GAME-BASED UPPER LIMB REHABILITATION UTILISING THE NOVINT FALCON

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ABSTRACT
This thesis documents the development of a prototype game-based rehabilitation system using the Novint Falcon. In the background chapter paralysis and stroke are outlined followed by a look into the haptic modality and force feedback. The chapter ends with look into existing desktop haptic devices and the Novint Falcon. In the analysis the state of the art in the context of Novint Falcon Rehabilitation is explored followed by a classification of exercises that can be mapped to the Novint Falcon. Based upon the background and analysis a game design is made and implemented. An experiment is executed to determine if a game reward mechanic can increase the exercise done with the Novint Falcon. Unfortunately the data are not statistically significant and the null hypothesis is retained. However the experiment yielded some positive qualitative results.

PREFACE

Attached to this thesis is a DVD with the following content:

- A video production titled `"Med Ten Video"`
- A folder called `"Source"` that contains all the source code
- An .exe file called `"mouseBuild.exe"`; run this to play with the mouse
- An .exe file called `"build3.exe"` which is the original version used in the experiment
- A folder called `"Report"` in which the LaTeX files are alongside the compiled .pdf version called `"report-ekn.pdf"`
- A folder called `"Patient Videos"` that contains all unedited footage from the experiment

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ACRONYMS

BNC Brønderslev Neurorehabiliteringscenter

CNS Central Nervous System

PNS Peripheral Nervous System

DoF Degrees of Freedom

CSV Comma Separated Value

XML Extensible Markup Language

GDD Game Design Document

1 INTRODUCTION

This thesis documents the development of a prototype game-based rehabilitation system in collaboration with Brønderslev Neurorehabiliteringscenter (BNC). Aalborg University was approached by Brønderslev Neurorehabiliteringscenter (BNC) and asked if they would be interested in developing new solutions for arm training.

The aim of this project is to use the consumer haptic device Novint Falcon for rehabilitation. The Novint Falcon was released in 2008 and is primarily targeted towards gaming for the primary purpose of providing realistic gun play. It has since recently been used in various projects involving rehabilitation. Mostly because it is very cheap and is nearly as good as similar non-consumer devices.

This is good because 15.500 people suffer a stroke annually in Denmark and it is the 3rd most common cause of death. 13.000 of these people are admitted to the hospital. Between 30.000 and 40.000 people live with the consequences from stroke, half of them have permanent damages and is the most common cause of acquired handicaps in Denmark[21].

The cost of stroke victims alone account for 2.7 billion kroner for treatment and care which is 4.4% of the entire health care budget[21]. In Denmark stroke patient care is the biggest sector of daily care[38]. Furthermore a third of the admitted people will get a depression at some point[21].

This shows that there is a great need for exciting new systems that utilise modern technology to improve the Quality of Life for people. By using game mechanics it is possible to create an engaging experience that simultaneously helps with rehabilitation.

1.1 INITIAL PROBLEM STATEMENT

Based on the above information the following initial problem statement is defined:

> ***How can a game-based rehabilitation system be designed that uses the Novint Falcon?***

And the following sub-problem is also defined.

> ***Can game mechanics be used to meaningfully enhance the rehabilitation provided by such a system?***

In order to answer the primary question various factors regarding current rehabilitation, the state of the art in the context of Novint

Falcon based rehabilitation and how tasks can be transferred to it are explored.

To answer the secondary question, the design is implemented in the Unity3D engine with the Novint Falcon and the effect of the proposed game mechanic is measured.

2 BACKGROUND

This chapter explores some of the background knowledge necessary to understand the field of rehabilitation and haptics. The first part concerns paralysis, the Central Nervous System (CNS) and stroke. The second section explores rehabilitation followed by a section based on a visit to Brønderslev Neurorehabiliteringscenter (BNC) that explores their method of rehabilitating. The chapter ends with a look into what haptics are and how they have been used in games as Force Feedback.

2.1 PARALYSIS

Before going into what paralysis is, it is important to mention the nervous system. The nervous system is compromised of two main components: the Central Nervous System (CNS) and the Peripheral Nervous System (PNS). The CNS is the brain and spinal cord while the PNS is the network of nerves going through the entire body[40].

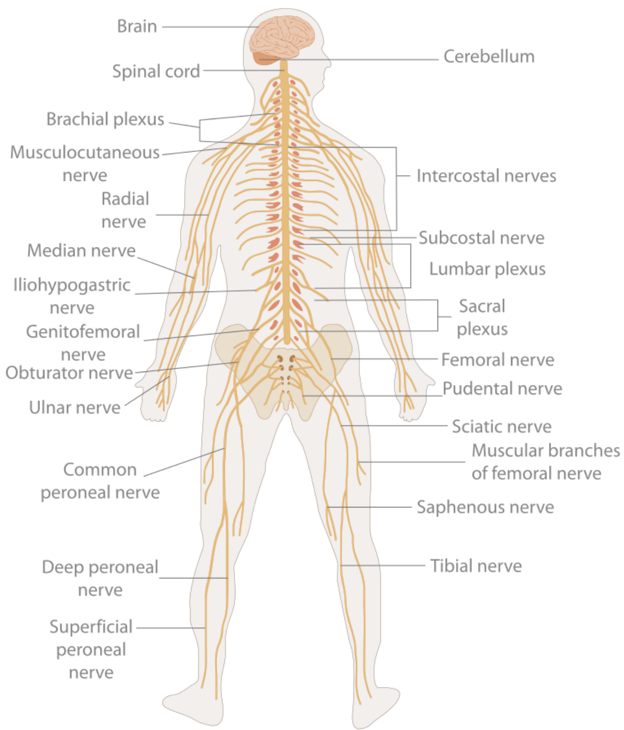


Figure 1: The human nervous system with the CNS and the PNS. Image taken and modified from http://upload.wikimedia.org/wikipedia/commons/b/b2/TE-Nervous_system_diagram.svg

Paralysis refers to the partial or total loss of power in a muscle. Paresis is generally used when the loss is partial. There are two main categories of paralysis:

- Peripheral Paralysis - paralysis caused by damage to the PNS
- Central Paralysis - paralysis caused by damage to the CNS

In peripheral paralysis the loss of function is usually caused by an illness directly affecting the nerves. In central paralysis there can be many different causes. One of the most common causes for central paralysis is Apoplexy or more commonly known: Stroke[39]. 80% of stroke victims get hemiparesis; paresis that only affects one side of the body[7]. In rare cases paralysis is not caused by physical damage but rather psychological trauma.

2.2 STROKE

Apoplexy is a general term that describes bleeding within the body. In older times this used to refer to bleeding in the brain. However the general term "'Stroke"' is now used to describe these incidents and apoplexy is used more specifically[16, 33].

There are two different causes for a stroke. In approximately 15% of cases it is caused by a hemorrhage in the brain while the remaining 85% are caused by blockage such as thrombosis or embolism[33]. In either case the result is ischemia - the loss of blood flow - to the affected part of the brain. This effectively kills the brain cells resulting in loss of functionality and is ultimately the reason why stroke victims are left with permanent damages[38, 19]. This is because that most of the brain cells cannot be replaced. However some functionality may be restored due to brain plasticity.

2.3 REHABILITATION

The main goal of rehabilitation is to restore functional capacity to full, integration into the community and perhaps work again[22]. Rehabilitation should start immediately after the incident occurs because the sooner rehabilitation starts the better results can be expected. This is also applicable in terms of intensity. Higher intensity means better results but unfortunately therapists cannot accommodate such high intensities where people need several hours of supervision daily[22].

Continuous and intensive rehabilitation efforts done even 6 months after the incident have an effect on improving motor functionality[11]. Research has also shown that rehabilitation of upper body limbs can have an effect in rehabilitating neglect, a condition in which the person is unable or has a hard time attending to one part of the visual field[14].

Virtual reality devices are generally good because if immersed they allow the patient to do tasks that are normally impossible thus further motivating them[22].

2.4 A VISIT TO BRØNDERSLEV NEUROREHABILITERINGSCENTER

BNC is a hospital facility in Denmark that focuses exclusively on patients who have neurological disabilities. As part of this they do extensive physical rehabilitation. This section is an insight into the upper limb rehabilitation efforts done there. It is based on a visit by me, Emil Kaihøj Nielsen, to BNC on the 5th of March 2014. The goal of the visit was to experience a session of group-based upper limb rehabilitation and learn of their methods.

Figure 2: The room at BNC seen from the far end of the wall. Note the computer on the left, which is the only other electronic haptic device they possess

The session occurs daily for one hour. The number of participants is around six and both an ergotherapist and a physiotherapist usually participate. It is meant for patients who are neurologically fit enough to execute and maintain exercises without too much direct supervision. Each patient has their own personal exercise book that lists the exercises to be done including repetitions for each.

The spatial layout of the room can be seen in Figure 2. The room itself is furnished in such a way that each patient has plenty of space. Each table and chair is fully adjustable to accommodate different needs. The seating position is critical for the rehabilitation effort as different sitting heights influence the muscles used.

The current effort is mostly based on using simple tools or games as depicted in Figure 3. In some cases the exercises done are based on real life actions. An example of this was an exercise using a piece of cloth to simulate a dish rag. The point was to wipe along two diagonal lines marked with tape on the table.

Figure 3: Shelves displaying the tools used at BNC. Note that the tools are ordinary physical games and objects rather than specialised tools

Figure 4: A shelf containing some of the wooden tools used at BNC. These tools are more specialised for rehabilitation exercises

Other tools are designed specifically with rehabilitation in mind. This is done by enlarging them greatly or adding different materials that benefit usage such as increased grip. The design of these tools focus on enhancing the haptic sensation. Some of these tools can be seen in Figure 5.

2.4.1 *Exercises Observed*

Most of the exercises observed were focused on fine motor skills that involved manipulating relatively small objects with the fingers. Other exercises concerned more full body motion such as moving a ball around oneself. It is interesting to note that they had a haptic device called MULE. MULE works by twisting a handle to move an object on a computer screen. This was the only electronic haptic device present. The full list of exercises observed can be found in Appendix A.

Figure 5: A different shelf containing some of the wooden tools used at BNC. These tools are more specialised for rehabilitation exercises.

2.4.2 *Summary of Visit*

The visit to BNC gave many valuable insights. One of the most important things was that it highlighted the value of proper seating positions. The importance was not limited to the actual effect on the rehabilitation but also in terms of reducing pain or discomfort during exercises. The session also showed that exercises are necessarily simple. They need to be easy to repeat in order to ensure the movement is correct and beneficial for the patient. Furthermore each exercise had very clear goals and limitations. Even outside of the task itself, clear goals are enforced by the exercise book each patient had that specifies the repetitions of each exercise.

2.5 HAPTIC MODALITY

The haptic modality is the sense of touch. There are two main systems that together constitute this modality, the cutaneous and the kinaesthetic inputs. The cutaneous input is measured by sensors on the skin while the kinaesthetic input comes from internal sensory organs. The sense of touch is actually better at noting temporal differences than sight but worse than hearing. Gaps as small as 5 milliseconds can be felt[25].

A two part model is presented in *"Haptic Perception: A Tutorial"*[25]. Similar to the visual input model, two core engines are present a "what" engine and a "where" engine.

In the "what" engine objects have haptic properties. These properties can be divided into two broad categories: geometric and material. texture, compliance(soft/hard) and temperature are material qualities while shape and size are geometric. Weight is part of both categories as the density is a material property while volume is a geometric property.

In the "where" engine there are two sub-parts. Where on the body is haptic input happening and where relative to the body am i interacting. Spatial measurements external from the body must have an origin. This is usually the egocenter. It varies depending on posture and distance to an object.

2.6 FORCE FEEDBACK

Force Feedback is the simulations of physical attributes. It is mainly a form of kinaesthetic feedback and is commonly used to simulate a sense of weight to objects.

2.6.1 *Video Game Peripherals*

Force Feedback in video games begun in the early 80's arcade halls. However it was not until the rumble pack for the Nintendo 64 controller was launched that it gained significant momentum. It led to the main stream integration of rumble, continuously applied force feedback that gives sensation of shaking or "rumble" as it were. Future generations now include this form of force feedback built in the controllers[13, 4].

The use of force feedback is especially popular in racing game peripherals such as steering wheels or pedals. Here the feedback is used to provide resistance by providing a sense of weight[12]. This is also true for flight stick controllers.

The forefront of haptic interaction is led by the Valve Corporation who are developing a PC console with a new type of controller. This controller uses a new type of haptic technology that is extremely accurate[15].

2.6.2 *Haptic Devices*

A haptic device is a device that is capable of simulating various aspects of touch. On a basic level this involves the application of kinaesthetic forces - force feedback - in a Cartesian real world coordinate system. This is usually a 3 dimensional system based on the x, y and z axes. In mechanics a device that is able to move on 3 axes is referred to as having 3 Degrees of Freedom (DoF). A device can add 3 more DoF by allowing rotation in the form of pitch, yaw and roll.

For this project a 3 DoF haptic device known as Novint Falcon is used. Similar devices should be investigated in order to understand the capabilities of it. There are many types of haptic devices for different applications. For comparison purposes those that widely differ from the Novint Falcon are omitted.

This includes devices with 3 DoF, designed for desktop usage and roughly the same physical size. One notable exception is the Moog HapticMaster. It is still included because it has been mentioned and used in numerous other studies.

MODEL	AREA(CM)	RES.(MM)	FORCE(N)
Omni Phantom[10]	16x12x7	0.055	3.3
Haption Virtuose 3D[5]	20x20x20	n/a	3(10)
FD Delta.3[1]	40x26	0.02	20
FD Omega.3[9]	16x11	<0.01	12.1
Moog HapticMaster[6]	40x36	0.004	100/250
Novint Falcon[3]	10x10x10	0.049	10

Table 1: A comparative list between different desktop haptic devices. The Force Dimension Delta.3 and Omega.3 each have elongated spheres to represent the workspace. The HapticMaster's workspace is shaped like a wedge, for further information on the HapticMaster's workspace please see Appendix B

The cost of the devices have been omitted because the price of all other devices are not mentioned anywhere except if you are interested in a purchase. Unreliable sources on the internet[2] have attested that the Omni Phantom costs around 1000$. The omni phantom is supposedly one of the cheaper haptic devices. In terms of costs it can then be said that the Novint Falcon is at least 5 times less expensive.

Based on Table 1 it is clear that the Falcon is comparable to similar solutions. The biggest difference lies in the size of the workspace.

2.6.3 *Novint Falcon*

In the middle is the Novint Falcon as depicted in Figure 6. A device originally meant for video games but its functionality is similar to that of the more expensive devices as mentioned in Section 2.6.2. The Novint Falcon is only able to provide kinaesthetic feedback.

The grip on the Falcon can be changed. Only two official grips are made, the default orb and a gun attachment. The gun attachment has been shown to give better grip to some patients with fine motor control problems by using tenodesis grip[22]. It is also possible to or-

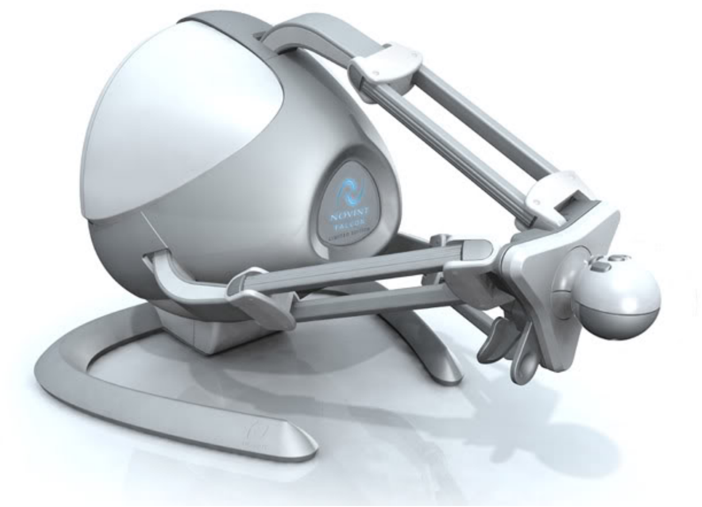


Figure 6: The Novint Falcon

der custom grips from the company itself, examples include syringe, scissors and similar grips[8].

A direct comparison between the Falcon and the Omni Phantom Premium was made in the paper: *"The Phantom versus the Falcon: Force Feedback Magnitude Effects on User's Performance during Target Acquisition"*[34] . This study showed that there was difference between the devices in terms of task completion time. This difference was statistically significant but in reality it was a small effect size, in terms of milliseconds, and would not affect real world performance.

The Novint Falcon can be used to assist, resist or support the patient. However, a drawback of the consumer oriented approach is that the Falcon is not strong enough to help people with severe motor handicaps or spasticity[28].

While the falcon is an interesting device, its limited work space of ~10 cm^3 put it at a disadvantage when comparing to other interaction devices such as the wii, playstation eyetoy or the kinect that allow much freer movements[22].

It has been shown that using the Falcon to give force feedback activates the Alterior Deltoid and Extensor Carpii Ulnaris muscles. This was demonstrated by applying varying degrees of haptic feedback in an exercise where participants would press down on a vibrating cube. The activity in the muscles were measured by electromyography[27].

3 ANALYSIS

In this chapter is a look into the State of the Art concerning the Novint Falcon. In the first section the aim is to provide information on the capabilities. In the second section the focus is on exploring the tasks that have been done before with the Novint Falcon and categorising them.

3.1 STATE OF THE ART

This goal of this section is to highlight existing research that use the haptic device Novint Falcon for rehabilitation. The field of game-based rehabilitation is not unknown however using the Novint Falcon in conjunction with it is somewhat new.

Research has generally been concerned with establishing whether or not the Novint Falcon is a feasible haptic device for rehabilitation.

One study used the falcon as a device to train fine motor skills by teaching children how to draw letters[28]. The Falcon was affixed with a pantograph with a pen shaped end effector. In the experiment children use the Falcon two times per week for 45-60 minutes per session over 8 weeks. The study established that the Falcon had no significant difference in effect compared to "'Handwriting Without Tears"' workbooks, books especially designed for training handwriting. However for a singular individual the Falcon provided a significant increase in hand writing performance. This may suggest that for some people the Falcon may be better.

A different study investigated the viability of Novint Falcon native applications for rehabilitation at home. Six of the games included with the Falcon were used by a patient group while a control group was subject to relaxation. The study showed no clear results in terms of improved motor functionality but highlighted an interesting point. Some participants showed increases in errors committed during play, where an error is defined as when the movement is not correct in context with rehabilitation. Their game scores however increased. This suggests that some participants may become too focused on playing the game rather than the rehabilitation effort resulting in the game becoming a hindrance[18].

Another study used the Novint Falcon for investigating the use of a low-cost haptic device in combination with different end-point behaviours. An end-point behaviour is a force mode for the end-effector of the Novitn Falcon. The task was to move a virtual representation of an arbitrary point along a set path in a top-down view of a zoo. The interesting part of this study was that they investigated four different end-point behaviours for the Falcon. Two of these applied no forces at all but one of them provided additional scientific content during play. The remaining two were different kinds of force fields. The first is a converging field in which the corrective force pushed the hand towards the correct path. This can be analogous to a valley mode. The seconds is a diverging force field that pushes the hand away from the path, constantly requiring the user to correct. This can be seen as walking on a long ridge and constant strength is needed to stay on the edge. When no force was applied the test could be completed the fastest. Using a converging force field also sped up the task. The study concluded that the application of external forces causes fine and continuous adjustments to the hand position which may have an unproven effect on rehabilitation[17].

In other cases the papers focus on secondary properties to game-based rehabilitation with the Novint Falcon. An example is in "The Social Maze: A Collaborative Game to Motivate MS Patients for Upper Limb Training[37]" in which they investigate the motivational properties of game-based rehabilitation and cooperation. For this they made a two-player cooperational game in which two characters must be guided to the goal of the maze. The two players are dependent on each other to achieve success. The characters are controlled by haptic devices. In the study patients were set to use the Haptic Master rather than a Novint Falcon. In cases were the second player is not a patient other devices can be used. Results were unclear.

A different study uses haptic devices to perform a brain assessment test called a Rey-Osterrieth Complex Figure(ROCF) drawing. The reason for using haptic devices for such tasks is that the mechanical and digital nature can be used to accurately measure the defining characteristics of the drawing action of the ROCF. The main goal of the study was to determine if the new system using digital performance measures can be compared to regular analysis of an analogue ROCF drawing. The study only highligths the design of a VR-based rehabilitation system using haptics rather than actually performing the experiment[26].

The final study actually has two parts. In the first paper author Xibo Wang examined the feasibility of a tele-rehabilitation system using haptic devices. The goal was assess the performance of the system. The exercises used were designed to be simple follow-the-path exercises. The rehabilitation system consisted of two terminals with a Novint Falcon connected together over the Internet. The patient uses the Novint Falcon at one terminal to follow the path and if the he/she diverges from the path, the therapist at the other terminal can correct them. The corrective force is modelled after a spring(Hooke's Law). The results of the test showed that the corrective force came too late and was applied when the patient had already changed the course, culminating in the patient over-correcting[35]. This problem was addressed in the second part of the study. In this part the authors examine and develop a method for reducing this time lag. The method is ultimately successful as the system no longer over-corrects[36].

3.1.1 *Summary*

It is apparent that very few games that feature the Novint Falcon and are used for rehabilitation exist. Additionally research on the subject of how game-based rehabilitation work together with haptic devices is limited.

Cooperation has been shown to increase motivation[37]. In terms of patients there are two major types of collaboration: sympathetic and empathetic[37]. In the sympathetic scenario two patients cooperate while in the empathetic a patient and a healthy individual play the game(can be a therapist or a family member). During cooperation player will encourage each other and discuss strategy. In order to promote these qualities it is important that the game enforces cooperation by forcing the players to be dependent on each other[37]. Collaboration has also been shown to result in more movement which may be the result of people getting excited by the (social) situation[24].

3.2 REHABILITATION TASKS AND EXERCISES

The aim of this section is to look at the existing exercises done with the Novint Falcon, categorise and label them.

3.2.1 *Exercise Categories*

Based on the State of The Art the "Steering" category was established. Steering exercises require the user to either follow a path or stay within a path. Furthermore Steering also encompasses exercises in which control is exerted over an entity. From *"Haptic Perception: A Tutorial"*[25] the category exploration" is made. In exploration exercises the user must use the Novint Falcon to feel an environment. Based on the games that accompany the Novint Falcon a different category can be added: Simulation. This covers exercises in which the Falcon is used to mimic very specific tools or actions such as "firing a slingshot"

In rehabilitation there is two types of exercises. Functional exercises essentially try to mimic real daily tasks as closely as possible. Non-functional are not tied to anything specific and can be completely unanalogous. Using functional tasks may increase the benefit of exercises[30] and are normally used by ergo-therapists.

In terms of the categories they each individually can be determined to be either functional or non-functional. Here the Steering and Exploration are both representative of non-functional exercises while the

Simulation category can be deemed to be functional. This also means that the Simulation category can be renamed to Functional.

In the end three categories are established:

- Steering
- Exploration
- Functional

3.2.2 *Force Models*

From the state of the art in Section 3.1 it became apparent that at least two different force models exist: converging and diverging. They can each be correlated with more familiar concepts such as "valley" and "ridge". In the valley mode the force will assist by pushing towards the zero point at an increasing rate in relationship with the distance. In the ridge mode the force will push at an increasing rated in relationship with the distance.

3.2.3 *Exercise Actions*

It can be a good idea to try and isolate the actions used in each exercise and afterwards categorise them for a better overview. Four categories: pull, push, reach and grasp are suggested by [18, 32] while lifting, transporting, turning, pushing and reaching is suggested by [37]. By identifying these categories is possible choose and isolate exercises based on their category. By combining exercises from different categories it is possible to make a more intensive and higher level rehabilitation session.

3.2.4 *Example Exercises*

Table 2 showcases some of the exercises found and their new categories and actions.

3.2.5 *Knowledge of Performance and Results*

Knowledge of performance is a term used to describe the how well a person is currently doing an exercise while knowledge of results describe the sum total the performance in a past exercise. Knowledge of performance and results may cause patients to be self-competitive and progressively improve[30]. It has also been shown to increase learning rate[26].

Videoconferencing with a therapist helps by giving more knowledge of performance and promotes supervised learning[29]. Knowledge of performance also helps to promote learning by imitation and

DESCRIPTION	CATEGORY	TYPE(S)
"Feel" a painting, i. e.feel the various elements on the painting[23].	Exploration	Pull, Push
Explore a simple maze in first person perspective. Walls and other objects can be touched[31].	Steering	Pull, Push
Guide a car alongside a road. The force feedback is applied to guide the patient[34].	Steering	Pull, Push
Activate circles by moving a virtual marker over them[34].	Steering	Pull, Push
Push down on a virtual object that is vibrating horizontally[27].	Functional	Push
Using two Falcons in a bimanual setup to balance a block on a platform. Each Falcon controls one side of the platform[22].	Steering	Pull, Push
Follow a specified path. Examples of paths are square, circle and a line[35].	Steering	Pull, Push

Table 2: Different exercises done with the Novint Falcon and their categories.

trial and error[30, 29] on the other hand knowledge of results helps promote reinforcement learning, i.e. learning by getting rewards. An example could be to give a reward once the score during rehabilitation exceeds a certain limit[30, 29].

Most existing game-based rehabilitation solutions use both knowledge of performance and knowledge of results in the form of showing the current score during play and the total score at the end of play[32, 26].

3.2.6 *Effects of Game-based Rehabilitation*

Sometimes people will get too focused on winning the game rather than the rehabilitation part[18].

It is also important to take the individual patient's needs into account as someone who has poor fine motor skills will have trouble pressing the buttons on the Novint Falcon[18].

Using a Novint Falcon for rehabilitation might improve the duration that patients spend on exercises because the process can be automated in some measure and therefore require no input from a therapist[28]. However an early usability test showed that people thought the haptic feedback from a Novint Falcon was interesting but they felt they did not use their arms enough compared to other exercises with other tools[22].

While the Novint Falcon might not be for everyone some patients may have more success using a novel method for rehabilitation[28].

It is easy to imagine that as we progress and games become more mainstream someone might want a game for rehabilitation.

4 SYSTEM DESIGN

In this chapter the overall design of a proposed game-based rehabilitation system using the Novint Falcon is outlined. This chapter includes all design relating to the system as a whole, a separate game design document can be found in Chapter 5.

4.1 DESIGN CONSIDERATIONS

Rehabilitation is a very different environment for games and as such special design consideration should be made. This is to ensure that the game aspect does not compromise the rehabilitation effort[22].

The System is expected to be used at the facilities of Brønderslev Neurorehabiliteringscenter (BNC). It will be an extra tool as part of the existing rehabilitation regiment and as a result will be set up by the therapists.

One of these design considerations should be to make sure that the tutorial or instructions of the game clearly highlight how the therapeutic part works both for the patient and the therapist. Additionally it should be made clear how the device is used which includes setup, navigation and positioning of the patient[22].

An important part of the application should be the ability for a therapist to modify individual exercises as well as an entire session[28, 37, 34]. Modifications to individual exercises could be to increase or decrease weight or force applied through haptics[37, 22]. This can also help limit the time a therapist has to spend because the process can be somewhat automated[34].

Allowing this sort of customisation is expected to improve the usability of solutions[22]. The set up of the device should also be as easy as possible as a usability study using a focus group determined that people do not feel comfortable setting up a Novint Falcon[22].

In total the following observations have been made and compiled into a list of concrete design guidelines when making a game for rehabilitation purposes.

- The game should be simple
  - Clear visuals
  - Gameplay that affords simple movements
  - Gameplay that affords constant repetition of movements
  - Easy to understand
- The difficulty of the game can be customised by the therapist

For the genre of the game it may be prudent to look at the top games on Android and iOS. These games have gained immense popularity mostly because of their simplicity which can be attributed to their casual nature. Most games for tablets and phones are also slower paced.

4.2 SESSION ADJUSTMENT

Adjustable settings.

SETTING	RANGE	DESCRIPTION
Strength Level	0 ... 100%	The percentage of force used by the Falcon
Distance Level	0 ... 100%	The percentage of the max distance used in exercises
Exercise Count	1 ... 200	The number of exercises that must be completed for the session to finish
Exercise Interval	0.2 ... 20	The rate at which exercises must be completed in seconds
Bonus Balloon Chance	0 ... 100%	The percent chance for a bonus balloon to appear
Bonus Balloon Distance	0 ... 200%	The percent increase in distance for bonus balloons

Table 3: A list of the adjustments that can be made and their effect

For more information on the Bonus Balloons please see Chapter 5.

The ideal system will allow multiple users and track individual settings and improvements. For this iteration of the product there is only a single user but it is important to highlight the necessity of a multi-user environment.

4.3 GAME

The endless runner genre is chosen due to the fact that maximum adaptability is a priority for a game-based rehabilitation system as mentioned in Section 4.1. An endless runner is typically a game in which the player character moves continuously forward. At set intervals an obstacle appears which the player must avoid. There are many variations of obstacles. Normally the player character will accelerate until an obstacle is hit at which point the game ends. The games are usually fast paced and intense.

In terms of rehabilitation this genre is a good idea because the interval can help set the intensity of the training. Meanwhile the variety of obstacles can engage different types of actions with the Novint Falcon. The fast paced nature should be avoided and as such the game should be a slow paced endless runner in order to utilise all of the properties.

The following concept is suggested: A game in which the player must control a plane(this engages x, y axes), the z axis can be used for controlling speed(or ignored). Furthermore the plane's engine can be an excuse to apply a slight vibration, shown to improve rehab. Finally, if a player has a specific weakness a "wind" can be added that constantly adds a bias to the force, i. e.it pushes you in a specific direction and the player must constantly work against it. Thematically this is also a good decision because the theme of flying through the sky requires few visual effects and is simple.

5 GAME DESIGN

The following chapter details a Game Design Document (GDD). A GDD is a very important part of game development because it helps the entire team keep a unified vision of the product. The GDD is so complete that it functions as a recipe for the game. The team should be able to follow the document and have little to no further questions[20].

For this project I have omitted some of the details. This in collaboration with the limited scope of the project means the GDD much smaller that it would otherwise have been.

5.1 CONCEPT

You are a pilot and must fly into balloons to earn points.

5.2 GAMEPLAY

The core gameplay is to fly a plane and destroy balloons by flying into them. Points are earned each time a balloon is destroyed. A secondary mechanic is added in which bonus balloons appear. They award more points than regular balloons but are further away from the centre.

The plane will automatically fly forward at a fixed speed which can be adjusted by the system.

5.3 INTERACTION

The Novint Falcon is used as the input device during gameplay. Outside gameplay both the Falcon and Mouse/Keyboard can be used for controlling the menus.

The game is controlled by moving the end effector(grip) of the Novint Falcon. The plane will move accordingly.

In order to destroy a balloon the grip must be moved *distance a* from the centre as seen in Figure 7. Furthermore bonus balloons require the player to move the grip an additional *b distance* for a total of $a + b$ *distance* away from the centre.

5.4 GRAPHICS

Graphics are very simple with little to no extra elements. This is because the target group may have attention problems. Additionally

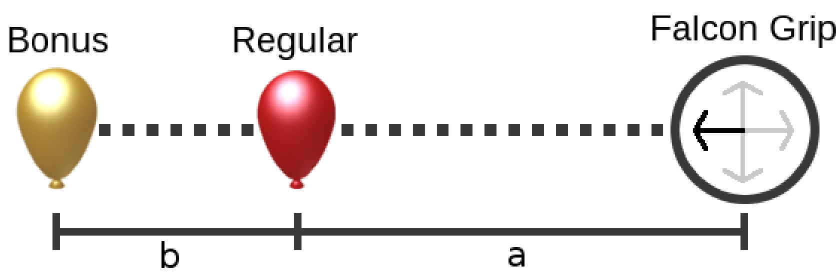


Figure 7: Illustration of how the interaction works in context of a single direction: West

most of the players are expected to have little to zero experience with games.

5.4.1 *Models*

Two models are needed: Airplane and a Balloon. The balloon is a simply a regular red balloon. The bonus balloon is gold coloured. The player Airplane is based loosely on a Cirrus Aircraft SR22: http://www.electrifly.com/largeelectrics/gpma1166-4view-lg.jpg.

5.5 LEVELS

The environment is high up in the Sky. Levels in the game are procedurally generated based on settings from the pre-session wizard. The following are the elements that can be placed during level generation:

- Balloons
- Bonus Balloons

5.6 AUDIO

The soundscape is to be soothing and as unobtrusive as possible.

5.6.1 *Music*

The music in the game was retrieved externally. The music used was "Dream Culture" by Kevin MacLeod of www.incompetech.or and is Licensed under Creative Commons: By Attribution 3.0.

5.6.2 *Effects*

The following audio effects are used in the game:

- Balloon pop

- Plane Engine
- Button Clicks

In a similar fashion to the music, the effects were also found externally on `http://www.soundjay.com/tos.html` and `http://www.freesound.org/people/suburban%20grilla/sounds/2166/`

6 IMPLEMENTATION

This chapter details the more interesting and challenging aspects of the current implementation. For a more in-depth look see the source code attached to the DVD under the folder:

`Source/Falconeer/Assets/Scripts`.

At the end of the chapter there are a few screenshots from the game.

6.1 UNITY3D AND NOVINT FALCON

Unity3D does not natively support the Novint Falcon. As such a bridge or commonly known API should be made. A native c++ library is made and compiled into dynamic linked library(.dll file). Unity3D can then access the methods defined by the `[DllImport(falcon)]` flag. This flag is used inside Unity3D in a class called `Haptics`. Through the class all the actions of the Novint Falcon are retrieved and used in the other parts of the game.

```

    [DllImport(falcon)]
    private static extern void SetServoPos(double[] pos, double strength);

⋮

    public static void SetServoPos(Vector3 pos, double strength)
    {
        double[] _pos = new double[3];
        _pos[0] = pos.x;
        _pos[1] = pos.y;
        _pos[2] = pos.z;
        SetServoPos(_pos, strength);
    }

```

Figure 8: Code snippet from the `Haptics` class

In the code snippet seen in Figure 8 is a good example. The Native Code method called `SetServoPos(double[] pos, double strength)` is imported from the .dll file. Further down a new static method called `SetServoPos(Vector3 pos, double strength)` is defined. Other parts of the code can now call the new static `SetServoPos(Vector3 pos, double strength)` and manipulate the Novint Falcon through it.

A Haptic Device such as the Novint Falcon requires an extremely high update rate of at least 1000 Hz. This means that the standard `Update()` and `FixedUpdate()` cannot be used because they simply update too slow. The settings for the internal physics engine in Unity3D can be changed to update at 1000 Hz however at this level it is impossible to run any physics and will ultimately result in an unusable game with a low frame rate.

```
public class CustomFixedUpdate
{
    private float m_FixedDeltaTime;
    private float m_ReferenceTime = 0;
    private float m_FixedTime = 0;
    private float m_MaxAllowedTimestep = 0.3f;
    private System.Action m_FixedUpdate;
    private System.Diagnostics.Stopwatch m_Timeout = new System.Diagnostics.Stopwatch();

    public CustomFixedUpdate(float aFixedDeltaTime, System.Action aFixecUpdateCallback)
    {
        m_FixedDeltaTime = aFixedDeltaTime;
        m_FixedUpdate = aFixecUpdateCallback;
    }

    public bool Update(float aDeltaTime)
    {
        m_Timeout.Reset();
        m_Timeout.Start();

        m_ReferenceTime += aDeltaTime;
        while (m_FixedTime < m_ReferenceTime)
        {
            m_FixedTime += m_FixedDeltaTime;
            if (m_FixedUpdate != null)
                m_FixedUpdate();
            if ((m_Timeout.ElapsedMilliseconds / 1000.0f) > m_MaxAllowedTimestep)
                return false;
        }
        return true;
    }

    public float FixedDeltaTime
    {
        get { return m_FixedDeltaTime; }
        set { m_FixedDeltaTime = value; }
    }
    public float MaxAllowedTimestep
    {
        get { return m_MaxAllowedTimestep; }
        set { m_MaxAllowedTimestep = value; }
    }
    public float ReferenceTime
    {
        get { return m_ReferenceTime; }
    }
    public float FixedTime
    {
        get { return m_FixedTime; }
    }
}
```

Figure 9: The code for the `CustomFixedUpdate`

The solution is to implement a separate new "Update" method which updates at the desired frequency. This new `CustomFixedUpdate` allows the Novint Falcon to update its servos and position information at the necessary rate.

6.2 level generation

The level generation in the game initially used the Unity3D function `Random.Range` which produces a random number. However early tests showed that sessions with low task counts would result in bad task distributions. As seen in Figure 10 several of the test runs sometimes had zero task in one or more directions.

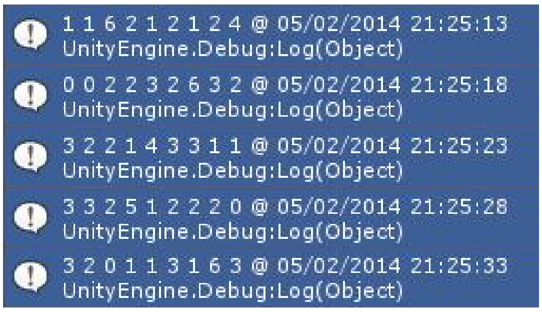


Figure 10: Five test runs of a 20 task example with the default "distribution" using `Random.Range` only

A system to circumvent this was implemented. It generates the level based on a list of the available positions. Each time a balloon is spawned, the position is removed from the list. When the list is empty it will be refilled with the original eligible positions.

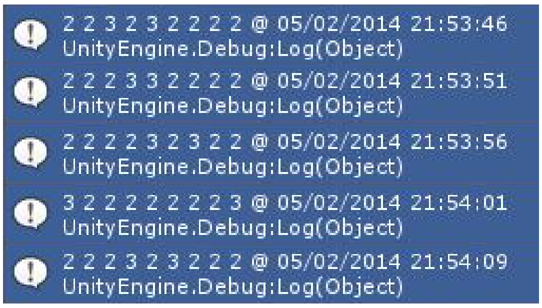


Figure 11: Five test runs of a 20 task example with the new method using `Random.Range` and a `List<Vector3>`

This ultimately still has errors as some tasks will occur more often than others if the number of tasks is not a multiple of the amount of available positions.

6.3 data collection

The data collection is not a key part of the project but it is made interestingly none-the-less.

Since data is only collected on a local level it is done using Comma Separated Value (CSV) files. While it is more popular to use Extensible Markup Language (XML), CSV are easy to make and very well documented. A CSV file is essentially a text file but comma(and other characters) can be used to separate values. This is highly useful when the data is imported into a spreadsheet program.

A class that manages the data collection was written called `DataCollector`. Most of the methods in this class are static such they can be used from anywhere without a reference.

```
//using System.Collections;
using System.IO;
using UnityEngine;

public class DataCollector
{
    private static TaskData[] _tasksData;
    private static int _patientCount;

    private static string _saveLocation;

    public static void Initiate()...

    public static void CreateFile(ExperimentType testType)...

    public static void WriteToFile(Vector3 value, string name, ExperimentType testType)...

    public static void WriteLevelGenerationToFile(
        InputDirections one,
        InputDirections two,
        string name,
        ExperimentType testType)...

    public static void Reset()...

    public static void WriteTaskData(TaskData dataToWrite)...
}
```

Figure 12: The `DataCollector` method

6.4 SHOWCASE

This sections contain some images of the game. There is not a lot to show as the visuals are very simple. The following two screenshots show the two most important aspects of the game, balloon spawning and balloon popping.

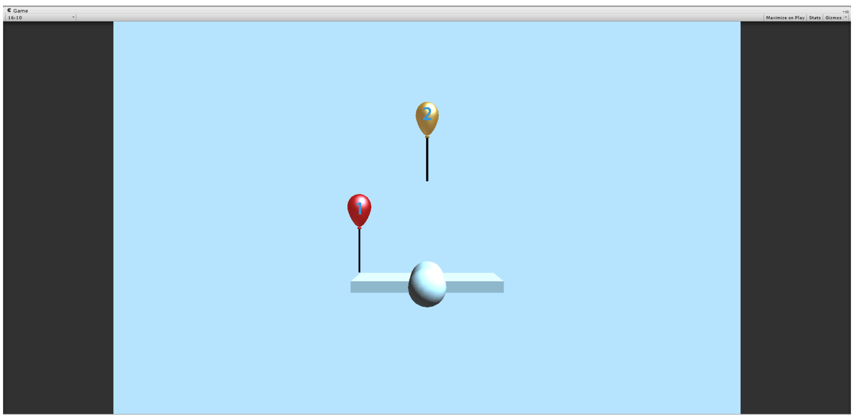


Figure 13: Gameplay Screenshot - what it looks like when you just started the game. Note the gold balloon is further away from center.

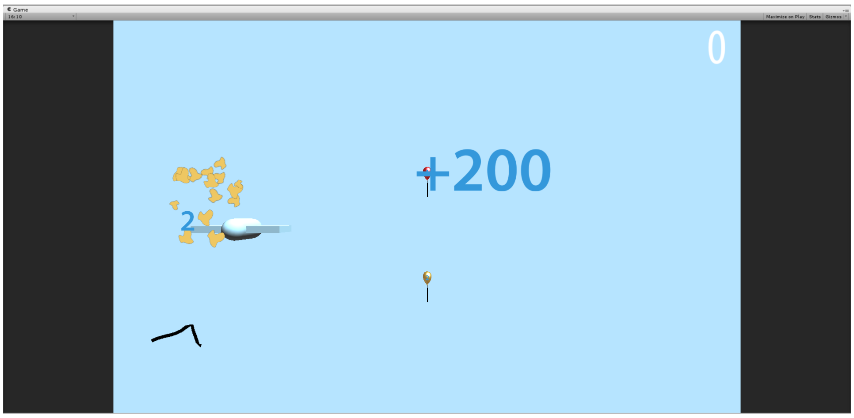


Figure 14: Gameplay Screenshot - once a balloon is popped the string will fall to the ground, particles will spawn and points pop up in the center screen.

6.4.1 *Launch Menu*

The following four screenshots showcase the launch menu which was designed based on the assumption that the game should be very modifiable.

Figure 15: The start screen

Figure 16: The first screen in the customisation wizard where you can edit the basic parameters of the system.

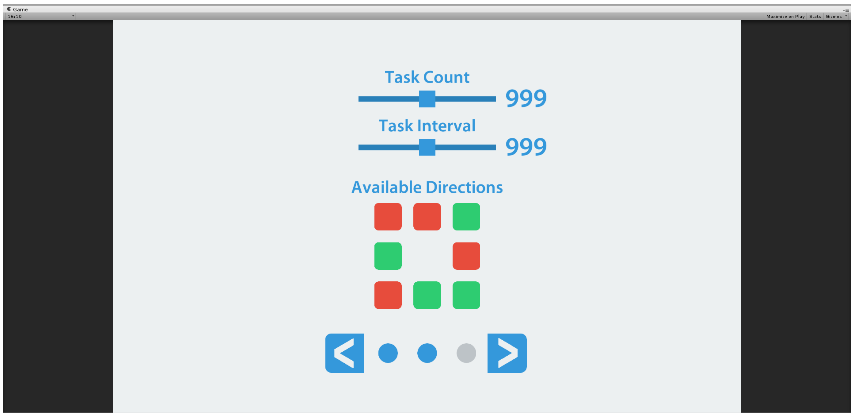


Figure 17: The second screen in the customisation wizard where you can edit the task related variables of the system.

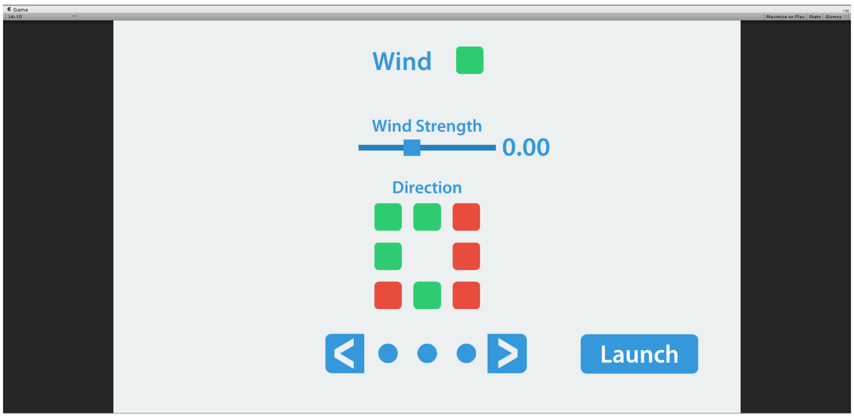


Figure 18: The third and final screen in the customisation wizard where you can edit the parameters of the wind effect.

7 TESTS & EXPERIMENTS

7.1 DESIGN

The experiment was designed to be within-subjects with three different treatments. In the first treatment participants played a version of the game in which the bonus and regular balloons gave the same amount of points. For the second treatment the bonus balloon awarded twice the amount of points. For the final and third treatment the bonus balloon, in addition to awarding double points, is also made of a different material: Gold. The treatments were labelled as follows: Normal, High Value and Gold. The bonus balloons for each treatment can be seen in Figure 19.

(a) Normal Balloon (b) High Value Balloon (c) Gold Balloon

Figure 19: The balloon designs used for each treatment

Counter balancing was done by the system itself which monitored the participant count and automatically set the order of treatments.

7.2 TEST SETUP

The setup seen in Figure 20 is the proposed test setup. The position of the Novint Falcon can be changed if needed from right to left.

The camera itself is slightly elevated in comparison to the Novint Falcon. The goal of the camera is to capture the grip during use. The exact positioning of the Falcon with regards to the patient was subject to best practice determined by the present Therapist. The seating position, table height and participant support were all subject to change depending on the Therapist's recommendation.

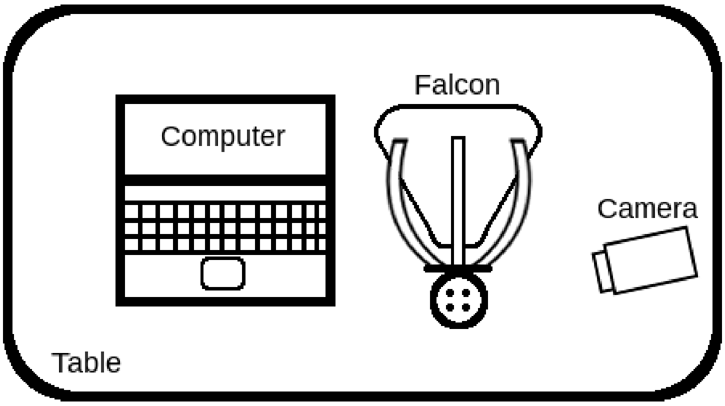


Figure 20: The test setup

For the experiment some of the settings of the system had been locked. A full list of settings can be seen in Section 4.2. The distance to move the Novint Falcon had been set to 50% of maximum which is approximately 5 centimetres. The rate at which bonus balloons appear was set to 100%. The task directions were set to four out of eight possible: North, South, East and West. This was chosen to accommodate as many different people at once as possible. The interval between tasks had been set to 5 seconds and the task count was set to 64.

The strength level of the Novint Falcon can be changed based on the therapist's recommendation. By default this was set to 50% of maximum capacity, circa 5 Newtons of Force. Furthermore

During the test participants could pause for any number of times for an unlimited duration but would be encouraged to continue as soon as possible by the facilitator.

7.3 MATERIALS

For the experiment a Novint Falcon was used in conjunction with a 15,6 inch laptop. For further stability a rubber mat was used under the Falcon. Highly adjustable chairs and tables were used as the platform. Furthermore a therapist should be present to ensure correct handling of participants according to therapy guidelines.

7.4 PROCEDURE

The participants were found and presented to the consent form by the therapist prior to the experiment date. They were then allotted into time slots by the therapist. Patients were then retrieved by the therapist once the time slot was reached. Upon entry participants were greeted and begun answering the background questionnaire in collaboration with the facilitator. Afterwards the participants were prepared by the therapist for using the Novint Falcon this included adjusting the seating position, table height and Falcon position. Once completed they were subject to a simple pre-experiment calibration of the Falcon's strength level. This was done by assessing the capability of the participant to move in all four directions by the therapist and the facilitator. Then the first treatment is applied. After a short break the second was started and at its conclusion another short break followed by the third and final treatment. Upon completion of the third treatment participants were then asked to fill out a post-experiment questionnaire in collaboration with the facilitator.

Based on the sub-problem established in Section 1.1 the following Hypotheses were defined:

Hypothesis 1. *The bonus zone time spent of the Gold and High Value treatment will be different from the Normal treatment.*

Hypothesis 1.1. *The bonus zone time spent of the Gold treatment will be more than the High Value treatment.*

Null Hypothesis. *There is no difference between bonus zone time spent in each treatment.*

7.5 OUTCOME MEASURES

The primary outcome measure is the time spent with the falcon grip in the bonus zone, shown as green in Figure 21. The time spent in this zone is directly proportional with the amount of exercise gained.

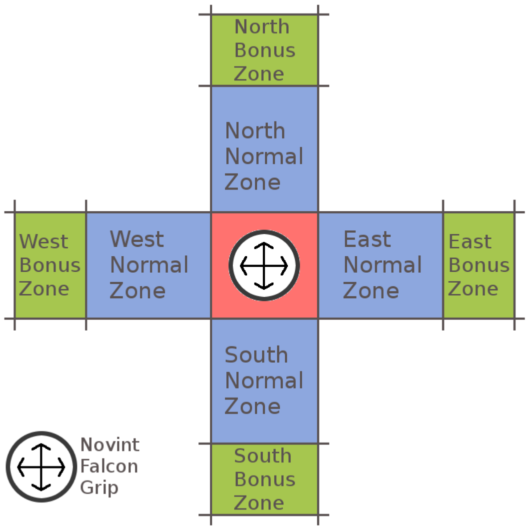


Figure 21: Illustration of the various zones on the Falcon. In the red, bonus, zone bonus balloons can be collected.

Additionally further data is collected. A full list can be seen in Table 4.

DATA	TYPE	CAUSE
Strength Level	Float	Percent strength of max
Distance Level	Float	Percent distance of max
Pause Count	Int	Number of times paused
Pause Time	Float	How much time was spent
Time in Dead Zone	Float	How much time was spent
DATA FOR EACH DIRECTION(N, S, E, W)		
Balloons Popped	Int	Measure of accuracy
Bonus Balloons Popped	Int	Measure of accuracy
Time in Normal Zone	Float	How much time was spent
Time in Bonus Zone	Float	How much time was spent
Points	Int	Measure of accuracy

Table 4

For further information please see Section 6.3.

7.6 FORMS AND QUESTIONNAIRES

Common to all of the following items is the fact that they are designed to be administered verbally and to allow for guidance. Furthermore they are reduced as much as possible as it is expected they will take some time to fill out. This is because some participants are expected to have minor brain damage.

7.6.1 *Consent Form*

Please see appendix. Basic consent form that asks about permission to record audio and video and permission to publish the recordings. Attached to the consent form was a small description of the project and the contents of the experiment. Please see Appendix C for the full consent form.

7.6.2 *Background Questionnaire*

The questionnaire was made using Google Forms. The original untranslated version can be found in Appendix D. It consists of three parts. The first part concerns background information such as gender, age, illness, time since incident and how much time spent on rehabilitation. The second part is about the current rehabilitation effort. Participants are asked to rate some expressions from 1: strongly disagree to 5: strongly agree:

- "The current methods bore me"
- "Rehabilitation is not fun"
- "I look forward to the next exercise"
- "I feel motivated towards completing exercises"

For the final and third part participants are asked about their media habits. Their weekly computer game consumption on a scale from less 1 hour, 1 to 4 hours, 4 to 7 hours, 7 to 10 hours, 10 to 14 hours and more than 14 hours. They are then asked about their experiences with four different media types: Smartphone, Tablet, Computer, Game Console on a scale from 1(no experience) to 5(a lot of experience).

7.6.3 *Post Game Questionnaire*

This questionnaire consists of two parts. The first part concerns the Novint Falcon while the second part focuses on the game. In the first part the first question is whether they knew the Novint Falcon beforehand. Afterwards participants are asked to rate some expressions on a scale from 1: strongly disagree to 5: strongly agree:

- "It was hard to use the Novint Falcon"
- "The resistance was adequate"
- "I felt in control over the Falcon"
- "I did not understand how the Falcon worked"

Finally they were asked if they would be interested in seeing more products that use the Falcon on a scale from "Not at all" to "Yes, absolutely".

For the second part participants are first asked if they noticed a red balloon which gave additional points, secondly they are asked if they noticed a gold balloon. Then they questioned on their opinion of the gold balloon, did they notice it and did actively try to collect it. Then a question follows about the opinion of the music and sounds used. Afterwards participants are asked to rate some expressions on a scale from 1: strongly disagree to 5: strongly agree.

- "The game was fun"
- "I understood what to do"

- "I tried to collect the balloons that gave the most points"
- "I did not want to continue"

Ultimately the participants are asked if they would change anything about the game and if they have any general comments.

7.7 PILOT TESTING

Two separate pilot tests were performed. Based on the first test some changes were made. The camera will no longer follow the plane and the distance that the plane moves and the balloons are created is three times larger. This is to make it easier to determine the direction to move.

After the first test a final pilot test was made with the first patient at BNC. This pilot was mostly to ensure that all data collection worked as intended.

8 RESULTS

I conducted the experiment the 12th and 13th of May 2014 on eight participants who were patients at BNC, five males and three females. They had varying degrees of handicaps caused by illnesses. Common for all was paresis in either upper body limbs. The participant are shown in Table 5

NO	AGE	GENDER	CAUSE	PARESIS	NOTES
1	73	Male	Intracranial hemorrhage	Right	Slightly reduced hearing and understanding
2	78	Male	Intracranial hemorrhage	Left	Less attention towards left
3	67	Female	Cerebral thrombosis	Left	Less power in both arms and shoulders
4	69	Male	Cerebral thrombosis	Left	Slightly less power, control and sensitivity
5	75	Male	"Wrong" Operation	Right	Uncoordinated, reduced attention
6	36	Female	Neck Tumor	Right	Less control, hard to write with pen
7	62	Female	Cerebral thrombosis	Left	Reduced attention and neglect issues
8	54	Male	Cerebral thrombosis	Right	Inreased tonus, weak grip, reduced sensitivity

Table 5: A table listing each patient in the test along with the location of the paresis and cause. Also additional specific issues are noted.

The experiment was filmed according to the design outlined in Section 7.2. These videos can be found on the accompanying DVD in the folder called:

`PatientVideos`.

BACKGROUND QUESTIONNAIRE RESULTS

None of the participants had seen a Novint Falcon. In terms of computer experience 3 of the 8 participants had a medium level, while 4 of 8 answered a lot and the final participant answered none. Answers to weekly hours spent playing computer games can be seen in Figure 22.

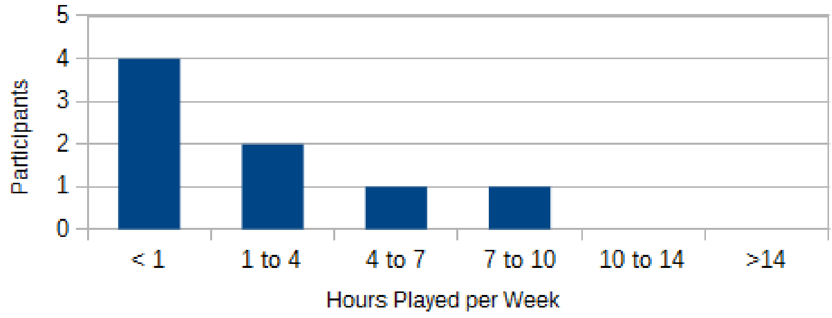


Figure 22: Responses to how many hours each participant spent per week playing computer games

The responses to the statements on the current rehabilitation effort by BNC can be seen in Figure 23.

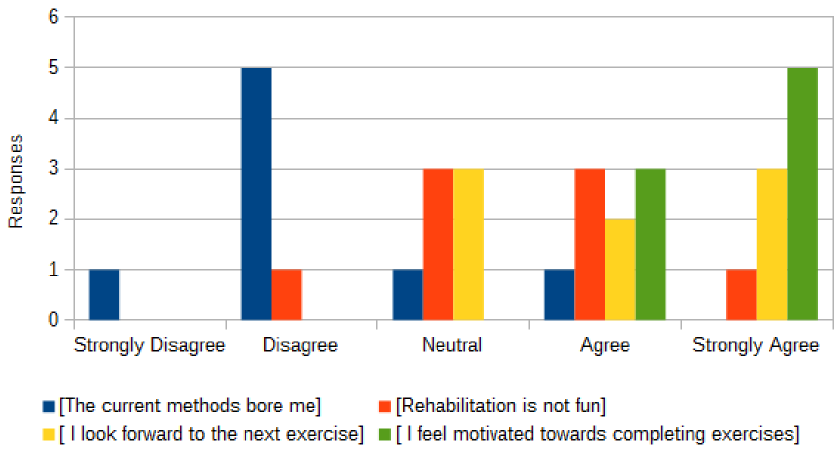


Figure 23: Responses to the statements regarding the current rehabilitation methods

EXPERIMENT RESULTS

I conducted a within-subjects ANOVA on the bonus zone time spent in the three treatments of game mechanics: Normal, Gold and High-Value. There was not a significant effect of bonus zone time spent in each treatment, *Wilks' Lambda* $= 0.582$, $F\ (2,6) = 2.159$, $p = .197$. The alternate hypothesis 1 is therefore rejected and subsequently also hypothesis 1.1. If a statistical difference was determined a post hoc analysis would normally be completed to determine which condition was responsible.

However based on the answers to the questionnaires it was apparent that some participants noticed the gold balloon while others did not. Further analysis was made by separating those who selected "Strongly Disagree" and "Disagree" to the *"I tried to collect the balloons that gave the most points"* statement into a group called "non-collectors" and grouping those who answered "Strongly Agree" and "Disagree" into "gold collectors". The participants who answered "Neutral" were ignored which in this case was zero participants. The groups are shown in Table 6 alongside their answers.

NON-COLLECTORS		GOLD COLLECTORS	
PATIENT	ANSWER	PATIENT	ANSWER
Patient 1	Disagree	Patient 2	Agree
Patient 5	Strongly Disagree	Patient 3	Strongly Agree
Patient 6	Disagree	Patient 4	Strongly Agree
Patient 7	Disagree	Patient 8	Agree

Table 6: The two groups that emerge based on questionnaire answers

A paired sample t-test was conducted between the bonus zone time spent means of the non-collectors and the gold collectors groups. The mean time spent in the bonus zone for the Gold Collectors group was 123.66 with a standard deviation of 35.69. The mean time spent in the bonus zone for the Non Collectors group was 96.61 with a standard deviation of 8.78. There was no statistic difference between the non-collectors and gold collectors group: $t(3) = 0{,}836$, $p = 0{,}464$.

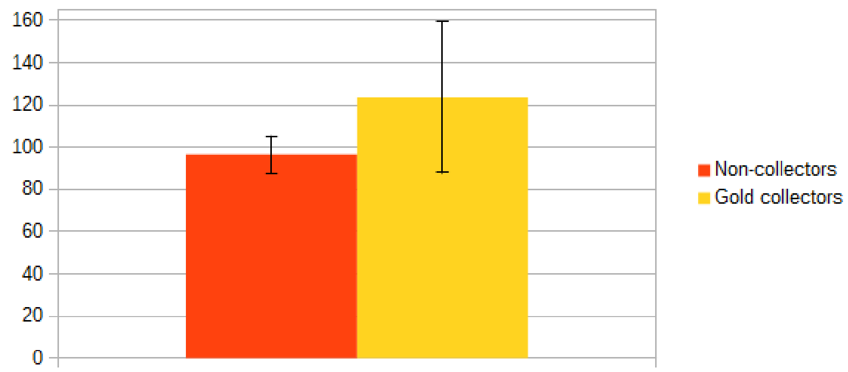


Figure 24: Bar graph showing the means of the non-collector and gold collector groups along with standard error bars

QUALIATATIVE AND POST-GAME QUESIONNAIRE RESULTS

The responses to the statements on the Novint Falcon and the game can be seen in Figure 25 and Figure 26.

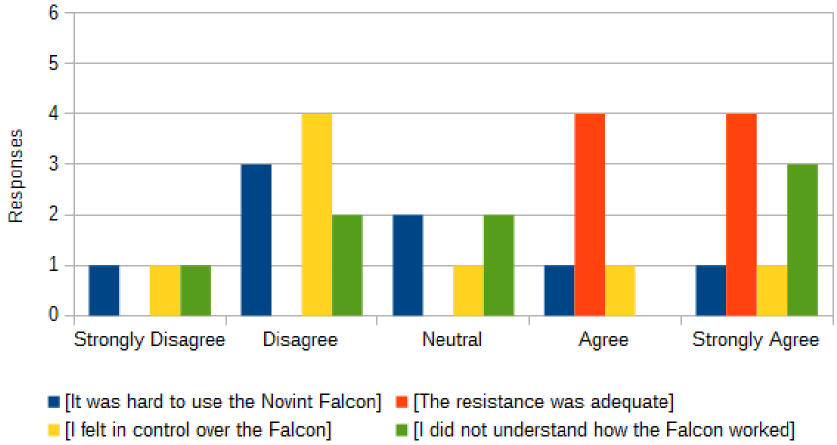


Figure 25: The responses to the statements regarding the Novint Falcon from the post-game questionnaire

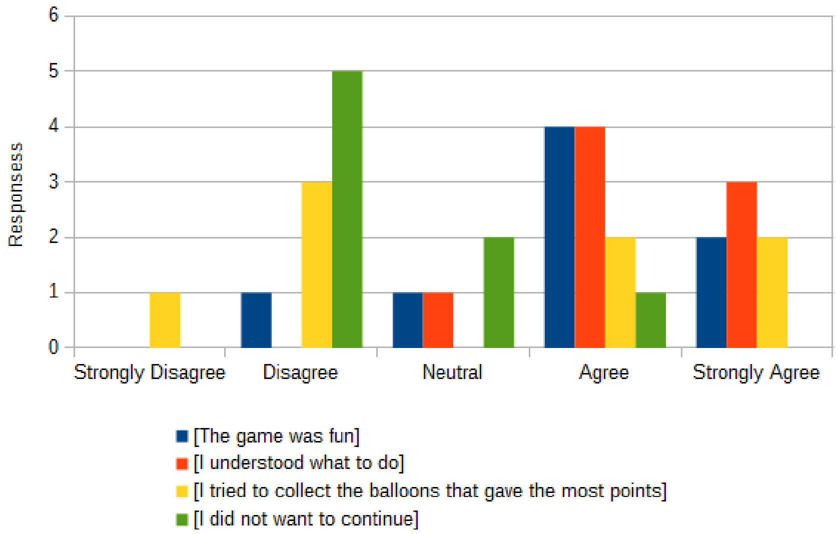


Figure 26: The responses to the statements regarding the game from the post-game questionnaire

In regards to the question on *"Would you be interested in more solutions that use the Novint Falcon for rehabilitation"*, 1 answered Not at All, 2 Maybe, 4 Yes and 1 Yes Absolutely. Furthermore the following remarks were made on this subject:

> *"To old for such nonsense"*

"More interesting than putting small rings on a stick"

Re

"The more the better"

"Good effect it worked"

"It could be fun"

The participants made the following comments on which kind of changes they would like to see:

"Control over shooting, add shooting"

"Bigger balloons"

"Less difficult"

Besides them, the following general comments were made:

"The grip was bad"

"Fun to try"

"Interesting what it means for the future of rehabilitation"

"Nice to use the arm, more exciting than moving small objects(such as toothpicks)"

Please note that the comments have been translated. The original untranslated versions can be found in Appendix E.

During the experiment several of the participants appeared excited and to have fun based on subjective observations by the therapist and facilitator.

9 DISCUSSION & CONCLUSION

9.1 DISCUSSION

The most critical fault in the experiment is the lack of a way to discern the distance between the plane and the balloons. Almost everyone including the therapist had a hard time judging whether the plane was about to hit the balloons or not. It led to the misbelief that you had to stay above the balloons for a certain amount of time to hit them.

Also the numbers on the balloons do not lend themselves well to the test as several players had a hard time interpreting the numbers. Most thought that the "1" and "2" symbolised the order in which the balloons must be popped rather than the points they gave.

Furthermore the experiment needed some calibration. While only two of the eight participants had adjustments to their strength level. This was not the only fault as many patients had varying degrees of movement and excitation required. A short calibration test could be made to ensure that the distance, strength and directions were set accordingly.

The test was unbalanced with 8 participants. The numbers of users should ideally be a multiple of six in order to achieve perfect test balance with three treatments(because there are six permutations 3!, 3*2*1). The current results are further unbalanced because the treatment order depended on internal mechanics. The game automatically registered a new player on each launch. Sometimes the test was launched to check something or make sure it worked. Each time this was done the player count increased and the order of treatments became unbalanced as a result.

	NORMAL	GOLD	HIGHVALUE
First	3	1	4
Second	2	4	2
Third	3	3	2

Table 7: Table showing the count of when each treatment was first, second and third

The unbalanced order of treatments can be seen in Table 7. For example the HighValue treatment was first for half of the participants. This is easily fixed by simply only registering a new player on a certain button or key press.

Ultimately the best thing for the test, as with most others, would be if it was possible to recruit more participants. This along with the other proposed fixes would greatly increase the validity of the data.

9.2 CONCLUSION

The initial problem statement was:

> ***How can a game-based rehabilitation system be designed that uses the Novint Falcon?***

During this thesis this question was answered by examining the state of the art in the context of rehabilitation with the Novint Falcon. Through this existing solutions were found and their and gaps. This led to the analysis of the exercises done with the Novint Falcon in an attempt to categorise just precisely what it could do. Based upon this and other design considerations a prototype game was designed.

The design was implemented and an experiment designed to answer the secondary problem:

> ***Can game mechanics be used to meaningfully enhance the rehabilitation provided by such a system?***

Unfortunately the results were statistically insignificant and the null hypothesis was retained. However even though the results were poor the qualitative responses were good. Most participants felt per own description engaged and excited while playing the game. This corresponds with observations made during game play by myself and the therapist whom helped.

It is also interesting to note that all of the participants answered positively towards being motivated to complete exercises. This may be explained by the fact that there is a very tangible result from rehabilitation: achieving full body function.

A

VISIT TO BRØNDERSLEV MATERIALS

- Slide paper towel along a line made with tape, sitting
- Push wooden tube up a slide so that it rings a bell, pushed by only moving the fingers while grasping a different tube at the bottom, sitting
- Try and grasp different sizes of wooden cubes, tubes and spheres, sitting
- A inflatable brace is used for stabilizing the arm movement, then the arm is placed on a trolley and the objective is to move it sideways(focus on shoulder muscles), sitting
- Lift three different kinds of pairs of glasses up on a shelf(sitting down)
- Rolling a large exercise ball on the floor, sitting
- Rolling a large exercise ball up the wall, standing
- Moving a soft ball around one self
- Move discs from one tower to another, twisting the entire body, moving from left side to right side
- Grasp small gravel that are warmed for getting ready
- Lift fingers to reach a straw attached to wrist
- Lift wrist to reach a straw attached to arm
- Electronic devices, MULE, user has to twist wrist to move a basket in order to catch falling balls(can be adjusted prior to use, difficulty etc etc)
- Roll two balls around in the hand

B

HAPTIC MASTER

Image of HapticMaster Workspace

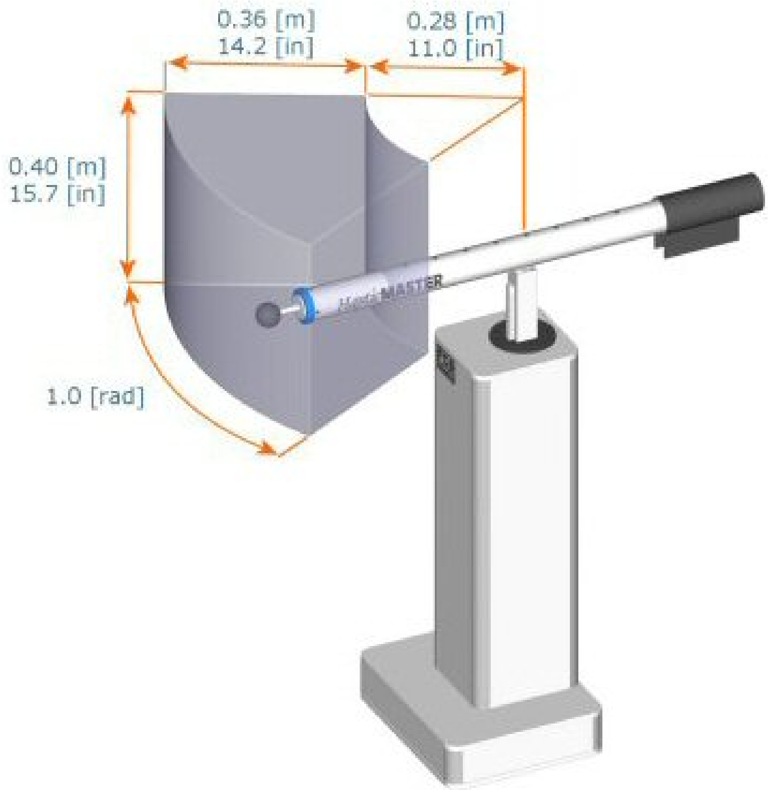


Figure 27: An image of the hapticmaster's workspace, taken from: http://www.h3dapi.org/modules/mediawiki/index.php/Image:HapticMaster_workspace.jpeg

Velkommen

Mit navn er Emil Kaihøj Nielsen, jeg læser Medialogi(Medie Teknologi) på Aalborg Universitet og er i øjeblikket ved at skrive min kandidatafhandling der omhandler nye behandlingsmetoder til armtræning af personer med lammelser.

Hertil bruger jeg et stykke udstyr kaldet Novint Falcon:

Novint Falcon er et såkaldt 3 dimensionelt force feedback device, hvilket vil sige at den kan udøve varierende mængde kraft på x, y og z aksen. Jeg har til projektet udviklet et spil der gør brug af Novint Falcon med henblik på armtræning.

Til projektet har jeg brug for at udføre et eksperiment. Eksperimentet varer ca. 30-40 minutter og involverer at skulle spille med Novint Falcon. Forløbet af eksperimentet er følgende:

1. Udfyldelse af baggrundsspørgeskema
2. Gennemspilning af første version
   a. Udfyldelse af spørgeskema vedrørende ovenstående
3. Gennemspilning af anden version
   a. Udfyldelse af spørgeskema vedrørende ovenstående
4. Gennemspilning af tredje version
   a. Udfyldelse af spørgeskema vedrørende ovenstående
5. Udfyldelse af slutspørgeskemaet

Samtykkeerklæring

Undertegnede giver hermed tilladelse til at der optages video og lyd under eksperimentet med videnskabeligt formål.

☐ Ja

☐ Nej

Undertegnede giver hermed tilladelse til at førnævnte video- og lydoptagelser må offentliggøres med videnskabeligt formål.

☐ Ja

☐ Nej

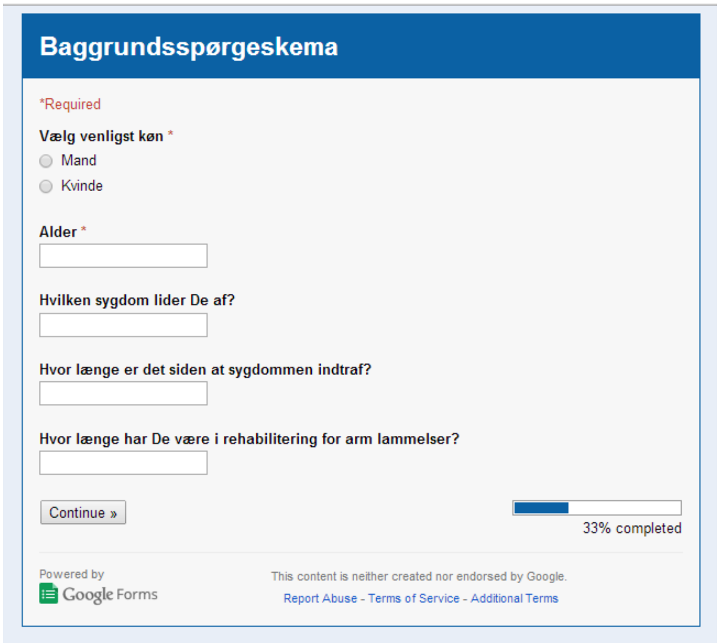
Navn

____

Underskrift | Dato

____ ____________

QUESTIONNAIRES



Baggrundsspørgeskema

*Required

Vælg venligst køn *

Mand

Kvinde

Alder *

Hvilken sygdom lider De af?

Hvor længe er det siden at sygdommen indtraf?

Hvor længe har De være i rehabilitering for arm lammelser?

Continue »

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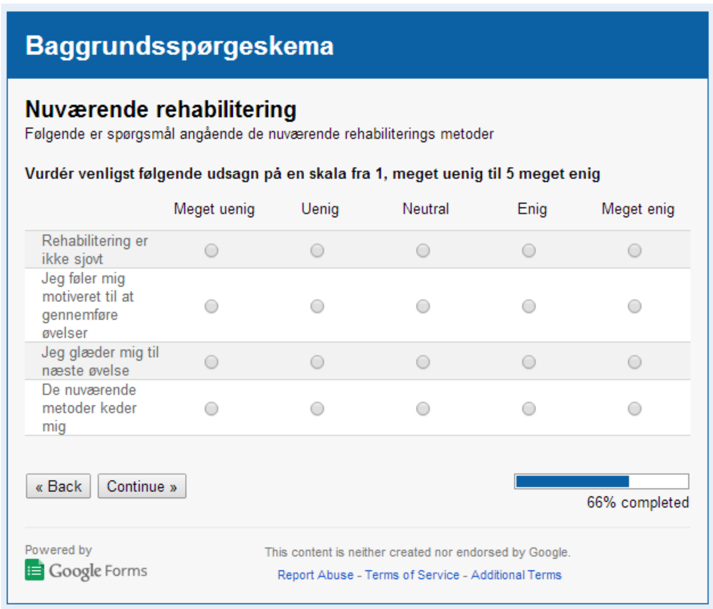
Figure 28: Background Questionnaire 1/3: Core information



Baggrundsspørgeskema

Nuværende rehabilitering

Følgende er spørgsmål angående de nuværende rehabiliterings metoder

Vurdér venligst følgende udsagn på en skala fra 1, meget uenig til 5 meget enig

	Meget uenig	Uenig	Neutral	Enig	Meget enig
Rehabilitering er ikke sjovt					
Jeg føler mig motiveret til at gennemføre øvelser					
Jeg glæder mig til næste øvelse					
De nuværende metoder keder mig					

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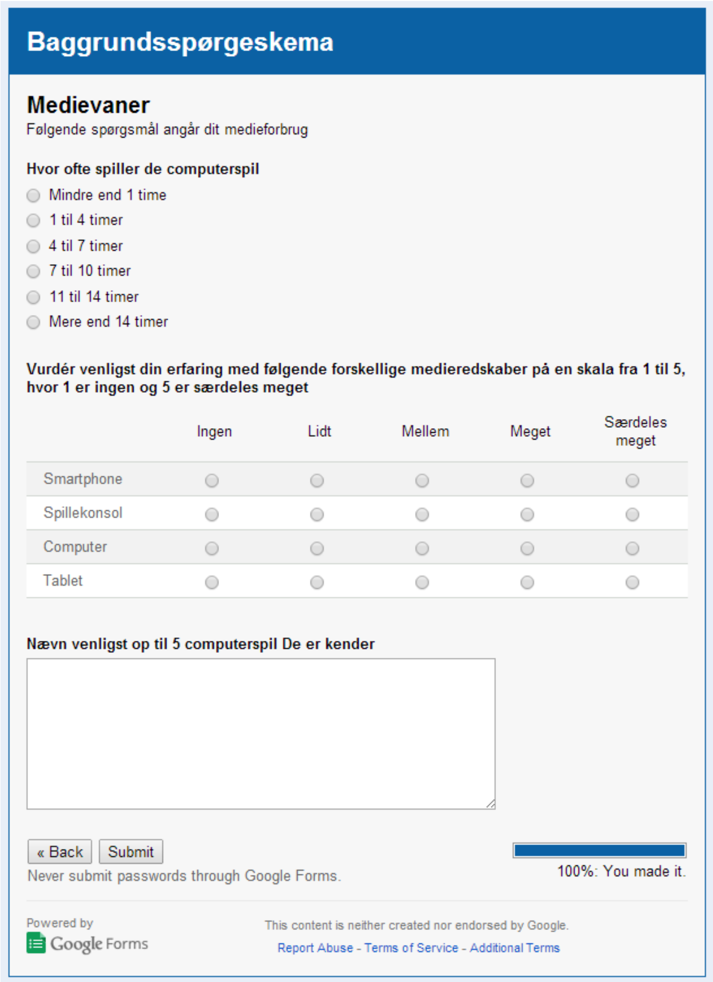
Figure 29: Background Questionnaire Part 2/3: Current rehabilitation



Baggrundsspørgeskema

Medievaner

Følgende spørgsmål angår dit medieforbrug

Hvor ofte spiller de computerspil

- Mindre end 1 time
- 1 til 4 timer
- 4 til 7 timer
- 7 til 10 timer
- 11 til 14 timer
- Mere end 14 timer

Vurdér venligst din erfaring med følgende forskellige medieredskaber på en skala fra 1 til 5, hvor 1 er ingen og 5 er særdeles meget

	Ingen	Lidt	Mellem	Meget	Særdeles meget
Smartphone					
Spillekonsol					
Computer					
Tablet					

Nævn venligst op til 5 computerspil De er kender

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100%: You made it.

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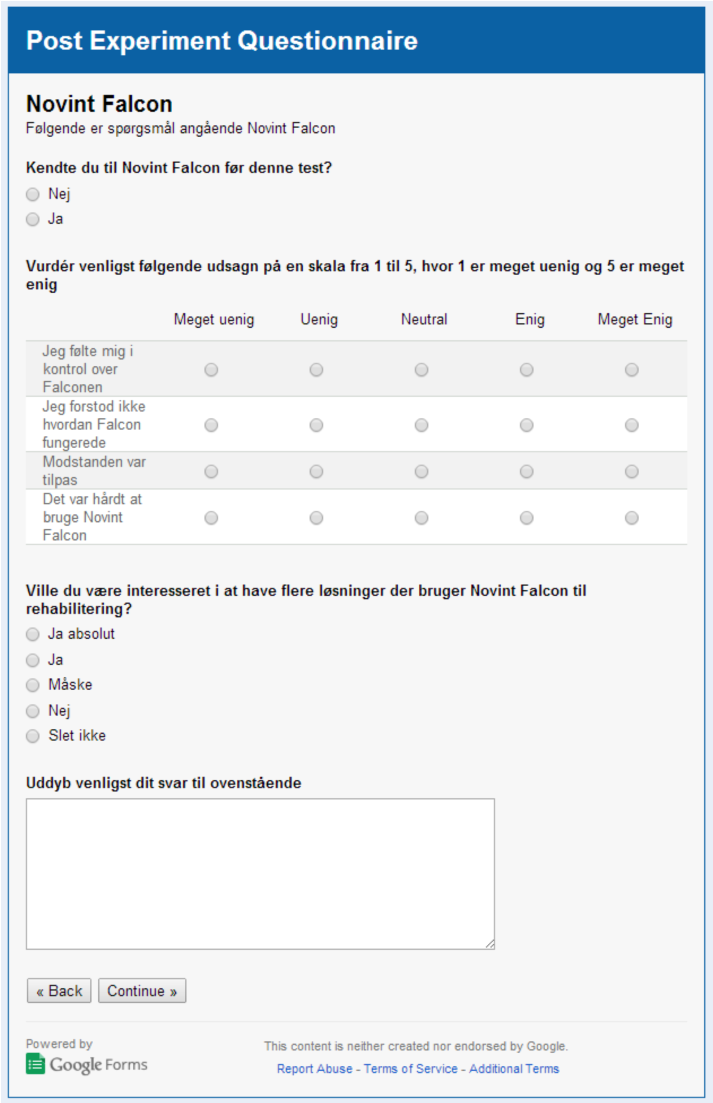
Figure 30: Background Questionnaire Part 3/3: Media habits



Post Experiment Questionnaire

Novint Falcon

Følgende er spørgsmål angående Novint Falcon

Kendte du til Novint Falcon før denne test?

- Nej
- Ja

Vurdér venligst følgende udsagn på en skala fra 1 til 5, hvor 1 er meget uenig og 5 er meget enig

	Meget uenig	Uenig	Neutral	Enig	Meget Enig
Jeg følte mig i kontrol over Falconen	○	○	○	○	○
Jeg forstod ikke hvordan Falcon fungerede	○	○	○	○	○
Modstanden var tilpas	○	○	○	○	○
Det var hårdt at bruge Novint Falcon	○	○	○	○	○

Ville du være interesseret i at have flere løsninger der bruger Novint Falcon til rehabilitering?

- Ja absolut
- Ja
- Måske
- Nej
- Slet ikke

Uddyb venligst dit svar til ovenstående

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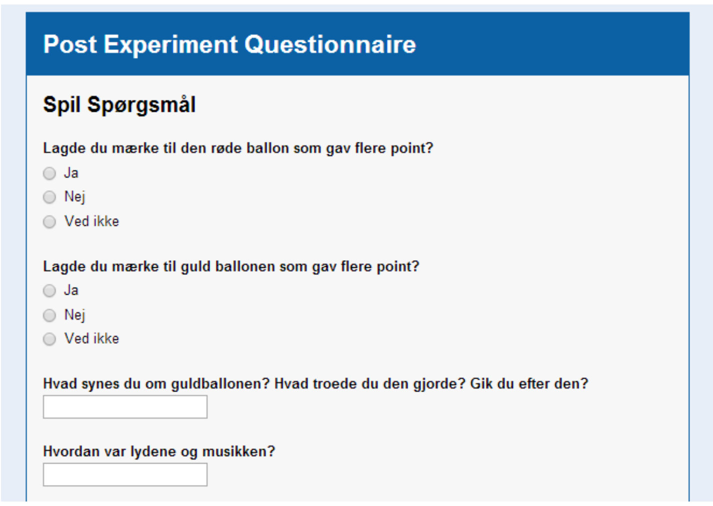
Figure 31: Post-Game Questionnaire Part 1/2: Information on Novint Falcon



Post Experiment Questionnaire

Spil Spørgsmål

Lagde du mærke til den røde ballon som gav flere point?

- Ja
- Nej
- Ved ikke

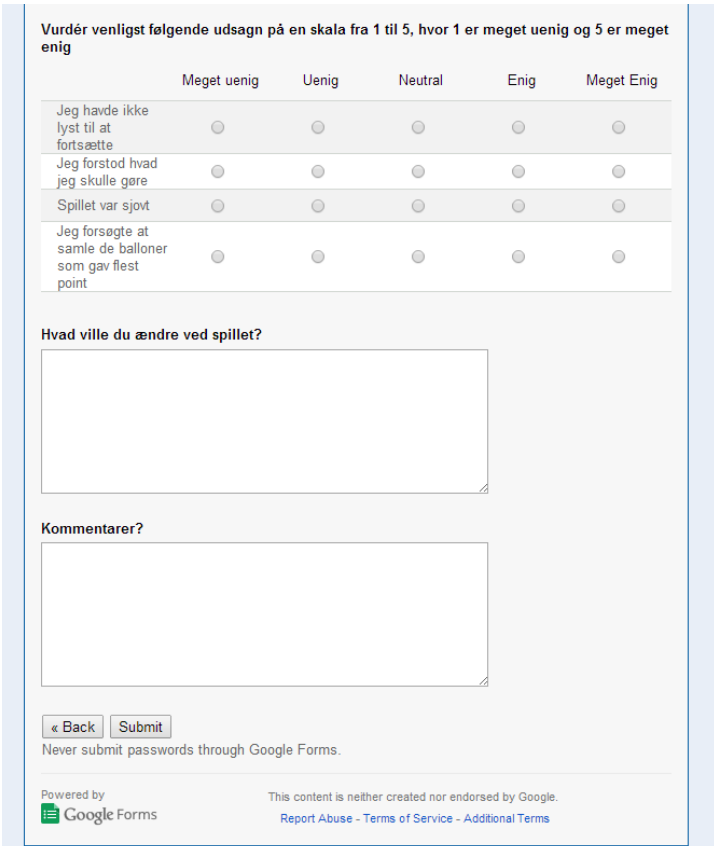
Lagde du mærke til guld ballonen som gav flere point?

- Ja
- Nej
- Ved ikke

Hvad synes du om guldballonen? Hvad troede du den gjorde? Gik du efter den?

Hvordan var lydene og musikken?

Figure 32: Post-Game Questionnaire Part 2a/2: First half of game questions



Vurdér venligst følgende udsagn på en skala fra 1 til 5, hvor 1 er meget uenig og 5 er meget enig

	Meget uenig	Uenig	Neutral	Enig	Meget Enig
Jeg havde ikke lyst til at fortsætte	○	○	○	○	○
Jeg forstod hvad jeg skulle gøre	○	○	○	○	○
Spillet var sjovt	○	○	○	○	○
Jeg forsøgte at samle de balloner som gav flest point	○	○	○	○	○

Hvad ville du ændre ved spillet?

Kommentarer?

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Figure 33: Post-Game Questionnaire Part 2b/2: Second half of game questions

E

QUALITATIVE RESULTS

Untranslated original general comments given to questionnaire:

1. grip er dårligt
2. nej
3. dejligt at fåarmen brugt, mere spændende end at flytte smågenstande (såspm tandstikker)
4. sjovt at prœve
5. spændende hvad det betyder påsigt for genoptræning

Untranslated original comments on why they (don't) want to see more products:

1. for gammel til sådan noget pjat(spil)
2. mere interessant end hœnseringe påen pind
3. jo mere jo bedre
4. god effekt, det virkede
5. det kunne være sjovt

Untranslated original comments on what would you change about the game:

1. nej, såmeget ved jeg ikke om spil
2. kontrol over skydning, skydning
3. det ved jeg ikke noget om
4. stœrre balloner
5. at det ikke var sÃ¥ svært

Untranslated original comments on the gold balloon:

1. fin, gik ikke efter den
2. troede ikke den gav point , troede man skulle undgåden
3. gik ikke efter de, gik efter de nemmeste
4. såden ikke

5. ja gik efter den
6. lagde mærke til den, flere point
7. gik efter den
8. den gav flest point
9. forklarede det ikke, giver mange point

Untranslated original comments on music and audio:

1. ok
2. fin
3. neutral
4. dejlig
5. stille og roligt
6. fin musik
7. beroligende, lagde ikke specielt mærke til det
8. neutral

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