at the Kloster remake button	2.2 Look at the desired options to change
3. Play Game	2.3 Save choice and exit menu
3.1 "Shoot" boxes	
3.2 See score after time runs out.	
3.3 Exit game and close application	

TABLE 4: COGNITIVE WALKTHROUGH TASK LIST

5.3 First Design Iteration

The first design iteration was focused on quick production of the ideas conceived in pre-production. A VR movement scheme, a functional menu system and google cardboard compatibility were deemed the three most important parts of production. Afterwards the aim was to produce as many functional high-fidelity prototypes of the ideas conceived during the prototype phase. Lastly the whole artefact would be evaluated using CW.

5.3.1 Hardware and software setup

Setting up a VR movement scheme using the GoogleVR API was found to be simple. A general movement scheme is available *out of the box*, which was easily transplanted to the project. A basic menu of consisting of two buttons (Start and options) were created and rigged for use in a VR environment.

Before production of the high-fidelity prototypes could start, an HMD was needed to identify problems. Guiding factors when procuring these was cost, difficulty of assembly and availability. The first version was built out of spare cardboard and a half liter plastic bottle. Several guides were read/watched to find possible versions. The goal was to see if a homemade version was viable. From this test it was found that if the user has a form of super glue and a piping apparatus like a syringe, then usable glasses can be made quite easily. These however needed some manual focusing and did not last very long without leaking. Professionally produced lenses should be able to last for a long time. For this project it was decided to use a professional set of lenses as they are affordable and more reliable.

When using cardboard HMD there are two major challenges for the user. The first one is that they are rarely designed for use when wearing glasses. While they can be modified to accommodate frames, it still presents a slight roadblock for users with impaired vision. Secondly, screen size is a factor when finding a right focus range. A miss-calibrated phone will not produce sharp images and can produce a doubling effect. Most cardboard HMD do however come with calibration settings which can be loaded into the carboard app.

5.3.2 Module production

When producing high fidelity prototypes based on the sketches, production speed was deemed the most important factor. Each version was allotted one-week sprints. This limitation was added to avoid spending too long on one idea and to avoid feature creep. Feature creep refers to many functions and features that are added to a product during development, making later stages of production extremely slow and cumbersome.

Production of the Moving Targets module was unsurprisingly quick as its design was the most fleshed out. It was renamed to Box Shot to appear more cohesive with the naming scheme of the other modules.

There were many problems during the development of the bird flight module. The biggest obstacle was depth of view. While VR does help in this regard there is still a lot of visual effects that are needed to sell the effect. To mitigate this problem the rings were turned into skyscraper like towers which the seagull would fly by. While this was better it still had problems with objects clipping into the camera and play space feeling cramped. After a week these problems could not be fixed, and the module was therefore put on hold.

While developing the labyrinth module several challenges in the design were found. Pen and paper labyrinth usually have one entrance and exit on each side of a box or circle. To avoid this the labyrinth design placed the user in the middle and made them work outwards. The version featured a simple image of a labyrinth with two exits and once the user exits one of them, they are shown how much time they used. This was another design challenge as it allowed for reward hacking, the user could get a better score by playing the system not the game, by simply looking at the exit.

Rolling ball was the fastest produced module of the five. Due to its inherent simplicity the original design worked without any obvious flaws. The play however might seem to be boring to some users.

The Watering can module had design flaws from the start. When using the basic GoogleVr movement scheme the user cannot move backwards, forwards or to the sides. This produced a space constraint which had to be worked around. The action of watering the plant was also hard sell visually. Using Unity's particle system added a watering feeling, but often blocked to much of user's view. In general, this was the most visually challenging idea and was for this reason put on hold.

The first iteration ended with the following features:

- Full VR functionality in the form of rotational controls.
- A functional VR menu based on NeckVR (Section 2.2.2), with dummy options and ability to choose between three different modules.

- Box shot, with a scoring system, but lacking in visuals and player feedback
- Labyrinth, a picture of a maze with a start and end state. Very unpolished scoring.
- Rolling ball, close to no functionality other than feedback when looking at ball.
- Application icon and name, VNA.

5.3.3 Cognitive walkthrough of first iteration

When the prototype was deemed ready it was tested using the previously prepared CW task list see Table 4. Feedback was categorized into successful design (SD) and problematic design (PD).

Task 1. Play Kloster remake	Results
1. Set up HMD.	**1. Set up HMD.**
1.1 Launch application. 1.2 Put phone in HMD.	SD. Bright colour icon helps. PD. Cardboard can tilt phone creating a doubling effect.
2. Start the game	**2. Start the game**
2.1 Look at the "choose module" button 2.2 Look at the Kloster remake button	PD. Easy to accidently choose options. PD. Accidental choose wrong module.
3. Play Game	**3. Play Game**
3.1 "Shoot" boxes	SD. Easy to grasp concept. Target reticule feedback confirms hits.
3.2 See score after time runs out.	SD. Visible through play and after.
3.3 Exit game and close application	PD. Return by tapping screen not communicated. Missing exit button from main menu.

TABLE 5: RESULTS OF TASK 1 OF COGNITIVE WALKTHROUGH

Task 2. Change settings	Task 2. Change settings
1. Set up HMD.	**1. Set up HMD.**
1.1 Launch application. 1.2 Put phone in HMD.	SD. Bright colour icon helps. PD. Cardboard can tilt phone creating a doubling effect.
2. Change Options	**2. Change Options**
2.1 Look at options button	PD. Possible for misinput high.
2.2 Look at the desired options to change	PD. Requires precision to avoid reselecting wrong options. Buttons take up a lot of space.
2.3 Save choice and exit menu	SD. Chosen parameters stay the same and follow settings conventions seen in other applications

TABLE 6: RESULTS OF TASK 2 OF COGNITIVE WALKTHROUGH

Several possible design problems were identified. Based on this a deeper analysis of the results shown in Table 5 and 6, were conducted. During this analysis, these questions were asked:

- Will the user notice that the correct action is available?
- Will the user associate the correct action with the desired effect?
- If the correct action is performed, will the user see that progress is being made?

The first problem identified was that the phone could be misaligned when slotted into the HMD, which the user could fix with a little bit of exploration, however an inexperienced user might believe that double cursors are intended. To mitigate this risk the user should be informed that only one cursor should appear when the equipment is properly in place. This problem is however not large enough to warrant a redesign.

When it comes to interacting with the menu the correct path is obvious to the user. They are only presented with two options which should both be self-explanatory. The problem comes in the form of question two. Even if the users try to undertake the correct action, looking at button 'a' or 'b', there is a large chance that they could graze the other button with the cursor. This would immediately move them to the wrong area. If the action carried out as anticipated, the expected changes happen.

There are just few available actions for the user during the play. They can either avoid looking at the boxes or look at them. After some it becomes very hard to avoid all boxes and once, they look at one they are given positive reinforcement in the form of their score going up. There is however no information to suggest the user that they have to tap the screen to leave the play area after a finished round. This action is also counter intuitive as it requires the user to slide the phone out of the HMD.

In task 2 many of the same problematic design choices as in task 1 were found. The options menu was based on the NeckVR application (see Section 2.2.2) which contained boxes that allowed to alter settings based on an abstract numbering system. Long texts in VR can be hard to read so the information about each option is quite sparse. Therefore, it can be hard to figure out what action is correct based on what is presented. Feedback is not a problem as buttons change color based on which setting is activated. The biggest issue found was the need for precision when operating the settings. As the target group comprises of people with NSCNP this is not acceptable.

5.3.4 Medical expert interview

Once development of the first iteration was complete an interview with Ingvill Naterstad, Assistant Professor at department of Global public health and primary care, was conducted. Her expertise and knowledge of physiotherapy was acquired to guide the further development of the VNA. The interview was set up as a semi-structured expert interview which was later subjected to a thematic analysis based on (Braun and Clarke, 2006)'s explanation (Section 3.7.6).

The most relevant findings which impacted further development were:

- **The most suitable target group:**

  People who have experienced non-specific chronic neck pain (NSCNP) in a period lasting more than three months. This group does not include people suffering from more specified injuries like prolapse or fractures requiring more careful handling to avoid damage. With this grouping there is no dangerous movements which must be avoided in the design. People with NSCNP are at low risk, there are no dangerous movements to avoid when designing. This is also the largest group of patients/users.

- **Movement types and exercises:**

  People suffering from NSCNP mostly require mobility and coordination training and not strength training. Movements should primarily be dynamic, as in flowing and continuous movement without too much stopping and holding. Training should start with slower easier movements and build up in complexity and difficulty to allow users ease into difficult or painful movements. Pain during exercise is acceptable.

- **Possible usefulness of the VNA:**

  Patients are often given tasks to complete on their own at home, but it frequently happens that patients do not really complete these tasks since they often forgets the specific movements or tasks they were instructed to do. The expert has previously used lasers pens during sessions but has stopped the practice due to the time needed for setup. During exercise, the users might also stop themselves from doing full movements due to pain avoidance, so having a system that could help them push through this fear would improve the exercise quality.

Based on these findings the VNA target group was set to focus on users experiencing NSCNP. Modules would all require some form of dynamic movements in favor of more static movements.

5.4 Second iteration

The Cognitive Walkthrough (CW) identified several problematic designs with VNA. These problems were mostly centered around the operation of the menu in VR. The two main issues were the need for precise neck movements and the likelihood of erroneous inputs. To handle these problems new designs were required classified into two categories, VR menus and non-VR menus. Another goal with the second iteration was to test different font styles and colorings used. While the VNA has little text, the used text requires good readability as it is the main modus of feedback at the end of rounds.

5.4.1 VR menu

During the design process of a new VR menu different features needed to be graded on their impact on the user experience. For some of the interactions, paper prototypes were sketched, and interaction was tested by mounting a laser pointer on a baseball cap to simulate the VR controller. Distance was gauged

by creating a paper version of the current menu and setting up the test variants to scale. For each element and interactions, a series of questions were asked to help identify potential problems. The questions were based on the problematic designs found in the CW.

- *Precision needed check* to see whether the user must navigate the reticule in a specific way to achieve the desired action.
- *Slow to use* explores at how cumbersome the required tasks are for experienced users.
- *Hard to understand* encompasses how complex the task is and if it requires some form of extra information not given through inherent design.
- *Risk of erroneous input* looks at the possibility of a wrong action if the user is inaccurate in their movements.
- *High screen requirements* explore the required screen real estate of the design choice; the expectation is that less clutter is better.

The first interaction evaluated were targeting buttons:

- Non-timed buttons activated immediately when the user gazes on them.
- Timed buttons where a 1-2 second delay is added, requiring the user to keep looking at it for some time before the command is registered.
- Confirmation box approach, the users looks at a button and is presented a textbox where they can choose 'yes' or 'no'. If the user selects 'yes' the button is activated.
- Multitap, the user is required to gaze at the same button two times before the input is accepted. Looking at any other button resets the counter.

	Precision needed?	Slow to use?	Hard to understand?	Risk of misinput?	High Screen requirement
Non-timed buttons	Yes	No	No	High	Yes
Timed buttons	Yes	Yes	No	Low	No
Confirmation box	No	Yes	No	Low	Yes
Multitap	Yes	No	Yes	Medium	Yes

TABLE 7: REQUIREMENTS AND RISKS OF DIFFERENT VR MENU APPROACHES

	Positive	Negative
Non-timed buttons	Very fast for experienced user	Very easy to select wrong option
Timed buttons	Small screen req. Low risk of misinput	Slow to use, need precision
Confirmation box	Easy to use and low risk of misinput	Very slow
Multitap	Fast	Can be difficult to use without experience

TABLE 8: POSITIVE AND NEGATIVE ATTRIBUTES OF DIFFERENT VR MENU SETUPS

Based on the results presented in Table 4 and 5, it was decided that either timed buttons or multitap should be developed further if a VR menu was chosen. Timed buttons come with the disadvantage of requiring the users to hold their head steady in one place and making menu interactions slower. These disadvantages are however counter balanced by removing the chance of erroneous inputs, allowing for tighter designs, and being easily understandable with a small amount of visual feedback. Multitap is faster to use once the user is experienced with the system but comes with the drawback of needing a form of explanation.

5.4.2 Non-VR menu

The first test of having a menu without VR controls was set up by repurposing the current menu. VR controls would only be activated once the user selected a module to play. This version was evaluated using the same criteria as the VR version. Immediately several of the previous problems were solved. The first advantage of this approach is user familiarity with the input method which has been learned by most evaluators through usage of other mobile applications. By keeping menus sparse and buttons large, the required precision from users was kept low. Classic mobile menus are neither hard to use or understand, the only exception comes from vague labelling or a lack of consistency in design. The biggest challenge this version has been the transition between the non-VR menu to the VR operated modules.

5.4.3 Expert evaluating of font readability

All modules contained in VNA have some form of text feedback. Both information about time left and score were presented as outlined by Hines (Section 2.1.6), which could cause some problems related to

presenting text in VR. Smaller thinner fonts might easily become jagged and hard to read. To decide which type face to use a method of evaluating readability was devised. Two menu variations were created to cycle between eight different size and font options. The two version had the text placed at different distances from the player camera. This made it possible to account for clipping, jagged lines and blurriness.

To evaluate readability both versions were tested three times each by game developer Vincent Jalland, followed up by an informal interview about the possible game design elements to include in the VNA. The goal of this evaluation was to create a guide for all text that would appear in VR.

Table 6 shows Jalland's feedback from the font trial. The two fonts tested were Arial and Roboto-Medium (RM). Arial is the default text given by Unity while Roboto-Medium is provided by GoogleVR. Readability scores was split in close/far and scored on three categories: low, medium, and high. Overall score was calculated by adding 1 for low, 2 for medium, and 3 for high.

	Font	Size	Bold	Far/small	Close/big	Score
1	Arial	14	No	Low	High	4
2	Arial	14	**Yes**	Medium	Low	3
3	Arial	23	No	Medium	High	5
4	Arial	23	**Yes**	Low	Low	2
5	RM	14	No	Medium	Medium	4
6	RM	14	**Yes**	Low	Low	2
7	RM	23	No	High	High	6
8	RM	23	**Yes**	Medium	Medium	4

TABLE 9: FONT EVALUATION BASED ON AGGREGATED SCORES FROM EXPERT EVALUATION

Based on the score and informal interview, it was found that use of bold made text too muddy to read efficiently. All the smaller sizes were hard to read even when up close, the exception was version one which scored high when the text was closer to the screen. Roboto-medium scored generally better than Arial, which the expert put down to RM's already thicker font which did not suffer from the same muddy feeling the font bold produced.

5.4.4 Updating the menu

Based on the VR and non-VR menu tests it was decided to completely switch over to a non-VR menu for VNA. The biggest change from the earlier menu system was how options were altered. Three possible settings could now be altered, i.e. starting difficulty, difficulty growth rate, and round duration. These were imagined to be universal settings which could change the gameplay for all three versions of the game. Based on the results from the font evaluation, all text in VNA was changed to Roboto-Medium

without bold. Font sizes is weighted towards larger variations with 17 being the smallest size used and 23 the largest.

5.5 Third Design Iteration

The third iteration focused on refining the modules present in the VNA while also ensuring a consistent visual design.

5.5.1 Creating the Labyrinth module

During development of the first iteration of Labyrinth two possible design challenges were identified. Firstly, was the fact that the majority pen and paper labyrinths ask the user to enter and exit the maze from the outside. While possible to recreate in VR it could force the user to look at extreme angles from the start. According to the first medical expert interview, it is better if the user can start out slow and easy before increasing the challenge. This idea was also found in (Finkelstein *et al.*, 2011) where they sectioned a game session into three phases, warmup 15%, exertion 70%, and cooldown 15% based on the American College of Sports Medicine's guidelines for exercise. While VNA's modules are only a part of one session they should still be able to work as the first module of any given session.

To avoid forcing the user to start with any extreme angles the labyrinth starts with the user trapped in the middle working outward. This was accomplished by making the labyrinth invisible and only showing

a square with the text "Look here to start" (Figure 6). This start lock would both give the user time to place their phone in the HMD and ensure that they look in the correct spot before game start. Once the gaze cursor is over the square a countdown timer starts and when it reaches zero the labyrinth appears.

FIGURE 6: LABYRINTH MODULE START LOCK

The second design challenge was scoring. The first version of the maze used time from start to finish as a score metric. This version had no penalty for *jumping* over walls and ignoring the maze layout. Two methods excluding this behavior were considered; one version is where the user is penalized with more seconds if they gazed at a wall, this version however could quickly teach poor performers that jumping walls would still be better than trying to solve the maze correctly. The second version envisioned was adding a trail to the user's gaze. The trail would stop if the user looked at a wall which would force them to return to the correct path. This version avoids concrete negative feedback while also making sure that the user does not simply jump to the exit.

To test the second idea, a demo of the module with a trail was created. During development it was found that stopping the trail induced a mild form of motion sickness in the developer. This might be due to an underdeveloped visual style which was the reason to switch the scoring to a system where the user gained points based on how much of the maze they traversed. This was done by creating an invisible grid which lights up when gazed at. Figure 7 shows how the squares are configured before being hidden. If the user gazes at a wall the next square does not award points, this is signaled to the user by lighting every wall red. While this version allows the user to jump wall and go straight to the exit, however this does not award many points. It is possible to sweep back and forth over the labyrinth to gain point; while this is not the intended interaction it does not cause a problem as these motions are still controlled neck motions which is the target practice. This allows for a form of self-expression not expected when the module was designed.
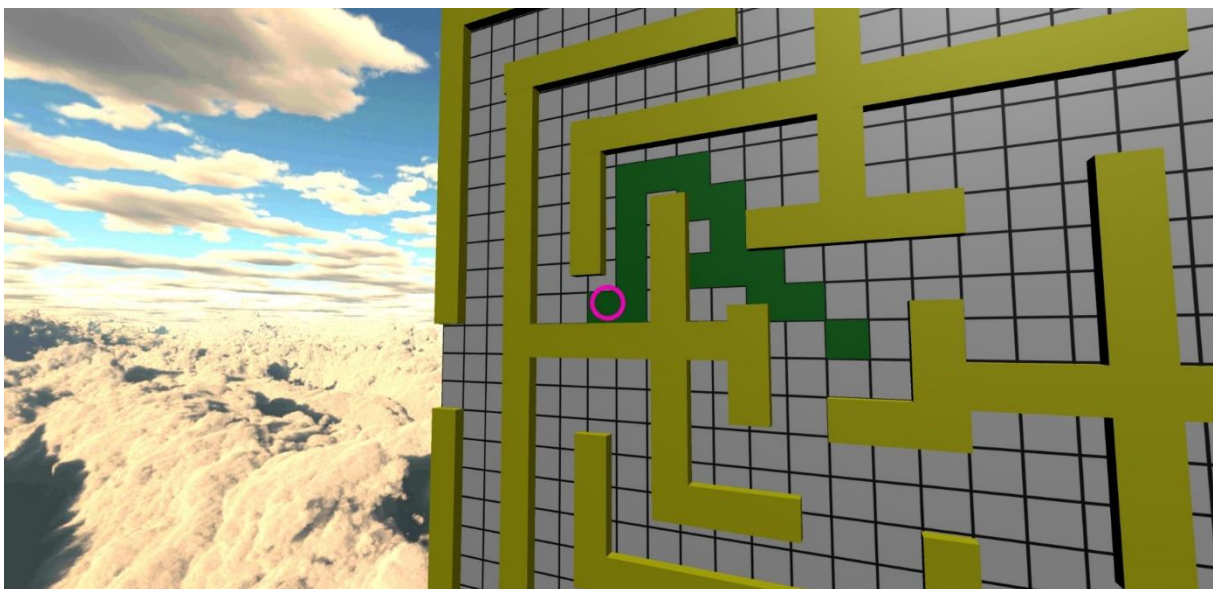

FIGURE 7: LABYRINTH HIDDEN SCORING SYSTEM

5.5.2 Updating the options menu and skyboxes

Of the three settings in the options menu, it was decided that only the round duration setting would be reflected during gameplay. This decision would both save time by avoiding further development while also ensuring that every round of testing was identical. The two difficulty sliders could be implemented later based on user feedback. The round timer was implemented however and a scale between one and two minutes was opted for. Additionally, skyboxes were added to the different modules. Skyboxes are 3d background which tile seamlessly around the user in a sphere. Calm clouds and a space theme were chosen to give the player a sense of being in a place instead of a nebulous void. It was also decided not to add a start lock to the Box Shot module to test user preference in the upcoming usability test.

5.5.3 Expert interview medical and VR expert

To help with evaluation the VNA a semi structured interview with a physiotherapy and virtual reality expert was set up. Lars Peder oversees a laboratory ab at Høgskulen på Vestlandets which focuses on using technology in physiotherapeutic research. During the interview, the current VNA was showcased and the medical expert was asked to comment on both the usability, functionality and relevance. The answers where afterwards analyzed and sorted based on content analysis of the interview.

- **Pain and patient safety:**

  To ensure that any safe use of the VNA is safe, a physiotherapist must be consulted. The major danger is that people experiencing pain might start before having their symptoms evaluated. It is however usually fine if a person with NSCNP experiences pain during exercise as long as this pain abates during the next 24 hours. It could be recommended that apps like the VNA should not be distributed freely at this stage of development.

- **VNA menu and customizability options**

  There should be some form of information which advises the user what is the function of the different options provides details about the different modules. Normally in more custom-made applications the therapist will have a more complex settings system allowing for specifications such as range of motion.

- **Supported movement types in VNA**

  In box shot the patient is asked to work with flexibility, dynamic movements, and quick changes in movements. This form of exercise stimulates neck musculature and allows the patient to master varied movements required in everyday interactions. In the Labyrinth the patient requires controlled movements. The Ball Tracker is very solid in its design where movements are linear and presents little variation.

- **Box shot**

  There should be some form of timer or lock to allow the users to get phone in the HMD. The format on the timer could also be simplified by removing the seconds and minutes text and separating them with a colon. The timer should count down instead of counting up.

- **Labyrinth**

  There should only be one exit instead of four to make each round too easy and too fast. Scoring should be converted to how long a user took to come out of the labyrinth. The user should be penalized for hitting the wall by adding time to the final score.

- **Ball Tracker**

  The mode has the potential to add the movement principles found in the two other modules by making the ball move in more complex patterns. If the ball moves in a pattern unseen by the user, it will force them to execute quick movement changes. We thought of a scoring system based on a background animation where a something like a flower or garden grows when the user is looking at the ball. Difficulty can be expressed in how quickly the ball moves and how long it takes for the background animation to finish.

- **Module design and exercise goals**

  Instead of focusing on specific exercises used by physiotherapist the modules should focus on movement principles found in literature. This is especially relevant when making system for generic therapy instead of targeted workouts for certain kinds of pain.

5.5.4 Updates based on expert interview

The interview with the medical expert provided many good points on the further development of the VNA. It was decided that most of these would be added during development of the final iteration rather than implementing them during this iteration. This way it was possible to test the current design more thoroughly before adding any major changes. With this in mind, only one new feature was added based on the expert feedback and that was two information sources which the user could access. One source was a button in the options menu which explained each sliders function and the other source was an information box in the module select screen informing the user on how to exit the modules once VR was turned on.

5.5.5 Usability testing and system usability scale design

Further development of the VNA depended on a larger evaluation of the artefact's usability. This was done in a twostep procedure where an evaluator would first follow a list of suggested actions and fill out a SUS survey. The usability task list was based on the original CW tasks. This would not only

either reaffirm or disconfirm the earlier analysis, but also lead the user to test out all parts of the VNA's design. The usability tasks were as follows:

1. Go to the options menu.
2. Edit the options so that any round length is a short as possible
3. Edit the options so that the difficulty will increase as fast as possible
4. Start a round of Box Shot
5. Tell me your score once you are done
6. Return to the main menu
7. Start a round of labyrinth
8. Tell me your score once done
9. Return to the main menu once done
10. Close the application

The evaluators got no help during testing except for an explanation that the application did not start in a VR mode and that, if two dots appeared in VR, then the phone should be tilted to pair it correctly with the HMD. By limiting outside help it was hoped that the evaluators would explore the interface when stuck, rather than ask for help. They were however encouraged to talk while performing the tasks.

This task list was aimed at identified design weaknesses. Firstly, was the naming convention mentioned during the medical and VR expert interview. Secondly, the newly added information boxes added to both the options menu and the module select screen. The options menu information could be displayed if the user tapped a question mark button (Figures 8 and 9). Information about how a user could exit a game was included to an always present information box located over the module selection (Figure 10). Instruction on how to return from a VR screen was only conveyed with this information box and by testing whether users actually read the information, which was considered essential.
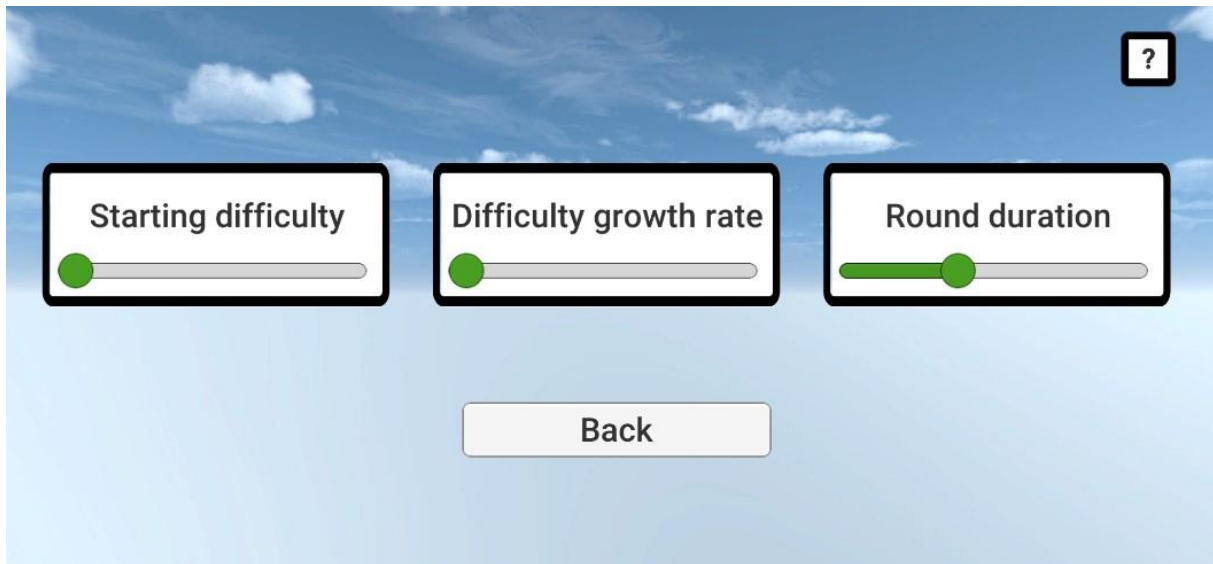
FIGURE 8: OPTIONS MENU AS SHOWN DURING THE USABILITY EVALUATION. PRESSING THE QUESTION MARK PROVIDES THE EVALUATOR WITH MORE INFORMATION.
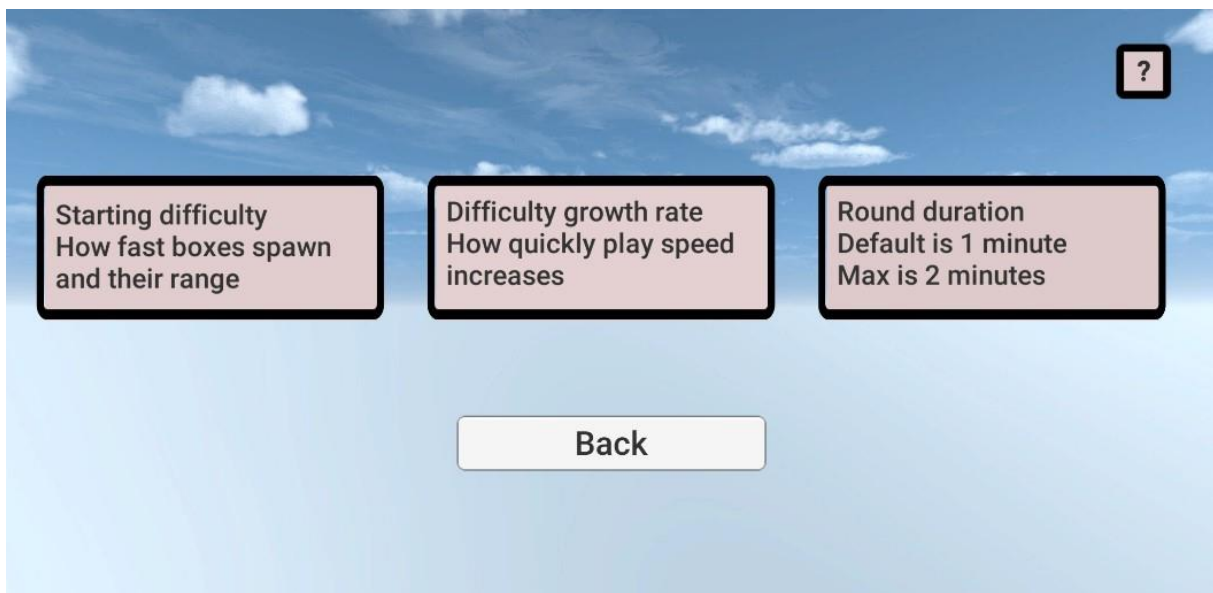
FIGURE 9: OPTIONAL INFORMATION BEING SHOWN IN THE OPTIONS MENU
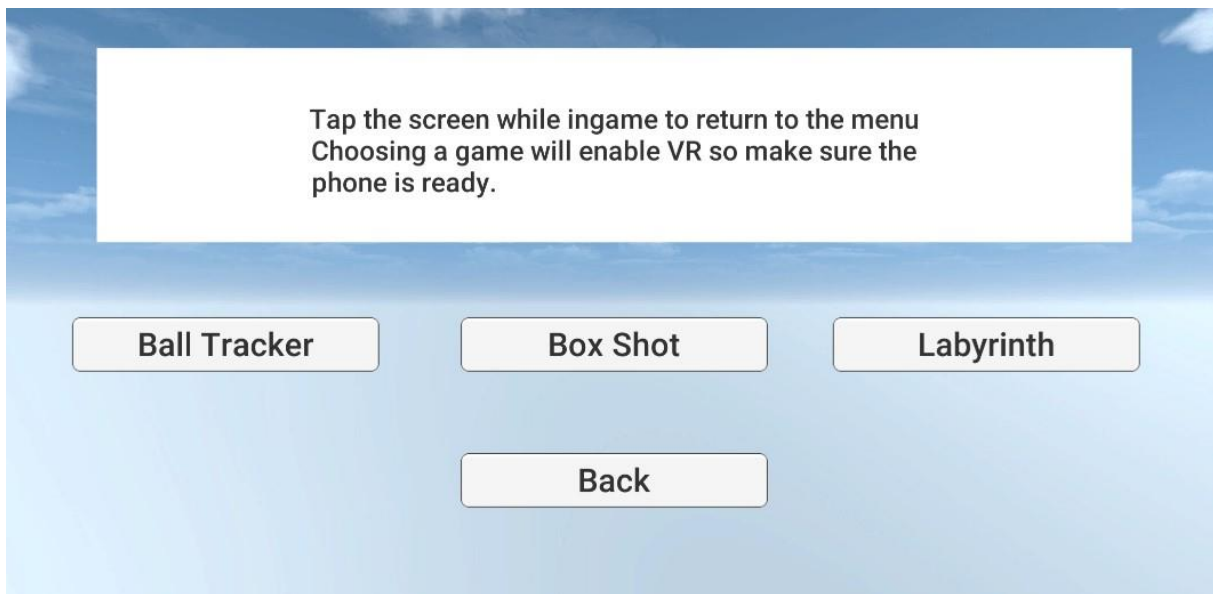
FIGURE 10: MODULE SELECTION SCREEN WITH INFORMATION BOX INFORMING THE USER ON HOW TO RETURN TO THE MENU DURING PLAY.

5.5.6 Usability and SUS results

After completing the tasks, the evaluators were asked to fill out a SUS questionnaire. The only modification done to the questionnaire was changing the first question from "I think that I would like to use this system frequently" to "I was engaged by the system". Participants filled out the SUS forms before any discussion or debriefing as suggested by (Brooke, 1996). Evaluators were asked to score as soon as they were done to capture their most spontaneous judgment and without spending too much time on one of the questions. The final score for the iteration was 87.25 out of 100. For a more detailed breakdown of the numbers, relevant explanation can be found in Chapter 7.

During the usability test a few design challenges were identified and categorized. Nearly every participant ignored the text boxes with information about the options and how to exit the VR environment. Most of the users did also struggle with exiting VR, four of the users tried to find an exit within the VR environment while six of them tried to use the Google Cardboard provided buttons to exit. Only three participants tried using these buttons on their second round which seemed to be mainly a first-time problem. Four participants found a bug in the program which turned the starting orientation 180 degrees if the phone was flat during the transition to VR. Three of the users were also unsure of where the exit was in the labyrinth module.

5.6 Final Design Iteration

5.6.1 Implementing changes based on feedback and tests

The first change added to the VNA was a text box at the end of each round which instructed the user to tap the screen to return to the main menu. Another change was modifying the formatting for the timer in Box shot as suggested in the expert interview that was also altered to count down instead of up.

5.6.2 Creating the final module, Ball Tracker

By far the biggest update to the project was the update to the Ball Tracker module. All features added were based on the expert interview, the suggestion from Babic, and design from the Fly paper (Kristjansson and Oddsdottir, 2010). During play the player is presented a yellow ball, the Target, in front of a gray background. When the player gazes at the ball it changes color to red and starts moving in a pseudo random direction with a speed based on the user settings. As long as the reticule is placed over the ball, a flower in the background grows based again on the user's difficulty setting. When the flower is fully formed the ball and gray background disappear and the player is left with a flower and a score in the form of time spent.
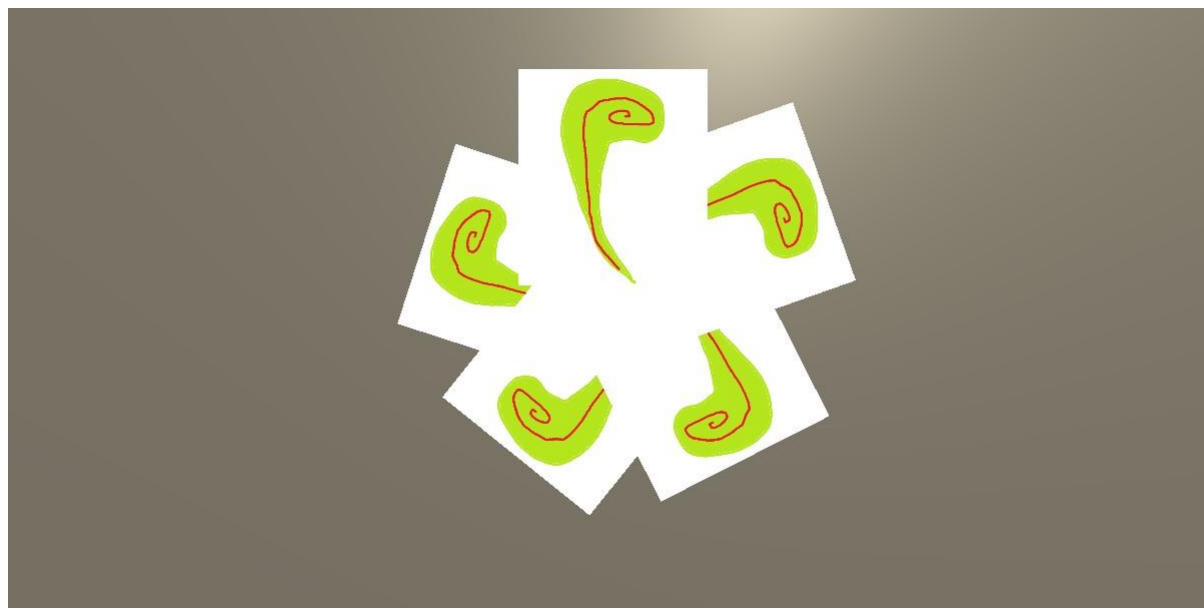
FIGURE 11: EARLY ANIMATION TEST OF FLOWER ANIMATION

During the design phase the major challenge was to decide how the Target would move. In their paper, Kristjansson and Oddsdottir use a set pattern for the movement (Kristjansson and Oddsdottir, 2010). In VNA however it was decided to use a weighted waypoint system where the users could themselves set the difficulty. In Figure 12 the Target's movement grid is shown. Three colors are used to designate the three different difficulty weights. Red is set to the easy checks, yellow for medium and blue for difficult. the colors were arbitrarily picked since the points are not visible during play. At maximal

difficulty, the Target uses a pseudo random number generator to pick one, but at lower difficulties the points further out have a lower chance to be picked. At the lowest difficulty, the inner four points will be picked 75% of the time.
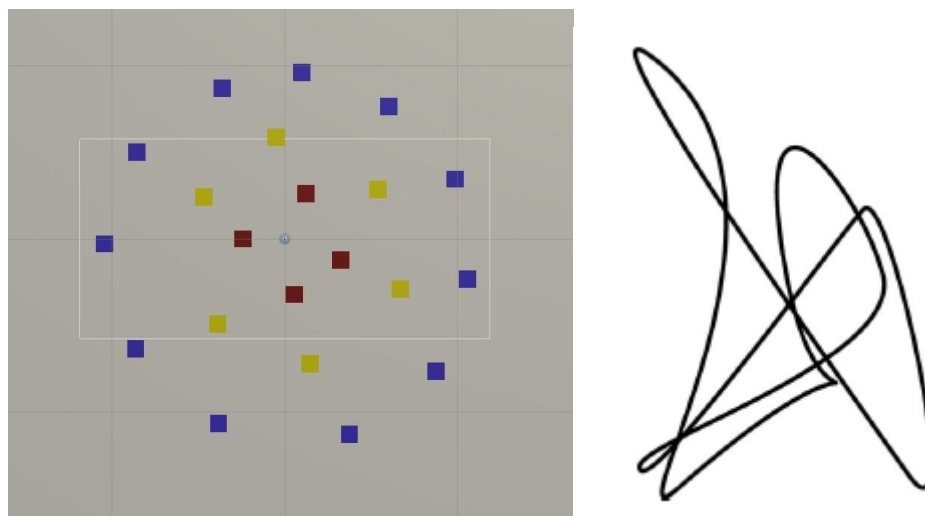
FIGURE 12: ON THE LEFT: VNA BALL TRACKER MOVEMENT GRID. RIGHT: THE FLY HARD PATTERN

To further add randomness to the Target movement, a check will monitor how far it is from its last checkpoint. When it has traveled far enough it will start having a small chance to choose a new checkpoint before arriving at its destination. This chance is also based on difficulty where a higher difficulty increases the chance that the fly changes target. This was implemented to avoid a situation where the fly would move in a straight line for too long. Finally, the Target's movement speed and the flowers growth speed were both based on the difficulty stetting and design in such a way that each round would last between 15 to 60 seconds based on the players skill.

5.6.3 Final interview with the medical expert

After completing development, a last interview with the expert was scheduled to discuss the project and possible paths forward. This interview was semi-structured. This time the expert evaluated the VNA with an HMD and the test was conducted in person. The transcript was analyzed and sorted following the main themes.

- **Evaluating the user experience and module changes**

  The user can get exact information about the different sliders in the settings. Using Googles HMD feels pretty natural and fixing user error is fairly easy. The changes done to Ball Tracker are very good. The flower animation really motivates the user to finish the task quickly. Having randomized movements per round is good. The labyrinth really makes user work. The scoring system should be based on how long the user took finishing the labyrinth and how many times they hit the walls.

- **Esthetics, animation and visual complexity**

  No additional visuals should be added to the Ball Tracker in its present form. The user's focus is drawn to it and the more that happens the harder it is to keep focus on the task. Visuals should be seen as a form of difficulty. The balance is between engagement and focus. One could instead add different animations which the user can choose between. This can both be used as a reward and a difficulty.

- **Implementing more settings for labyrinth**

  With the current setup for settings it is possible to put the width between the labyrinth walls close to the beginning as starting difficulty and the path further out as difficulty growth. Duration could be determined by the actual size of the labyrinth.

- **Specificity**

  The VNA is a tool for a more generic form of exercise. Trying to add too many options for all kinds of situation is not needed. If a patient experiences pain when looking to the left the therapist can start them with an offset by making the patient turn more to the right before starting. For some patients, larger movements are more difficult, but VNA is well suited for challenges where the patient must do faster movements in a small area. It is the therapist's task to individualize exercises.

- **High scores and GDPR**

  A scoreboard could be added to computer generated scores which the user could try to beat while saving the users scores only on their own device.

- **Further work**

  A natural next step would be to explore gamification. Maybe adding more levels and specific scenarios based on the existing concept. Different animation could be unlocked by playing. In this project the foundation of the treatment was created, so the next step is to explore how to motivate people to continue playing.

5.5.4 SUS with Users

The last evaluation done on the VNA was a repeat of the usability and SUS done with iteration 3. Participants were mostly new, but some overlapped with the last round. For greater detail see chapter 7. This time the users were asked to do the following tasks before filling out the SUS:

1. Go to the options menu.
2. Edit the options so that any round length is a short as possible
3. Edit the options so that starting difficulty is at 20%
4. Start a round of Labyrinth
5. Tell me your score once it is done
6. Exit back to the main menu
7. Start a round of Ball Tracker
8. Tell me how long you took
9. Return to the main menu once done
10. Close the application

The tasks were kept as close to the first round to see if the new changes impacted the scores while also exploring the new version of Ball Tracker. After the user filled out the SUS they were asked to briefly comment on their thoughts.

Most evaluators thought the labyrinth was the hardest of the two modules. Due to the perspective, first person looking at a 2D plane, the edge paths seemed narrower which some found challenging. Three users also experienced a bug where the reticule would not immediately show up when the round of labyrinth started. Feedback on Ball Tracker was very positive and most liked both the colors however, two participants liked the visual style of the labyrinth more due to its simple nature. Two participants also wanted a visible percentile or categorization for the options. No participants had trouble exiting the VR environment.

Chapter 6

VNA Features

This chapter is an overview of the final features implemented in the artefact. VNA contains two main sections, the VR and the non-VR sections referring to all features providing other functionality.

6.1 Non-VR features
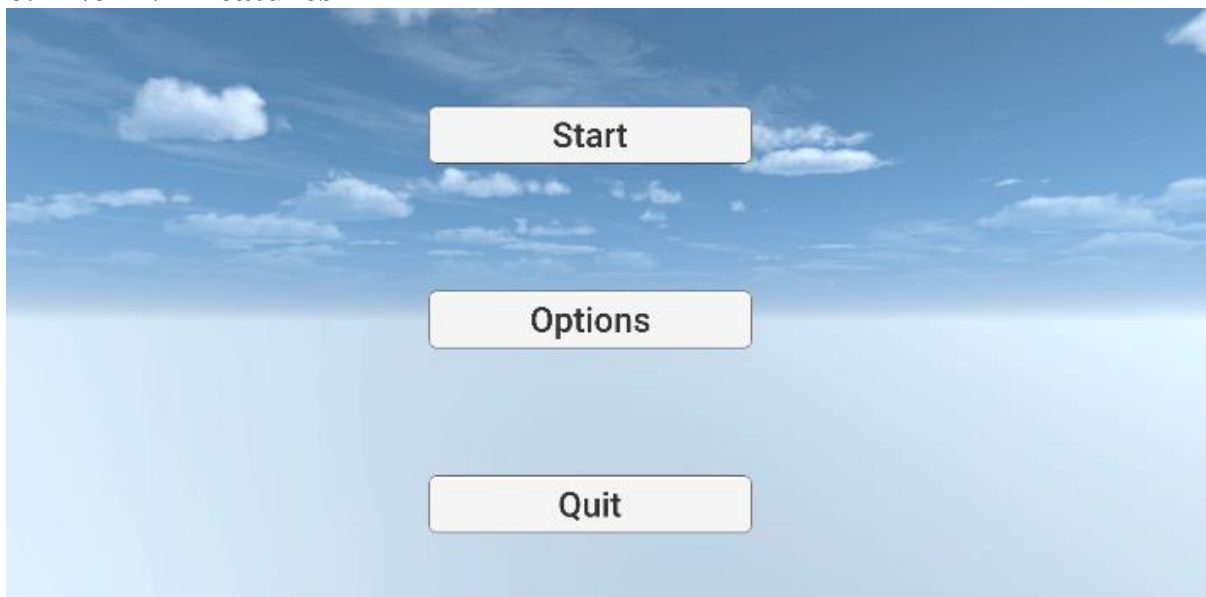
FIGURE 13: MAIN MENU OF VNA WITH THREE POSSIBLE ACTIONS; START, OPTIONS, AND QUIT

All menus in VNA are functional outside of VR to make navigation and interactions easier. These menus have three roles: navigation, customization and game selection. Navigation has been designed to minimize possible user errors by keeping the number of buttons to a low number, labeling all buttons with short descriptive text (Figure 14), and by providing help boxes with more detailed information (Figure 15). Customization comes in the form of slider bars which the user can fill or empty by sliding a knob left and right. Values presented are abstracted and it is expected that the user would be biased towards *left to right* reading. These values are also saved into the application memory. The start option is the least intuitive option available to the user as it does not start a game but takes them to a module select screen.
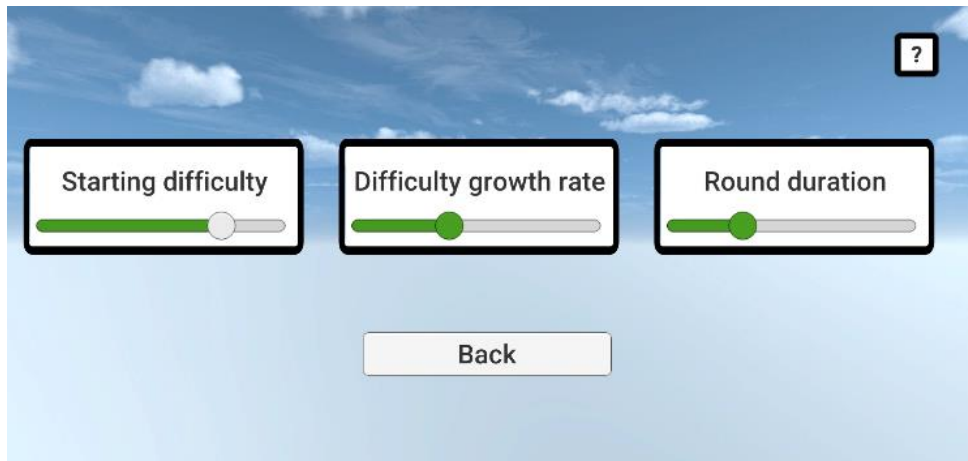
FIGURE 14: OPTIONS MENU WITH SLIDERS
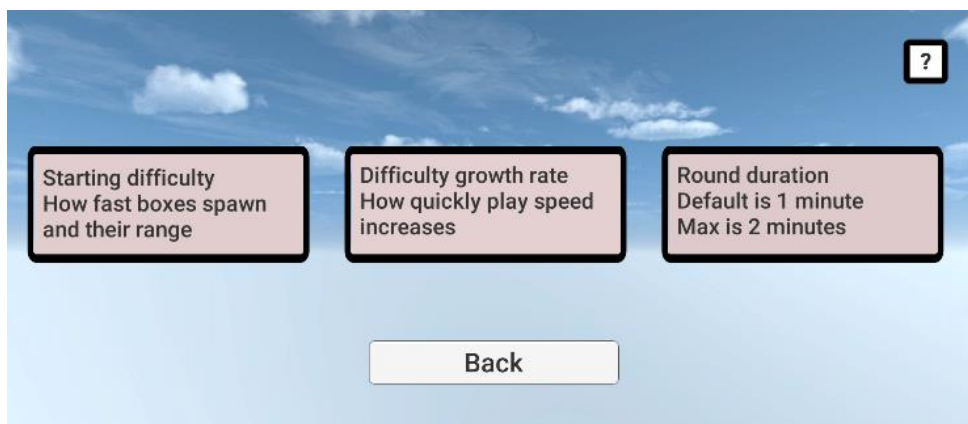
FIGURE 15: OPTIONS MENU WITH FUNCTION DETAILS

6.2 VR features

6.2.1 General VR features

All modules share the same camera system and movement system. When a chosen module is 'selected' the camera orientation is aligned with where the phone was pointed at initialization. The player can change this view by rotating their head, allowing for 360-degree rotations. All modules also feature a responsive cursor which expands and shrinks based on different events (hovering over a target in box shot, gazing at a wall inn Labyrinth, or when tracking the target in ball tracker).

6.2.2 Box Shot

FIGURE 16: GAMEPLAY EXAMPLE FROM BOX SHOT MODULE

The box shot is aimed at promoting varied and dynamic neck movements. Flexibility, reaction speed and quick movements are all challenges presented by the game elements and design. Each round starts with the user looking at a gray background featuring text telling them how long they have been playing and how many points they have scored Figure 16. Once play starts the user's goal is to look at flying squares that travel at a fixed speed towards the background. When the user gazes at a square their reticule expands, and the square disappears Figure 17. The challenge comes from the pseudo-random nature of where the square appears in the play space. A default round ends end after a minute of play, which can be extended to a maximum of two minutes.

FIGURE 17: EXAMPLE OF RETICULE FEEDBACK WHEN GAZING AT CUBE IN BOX SHOT

6.2.3 Labyrinth
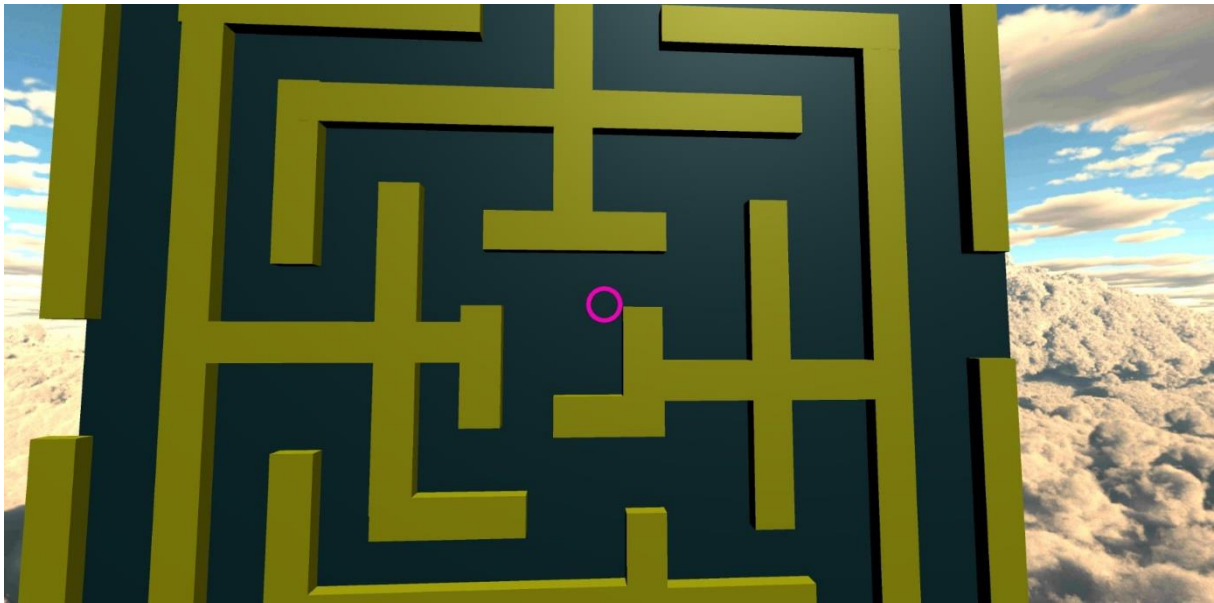
FIGURE 18: EXAMPLE OF PLAY IN LABYRINTH MODULE

The labyrinth module consists of one static labyrinth where the user starts gazing in the middle of the labyrinth and must work towards an exit at the edges Figure 18. Scoring is based on how much of the labyrinth is traversed. Unseen by the user there is a grid of squares which gets activated when gazed at, these get tallied up at the end of a round to calculate final score Figure 19. If a user gazes at a wall, all walls change color to red and the next tile the user looks at does not award points to the user. Play end when the player looks past the exit.
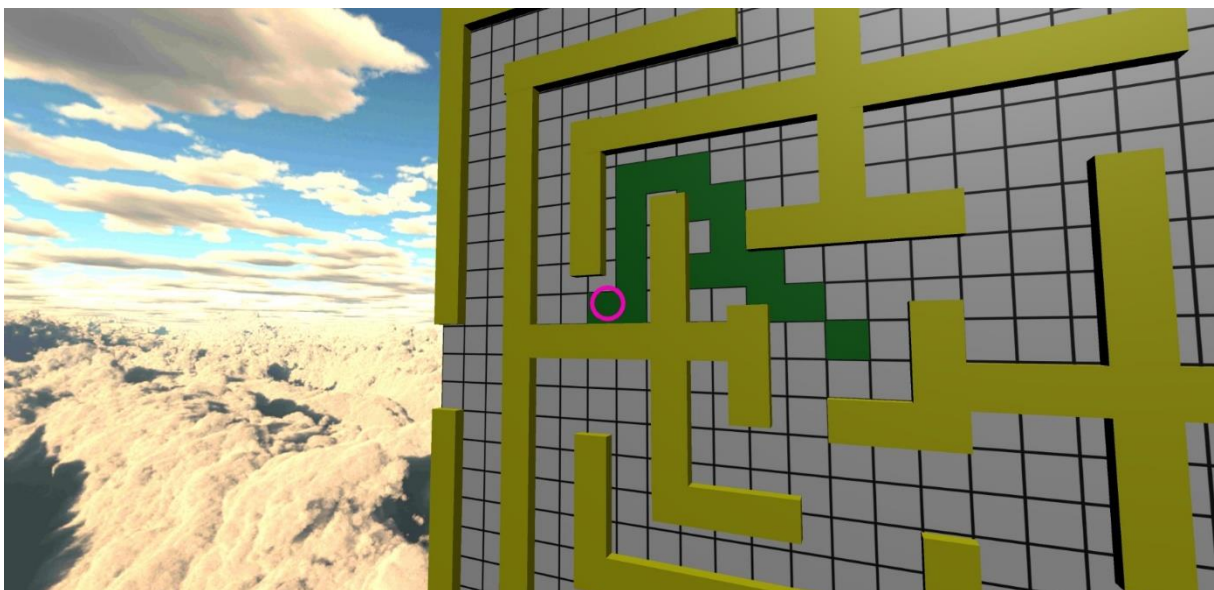
FIGURE 19: EXAMPLE OF HIDDEN SCORING SYSTEM IN LABYRINTH MODULE

6.2.3 Ball Tracker

Ball Tracker presents the user with a ball floating against a gray background. When the ball is followed, it changes color and starts moving and a flower starts growing in the background Figure 20. The flower will continue to grow as long as the user looks at the ball. The ball will move in a random pattern determined by the user difficulty settings and a hidden waypoint system. Once the flower has grown to its full size, the background and ball disappear and the user is left with a flower showing their completion time   Figure   21.
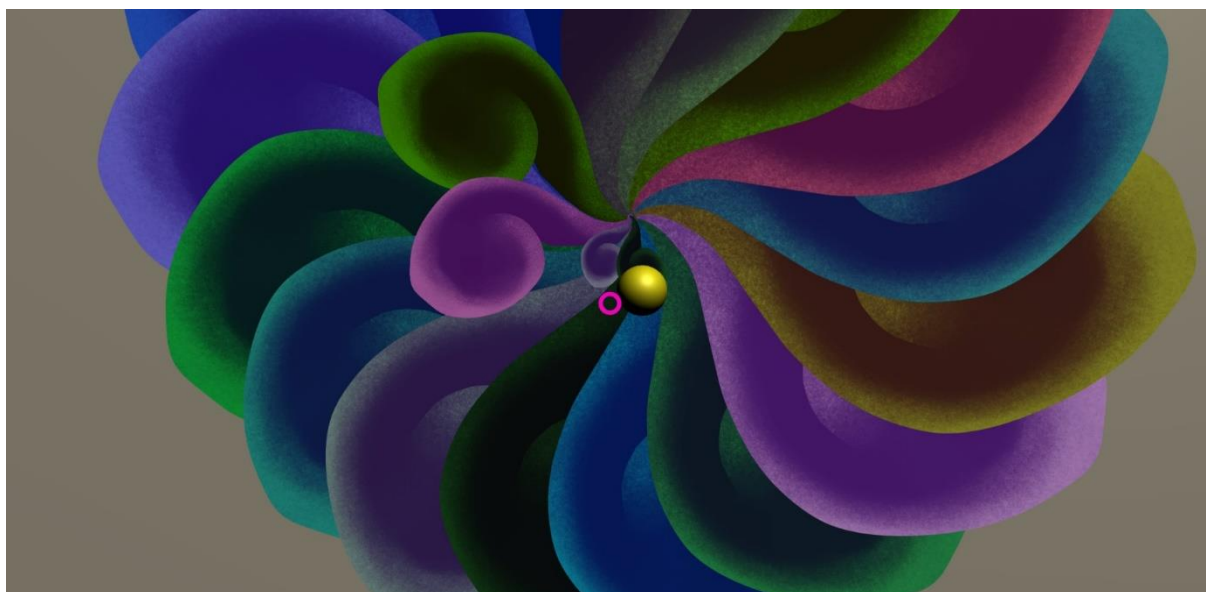
FIGURE 20: EXAMPLE OF PLAY IN BALL TRACKER MODULE
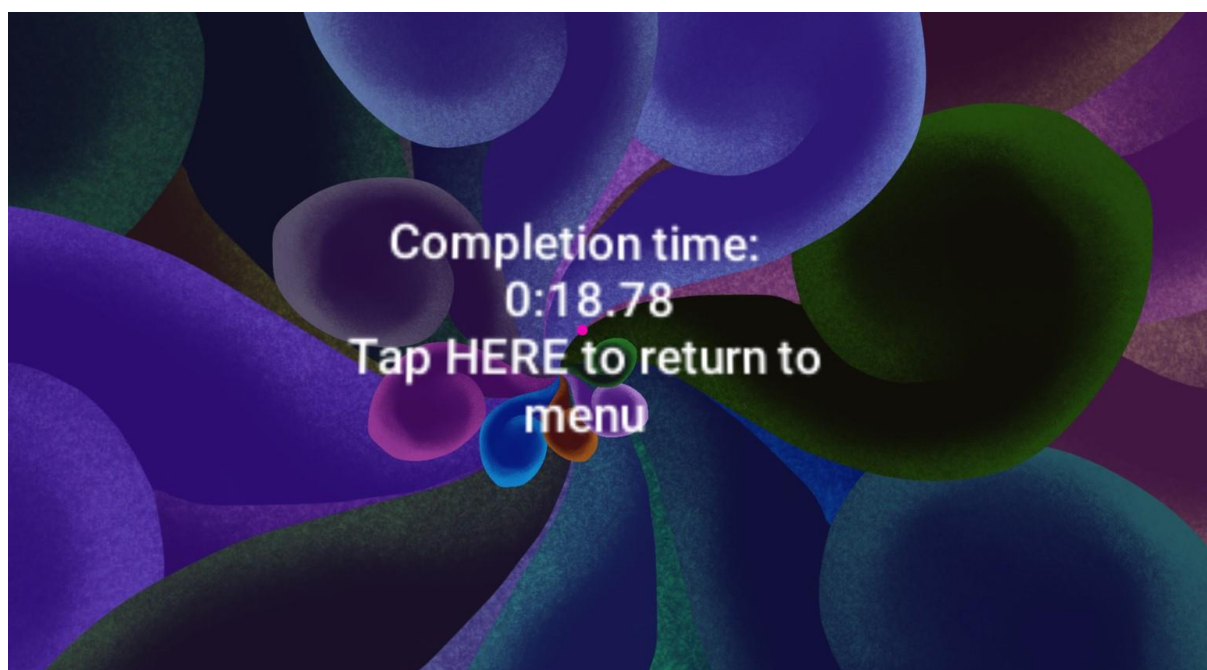
FIGURE 21: BALL TRACKER END SCREEN WITH SCORE AND FULLY-GROWN FLOWER

Chapter 7 Results

7.1 Participants

The three experts engaged in this thesis were all sourced from personal contacts and previous projects. All participants used in usability testing and SUS were master or bachelor students at the Department of Information Science and Media Studies except for two evaluators, one from a visual design bachelor studies and the other an archeology bachelor student. Due to their overall high academic experience and knowledge of visual design their expertise was considered higher than the one of expected end user. Participants were also informed that giving "nice" scores to be friendly would be a detriment to the project, but it is not possible to eliminate all bias this bias that is most likely present in both evaluation sessions. All participants were in the age range between 20-35 years old. Out of the total 16 participants 12 were men. Round one of SUS testing had 10 participants and the second round had 8 participants of whom 2 participants had participated in the first SUS.

7.2 System Usability Scale

7.2.1 SUS third iteration

The third iteration generally got high scores from all the participants. There was little to no correlation between the scores given by participants with low scores and participants who experienced bugs or got stuck. Participant TE-4 gave the overall lowest score but did not experience any bugs. The total numerical score ended up at 87.25 Graph 1. Based on the scale shown in 3.9.2 the final score for this round of SUS would be deemed a strong B or excellent.
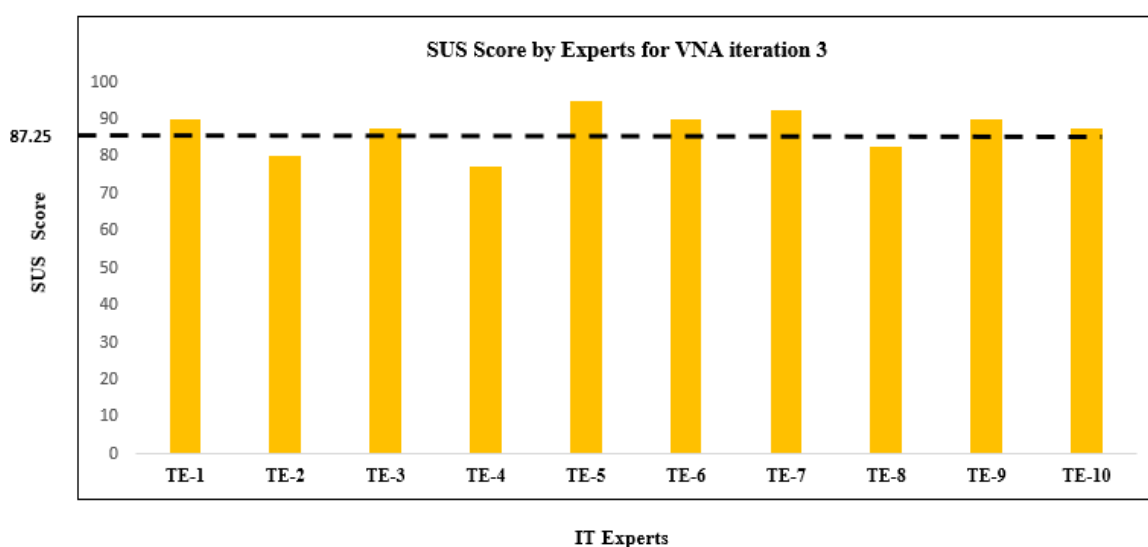
GRAPH 1: RESULTS OF FIRST SUS PERFORMED ON THIRD ITERATION OF VNA

7.2.2 SUS final iteration

The final iteration got a score of 90 is at the intersection of a grade of B and A on a letter grade system (Bangor, Kortum and Miller, 2008) (Graph 2). However, two participants of the SUS were returning evaluators. In this SUS participant TE-7 is the same person as TE-2 (in the first SUS) and TE-8 is the same person as TE-1(in the first SUS). Both participants gave higher scores this time, especially TE-7. This might be due to the expectation that further development is the same as better usability. When using their old score, the total for the last SUS ends up at 87.50 which is an increased score from the previous evaluation by 0.25 points.
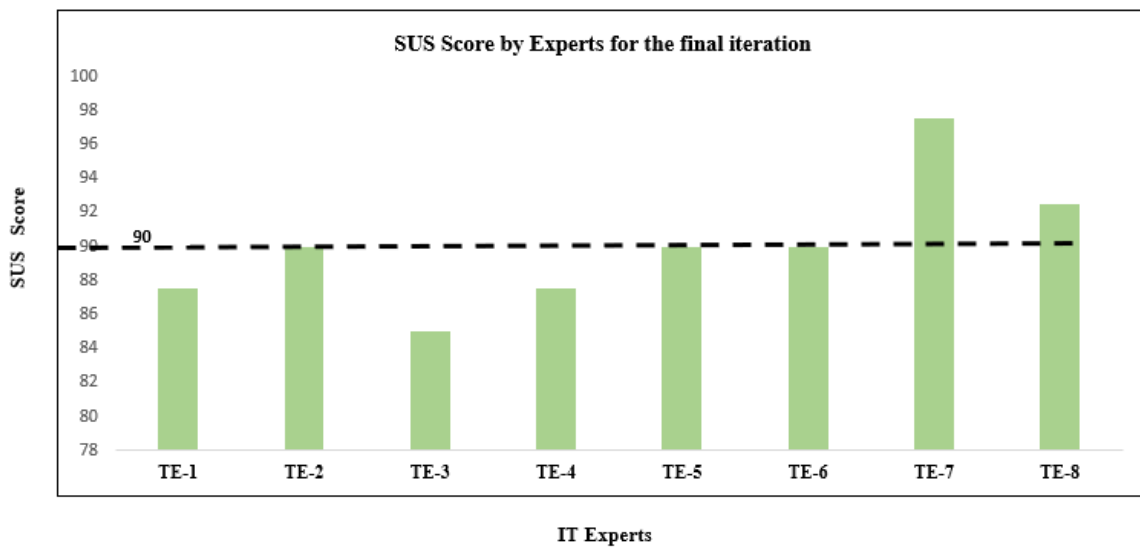
GRAPH 2: RESULTS OF SECOND SUS PERFORMED ON FINAL ITERATION OF VNA

Chapter 8

Discussion

Results and issues related to the development are discussed here structured around the research questions.

8.1 RQ1: What design principles are suited for phone based virtual reality when creating a support tool for physical rehabilitation?

8.1.1 Design Science Research

Throughout development the seven guidelines for researchers using the design science research approach (Table 1 Section 3.1) were used to keep development on track and focused. The first guideline demands some form of production. From the beginning the end goal of creating a functioning high-fidelity prototype was set in stone. This choice was used as both a limiting factor and a focus during development. In the earlier parts of the process several low fidelity paper prototypes were constructed and their possible scope and complexity could not outpace the expected productivity of the researcher. This meant more time was spent on ensuring that the proposed solutions would provide some relevance with very few features that neatly fall in line with the second guideline which proposes that the technology-based solution should aim at fixing some sort problem.

Guidelines 3, 4, and 5 all focus on the reproduction of results found during research. This is done by ensuring that evaluation and design solutions are included in the iterative development that looks at methods and evolving design . This focus on reproducible results was used to inform many choices in the thesis design, from the system development method to the thesis text. This also ensured that a constant evaluation during the production was maintained which feeds into the sixth guideline of using design as a search process. Vigilant documentation enabled reflection of the problem space. The final guideline stipulates that the research must be communicated in a manner which is understandable both by technology-oriented readers as well as readers from medical background. A shorter paper based on the earlier parts of the production was outlined and will be considered for publication. This master thesis will be available through open source portal of the university of Bergen.

8.1.2 Agile development

During production, a hybrid method between Kanban and Scrum as outlined in Section 3.2.3. This system development structure was especially useful early in the development cycle. There was a constant temptation to continue development of a single module past its allotted time whenever a design problem presented itself. By limiting available time, tasks got naturally sorted based on how

much time or effort its production would take which was helpful to limit the amount of early over-scoping. The Kanban work in progress mentality and general visualization strategy also encouraged documentation of workflow which made identifying specific problems easier. Early versions of designs that were still challenging would often end up in the "cryo" category, so when different modules would face the same design challenges, the problems were more easily identified.

In the later development phases, the Kanban board was used more for its organizational effect than for its time management effects. This came about due to the way evaluation was structured. Each iteration ended up focusing on one major aspect of the VNA based on critical flaws found during analysis. Building the board for each sprint proved to be a design method in itself. Estimating time for parts of development meant an inherit cost benefit evaluation. For example, auto-generation of the labyrinth layout was planned as additional feature. However, after crafting stickers for each part that was substantial for the design to work, it became apparent what investment in time was needed. It was for this reason that the feature was scrapped in favor of a static layout which also provided the benefit of ensuring parity between evaluation sessions.

8.1.3 Exergame development

In Section 2.1.2 a list of design challenges that are explore by the Astrojumper paper is presented. While a tool for physical therapy is not the same as a exergame, it does share many of the same challenges. The interview with medical expert, Section 5.5.3 and 5.6.3, highlights this similarity in many ways. A frequent topic which often surfaced during both expert interviews regarded scoring systems and reward hacking. When designing reward systems for the VNA this idea of avoiding possible missuses was considered at all times. Both the Box Shot and Ball Tracker modules avoid this problem by having a rather straight forward scoring system which makes reward hacking close to impossible besides removing the phone from the HMD. Labyrinth module, however, required more design work for its scoring system. Early on a tile-based scoring system was chosen over a timer system so as to avoid the users just gazing past walls to go straight to the end. The medical expert provided possible solutions to a timer based scoring system, but the final product kept the earlier version that limited the user to "cheat" the system by exercising their neck more than required. Other possible designs are explored more in the future work in Section 9.1.

8.1.4 VR development

Another influential article was Rethinking design principles for VR, presented in Section 2.1.6. Many of the core ideas presented in this paper can be found in the earlier iteration processes. The focus has been on all and any UI, limiting the amount of screen used instead of trying to use every degree of the 360 freedom VR gives, avoiding small fonts, counteracting motion sickness, and aiming to use the VR systems strengths instead of trying to make VR do work where non VR could function instead. This

helped a lot when designing the menu used for the project. Due to the lack of input options most full VR menu setups seemed to be somewhat clunky and hard to operate.

8.1.5 Design Principles for phone VR

Deciding what design principles should be used in a project is never easy. The field of HCI has no shortage of clever and inventive solutions to different design challenges. During the development of the VNA several different approaches were used. These ranged from the more abstract design science research which worked as a foundation to the more specific methods focused on countering niche problems. Based on the experience gained through production of the VNA a list of design solutions was created. These principles were constructed with researchers and developers of specific and innovative solutions for medical therapy in mind.

Principle 1: *The Many*

Early design development should focus on exploring the problem space and possible solutions in a fast and efficient manner. No proposed solution should be given more time than the rest. Each solution should focus on a specific aspect. While general knowledge of the problem space is needed a researcher should avoid exploring current solutions until after they have generated a few proposals of their own. This allows for innovative and surprising design variations which had previously been discarded.

Principle 2: *The Few*

Any and all solutions should be scrutinized based on current medical literature and patient safety in mind. If a solution itself requires a manifold of design solutions it should be considered for exclusion. However, any such design problems should be documented and treated as valuable data. If most or all proposed solutions share the same design challenges, consider either making this problem the focus of a further development or changing the approach by adding or removing requirements.

Principle 3**:** *The One by One*

When exploring a singular design solution keep future production in mind and aim for a general design which can be reused. Each solution should be evaluated on its own before a holistic evaluation is done. A designer should always consider the cost of divergence from the whole against the gains of a more specialized approach. Solutions based on the same base design should be explored in a singular fashion to ensure cohesion in their design.

8.2 RQ2: What are the advantages and disadvantages of phone-based virtual reality as tool for use during neck therapy.

8.2.1 Immersion

The biggest selling point for virtual reality is an idea of immersion. By design all HMDs block out any visual information other than the screen the user is intended to interact with. During the usability evaluation many participants expressed surprise at how well the phone-based VR solution worked. Many seemed to expect a much lower quality result due to the inexpensive materials used. While the Cardboard HMD is not suited for highly detailed scenes it has shown itself to be very versatile and suitable for more abstract and lower detailed shapes used in the VNA. If the purposed tool requires high graphical fidelity to work a phone-based solution is not the best choice. Not only is the HMD a limiting factor, but once the visuals reach a certain complexity the user also requires a higher end phone which goes against the greatest advantages for a phone based-solution.

8.2.2 Cost, familiarity, and availability

Phone VR is more available than ever before, but as seen in Graph 3 there is little excitement around this form of virtual reality when compared to HMD's with more graphical fidelity. The Cardboard enjoyed some success when it first launched but was quickly overshadowed by the Samsung gear VR which also provided controllers that could drastically increase the possible complexity in terms of the user experience. So, while people might have heard of the Google Cardboard it seems far from synonymous with VR or even phone VR according to the google search trends shown in Graph 4.

Where the Cardboard solution has the main advantage is the cost and availability. As an early test a DIY cardboard HMD was constructed out of a cardboard box and a half liter soda bottle. This approach was based on one of the many DIY guides available both in article form and as a video tutorial (ZE, 2016). The lenses were circles cut from the bottle, filled with water and sealed using a lighter to fuse the rims. The total cost of the construction came to 30 NOK (approx. 3 EUR) and worked reasonably well. The HMD used in all tests were a precut kit costing which cost 10 EUR. The lenses could be bought without the cardboard for only 3 EUR. When compared to the average cost of other phone-based VR solutions the price is laughably small.

8.2.3 Hardware

The biggest limitation with a phone-based solution is the requirement of a smartphone. It is reasonable to expect that most people have one, but it cannot be expected that everyone has such a smartphone or a phone which can run even rudimentary VR applications. Cardboard requires at a minimum phone running Android 4.1/Jelly Bean (2012) or IOS 8 (2014). This means that phones produced before 2012 will probably struggle with performance due to the "*built to fail*" practices popular with mobile

manufacturers. This means that any solution must choose among graphical fidelity, range of features, and general availability.

8.2.4 Input variation

Any tool built with the Google Cardboard also faces the challenge of designing an experience where the only user input during play is head tilting. The solution used in this project was to make all menu interaction non-VR, but some early module designs were scrapped due to lack of support for elevation changes and movement on the Z axis (depth). This is a limiting factor when considering applications outside of neck therapy. It is possible to counteract this by using the Gear VR HMD and Google Daydream software which supports these features and more, this however comes with the added cost to the user in the form of more expensive gear and phone requirements.

8.2.5 Earlier works and generalization

In any design project some bias could be expected from earlier designs and projects. Using phone-based VR is not a new idea, but in most earlier variations the HMD used was more complex than the Google Cardboard. By going for a cheaper, more affordable solution new and varied design problems lacked earlier solutions. This contributed to a longer development time than a version using a more popular HMD. This lack of previous solutions can be seen both as an advantage or a disadvantage depending on the problem at hand. New workarounds tend to be less general in scope than solutions to more explored problems. This could manifest itself as a more bespoke design which probably works better for the singular project but can present further complications when expanding the project scope.
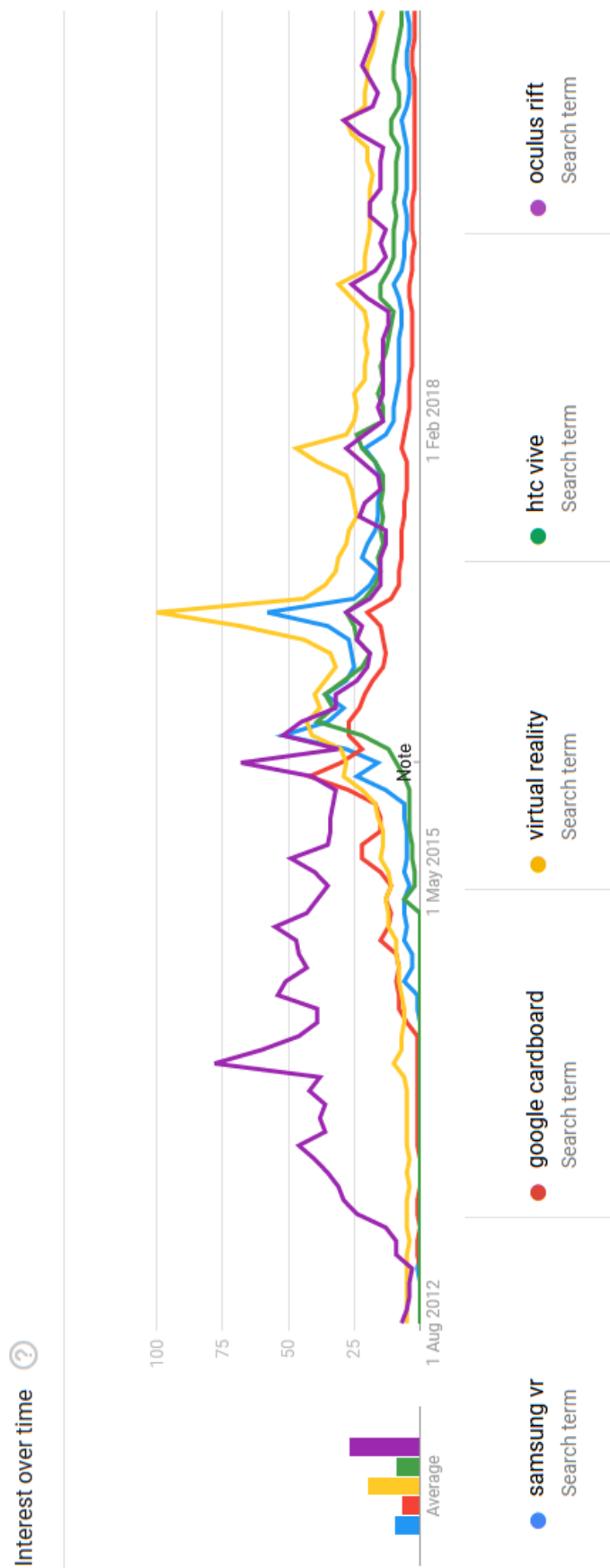
GRAPH 3: GOOGLE SEARCH TREND COMPARISON BETWEEN TWO PHONE-BASED VR SYSTEMS, TWO PC-BASED SYSTEMS, AND THE GENERIC SEARCH TERM "VIRTUAL REALITY"
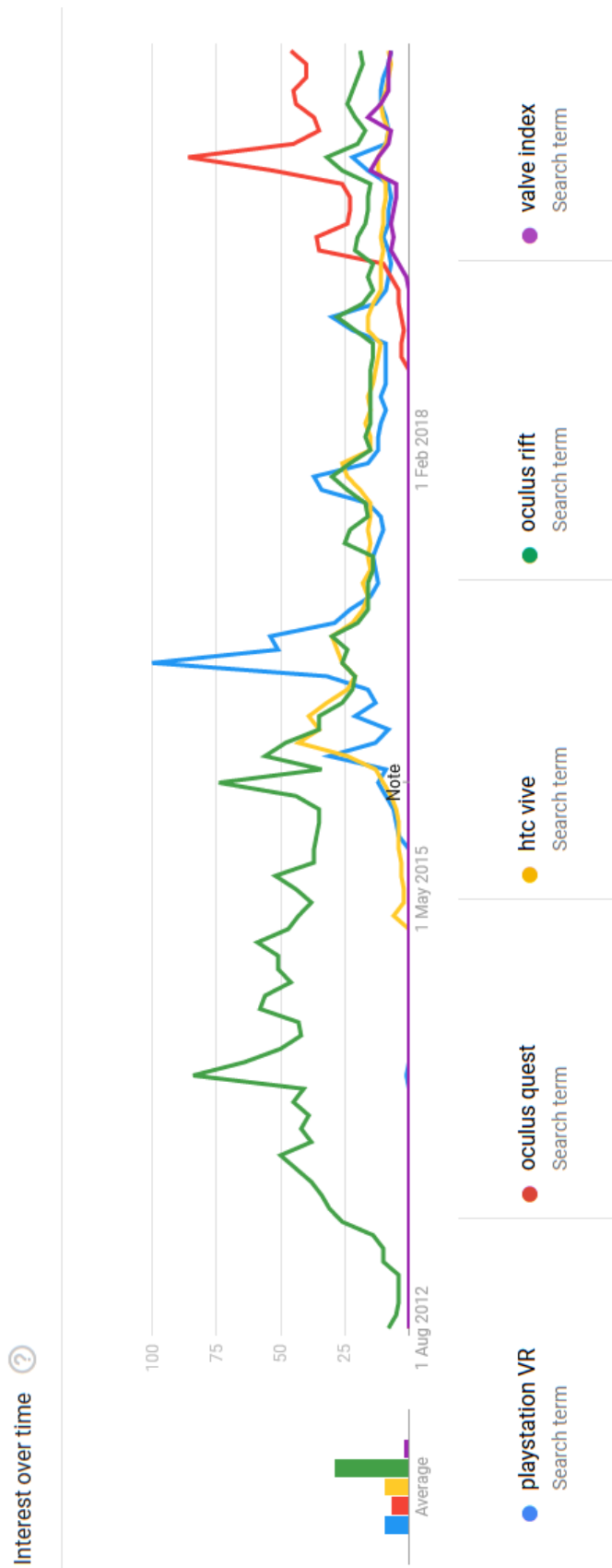
GRAPH 4: SEARCH TRENDS FOR THE FIVE MOST POPULAR VR HMDS

8.3 What gamification techniques are suitable for use in virtual reality assisted rehabilitation?

8.3.1 Gamification as game-like elements over game design

When deciding upon to what degree a form of traditional gamification should be present in the VNA a choice was reached early that its impact should be minimal to minimize the patient/ user risk. There were possibilities to introduce the normal variants such as badges and score tables, but to avoid too many variables only the use of simple scores were explored in the thesis. Another reason for this choice was due to the low amount of repetition utilized during evaluation. Gamification elements are often used to encourage repetition in the user such as Amazons use of badges in their Audio book application or time comparison in fitness applications. The efficiency of such tactics is difficult to gauge without observing the users over a longer period than a master thesis project can afford.

The definition used for gamification during development was based on the modified version presented by Conway (Section 2.1.9). The definition: "the use of game-like features in non-game contexts" allows for a broader application of gaming-based elements than the traditional version of games employ. In this context the VNA is in itself part of the gamification features outside of specific scoring system featured in the program. This appeals to a design philosophy where the user experience should be the main contributing factor in motivation.

8.3.2 Self-perception and subjective scoring

During the usability testing the participants were not given any detail of the metrics used or what was a "good" score. The evaluation was designed thus to avoid introducing unnecessary biases while also testing if the scoring system was implicitly understandable. In two of the three modules higher scores were better, but Ball Tracker introduced time as a score metric where lower is better.

One discovery during the two usability test rounds was that the user's perception of confidence and skill seemed not to correlate with their actual scores. While individual questions presented in a SUS should not be used as a reliable metric on its own, it ended up reinforcing the verbal feedback given by evaluators. Both question 7 (*I would imagine that most people would learn this system very quickly*) and question 9 (*I felt very confident using the system*) can indicate the users self-perceived mastery of the system and the imagined difficulty of said system.

Certain participants scored outside the norm either due to complications with the VNA or by their own conduct. Two users who scored much better than the average participants, both of whom mentioned being disappointed with their poor scores, despite being the accruing the highest overall scores. Given no feedback of their accomplishment they recontextualized their results as something poor which should be easy to beat. One participant exhibited the opposite behavior. The participant did not perceive the exits in the labyrinth as targets and ended up playing for a much longer time than the other participants.

During debriefing the participant expressed excitement of their accomplishment due to mostly managing to avoid the walls for a long period.

Setting aside these outliers, the participants were generally all happy with their performance. Without a direct comparison most participants speculated that their score was slightly above average. Had the trial included more sequential runs of the same module, they would probably start constructing a more realistic picture of their performance, but this scoring metric would still be subjective while also ensuring that the only person to beat would be themselves.

8.3.3 Fussy feedback

During the second SUS evaluation the users were asked to pick a favorite module during the debrief. This round consisted of the Labyrinth and Ball Tracker module, between these most participants preferred the labyrinth. Their reasoning being that it was more difficult than the other module. Due to the perception shift the edges of the labyrinth give the illusion of shrinking close to the edges giving a good feeling of rising tension. All feedback for the labyrinth was generally given with gameplay terms: difficulty, mapping, tracking, and precision, as a focus. Feedback given about Ball Tracker was to near exclusion about the growing flower and esthetics. The participants favoring this module all enjoyed the fussy feedback given by a growing flower. There is nothing that indicates how large the flower has to grow and many continued looking around after gameplay had ended.

Chapter 9

Conclusion and Future Work

9.1 Conclusion

This thesis has explored the problem area of phone-based virtual reality with an aim to create a set of general design principles to guide future design, while also judging the advantages and disadvantages of this form of VR when applied to therapy of patients with non-specific chronic neck pain. The Design Science Research methodology was applied to ensure rigor and quality during the design and development of a high-fidelity prototype named the Virtual Neck Application (VNA). By testing and evaluating VNA with the help of medical-, and design professionals over a span of four iteration, a set of design principles were constructed based on the resulting data.

The three principles proposed based on the findings concern the development and design focus. *The Many, The Few and The One by One,* is intended to help avoid common challenges experienced when using more generalized principles. They have the potential to be useful outside of the problem domain of neck therapy, but their usefulness comes mostly in helping to guide a more exploratory design process in a less researched field. It can also be concluded that the major advantages of a phone-based VR solution come from its inherit low cost. This alone is a good justification for further exploration as other VR solutions usually require the patient to be at a specific place which excludes the possibility of individually steered therapy. However, any such solution must be applicable to a large range of different hardware and the scope of possible inputs is severely lacking when compared to more costly solutions.

9.2 Future Work

9.2.1 Exploring gamification and user retention

As mentioned briefly in Section 5.5.3 a natural next step in the exploration of the research topic would be gamification. The challenge remains how do we ensure that a patient continues using the VNA without constant supervision and at minimal health risk. This could be done with a more complex scoring system or reward system, maybe in the form of scoreboards or badges. Personalization of the experience and visual customization should also be explored in this context

9.2.2 New Features

Outside of new gamification features further research could explore the possibility of a control panel aimed at the therapist. This feature would require close cooperation with medical experts to determine what sort of customizability is needed during normal therapy and rehabilitation.

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Appendix A

A 1 - Approval from NSD

NSD sin vurdering

Prosjekttittel
Design principles in phone based virtual reality as a tool for physical rehabilitation

Referansenummer
872006

Registrert
06.05.2019 av Patrick Kraft Solbue - Patrick.Solbue@student.uib.no

Behandlingsansvarlig institusjon
Universitetet i Bergen / Det samfunnsvitenskapelige fakultet / Institutt for informasjons- og medievitenskap

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)
Ankica Babic, Ankica.Babic@uib.no

Type prosjekt
Studentprosjekt, masterstudium

Kontaktinformasjon, student
Patrick Solbue, pso007@uib.no

Prosjektperiode
12.06.2019 - 01.12.2020

Status
17.06.2020 - Vurdert

Vurdering (2)

17.06.2020 - Vurdert
NSD har vurdert endringen registrert 13.06.2020.

Vi har nå registrert 01.12.2020 som ny sluttdato for forskningsperioden og at Zoom benyttes som databehandler.

NSD vil følge opp ved ny planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til videre med prosjektet!

Kontaktperson hos NSD: Elizabeth Blomstervik
Tlf. personverntjenester: 55 58 21 17 (tast 1)

13.05.2019 - Vurdert
Det er vår vurdering at behandlingen av personopplysninger i prosjektet vil være i samsvar med personvernlovgivningen så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet med vedlegg 13.05.19. Behandlingen kan starte.

MELD VESENTLIGE ENDRINGER
Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilke type endringer det er nødvendig å melde:

https://nsd.no/personvernombud/meld_prosjekt/meld_endringer.html

Du må vente på svar fra NSD før endringen gjennomføres.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige kategorier av personopplysninger frem til 01.06.2020.

LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse som kan dokumenteres, og som den registrerte kan trekke tilbake. Lovlig grunnlag for behandlingen vil dermed være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 bokstav a.

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen om:

- lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke behandles til nye, uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet

DE REGISTRERTES RETTIGHETER
Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: åpenhet (art. 12), informasjon (art. 13), innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18), underretning (art. 19), dataportabilitet (art. 20).
NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.
Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER
NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).
Dersom du benytter en databehandler i prosjektet må behandlingen oppfylle kravene til bruk av databehandler, jf. art 28 og 29.

For å forsikre dere om at kravene oppfylles, må dere følge interne retningslinjer og/eller rådføre dere med behandlingsansvarlig institusjon.

OPPFØLGING AV PROSJEKTET
NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Lykke til med prosjektet!
Tlf. Personverntjenester: 55 58 21 17 (tast 1)

Appendix B

B 1 - Informed Consent Form

Vil du delta I forskningsprosjektet
"Design principles in phone based virtual reality as a tool for physical rehabilitation"?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å analysere design metoder brukt i telefon basert «*virtual reality*». I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

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

Hva skal vi gjøre?

Deltakelse innebærer evaluering av design og utførelse av et eller flere spill programmer. Etter gjennomgang blir du intervjuet som om dine tanker og ideer rundt design/evaluering. Dette intervjuet blir tatt opp i form av video og lyd for bruk i transkribering. Det transkriberte intervjuet blir lagt ved i oppgaven med modifikasjoner som fjerner personlige identifikatorer utenom navn og jobbstilling.

Dine Rettigheter

Du har retten til:

- Å få innsyn i hvilken personopplysninger som er registrert om deg.
- Å få rettet personopplysninger om deg.
- Få slettet personopplysninger om deg.
- Få utlevert en kopi av dine personopplysninger (dataportabilitet)
- Å sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysning om deg?

Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra Universitetet i Bergen / Det samfunnsvitenskapelige fakultet / Institutt for informasjons- og medievitenskap har NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Ditt personvern – hvordan vi oppbevarer dine data 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.

Det er to personer som kommer til å ha tilgang til dine data mens prosjektet pågår: Patrick Solbue, masterstudent og Ankica Babic, veileder. I løpet av prosjektets gang brukes det kodenavn der navn

ellers viller forekommet, lyd og videoopptak blir lagret på en mobil telefon gitt av prosjektansvarlig frem til innholdet er transkribert. Etter transkribering blir alle opptaksfiler slettet.

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Institutt for informasjons- og medievitenskap ved Ankica Babic, Ankica.Babic@uib.no, tlf: 55 58 91 39
- NSD – Norsk senter for forskningsdata AS, på epost (personverntjenester@nsd.no) eller telefon: 55 58 21 17.

Med vennlig hilsen

Prosjektansvarlig   Master student

Ankica Babic   Patrick Solbue

Appendix C

C 1 - System Usability Scale Form Modified for VNA evaluation

	Strongly disagree				Strongly agree
1. I was engaged by the system.	1	2	3	4	5
2. I found the system unnecessarily complex	1	2	3	4	5
3. I thought the system was easy to use	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this system	1	2	3	4	5
5. I found the various functions in this system well integrated	1	2	3	4	5
6. I thought there was too much inconsistency in this system	1	2	3	4	5
7. I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8. I found the system very cumbersome to use	1	2	3	4	5
9. I felt very confident using the system	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this system	1	2	3	4	5