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Active wheelchair.

Design of a concept for a novel product for wheelchair users to improve physical activity and sedentary behaviors.

Master thesis
Dima Politin

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Master thesis

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First we form habits, then they form us.

- Dr. Rob Gilbert

Preface

I am Dima Politin, an integrated product design student at the Delft University of Technology. You are currently holding the result of my graduation project for the department of Design Engineering of the faculty of Industrial Design Engineering.

When I started this project, I was not quite familiar with the context of wheelchairs and their users. Of course, like anyone else, I have seen someone in a wheelchair before, but never have I understood the daily challenges of these users better than before.

This journey started in the context of wheelchair rugby athletes. The Amsterdam Terminators have shared their love for the sport with me and I advice everyone to watch at least one match once in their life, since it is really spectacular. Despite the project reshaping into a context of everyday wheelchair users, many insights were still relevant.

The project was challenging, because I needed to discover unfamiliar territories. I needed to understand the context, learn about the problems experienced by wheelchair users and understand how to effectively change behavior using behavioral psychology theories. Designing a solution was a complex puzzle, but I am satisfied with the end result.

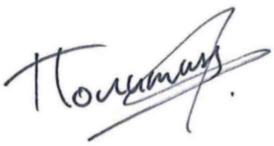
I would like to express my gratitude towards a number of people who have contributed to finishing this project.

First, I would like to thank my supervisory team: Gerd and Jo. Thank you for your patience, support, constructive feedback and occasional 'nudge' in the right direction.

Next, I would like to thank everyone else who kept supporting me during my project. Daniil, Reda, Resul and Emilio, for giving me insight in their life as wheelchair users during our interviews and user testing. Rienk from The Hague University of Applied Sciences, for introducing me with the world of wheelchair kinematics. My parents, Vladimir and Tatjana, for their support. And, of course, Emma, for daily motivation, checking my spelling and being there every step of the way.

Enjoy reading!

Dima Politin



Executive summary

The human body is not built optimally for wheelchair use. Maintaining sedentary position for long periods, being relatively less physically active and using the arm and shoulder muscles for propelling increases potential health risks. Common examples are obesity, diabetes, cardiovascular diseases, several types of cancer, pressure ulcers and overload of the muscles and joints.

Wheelchair users of all ages are advised by their medics to be as active as possible, relieve pressure on the buttocks as often as they can and to maintain a proper posture to reduce high pressure and shear forces on the skin and decrease the chance on spine problems. Most wheelchair users have difficulties to support this kind of lifestyle.

To study how human behavior can be changed effectively, theory of behavioral science, decision-making and persuasive technologies is explored. This study will conclude in a set of principles and criteria that will be used for ideation.

Prior technological researches for sedentary behavior measurement and wheelchair mobility behavior is used as a starting point.

A vision is created based on the results from the analysis. The design statement of this project is stated as:

'Design a feasible novel concept that integrates behavioral intervention principles to improve wheelchair behavior.'

Hereafter, a strategy is created in which a wheelchair and smartphone application are used to persuade the user into improved behavior, using the motivational principles: self-monitoring, data visualisation, goal-setting, coaching, rewarding and social interaction.

User interaction for both products is developed and tested using digital and rapid prototyping. In total, three prototypes are developed to test the features of the design. The first prototype is used to test the desirability and meaning of posture guidance, the second prototype simulates the wheelchair-user and user-wheelchair interaction and the last prototype is used to test the application structure and features.

One wheelchair user and two able-bodied participants are asked to explain the meaning of the interactions. Based on the insights from this research the concepts are redesigned. The research concludes that the features do have a motivational effect on people, but future research with a fully functional prototype should prove its effectiveness over time.

Lastly, a novel concept is designed by integrating the wheelchair interface and feasible technology in a design for an armrest of a wheelchair.

A recommendation is made to do research on maximizing the accuracy of posture estimations with minimal force sensitive resisitors, since these are the components responsible for the highest costs and energy supply. Also, suggestions for other appliances of the wheelchair data are discussed.

1. Approach & Assignment

In this chapter, the reader will be introduced to the report in which the process and report structure will be presented. Furthermore, the assignment and approach will briefly be discussed which will explain the different phases of this graduation project.

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Image 1 Artistic picture of a wheelchair and its user. Taken from: https://uk.rs-online.com/

1.1. Project introduction

1.1.1. Wheelchair users

The World Health Organisation (WHO, 2010) states that there are 65 million wheelchair users in the world. These physically or mentally impaired users depend on their wheelchair as an aid to translocate themselves to another location, either by being pushed by another person, powered by an electric motor or propelling themselves. Having an appropriate, well-designed and fitted wheelchair not only enhances mobility and independence, but also opens a world of daily activities, education, work and social life, improving their quality of life. (WHO, 2008)

1.1.2. Physcal inactivity and sedentary lifestyle

Physical activity is bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen, Powell and Christenson, 1985). Physical activities frequently are classified by their intensity using the MET as a reference. MET refers to metabolic equivalent for a task, and 1 MET is the rate of energy expenditure while sitting at rest. One MET is the equivalent to 1 kilocalorie per kilogram of body weight when the person is doing the task for one hour (PAGAC, 2008). The Physical Activity Guideline for Americans Committee (PAGAC) suggested a public health target range of 500 to 1,000 MET-minutes of moderate-to-vigorous physical activity or 150 to 300 minutes of moderate intensity physical activity per week (PAGAC, 2018). These guidelines are similar to those of other countries and also count for wheelchair users. Someone who does not meet these guidelines is considered having an inactive lifestyle.

Sedentary behavior has been defined as any waking behavior characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture (Tremblay et al., 2017). Inactive and sedentary lifestyles increase causes of mortality, double the risk of cardiovascular diseases, diabetes, and obesity, and increase the risks of some types of cancer, overall physical health and mental health (WHO, 2002; Sanchez-Villegas et al., 2008; PAGAC, 2018).

Since most activities are done in a sedentary position, this means the wheelchair users have much more difficulty reaching these guidelines. The majority of people with mobility impairments do not meet levels of physical activity recommended for health and disease prevention. Next to having a chronic disability, people using wheelchairs have an increased risk in contracting significant and costly secondary complications, such as obesity, diabetes, osteoporosis, and cardiovascular co-morbidities due to insufficient activity, shoulder and carpal tunnel injuries due to wheelchair propulsion, pressure ulcers, scoliosis or postural and pelvic deformities due to sitting duration and posture. The effects of age and duration of injury leads to significant increases in the cost associated with their healthcare (Requejo, Furumasu and Mulroy, 2015).

Secondary complications occur mostly because of poor sedentary postures, inactivity, propelling and prolonged sedentary bouts. Individuals who perform no or little moderate-to-vigorous physical activity, no matter how much time they spend in sedentary behavior, can reduce their health risks by gradually adding some or more moderate-intensity physical activity. Replacing sedentary behavior with light-intensity physical activity already reduces the risk of all-cause mortality, cardiovascular disease incidence and mortality, and the incidence of type 2 diabetes. (PAGAC, 2018)

Wheelchair users could benefit from improved wheelchair behavior. Research tells that proper wheelchair behavior decreases risks of injury and disease and improves health significantly.

1.1.3. Technological developments

There is an increase of people that are interested in tracking their activities. It is not only a trend to track one's sports activities to help them achieve personal goals and gain fitness, there is also an increase in monitoring activity levels, medication use, weight, sleep patterns, rehabilitation progress, and other personal health data, ultimately empowering them to improve clinical outcomes (AAOS, 2016). By doing so, users get to know their own body much better. These trends began after the introduction of tracking technology in professional sports and out of medical necessity. The understanding of the activity patterns and the evolution of tracking technology resulted in the possibility to produce affordable consumer products.

Millions of people are using the Nike+ Running App during their daily run (Welch, 2016). In 2017 alone, more than 15 million Fitbit products have been sold (Statista, 2018) making it able to track walking activity. Apple has one of the only and first features for their Apple Watch based on quantified research that can be used by wheelchair users to track their activity (Image 2). These activity monitors use sensors (smartphone, smartwatch or device) attached to the user's body (wrist, chest or ankle) to measure movement and body functions, while other products use GPS to measure movement activity outdoors.

Two researches prior to this project helped shape this graduation project. Researchers at the The Hague University of Applied Sciences are researching the use of inertial sensors and kinetic algorithms to create knowledge and insights in the movements of athletes in wheelchairs (Image 4). They already achieved achieved success during their first project by prodiving significant data and visualizations in the form of graphs and numbers to athletes and for insightful research (Van der Slikke, 2015). The second project was a previous graduation project focussed on measuring sitting posture and sitting duration. The graduate researched measuring sitting postures of wheelchair users using sensors in the seating surface of the wheelchair (Image 3). The project resulted in significant data that can be used to inform the user about poor seating postures and about the necessity of doing exercises to decrease the effects of prolonged sitting (Liu, 2018).

These two researches will be used as a starting point. This project will build upon the knowledge that measuring mobility activity and sitting posture is possible. They were used as stepping stones towards a consumer product that would help manual wheelchair users improve their wheelchair behavior, decreasing their injury risks and increase their fitness.

1.1.4. Behavior change

The sedentary and physical activity behavior of wheelchair users is seen as an important factor in decreased health. Individual-level interventions can increase the volume of physical activity performed by youth and by adults, especially when the interventions are based on behavioral change theories and techniques (PAGAC, 2018).

Image 2 Apple's feature for wheelchair users, motivating the user to be more active. Taken from: Apple.com

Image 3 Prototype of Liu using force sensitive resistors to measure pressure distribution of the wheelchair user. (Liu, 2018)

In this project, there will be looked into the theory of behavior, decision-making and persuasion to increase the effectiveness of behavioral interventions used to change the behavior of wheelchair users. The aim of this thesis in the shape of a question is:

How can behavioral interventions be applied to improve the sedentary and physical activity behavior of the wheelchair user?

Project focus

The popularity of the use of activity and fitness monitors is increasing, which helps people gain insight in their everyday behavior. Being active increases health and lowers the risk of many diseases. Here, activity is important, as well as improper sedentary behavior, which can result in physical problems for wheelchair users. Wheelchair users are a risk group because of their sedentary lifestyle and could therefore use a nudge to improve their wheelchair behavior.

This project will focus on sedentary and physical activity behavior. The goal is to improve the health of wheelchair users by improving their wheelchair behavior using behavioral interventions.

Image 4 Prototype of The Hague University researchers, using inertial measurement units (IMU) to measure the movements of wheelchair athletes. The data is processed and used to calculate metrics and visualized into graphs and numbers. (Van der Slikke et al., 2016)

1.2. Assignment

1.2.1. Scope

This graduation thesis is written in the context of wheelchair users and their problems with their wheelchair due to their physical activity and sedentary behavior. The main subjects of this project will be wheelchair users and their behavior, improving behavior using behavioral interventions and the integration of technology.

1.2.2. Project aim

The goal of this project is to provide wheelchair users with a solution that is a valuable addition to their life. It will be done by analysing the current wheelchair experience and designing behavioral interventions that will improve the experience and improve the wheelchair behavior of the wheelchair user to reduce physical problems and increase health benefits using only wheelchair-bound technologies and personal smartphone devices.

1.2.3. Assignment

The assignment has been formulated as:

"Design behavioral interventions in the current wheelchair experience that improve wheelchair behavior regarding physical activity and sitting behavior."

The value of this thesis will be will be found in creating an understanding of the problems of wheelchair users due to wheelchair use, technology and insights from prior research will be used as a starting point to design a novel wheelchair architecture with a strategy of using behavioral interventions to nudge the user into improven wheelchair behavior. Concept of this will be developed and user tested. The findings will be used to design a concept for a novel product and recommendation for further development.

1.3. Project approach

1.3.1. Project process

The project structure of this graduation thesis is based on the basic design cycle as mentioned in the Delft Design Guide (Boeijen et al., 2014). A visualisation can be seen in Figure 1. The process looks linear, but is actually a lot more iterative.

In this project the whole context of wheelchair use will be examined. Methods from service design approach will be used to create a holistic view and find pain-points and possibilities. All used approaches and methods will be based on the Delft Design Guide.

Analysis

The most problematic effects of wheelchair use on physical health were identified using interviews and literature research. These insights together with literature research of behavioral change theories and methods, these two topics were used as the theoretical background for the project.

– **Summary on page 42**

To understand the context of the problem, an understanding was needed to know who, how, where and when problems occur. An analysis was done of the wheelchairs, users, use environment and user journey, based on interviews with wheelchair users, literature research and brainstorms. This chapter concludes in requirements, insights and opportunities for the project.

– **Summary on page 64**

By analysing the existing markets, trends and technologies, more requirements, insights and opportunities were found.

– **Summary on page 82**

Combining the insights from the analysis phase were used to create potential opportunities. Insights and opportunities from the analysis phase will be summarized and requirements will be presented.

– **Summary on page 84**

Synthesis

A product strategy and design brief were formulated with the use of all knowledge. The objectives were defined as to develop a solution for an interface for the wheelchair, a smartphone interface and a feasible technology framework.

– Design brief on page 98.

Simulation

Fitting behavioral interventions were ideated, using principles from theoretical background. The objectives for the two interfaces were developed using iterative ideation, evaluation, prototyping and user testing. The wheelchair and smartphone interface concepts were built into prototypes to perform user testing.

– Final design on page 140

Evaluation

The design criteria from the design brief were used to validate the prototype. The final prototype is used for the last user testing. The findings from this testing are written into a conclusion and recommendations for future development.

– Conclusion and discussion on page 142

1.4.2. Reader's guide

Each phase starts with a chapter introducing the approach. At the end of every chapter, a conclusion can be found. The key findings, insights and requirements are shown on these pages. In this report, references to diagrams and graphs are defined as figures, references to pictures and images retrieved from the internet are defined as images.

If you do not have the time to read the whole report

You can find important findings and definitions in highlighted text

Read the main decisions in the colored boxes

Read the key take-aways in the grey boxes

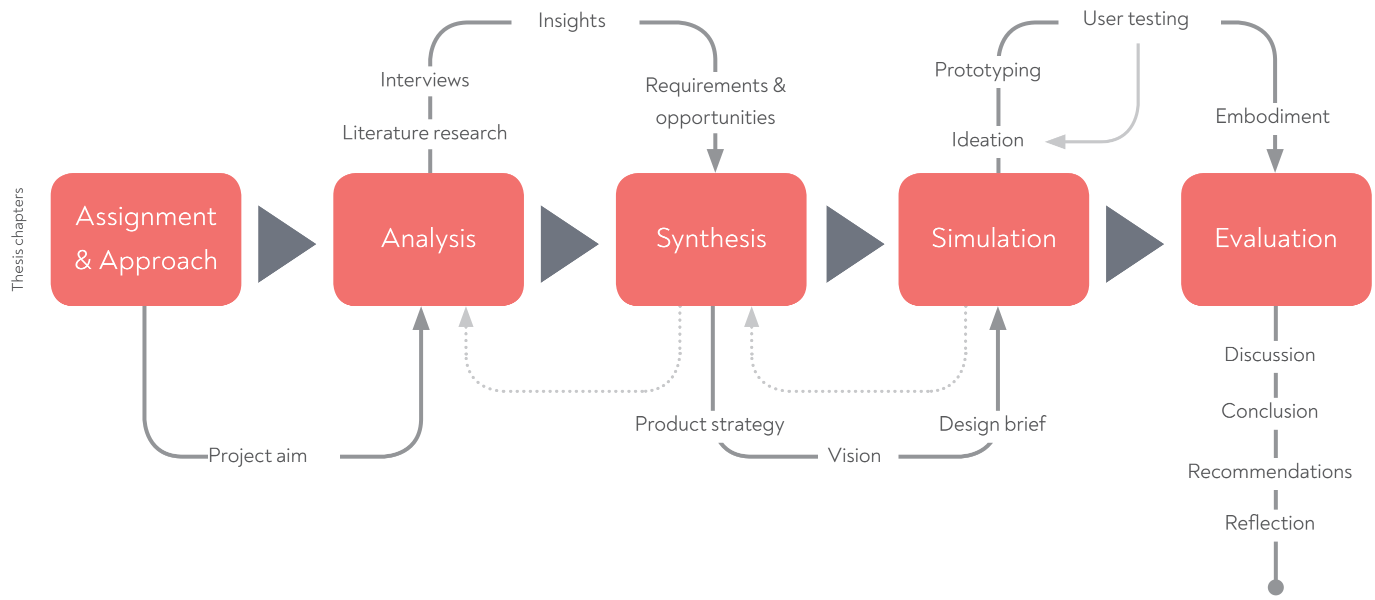

Figure 1 The design process of this project is inspired by the Basic design cycle from the Delft Design Guide (Boeijen et al., 2014). When knowledge is missing during the synthesis or simulation phase, more analysis is done to fill the gap.

2. Analysis

This phase starts by analysing the main physical problems from wheelchair use and behavioral intervention methods and principles, which will be the theoretical background of the project. The analysis of the wheelchair, user, use and use environment concludes in a holistic view on the context and in requirements and opportunities for the project. Market and trend are used as inspiration for the project and to understand the business-related requirements.

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2.1. Approach

To be able to create an improved experience for wheelchair users, all existing and new knowledge needs to be collected and found. To get a holistic view on the user, context, theory and market, this chapter will consist of three pillars (Figure 2).

2.2. Theoretical background

In the theoretical background, the theory behind the problems and behaviors of the wheelchair users can be read. In addition, the theory on behavioral economics, which will be used as inspiration for the solutions:

- **Wheelchair behavior theory**. *What are the most common physical problems due to wheelchair use? How to reduce these problems?*
- **Behavioral science theory**. *How does behavior work? How do people make decisions? How can behavior be changed using behavioral interventions (BI)?*

2.3. Internal analysis

It will start with the internal analysis to understand the people in the context and their current procedures and use situations:

- **Stakeholders**. *Who is the target group?*
- **Wheelchair users**. *How does the target group look and live?*
- **Wheelchairs**. *What is a wheelchair? What are the limitations on designing for wheelchairs?*
- **User journey**. *How does the current procedure of obtaining a wheelchair look? What problems will be solved in this project?*
- **Use environment**. *How is the wheelchair used? What kind of environments is the wheelchair used in? What requirements do these environments produce?*

2.4. External analysis

In the external analysis, an understanding is built up on what is currently happening in the market of wheelchair and monitoring. Also, an analysis of how competitors use technology and BI to monitor and influence behavior:

- **Trend analysis**. *What are developments need to be taken into account while designing a new solution?*
- **Competitor analysis**. *How do other products measure activity, visualize information and use behavioral interventions? What can be learned and improved?*
- **Technology analysis**. *What is needed to for functional measurement?*

2.5. Requirements and design criteria

In the last chapter an overview will be presented of the requirements and criteria for product development.

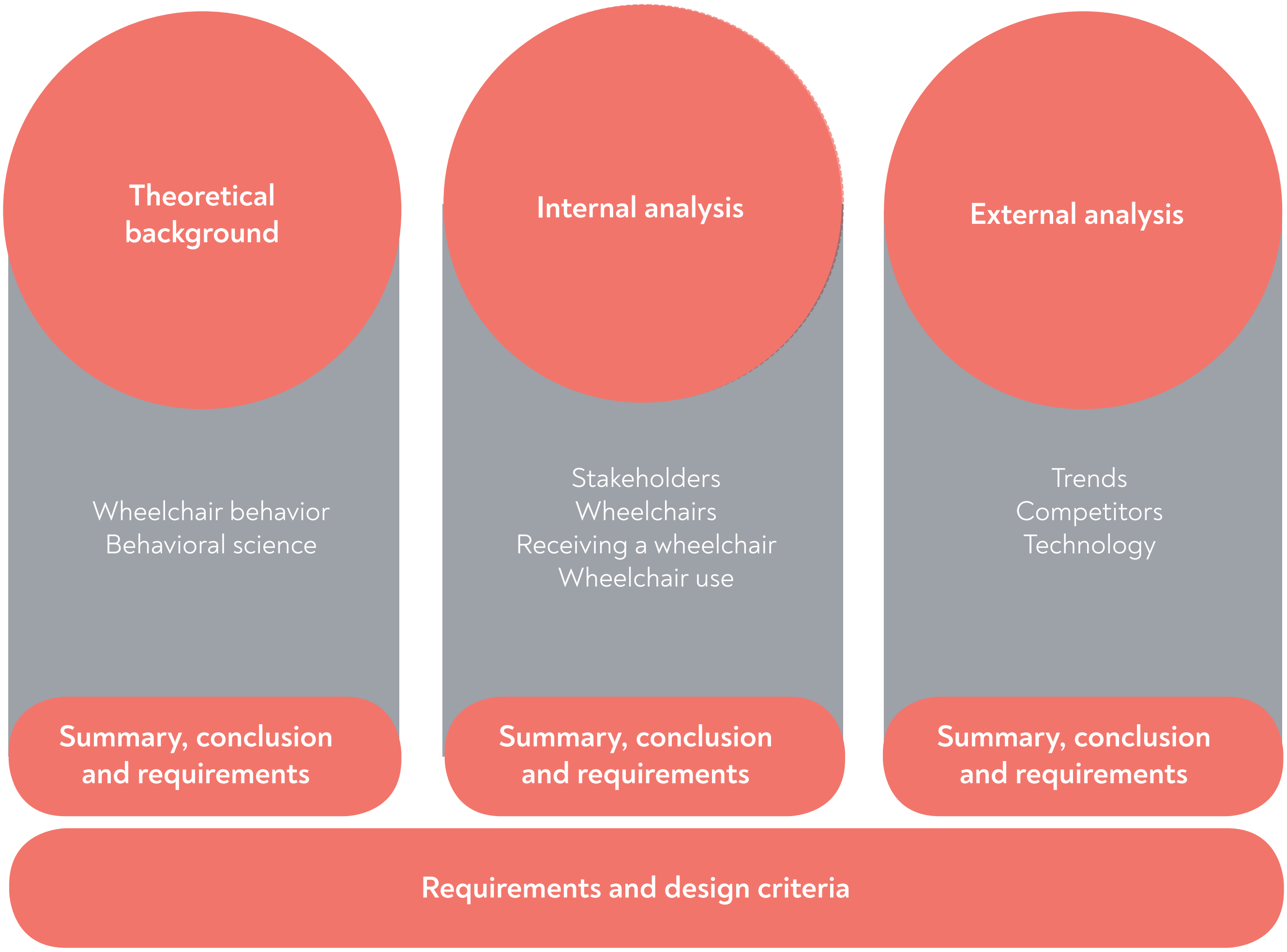


Figure 2 Three pillars of analysis resulting in the requirements for the project.

2.2. Theoretical background

In this chapter, the literature analysis is done for the causes and solutions of potential wheelchair problems and the way behavioral science can be used to influence behavior.

2.2.1. Wheelchair behavior and problems

Wheelchair problems can occur due having a poorly fitted wheelchair and poor wheelchair behavior.

A wheelchair, especially one that will be used for lengthy durations, should support the body in an upright and functional posture. Poorly fitting wheelchairs are likely to result in poor posture that will result in higher pressure and increased pressure ulcer risk (Sprigle, 2014). Appropriate wheelchairs can serve to reduce common problems such as pressure sores, the progression of deformities or contractures, and other secondary conditions (WHO, 2008). In this project, the focus will not be on designing a perfect wheelchair, but solely on changing wheelchair behavior. Thus, theory for fitting wheelchairs and wheelchair manufacturing will be excluded from this report.

Within wheelchair behavior, four risk behaviors are identified, that increase the health risks of the wheelchair user. The risk behaviors in the category of physical activity can be defined as insufficient physical activity and sudden peaks in physical activity. The risk behaviors in the category of sedentary behavior are defined as a combination of prolonged sedentary bouts, insufficient pressure relief and poor posture (Figure 3).

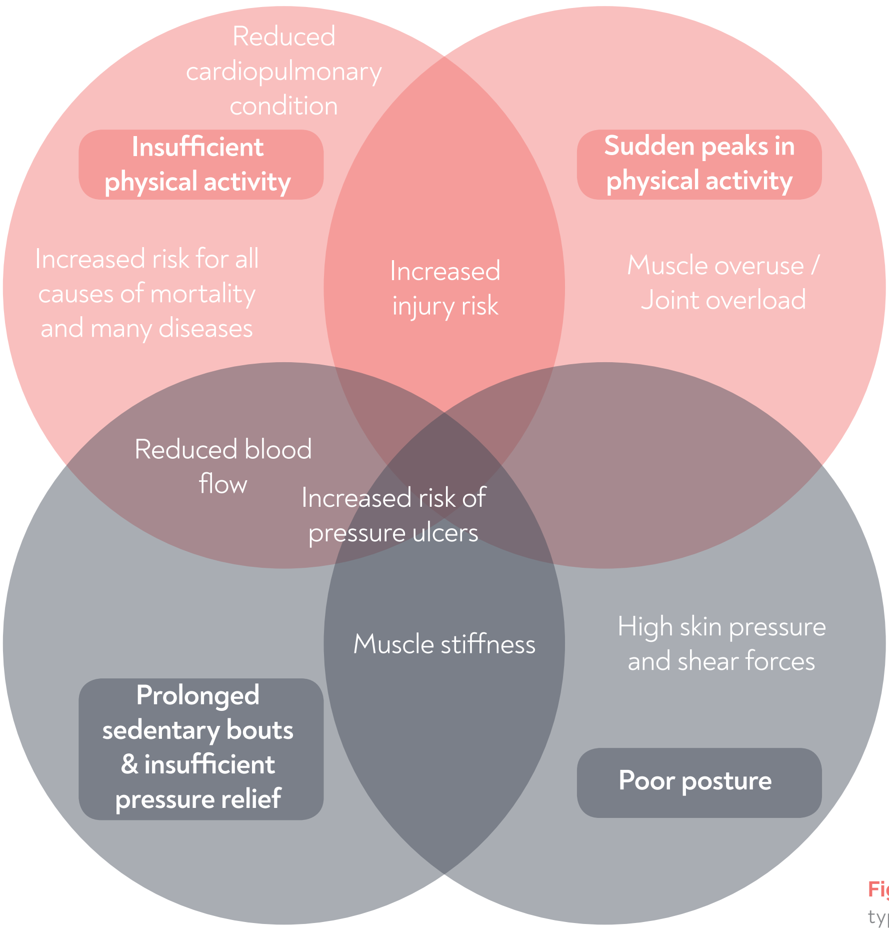


Figure 3 Summary of health risks due to four types of risky wheelchair behaviors

2.2.2. Insufficient physical activity

Physical activity is any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen, Powell and Christenson, 1985). Physical activities frequently are classified by their intensity using the MET as a unit of reference. MET refers to metabolic equivalent for a task, and 1 MET is the rate of energy expenditure of an able-bodied person while sitting at rest and is equivalent to the use of 3.5 ml of oxygen per kilogram per minute (VO2), and is the same as 1 kilocalorie per kilogram of body weight when the person is doing the task for one hour (PAGAC, 2008). Other definition are:

$$1\ \text{MET} = 1\,\frac{\text{kcal}}{\text{kg}\times\text{h}} = 4186.8\,\frac{\text{J}}{\text{kg}\times\text{h}} = 1.163\,\frac{\text{W}}{\text{kg}}$$

The Physical Activity Guideline for Americans Committee (PAGAC) suggested a public health target range of 500 to 1,000 MET-minutes (intensity of the task in MET multiplied by the duration of the activity in minutes) of moderate-to-vigorous physical activity. To make it easier to grasp for 'normal people' the guidelines are defined as 150 to 300 minutes per week of moderate-intensity physical activity or 75 to 150 minutes of vigorous-intensity physical activity. Adults with chronic conditions or disabilities, who are not able to meet the above key guidelines, they should engage in regular physical activity according to their abilities and should avoid inactivity (PAGAC, 2018). These guidelines are similar to those of other countries and also count for wheelchair users. Someone who does not meet these guidelines is considered having an inactive lifestyle (Tremblay et al, 2017).

Physical activity intensity is defined using MET as a unit as seen in Figure 4. Sedentary behavior has been defined as any waking behavior characterized by an energy expenditure ≤1.5 METs while in a sitting or reclining posture, and is also called passive sitting (Tremblay et al., 2017). Physical activity done while seated characterized with an energy expenditure >1.5 MET is called active sitting.

Inability to walk and use muscles in the legs to activate energy expenditure means that achieving the target of physical activity is much harder for people in wheelchairs.

Light intensity	1.1 - 2.9 MET
Moderate intensity	3-5.9 MET
Vigorous intensity	>6 MET
Sedentary behavior	<1.5 MET (while sitting, reclined or lying)

Figure 4 Physical acitivity intensity definitions

Example	Wheelchair User Energy Cost (kcal·kg^{-1}·hr^{-1})	Able-bodied Energy Cost* (METs or kcal·kg^{-1}·hr^{-1})
Dusting	1.8	2.3
Mopping	3.5	3.5
Vacuuming	2.7	3.3
Bed making	2.3	3.3
Dressing/undressing	3.1	2.5
Showering	1.9	2.0
Washing dishes	1.6	1.8
Driving	1.8	2.5
Grocery shopping	1.9	2.3
Fishing/casting	1.2	2.0
Deskwork	1.1	1.3
Sitting/reading	1.1	1.3
Sitting/watching TV	1.1	1.3
Resting (supine, awake)	0.8	1.0
Flat, firm surface (2 mph)	3.3	2.8
Flat, firm surface (3 mph)	4.3	3.5
Circuit training	2.3	4.3
Weight Training	2.2	3.5
Basketball (game play)	6.1	8.0
Basketball (shooting baskets)	3.2	4.5
Billiards	1.8	2.5
Bowling	1.8	3.0
Darts	1.6	2.5
Fencing	7.1	6.0
Nordic sit skiing	11.8	15.0
Table tennis	2.2	4.0
Tennis	4.1	7.3

Figure 5 Comparison of MET values for specific tasks of wheelchair users compared to able-bodied people (Conger and Bassett, 2011) .

The problem for wheelchair users, especially for those with spinal cord injuries (SCI), is that their resting oxygen consumption (VO2) is lower. The fact that wheelchair users have reduced function in the lower extremities, changes their VO2 rate. For them, 1 metabolic equivalent (MET) should be defined as 2.7 ml O2/kg/min. Therefore, quantification of physical activities must be approached differently than for able-bodied individuals (McCormick et al., 2015). Also, people with disabilities have lower rates of MET during most daily activities compared to able-bodied people, except for wheeling/walking at the same speeds (Figure 5) (Conger and Bassett, 2011).

Health risks

Since most activities are done in a sedentary position and many tasks require 20% less energy expenditure than for able-bodied people, wheelchair users have much more difficulty reaching the guidelines. The majority of people with mobility impairments do not meet levels of physical activity recommended for health and disease prevention (Requejo, Furumasu and Mulroy, 2015). Inactive and sedentary lifestyles increase all causes of mortality, double the risk of cardiovascular diseases, diabetes, and obesity, and increase the risks of some types of cancer, overall physical health and mental health (WHO, 2002; Sanchez-Villegas et al., 2008; PAGAC, 2018). Next to having a chronic disability, people using wheelchairs have an increased risk in contracting significant and costly secondary complications, such as shoulder and carpal tunnel injuries due to wheelchair propulsion, pressure ulcers, scoliosis or postural and pelvic deformities due to sitting duration and posture. The effects of age and duration of injury leads to significant increases in the cost associated with their healthcare (Requejo, Furumasu and Mulroy, 2015)

Due to muscle inactivity (slouched posture, low physical activity or those whose wheelchair is pushed by others) wheelchair users suffer from weakened core muscles. A weakened core results in less muscle power to maintain a proper sedentary posture. As an effect, the body slips in a poor sitting position more easily.

Target behaviors

Physical activity is important to maintain a healthy weight, good mood, energy, proper blood circulation and overall health benefits. By pumping harder and breathing faster and deeper, the heart and lungs stay in good shape and the blood brings nutrition and oxygen to the muscles and skin.

People are advised to be as active as possible, with additional physical activity resulting in additional health benefits. Individuals who perform no or little moderate-to-vigorous physical activity, no matter how much time they spend in sedentary behavior, can reduce their health risks by gradually adding some or more moderate-intensity physical activity. Replacing sedentary behavior with light-intensity physical activity already reduces the risk of all-cause mortality, cardiovascular disease incidence and mortality, and the incidence of type 2 diabetes (PAGAC, 2018).

To gain health benefits, physical exercises are needed to be done by the wheelchair user. Manual wheelchair propulsion (MWP) represents a readily available and commonly used form of physical activity for wheelchair users (McCormick et al., 2015), classified as a way of active sitting. Increasing physical activity should be done in a controlled way to reduce injury risk.

Image 5 Illustrative image. Taken from: IntelliWheels.com

Key take-aways

Some activity is better than no activity. Individuals should therefore be physically active as much as possible and, ideally, transcend guidelines to gain health benefits.

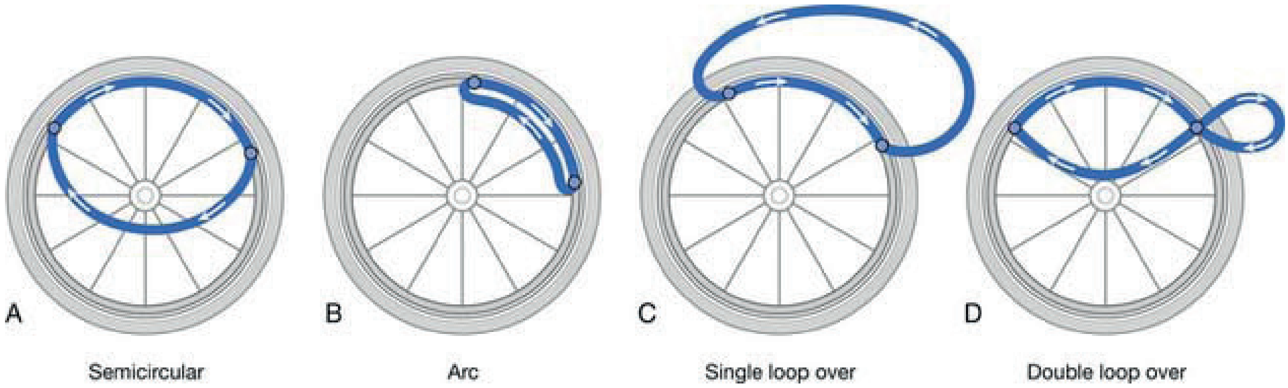


Image 6 Different propulsion techniques analyzed by Slowik (2015)

2.2.3. Sudden peaks in activity

The human body is not optimized for the use of wheelchairs. When propelling a wheelchair, the shoulder and arm muscles are the primary muscles that are used, in contrast to the legs during walking. This results in problems, because of over- and under-use of muscles.

Skeletal muscles use energy to move the body. To propel a manual wheelchair, the user needs to grab the rim of the wheel and push it forward to move forward. The exerted force from the hand results in torque in the joints of the wheelchair user. The volume, intensity and duration of the activity determines the total load on the body.

Health risk

When propelling a wheelchair, the majority of the forces are applied to the shoulder of the user. Ergonomics studies consistently suggest that there is a link between highly repetitive tasks and the occurrence of upper extremity pain and injury (Boninger et al., 2005). Prolonged repetitive motion, pushing technique and peak forces are factors that can result in overload of the shoulder muscles and joint, which on its turn shows as discomfort or body pain. Sudden overuse or prolonged underuse can have negative effects on the body and can result in a longer rehabilitation period and/or body pain.

Target behavior

Wheelchair users should have the proper knowledge of propulsion techniques to reduce the risk on shoulder injuries. Wheelchair users should be given advise on their propulsion behaviour. Consultation about the right pushing technique can reduce the load on the shoulder. For example, the semicircular and the double loop over propulsion (DLOP) had the lowest muscle stress in a research of Slowik (2015) (Image 6).

When needed, the user is advised to train the shoulder muscles with additional exercises in a controlled environment to make the muscle stronger, making them able to withstand more stress.

Increasing physical activity should be done in a controlled way to reduce risk of injury.

Key take-aways

Unusual high intensity activities and workload increase injury risk and potential muscle and joint overload.

2.2.4. Prolonged sedentary bouts & insufficient pressure relief

Sedentary time is defined as the time spent for any duration in sedentary behaviors and a sedentary bout is defined as a period of uninterrupted sedentary time (Tremblay et al., 2017). In this report, the term sedentary behavior will also be used to refer to behaviors while sitting (posture and pressure relief).

Wheelchair users are sedentary for almost the entire day while awake. The median daily wheelchair occupancy of wheelchair users is 11.2 hours (Sonenblum, Sprigle and Lopez, 2012).

Health risks

Health effects of sedentary time have been studied over the past decade with most studies showing negative associations between sedentary time and health outcomes in both adults and youth (Rivière et al., 2018). Excessive sedentary time has been associated with mortality independent of moderate-to-vigorous-intensity physical activity (Koster et al., 2012). Sedentary time and low physical activity are accountable for most secondary implication due to wheelchair use.

An estimated 36-50% of wheelchair users experience discomfort or pain due to pressure ulcers (Geyer et al., 2001). Due to prolonged exposure to high interface pressure, the blood flow gets restricted, resulting in a decreased supply of nutrients and oxygen to the tissue. This often happens in the contact areas as seen in Image 7. Most often pressure ulcers occur on the tailbone or buttocks, shoulder blades and spine, and on the backs of their arms and legs. If such a situation is maintained over a period of time, ulcers can occur on the skin of the person. In extreme situations ulcers can develop into ischemic necrosis in the affected area, which means that the skin and bone tissue are dying.

Prolonged sedentary bouts are not the only factor. Other external factors, such as shear stress in the skin due to sitting posture, friction, increased skin temperature and humidity of the skin, influence the evolvement of skin ulcers. Frequently cited internal causes are age, physical condition, degree of mobility, sitting posture, quality of skin and tissue, reduced sensibility (e.g. paraplegic patients), reduced reasoning, incontinence and nutrition (Eitzen, 2004) (Figure 7). Although numerous additional factors have been identified as contributing to pressure sore formation, the application of pressure over time is considered the primary cause of the complication (Grip and Merbitz, 1986).

Researchers found that 7.1% of elderly who had an ulcer while in hospital stayed in hospital for 19 days compared to 9.9 days for other older patients (Theisen, Drabik and Stock, 2012). This, in turn can result in the need of more care and an increase in health care costs. Reducing this problem not only benefits the user, but also the health care system.

A prolonged sedentary bout is also one of the reasons of discomfort. After a while stiffness of the muscles can occur.

Target behavior

Guidelines suggest performing pressure relief every 30 minutes lasting 30 seconds for individuals who can do so independently (Sonenblum et al., 2014). If this rule is not applied, a longer sedentary bout requires a longer pressure relief bout. If possible, it is best to stand up, but when this is not possible, stretching, weight-shift and pressure relief exercises can reduce health risks.

Pressure relief can be done by lifting the buttocks from the seat (if possible), leaning from side to side to relieve pressure of one side or leaning forward and sliding the hands underneath the buttocks, lifting them (Image 8 & Image 9).

Not all of the factors of pressure ulcer risk can be influenced by wheelchair behavior. The focus for this project will be on the duration of the sitting and the seating position. Temperature and humidity of the sitting interface could be influenced by the design of the wheelchair seat or measured using sensors.

Key take-aways

Frequent pressure relief of the buttocks allows bloodflow to the skin and reduces the risk for pressure ulcers.

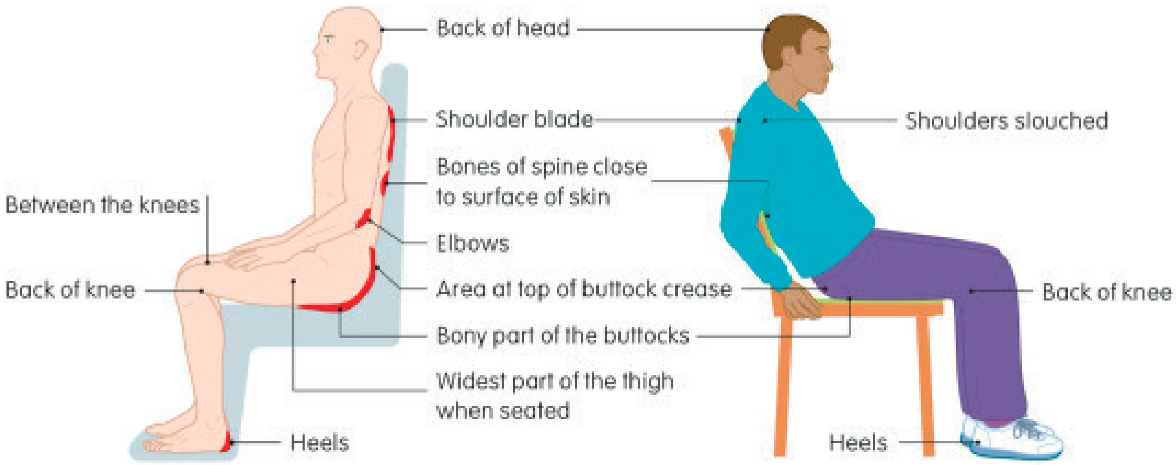


Image 7 Areas of the body most probable to be affected by pressure ulcers due to poor sitting posture. (Stephens & Bartley, 2018)

Image 8 Relieving pressure from the buttocks by leaning to one side, for blood circulation. (Stephens & Bartley, 2018)

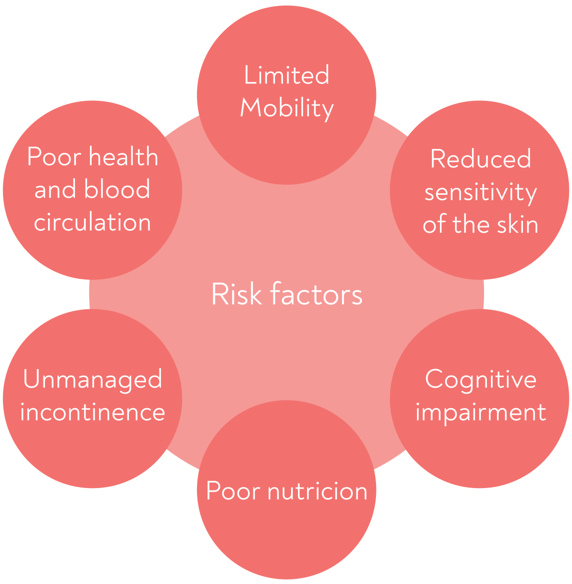


Figure 7 Factors affecting the occurance and development of pressure ulcers. (Stephens & Bartley, 2018)

Image 9 Relieving pressure from the buttocks by leaning forward for blood circulation and stretch. (Stephens & Bartley, 2018)

2.2.5. Poor posture

One of the causes of body pains for people in general is sitting with poor posture. When sitting in a wheelchair for almost the entire day, this problem becomes a lot bigger. By approaching the ideal sitting position and maintaining a healthy posture the problems should be minimized.

To understand what a healthy sitting posture is, it is important to understand the human anatomy concerning sitting. The position of the head, the curvature of the spine and angular tilt of the pelvis are considered as most important factors in sitting posture.

The human spine is curved in a natural s-curve in the sagittal plane. This curve consists of the pelvic (kyphotic), lumbar (lordotic), thoracic (kyphotic) and cervical (lordotic) curvatures. A healthy spine is also straight in the coronal plane (Image 11).

This healthy curvature is maintained by sitting on the sitting bones (Ischial tuberosity) and by keeping the pelvis symmetrical in the coronal and transverse plane with minimal tilt. This is assessed by measuring the angle of the ASIS and PSIS line (Image 13). Tilt backwards is called posterior, rotation forward is called anterior.

A healthy seating position is achieved when the person has a:

- Straight position of head
- Physiological curvatures of sagittal plane and
- straight spine in coronal plane (Image 10)
- Well-formed chest
- Shoulders slightly backward in relation to pelvis
- Symmetrical alignment of pelvis.

The diagnosis of an abnormal spine posture can be called kyphosis, lordosis or scoliosis, based on the type of deformity (Image 12) and tilt of the pelvis. A wheelchair should be designed in a way that the user can sit in a proper sitting position for their body. It should contain a healthy curvature in the sagittal plane and a straight line coronal plane, or a modified special position if necessary.

The pressure should be distributed over the back, buttocks and footrest in such a way that the user is comfortable, which is often accomplished by obtaining even pressure distribution, minimal friction and minimal shear forces on the skin.

Poor posture can also occur due to behavior. With regard to sedentary behavior in a wheelchair, the most common poor postures can be described as a slouched kyphotic posture, and asymmetry due to pelvic obliquity (Sprigle, 2014).

Health risks

When the spinal curves change due to sedentary behavior, this results in tension and pain in the muscles and can develop physical complications over time. Especially late adults and elderly are typically faced with increasing postural deformities that negatively impacts their ability to function in a wheelchair. Kyphosis and scoliosis are common spinal deformities due to a muscle imbalance, osteoporosis, weakness or paralysis and immobilization. The most common problem associated with kyphosis and scoliosis is pain, usually more in the lumbar (lower spine) than in the thoracic (upper spine) (Requejo, Furumasu and Mulroy, 2015).

Improper postures also result in high pressure and shear forces on the skin, which increases the risk of pressure ulcer development, like explained in chapter 2.2.4.

Kyphotic and lordotic posture

Postural kyphosis or lordosis is an abnormally excessive convex curvature of the spine in the sagittal plane. Both can be caused by physical deformity or trauma, but can also be developed after a long period of poor posture. In this chapter the focus will be on discussing these curvatures as a result of poor sitting positions in wheelchair use.

Kyphosis often occurs when a person who is seated is slouching and occurs in the thoracic curvature. It can be seen in two types of sitting postures, sitting with the buttocks forward leaning backwards (slouched) and sitting with the buttocks backward and leaning forward (Image 15 & Image 16).

Like normal chair users, wheelchair users tend to slouch and slide the buttocks forward in their seat, while having a posterior tilt in their pelvis. Wheelchair users do this

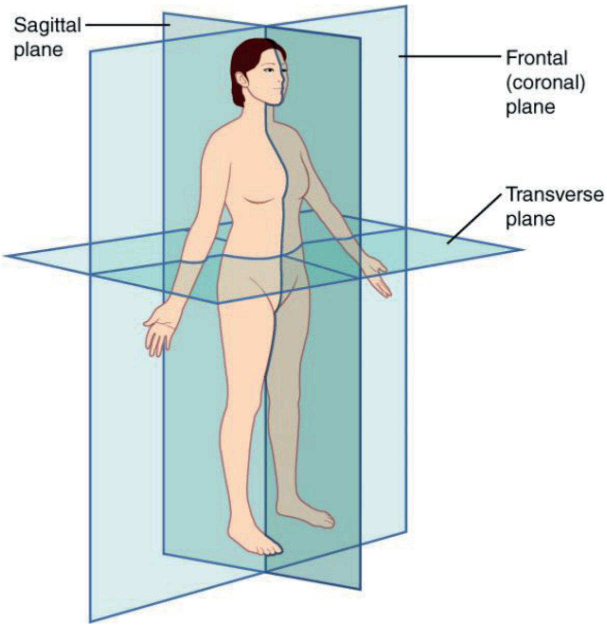


Image 10 Definition of the three planes used to discribe cross sections. Retrieved from: https://biologydictionary.net/sagittal-plane/

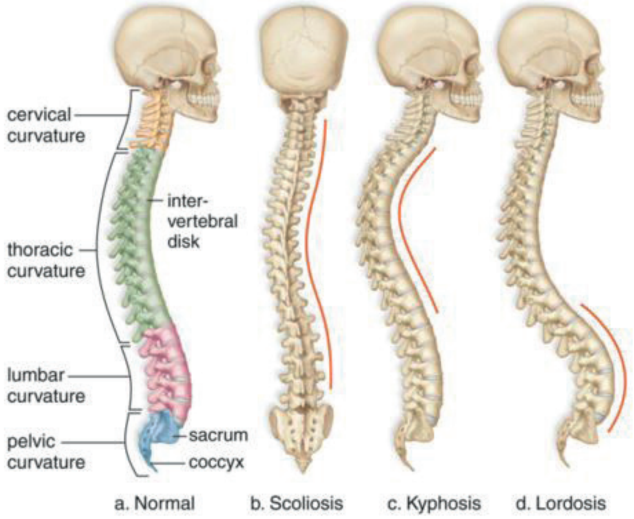


Image 12 Physiological curvatures of the spine. Examples of scoliosis, kyphosis and lordosis, which are definitions of excessive curvatures. Retrieved from:

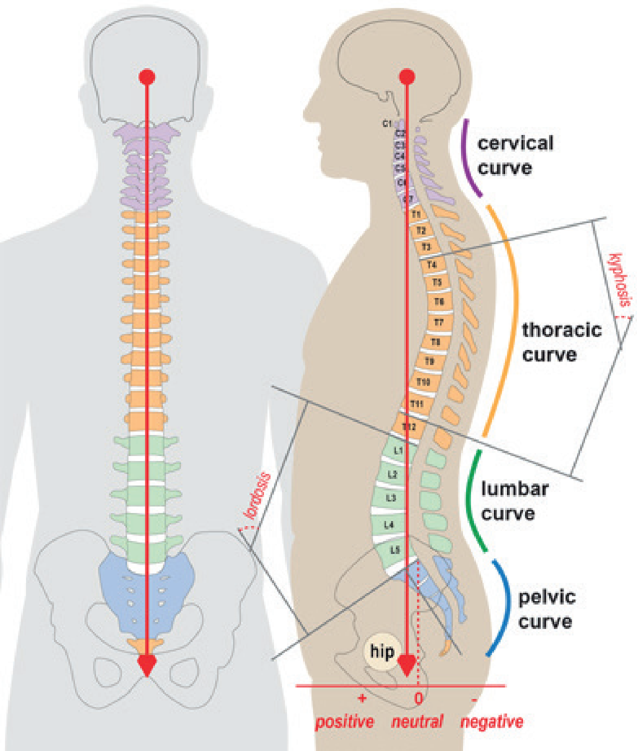


Image 11 Healthy physiological curvatures of the spine from the coronal and saggital plane and definitions of the curves. Retrieved from: http://www.mayfieldclinic.com/

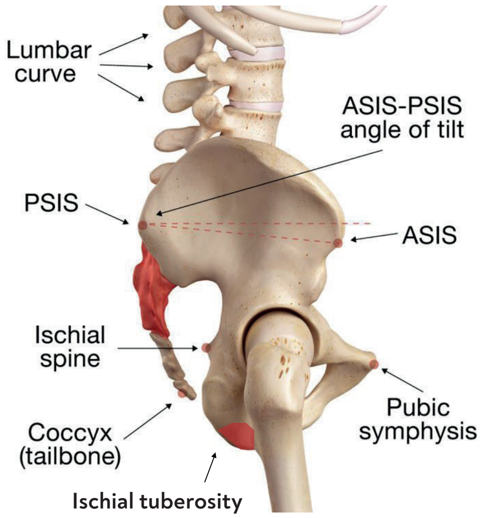


Image 13 Pelvis in saggital plane view. ASIS-PSIS line is used to measure tilt in pelvis. For healthy posture this angle should be minimal. Image retrieved from:

to increase stability or to reach the floor, when the dimensions of the wheelchair are not ideal for their body. This sitting position results in muscle tension in the lower back and increased pressure and shear forces on the back and buttocks. Doing this, the user has a higher chance on developing posture-related back problems and pressure ulcers.

Another improper sitting position is sitting deep in the chair and bend the upper body forward and occurs during activities when the user does something that is not within close reach. This position results in tension in the upper back and neck, also resulting in potential pain problems.

It is also possible for the person to have an abnormal excessive curvature in the lumbar and cervical curvature, this is called lordosis (Image 17). This is often caused by weakened abdominal muscles or due to heavy weight pressuring the lordotic curvature inward. In wheelchair use, this posture does not often occur due to sitting posture behaviour, but due to medical reasons. This curvature deformity is often controlled by changing the curvature of the seat and support.

Kyphotic posture can worsen over time and develop into hyperkyphosis. The posture also results in more pressure and shear forces on the buttocks and back. It can occur that the curvature results in impaired respiration, problems with swallowing food and excessive pressure on the intestines. If the position of the head cannot be positioned forward the person will experience decreased interaction with other people and isolation. The effects of postural kyphosis are reversible by correcting muscular imbalances, by having a fitting wheelchair and proper wheelchair use.

Scoliotic posture
When a person has an asymmetric spine posture in the coronal plane it is called scoliosis. This can have multiple reason: pelvic obliquity, pelvic rotation, asymmetrical deformity of the pelvis and deformity of the spine due to genetics or trauma.

A pelvic obliquity can be a fixed deformity that is not readily corrected or a flexible asymmetry that can be corrected with proper postural support. A correctable pelvic obliquity can result from a variety of reasons linked to a poor wheelchair, such as sitting slightly to one side of a sling wheelchair seat or from having to lean over to reach an armrest, or to achieve requisite trunk stability (Sprigle, 2014).

Like obliquity, pelvic rotation can also be the reason of developed back pains. In this situation, a rotation of the pelvis occurs in the transverse plane, resulting in a twist in the spine.

Asymmetrical positioning of the pelvic bones affects the whole posture above. It can cause lateral flexion in the cervical spine and an asymmetrical position of the shoulders. By correcting the asymmetry with cushioning and support the pressure in the spine due to pelvic obliquity can be balanced. Pelvic rotation is often part of improper posture and requires a change in posture.

Target behavior
Proper posture, most often, results in the best pressure distribution and least amount of shear stress. By maintaining proper posture, the risk for pressure ulcers and body deformations will be minimized.

Periodic changes in posture (in-seat activity), weight-shift, pressure relief and stretch exercises will reduce the development of muscle stiffness, by allowing bloodflow to the muscles. A few examples of exercises are:

- Lift body to release pressure from buttocks
- Sideways lower back stretch: Stretching the muscles on the sides of the body and the back by leaning to a side with the arms in the air.
- Forward back stretch: Stretching the muscles of the back by leaning all the way forward and trying to touch the ground.
- Spinal twist: Stretching the side and back muscles by twisting the upper body
- Neck stretch: Stretching the neck muscles by shrugging and leaning the head in all four directions.

Key take-aways

Good posture should be maintained to avoid injury risk and body deformities.

Image 15 Leaning backward kyphotic posture (slouch) with posterior pelvic tilt in saggital plane view. Original image retrieved from: http://hub.permobil.com/

Image 16 Leaning forward kyphotic posture in saggital plane view. Original image retrieved from: http://hub.permobil.com/

Image 17 Leaning backward lordotic posture with anterior pelvic tilt in saggital plane view. Original image retrieved from: http://hub.permobil.com/

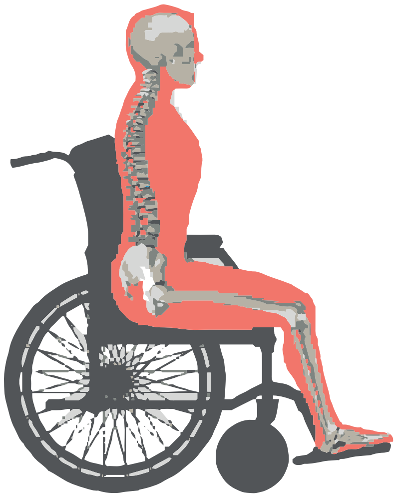


Image 18 Proper upright posture with no pelvic tilt in saggital plane view. Original image retrieved from: http://hub.permobil.com/

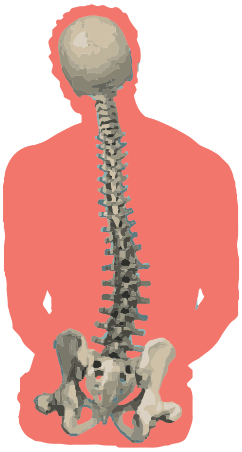


Image 19 Pelvic obliquity resulting in scoliotic posture. Imbalanced pelvis affect all posture above. Original image retrieved from: http://hub.permobil.com/

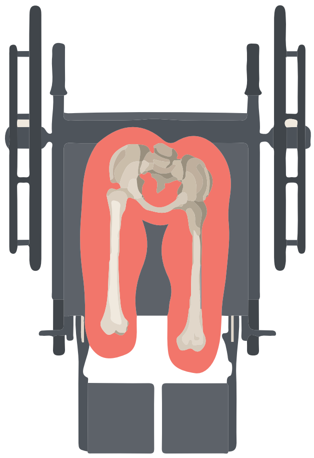


Image 20 Pelvic rotation resulting in scoliotic posture. Imbalanced pelvis affect all posture above. Original image retrieved from: http://hub.permobil.com/

2.2.6. Changing behavior using behavioral interventions and technology

The definition of the word behavior is: "The way in which one acts or conducts oneself". For this project, it will be the aim to improve wheelchair behavior. To create an effective solution, theory of behavior, persuasive technology, motivation, decision making and intervention tools were researched to be used in the development of a fitting solution.

Planned behavior theory

The theory of planned behavior (Azjen, 1975) suggests that behavior is dependent on one's intention to perform the behavior. Intention is determined by an individual's attitude toward the behavior (beliefs and values about the outcome of the behavior) and subjective norms (beliefs about what other people think the person should do or general social pressure). Behavior is also determined by an individual's perceived behavioral control, defined as an individual's perceptions of their ability or feelings of self-efficacy to perform behavior.

Zanna and Rempel (1988) say attitude might change based on internal or external cues. They say attitude is generated from cognition (a source of information), affect (feelings, emotions associated with an object that can influence attitude), and past behaviors. Individuals evaluate new sources of information against previous or other information and evaluate it as favorable or unfavorable.

In Figure 8 a visualization of the two theories are combined to show how the behavior is shaped.

Key take-aways

Providing information and experiences can possibly change the behavior of users. Therefore, the attitude towards the product should be kept positive. The strategy should target all elements that build up on the intention of behaviors (attitude, subjective norm and perceived control).

Persuasive technology

Persuasive technology is defined as technology that is designed to change attitudes or behaviors of the users through persuasion and social influence, but not through coercion (Fogg, 2002). Fogg describes three ways in which technology is used. Persuasive technology can be used as a tool, media or social actor. A tool can simplify a task normally considered difficult, as media it can use interactivity or narrativity to create persuasive experiences that support rehearsing a behavior and as a social actor the technology takes up a role to apply social influence.

The reason why technologies, like websites and applications, have advantages over human persuaders (Fogg, 2002), is because they:

- Are more persistent than human beings
- Offer greater anonymity
- Manage huge volumes of data
- Use many modalities to influence
- Scale easily
- Go where humans cannot go or may not be welcome

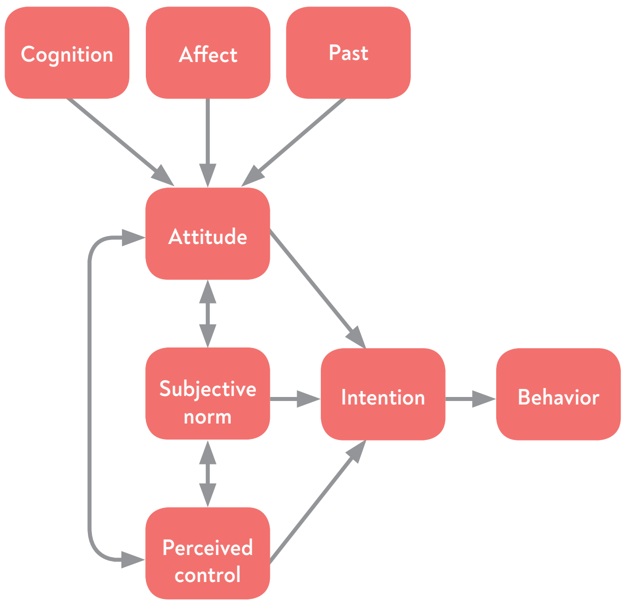


Figure 8 Combination of the theory of planned behavior (Azjen. 1975) and the theory of Zanna and Rempel (1988) on changing intention.

Persuasive system design

Inspired by the book on Persuasive technology by Fogg, Oinas-Kukkonen and Harjumaa (2009) developed a method to design persuasive solutions. They start by stating postulates on persuasive systems, discussing why they are important and how to apply them in the best way possible. In short these are:

- Information is never neutral
- Commitment and consistency is needed
- Direct and indirect routes are key persuasion strategies
- Persuasion is often incremental
- Persuasion should always be open
- Persuasive systems should aim at unobtrusiveness
- Persuasive systems should aim at being both useful and easy to use

They introduce a method to analyze the persuasion context. First, the intent (persuader and change type) of the persuasion needs to be analyzed, then the event (user context, use context and technology context) and the strategy (message and route).

Design principles can be user to achieve the target behavior. Oinas-Kukkonen and Harjumaa made four lists of principles. The principles are divided into primary task, dialogue support, system credibility and social support.

The design principles in the primary task category support the carrying out of the user's primary task. The design principles in this category are *reduction, tunneling, tailoring, personalization, self-monitoring, simulation, and rehearsal.*

Any interactive system provides some degree of system feedback to its users, potentially via verbal information or other kinds of summaries. There are several design principles related to implementing computer-human dialogue support in a manner that helps users keep moving towards their goal or target behavior. They include *praise, rewards, reminders, suggestion, similarity, liking, and social role.*

The design principles in the system credibility category describe how to design a system so that it is more credible and thus more persuasive. The category of system credibility consists of *trustworthiness, expertise, surface credibility, real-world feel, authority, third-party endorsements, and verifiability.*

The design principles in the social support category describe how to design the system so that it motivates users by leveraging social influence. The design principles that belong into this category are *social facilitation, social comparison, normative influence, social learning, cooperation, competition, and recognition.*

Approach strategies

Halko and Kientz (2010) concluded their research on literature about persuasive strategies and methods in a list of 8 main types of strategies of how the strategy could be designed, which can be grouped in four categories: *instruction style, social feedback, motivation type* and *reinforcement type.*

Instruction style

- *Authoritative:* Persuade the technology user through an authoritative agent. For example, a strict personal trainer who is instructing the user to perform the task that will meet their goal.
- *Non-Authoritative:* Persuade the user through a neutral agent, For example, a friend who encourages the user to meet their goals.

Social feedback

- *Cooperative:* Persuade the user through the notion of cooperating and teamwork. For example, allowing the user to team up with friends to complete their goals.
- *Competitive*: Persuade the user through the notion of competing. For example, users can play against friends or peers and be motivated to achieve their goal by winning the competition.

Motivation type

- *Extrinsic:* Persuade the user through external motivators. For example, winning trophies, as a reward for completing a task.
- *Intrinsic:* Persuade the user through internal motivators. For example, The good feeling a user would have for being healthy, or for achieving the goal.

Reinforcement type

- *Negative Reinforcement:* Persuade the user by removing an aversive stimulus. For example, using the feeling of loss of assets as a motivator to improve behavior.
- *Positive Reinforcement:* Persuade the user by adding a positive stimulus. For example, adding flowers, butterflies, and other nice-looking elements to a neutral nature scene as the user conducts more healthy behaviors.

The product will most likely be distributed or advised by the medic or purchased by the user. The product should be able to be personalized to personal goals (Locke and Latham, 2002). The product will be used by the users on a voluntary basis, that is why it should be designed while considering the voluntariness of the user towards the behavior change. Also, the user experience of the design should be rewarding enough, so the user will use the product for an extended period of time (Nawyn et al, 2006).

Key take-aways

Persuasion should be open and incremental, so that people are persuaded to commit. Also, persuasive technology should be unobtrusive, useful and easy to use. Direct routes are effective, but alternatives should be designed as well.

Use of activity monitors

The primary benefits of these technologies can be interpreted as bringing physical activity to the forefront of users' attention, making health-monitoring part of one's lifestyle (Bajarin, 2015). Mobile technologies have unique qualities that make them a powerful tool to promote healthy lifestyles: mobile devices are always on, widely adopted, and people tend to carry them with them everywhere (Klasnja and Pratt 2012). Common features of activity trackers are active minutes, step counts, stair counts, sleep, heart rate, energy burned and energy consumed (Maher et al., 2017).

In spite of their valued perception of this information, people continue to have difficulty in tracking and gaining insights from their personal data (Choe et al., 2014). Recent studies indicate that many such devices fail to deliver health benefits in the long term (Ledger & McCaffrey, 2014; Shih et al., 2015). Ledger and McCaffrey (2014) report that a third of users abandon their device within the first six months, and that not only had this short-term use been unlikely to have introduced a sustainably active and healthy lifestyle, but data from activity trackers may have failed to inspire many users to be active at all. Lazar et al. (2015) observe that many users of smart health technologies abandon their devices without gaining long term benefits, because among other reasons, their devices did not match up to users' self-perceptions.

To encourage long-term changes in physical activity, the strategies incorporated into technology should include evidence-based techniques derived from behavior change theories. These techniques should directly address the special barriers to increasing activity in vulnerable populations who are at highest risk for a sedentary lifestyle. This includes helping inactive individuals to decide how, where, when, and with whom they can exercise (Sullivan & Lachman, 2017).

Further, research makes it clear that the informational affordances, like data visualisation and self-monitoring, are not motivational enough. Users need additional motivators like coaching, social networking, gamification or rewards to adopt sustainable healthy behaviors (Cheon, Jarrahi, & Su 2016; Waltz, 2012).

Key take-aways

Motivational strategies are expected to be more effective for long-term use than solely informational affordances.

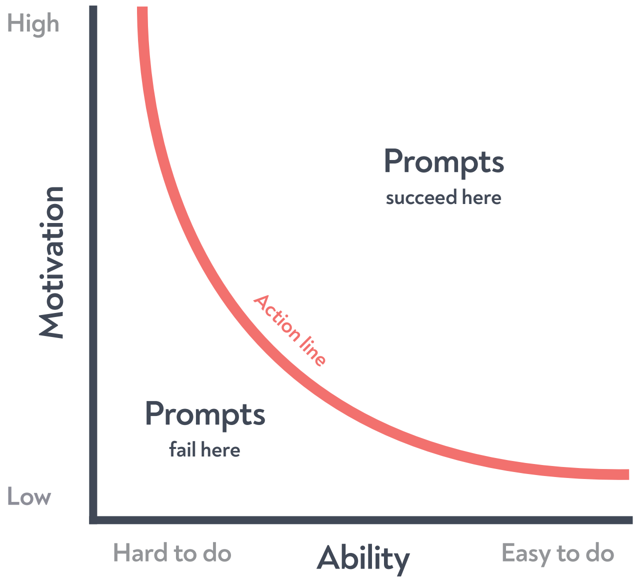


Figure 9 Diagram explaining the Fogg Behaviour Model. Tasks that need more ability can only be done when motivation is high. Prompts are only successful when the motivation is higher that the ability needed to complete the task. Image retrieved from: http://www.behaviourmodel.org/

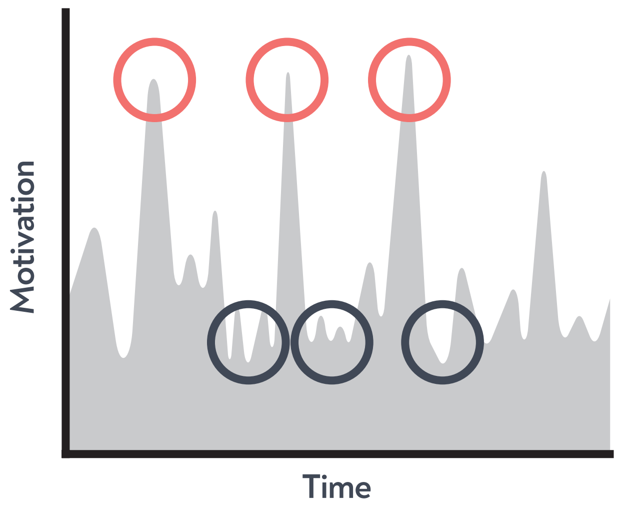


Figure 10 A conceptual visualization of the motivation of a person over time. In moments of hight motivation, tasks can be completed that require higher abilities.

Fogg behavior model

The behaviour model of Dr. Fogg (Fogg, 2009) discusses the important factors in facilitating behavioural change. It is set up to analyse every type of behaviour, whether it is website use, wanting to work out more or doing hard work.

He discusses his model with three behaviour change elements:

- **Motivation.** The amount of motivation at that specific time.
- **Ability**. The ability to do things at that specific time.
- **Prompts**. Triggers or cues to get things done.

The motivation determines the ability of the person to do a task at a specific time. At moments of high motivation a person can do harder tasks. Prompts are only successful when they are experienced in a period when the motivation is higher than the ability needed to do the task.

The model is summarized in Figure 9. The key idea about this model is that people who are highly motivated can get hard things done without artificially boosting the motivation, but using the natural waves of motivation during the day.

Dr. Fogg talks about the desirable health solution. Which concludes in the sentence: '...help people succeed on the most desirable behavior that matches their current motivation'. This sentence consists of three parts that are important for succeeding in behavior change:

- Current motivation
- Desirable behaviour
- Helping people succeed

Motivation

The theory has distinguished importance of motivation as one of the behavior change elements. People become motivated because of three types of core motivators:

- Sensation (examples: pleasure and pain)
- Anticipation (examples: hope and fear)
- Belonging (examples: social rejection and social acceptance)

People's motivation to do things changes a lot throughout the day. An example of a conceptual motivation curve can be seen in Figure 10. What can be seen is that at some moments during the day people temporarily experience a lot of motivation. At other moments motivation is low and these happen more often than high motivation moments.

During the moments of high motivation people are capable of doing things they normally experience as hard or difficult. In other words, their ability has increased. During moments when motivation is low people will not be able to do hard things.

Desirable behavior
Some examples of what are desirable health behaviors could be:

- Beneficial habits for the person
- Positive change in environment which affect future temptations
- Structure behavior to make the change a habit
- Fitting to the moment
- Thinking of the next step in a process of change

Helping people succeed
It is necessary to focus on the current situation and taking advantage of the high motivation moments for moments when motivation is lower. During these high motivation moments hard things can be done, like:

- **Structure future behavior**. example: Commit to a behavior, like sign in a weekly training program.
- **Reduce barriers to behavior.** example: People who work full day, but want to eat more health food, can use the moments of high motivation to do things that will help them during moments of low motivation. For example, when a moment of high motivation occurs the person is cooking food, but can also already cut some snacks and put them in containers and in the fridge for moments when motivation is low.
- **Increase people's capabilities**. example: Doing a hard thing multiple times, makes the task less hard to do. In the future it will require less motivation to do the task.

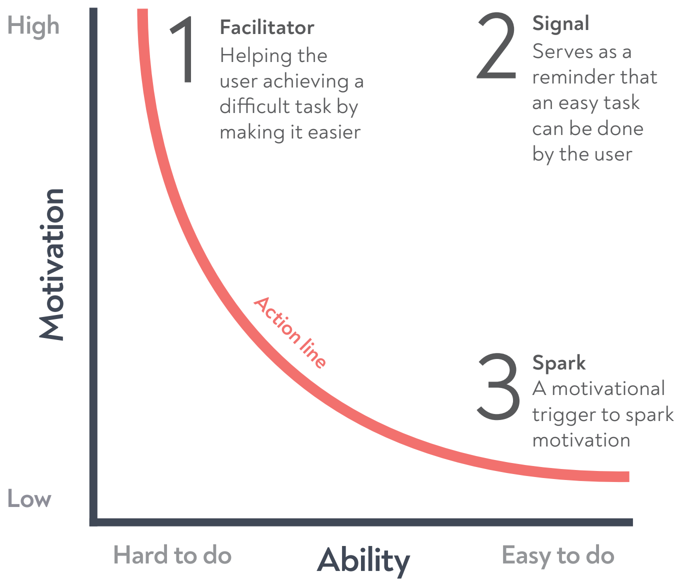


Figure 11 Visualization of when the three types of prompts are valuable. Based on theory from: http://www.behaviourmodel.org/

Ability
A person has six resources they can use that determines the amount of effort needed for the task. Tasks are considered simple when they require less resources, like time, money, physical effort, brain cycles. A task is also considered simple if it does not go against the norm and if the task has been done before. A task is perceived to require low abilities until it requires resources the person does not possess. It is also perceived as low ability when the person has to use less resources than expected.

Prompts
To notify a person to do a certain activity often a push is needed. It matters in what kind of state you are as a person. Again motivation and ability are used as axes in the diagram seen in Figure 11. When both motivation and ability are low, nothing will happen.

Prompting into product use
Overuse of notifications are often described as nagging and should be avoided. This could result in muting notifications or even deleting the application (Blair, 2018), which results in less interaction with the product. Push notifications are a great way to communicate with your app users, but only if they're used properly and

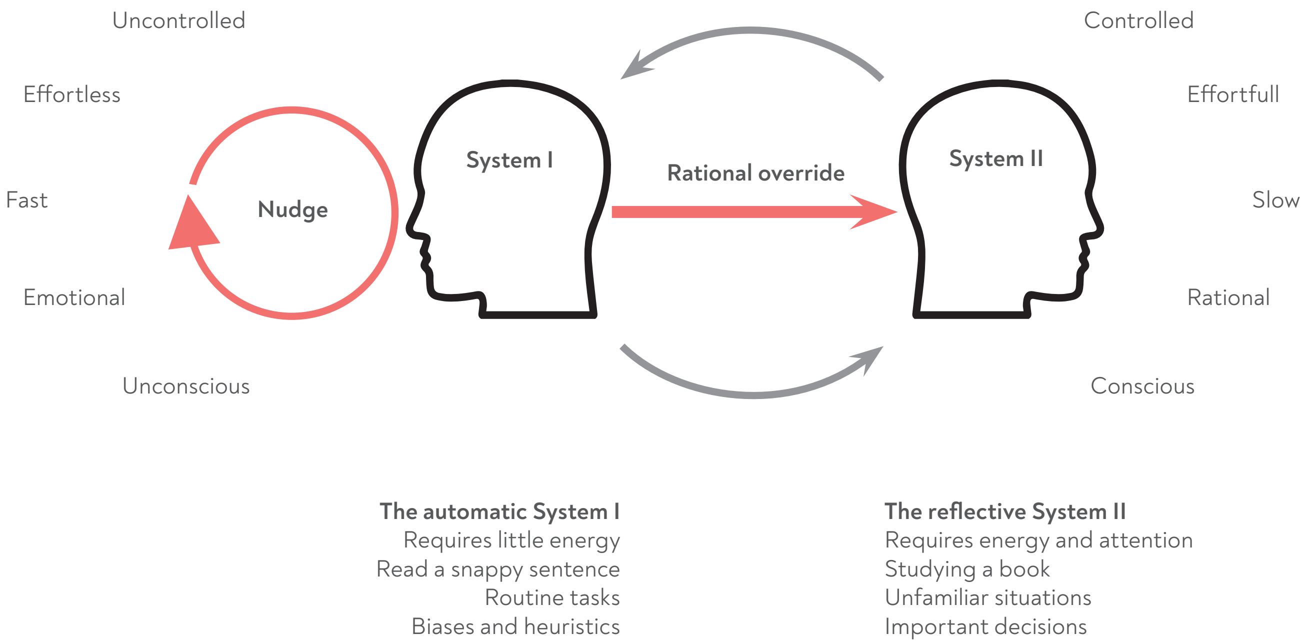


Figure 12 Dual system theory, nudging and rational override. Explaination of the two systems and how interventions work.

sparingly. People turn off push notifications when they start to become meaningless or annoying. But, there are certain types of notifications that people don't find annoying. Those are push notifications that:

- are personalized
- don't get sent too often
- add immediate value
- (offer free stuff and discounts)

Key take-aways

In order to help people succeed, future behavior should be structured, barriers should be reduced and capabilities and feelings of self-efficacy should be increased. Within this, use moments of high motivation, make tasks as simple as possible and design personal and timed prompts that add value.

Decision-making – Behavioral economics

Behavioral science is the understanding of human decision-making. In the neoclassical period of economics, economic theories, hypotheses and models were created. In this era, scientists developed the concept of the homo economicus, a human being whose actions are fundamentally rational. This concept is being challenged by behavioral economists.

Behavioral economics is a discipline that combines human psychology and economics to explain how humans make their decisions and what drives their behaviors. They, as opposed to traditional economists, take human irrationality as a starting point.

Dual system theory

Tversky and Kahneman's model implicated the idea that human-decision making is done with two systems: System I and system II.

System I: This system is fast, mostly unconscious, intuitive, effortless, based on previous experiences and influenced by emotions. It requires little energy to make fast decisions by using mental shortcuts, but it can be influenced by biases and heuristics.

System II: This system is slower, more rational and uses more energy. This system is used when the person, for example, experiences new situations or needs to process difficult information and requires thorough thinking. This is the type of thinking that makes us humans different from animals.

These systems can work together and people can switch between them while making decisions. Most of the time people operate on System 1 while System 2 is on stand-by. This can be considered as 'our autopilot' (Hansen & Jespersen, 2013). Research shows that 80-95% of the times our decisions are made within System 1, simply because we do not have the mental capacity to think through all our decisions and actions (Zaltman, 2003). For example, at moments when we are overworked, we tend to rely on system 1 more, resulting in less willpower and this can end in making the irrational choice (Alter, 2007).

Heuristics and biases

Heuristics are the mental shortcuts as stated in system I. When people are processing information in system I they use limited cognitive capacity and make decisions that are influenced by heuristics. These can quickly and intuitively generate an approximate answer or solution to a problem. Heuristics are programmed in the brain and their success depends on the structure of the context in which a decision is made (Gigerenzer, 2011).

Tversky and Kahneman (2011) stated a few of these:

- **Framing effect.** Using a gain or loss frame influences decision making. People tend to avoid risk when a positive frame is presented but seek risks when a negative frame is presented.
- **Availability**.The more you know and think about a topic, the more important it becomes for you
- **Substitution**. Substituting the question with a simpler question, which distorts rationality
- **Loss aversion**. The tendency to prefer avoiding losses to acquiring equivalent gains
- **Peak-end rule**. People judge an experience largely based on how they felt at its peak and at its end

These heuristics explain why humans tend to be more affected by losses than gains, avoid risk, prefer simplicity over complexity, remember past experiences differently than it happened and how emotional states influence them. They can be considered universal, but can differ slightly between individuals and cultures.

Behavioral intervention design tools

Thaler and Sunstein wrote *Nudge: Improving Decisions About Health, Wealth, and Happiness* (2008), in which they explain the way people are influenced during decision making. In this book, where they build further upon the theories of Tversky and Kahneman, they give examples of experiments that were done, that show the way so called 'nudges' were applied in real life situations. The writers give the following explanation for the nudge:

"A nudge is any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid. Nudges are not mandates. Putting fruit at eye level counts as a nudge. Banning junk food does not."

Thaler and Sunstein refer to influencing behavior without coercion as *libertarian paternalism*. This means that the user has a free choice, but the better option is made more attractive. This makes this method more ethical than mandatory choices.

The influencers are considered choice architects. They design the choices and moments of choice for the user to use. The nature of the nudge should always be in the favor of the one who is nudged.

In the book 'Nudge' they explain six principles of good choice architecture that will help people make better and healthy choices. These principles are:

- **iNcentives.** Our responses to incentives are shaped by predictable mental shortcuts
- **Understand mappings**. RECAP: Record, Evaluate, and Compare Alternative Prices
- **Defaults**. We "go-with-the-flow' of pre-set option
- **Give feedback**. Directly see confirmation of actions
- **Expect error**. Design the alternative options
- **Structure complex choices**. Simplify choices

After the release of the book, many companies and even governments incorporated this approach in their own way of working. The British Institute of Government and the Behavioral Insights Team (BIT) used behavioral economics and the nudging principles to develop a framework and made their own checklist for policy making. This checklist has been called MINDSPACE (Dolan et al., 2010). Later this checklist was simplified into the EAST framework (Algate et al., 2012). This simple list says that the interventions should be make it easy, attractive, social and/or timely. The principles are shortly described in Figure 13.

Anne van Lieren (2018) has used the theories of multiple behavioral intervention methods, including the models mentioned before, and made a framework for service design. She calls it the behavioral intervention design toolkit and it includes behavioral intervention cards for fast brainstorming and ideation, to be used by designers.

Types of nudging

As stated before, people tend to process most information in system I. This means therea are two ways to influence behavior and decision-making. A bias can be used to eliminate the another bias (counter-biasing) or the person needs to be pushed into reflective thinking (debiasing). Nudging is an example of a practical applied behavioral economics theory for counter-biasing (Brest, 2013). Debiasing is also referred to as mindful nudging (House, Lyons and Soman 2013) or rational override (A. van lieren, 2018). It depends on the context and situation which type of nudging should be applied.

Key take-aways

For effective nudging, make use of heuristics and biases. And in order to motivate people, use gain frames and confront people with the topic often. The information should also be clear to avoid substitution. People do not want to lose. Therefore, the experience should use a positive gain frame for motivation. To help people make better and healthy choices, use defaults, simplify choices and give feedback for actions. Design what happens when the choice is not made. And finally, nudge people into a state of consciousness.

Figure 13 EAST-framework for fast ideation using behavioral interventions (BIT, 2012)

In Figure 12 a visual can be seen showing the dual system theory and how nudging and rational override work in this context.

Goal setting

For a person to achieve their goal it is better to be concrete about the wanted outcome. It is stated that hard goals produce a higher level of performance (output) than easy goals, specific hard goals produce a higher level of output than a goal of “do your best” and behavioral intentions regulate choice behavior (Locke, 1968).

Goal setting affects performance in four ways:

- **It focuses attention.**
- **It mobilizes effort in proportion to the demands of the task.**
- **It enhances persistence.**
- **It encourages the individual to develop strategies for achieving their goals.**

Two methods will be used in this project for setting goals. The goals will be made by the user themselves, but also together with a therapist. For both ways a method is chosen to facilitate behavior change in a structured way.

SMARTER

Setting goals is part of all organized actions, whether it is a person trying to become better at sports or a business trying to boost their profit. One of the models often used by people is SMART goals. One of the first publication about this method were in a November 1981 issue of Management Review by George T. Doran (Doran, 1981). Since then the theory had slight changes and one of the variations had added two letters: ER. The letters SMARTER stand for:

- **Specific**. What is the activity they are going to do.
- **Measurable**. Quantity of change that is to be expected throughout the goal.
- **Attainable**. The goal must be attainable with the amount of time and resources available.
- **Realistic**. The goal must be reasonable to achievement with the available time and resources.
- **Time-bound**. Set a time-frame for when the objective will be achieved.
- **Exiting**. The goal motivates the person to do the work.
- **Recorded**. The goal and progress towards the goal are recorded.

GROW Model

A medic wants to help others to solve their problems, make better decisions and learn new skills or habits. One proven approach that helps with this is the GROW model (Whitmore, 1992). The letters GROW stand for:

- **Goal.** Setting up specific short term and long term goals.
- **Reality.** Have a conversation that raise awareness about their problem and promotes self-reflection and thinking about the current situation.
- **Option.** Allow the individual to come up with many options and ideas themselves. If the person runs out of ideas, the other person can offer suggestions if agreed.
- **Will.** Use questions to help them determine which option to take, how and when to take it.

By following this method the patient will be highly integrated into the conversation. This conversation can take place during check-ups or meetings with a medic or be integrated in the strategy of the product. It is expected to help establish commitment of the patient. With a clear set up of the goals, it becomes easier to achieve those goals.

Project focus

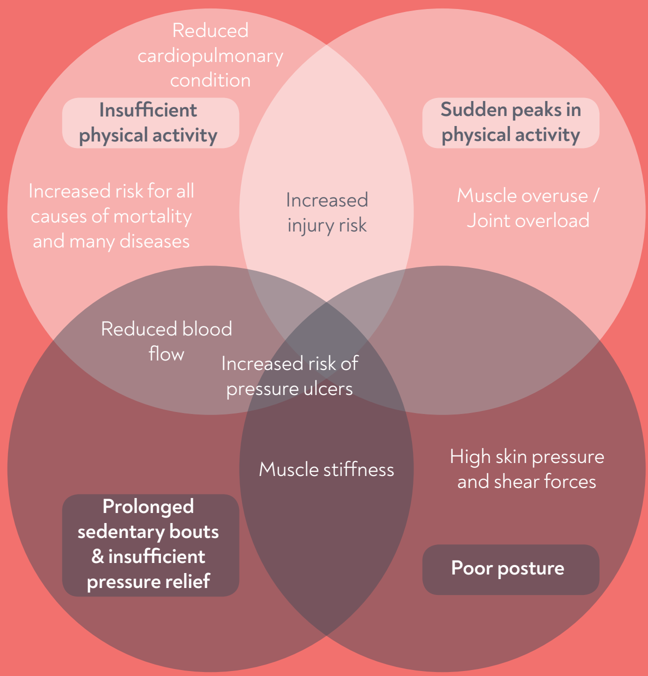
The user will be persuaded by the product into improving wheelchair behavior: physical activity and sedentary behavior. By setting personal goals and monitoring the users and using behavioral interventions, the product will remind and motivate the user to change.

Key take-aways

Make use of goals to increase the likelyhood of improving a behavior. Use the GROW approach to establish commitment. Set SMARTER goals to increase insintric motivation.

Image 21 In Hangzhou, China, subway users were nudged to use the stairs in stead of the escalator with the use of salience. Image retrieved from China News

Summary, conclusion and requirements theoretical background



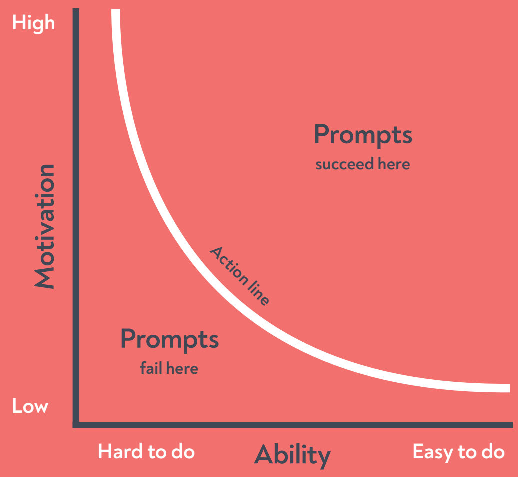
Health risks due to wheelchair behavior is caused by physical activity and sedentary behavior. By targetting the four identified poor wheelchair behaviors, it is expected that the health risks will decrease.

Risk behavior 1: Insufficient physical activity
The wheelchair user should be persuaded to increase their physical activity in a controlled and safe way. The aim is to increase the physical activity and transcend the guidelines of 150 minutes of moderate intensity physical activity per week.

Risk behavior 2: Sudden peaks in physical activity
Abnormal increases in physical activity increase the risk of injury. The wheelchair user should be guided into controlled and safe increase of physical activity. Potentially harmful situations should be avoided as much as possible.

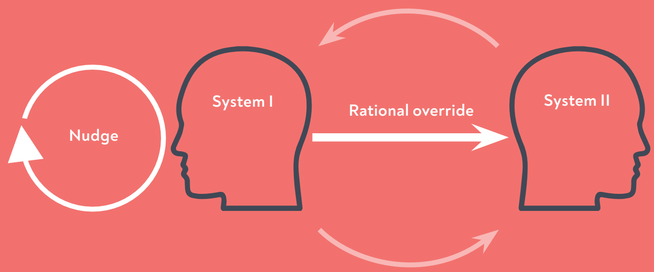
Risk behavior 3: Prolonged sedentary bouts & insufficient pressure relief
The wheelchair user should be persuaded to periodically break sedentary bouts with pressure relief exercises. A pressure relief bout of 30 seconds is advised after a sedentary bout of 30 minutes.

Risk behavior 4: Poor posture
The wheelchair user should be persuaded to maintain proper posture. Posture control will result in reduced risk for body pain, pressure ulcers and body deformities.



By using behavioral interventions, the wheelchair user will be persuaded to change their wheelchair behavior. To understand how to do this, behavioral science theory and methods were examined.

Persuasive technology principles will be used to persuade the wheelchair user into target behaviors.



Main requirements:

- Design should monitor wheelchair behavior, by measuring physical activity and sedentary behaviors. (2.2.1)
- Design should be useful and easy to use (2.2.6)
- Design should provide informational and motivational affordances. (2.2.6)
- Design should provide insights, knowledge and guidance on improving wheelchair behavior. (2.2.6)
- Design should make use of a GROW approach and SMARTER goal-setting. (2.2.6)
- Design strategy should use a positive, non-authorizative approach (gain-frame). (2.2.6)
- The design should provide the user with informational and motivational affordances; using data visualisation, goal-setting, rewarding and social interaction. (2.2.6)
- Nudging strategy should be timely, open, clear and unobtrusive. (2.2.6)
- Insight, knowledge and nudging should be personal, clear, simple and meaningful. (2.2.6)

Make it..

2.3. Internal analysis

To be able to design a wheelchair solution that helps the users better than the current situation, an analysis of the context is needed to fully understand the users and the user's real problem. For this chapter, research of online articles and literature is used and interviews with wheelchair users and a occupational therapist were done to gain insights in the context (Appendix A&B). This chapter results in a set of requirements the future concept should meet and insights in potential opportunities.

2.3.1. Stakeholders

The word stakeholders means: all parties that have interest or concerns regarding the topic. In this project, the topic is the developments of a behavior improving wheelchair with integrated wheelchair behavior measuring technology. The overview in Figure 14 is based on a brainstorm using information from interviews, literature and online information. The figure shows three circles, where the importance of the relationship of the party is growing towards the centre. Their role will be elaborated in the user journey.

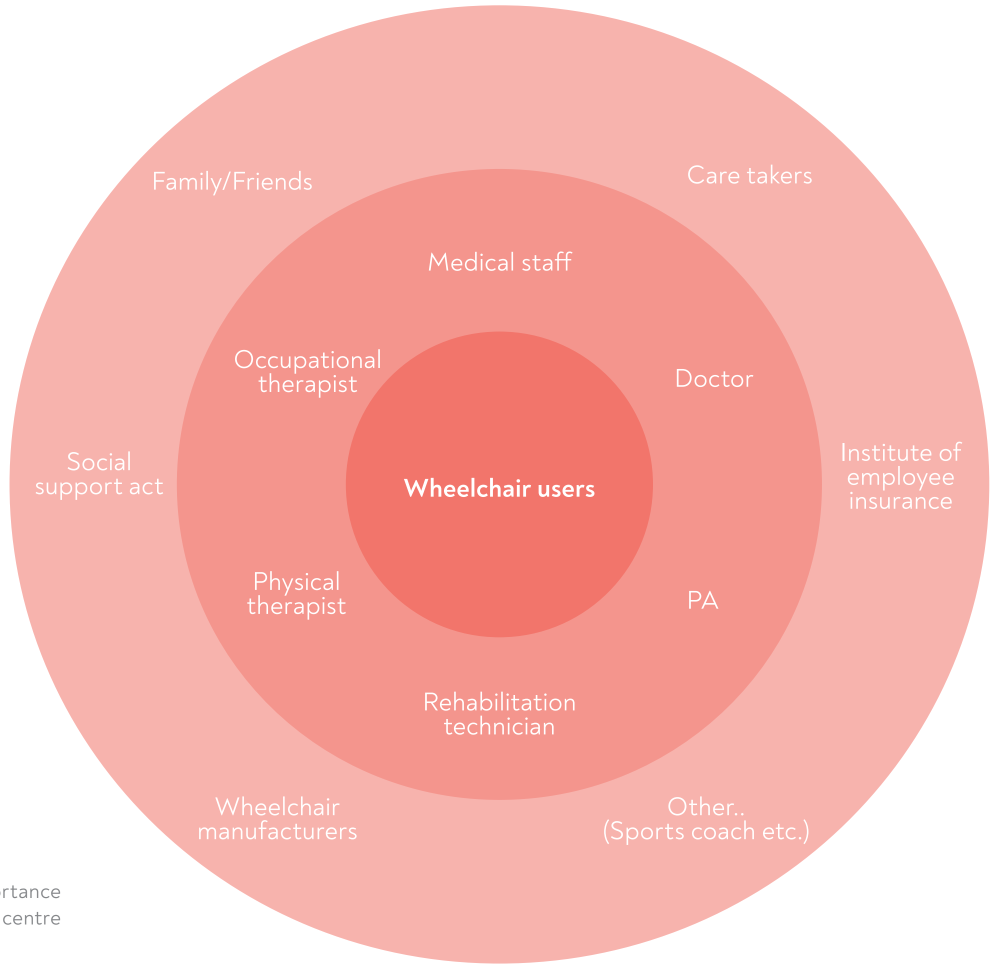


Figure 14 Stakeholder overview: Importance of the stakeholder grows towards the centre of the cirlce.

Wheelchair users

Most importantly are the wheelchair users, since they are using the wheelchairs and experiencing the discomfort and problems due to wheelchair use. It is important to focus on them to be able to design a valuable product that is going to be used by them.

Potential gain: Improved wheelchair experience, reduced injury risk and increase in health benefits.

Medics

These are all the people who are involved in the advising, measuring and improving the health, comfort and quality of life of the wheelchair users. Their interest is in helping as many wheelchair users, by reducing their discomforts and making them live their lives as comfortable and efficient as possible. In this report, the word medic is used for anyone from doctors, therapists up to caretakers.

Potential gain: Insight in patient's wheelchair behavior, guidance in the lives of patient outside of the practitioner's office

Wheelchair manufacturers

Producers of wheelchairs have an interest in the insights in the use of their product. It provides them with information that can be used to optimize their product to their user group.

Potential gain: Insights in wheelchair use by specific groups of users following by optimization of design

Government and social systems

In most developed countries, the government and their social care systems are the ones financially responsible for the wellbeing of the wheelchair users. Their interest is in reducing the medical costs of the wheelchair users to be able to help more people. In the Netherlands, the social support act (WMO) provides wheelchair for personal use and the Institute for Employee Insurance (UWV) provides wheelchairs for those who need a wheelchair to participate at work.

Potential gain: Decrease in secondary problems and medical costs due to wheelchair use and lifestyle choices.

Friends, relatives and others

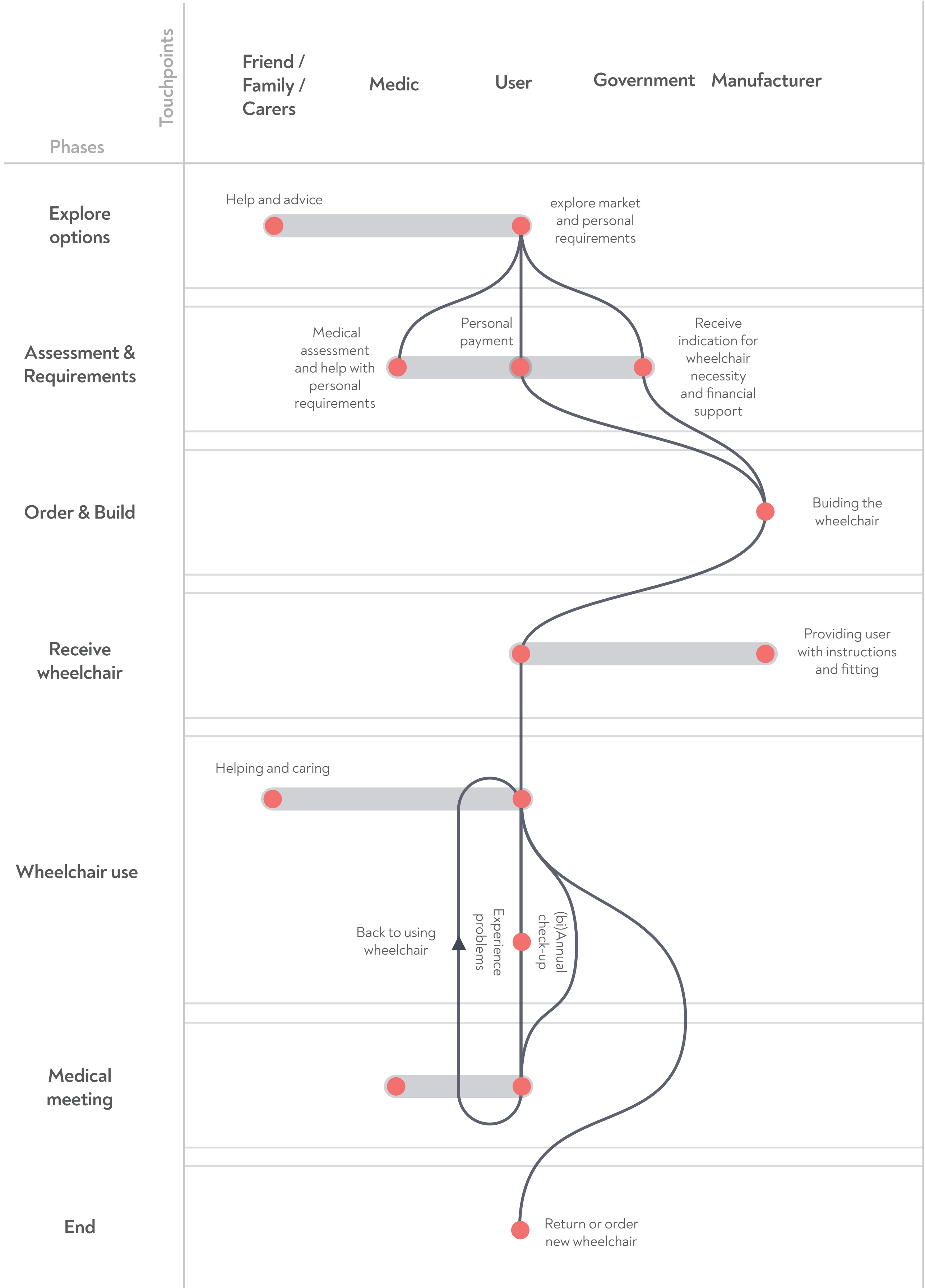
The people in direct contact with the wheelchair user are often there for help and mental support. Providing them with insights in wheelchair use, can help them understand the situation and behavior of the wheelchair user and possibly help the user improve their lifestyle and health. Also, external parties that are connected to the wheelchair user, like their sports coach, could be provided with more insight in the situation of the wheelchair user.

Potential gain: Understanding of the situation of a friend or relative

Project focus

However there are many parties who have interest or concerns around the topic of the wheelchair and their user, the focus in this project will be on the wheelchair user and their experience. Wheelchair users are the ones experiencing the wheelchair themselves and will gain most from behavioral change. The involvement of the other stakeholders will be used to map out the context around the user in the user journey.

Figure 15 User journey. The colored dots are the active touchpoint during the different phases. The lines resemble the flow of the journey. The light lines between the touchpoint resemble the interaction between touchpoints during phases.



2.3.2. User journey

In this chapter, the goal is to understand the current user journey of the service of obtaining a wheelchair in the Netherlands. To gain knowledge about the current procedure, a qualitative interview has been done with an occupational therapist at Reade Rehabilitation and Rheumatology Centre in Amsterdam (Appendix B) and insights from other interviews were used. Additional internet research is used to complement the analysis. This subchapter concludes in an overview of the current user journey with its painpoints and opportunities for improvement.

Process

A visualisation of the user journey can be seen in Figure 15. Wheelchair users start with the exploration of the market and their personal needs. The user will need to make up a list of requirements for their future wheelchair. In some cases, this is done with the assistance of a friend, family member, carer or medic. In many cases the governmental organizations can provide financial support, but for this the assessment of the necessity of a wheelchair is needed, after which funding is made available.

The manufacturer receives an order, payment and the requirements and builds an often personalized wheelchair. At reception of the wheelchair, the user receives a brief instruction for wheelchair use and has their last fitting after which they will use their wheelchair.

Depending on the need of medical supervision of the user, the user can be scheduled for a (bi)annual meeting with their medic. A meeting can also be scheduled by the user when the user experiences problems from wheelchair use. During the check-up, analysis is done of the wheelchair user and their potential problems. Wheelchair-related problems are often solved by making adjustments to the dimensions of the wheelchairs, adding cushioning or other interventions.

A more elaborate explanation of the user journey via medical assessment can be found in Appendix D.

Painpoints

From interviews and by analysing the user journey, potential painpoints could be found. The focus of these opportunities will be on the experience of the user with the wheelchair (in Figure 15 starting from phase 'Receive wheelchair').

Receiving the wheelchair

From user interviews and survey it is concluded that most wheelchair users did not receive a proper introduction on proper wheelchair behavior. Users do not have an thorough understanding of the effect of physical activity and sedentary behavior for their health and injury risk.

Wheelchair use

Wheelchair users receive a brief instruction and are dependent on their own motivation and reflection to maintain proper wheelchair behavior. In many cases, this results in insufficient physical activity and pressure relief behavior.

Medical meeting

The meeting with the patient is only a short snapshot of the total situation of the patient. The majority of the time the patient is using the wheelchair. Due to behaviour and small insufficiencies in the wheelchair, over time, secondary physical problems occur. These problems are often discussed with the medic, but the quality of the analysis is dependant on the situation at that specific moment in time and the word of the patient.

Opportunities

Based on the painpoints in the user journey and literature research an ideation was done to distinguish opportunities for future improvement. The main goal is to decrease the risk for injury and increase health benefits by improving wheelchair behavior.

Receiving the wheelchair

Information about proper wheelchair behavior should be provided in a clear way and easy to understand. The expectancy is that, when people know or are reminded of what is considered as right behavior, they will become more probable of acting out this behavior.

Wheelchair use

During use, the medic is unable to supervise and actively coach the wheelchair user. Determining issues in wheelchair behavior during daily use could result in the possibility to give better recommendations for wheelchair use and diagnose problems quicker. By seeing patterns in behavior, current problems can be helped, but also future physical problems can be foreseen. Patterns can change over the period of weeks or days, but also different behavior in the morning compared to late in the evening. It is also possible to offer exercises, which are personalized to the behavior of the person.

Research says that it is useful to increase patients engagement and accountability to document and share long term activity with medics. Dr. Lajam from the American Academy of Orthopaedic Surgeons (AAOS, 2016) gives an example of the importance of monitoring for different groups of patients.

Data generated by fitness monitoring devices can be applied across different levels of care:

- Non-surgical patients can track behavior, activity levels and medication use and alter these factors to lose weight and maintain the best possible function in their extremities.
- Pre-operative patients can reduce risk for post-operative complications by reducing their weight, preventing diabetes and identifying sleep disorders.
- Post-operative patients can evaluate rehabilitation progress and surgical outcomes by measuring mobility activity, and alter physical therapy for better recovery.

The monitoring of wheelchair mobility behaviour could be used by all three groups for the same purposes as stated above. They will be able to maintaining the best possible function in their (upper) extremities and lose weight due to physical activity and monitoring activity progress.

Assisting wheelchair users with maintaining proper sedentary behavior, like posture and pressure relief is also expected to improve the health status of the wheelchair user.

Medical meeting
The medic is said to be interested in data that can show the behavior of the patient during daily use. The discussed topics were sedentary behavior and physical activity.

It is expected that providing the medic with data from the development of wheelchair behavior of their patients will create insights in potential causes of problems or an incentive to change treatment strategies.

Project focus
Two phases in the user journey will be the focus of this project: receiving the wheelchair and wheelchair use. It is believed that most value for the user can be given by designing a solution that covers the problems in these areas.

Improving the user journey of obtaining a wheelchair and providing the medic with insights is left out of the scope of this project, because it would require policy change and/or additional product development.

Key take-aways

Information about proper wheelchair use is not always clear. Wheelchair use is the most valuable moment for focus, since most wheelchair users perform insufficient physical activity and pressure relief.

Image 22 Therapist giving aid to patient. Retrieved from: Getty images

2.3.3. Wheelchair users

First an analysis is needed to be done to get to know the primary users. For the development of a new product, it is important to know how large the potential target group is, know about their lifestyle and deeply understand their situation.

Demographics

Wheelchair users each have their own life with their own goals and problems. A wheelchair can help them achieve their goals better and overcome some of their problems. Providing people with mobility problems with comfortable wheelchairs not only enhances their independence and mobility, but also opens the possibilities to have education, work and a social life.

The World Health Organisation (WHO, 2010) states that there are 65 million people in the world who need the aid of a wheelchair, which is 0,1 percent of the total population. These wheelchair users are as diverse as the population of the world. They can be found in all ages, genders, disabilities, lifestyles, socio-economic statuses and environments. People of all ages can use a wheelchair. However, wheelchairs are most often used by people who are at an older age. In Figure 16 a visualization of the results from research of Vignier at al. (2008) is seen, on the percentage of wheelchair use at different ages, at home and in institutions, respectively in France. It is said that the mean of the age of wheelchair users is between 65 and 70 years old, and wheelchair users are predominantly (64-67%) female (Vignier et al., 2008; Smith et al, 2016).

With a rapid increase in the population of men and women over the age of 65, it is important to know about how to overcome the barriers to exercise that the elderly deal with on a regular basis. Specific recommendations include identifying realistic goals, such as making it easier for an older adult to play with loved ones, improving performance in activities of daily living, and improving the overall quality of life. These strategies might improve exercise adherence and eliminate perceived barriers (Gaz et al., 2016).

There is a hypothesis that elderly need different ways of communication than adults aged 18-64, because of their decreased familiarity with technology and expected reduced motivation for knowledge and information acquisition (Oppenauer, 2008). Social contacts play a major role in motivation at old age: (Oppenauer, 2009). Aging populations can benefit from robot solutions that provide guidance for them in their environments and reminders to perform routine activities (Villalobos-Zuniga and Cherubini, 2017).

Lifestyle

Wheelchair users, like able-bodied people, have their own daily activities, interests and hobbies. They want to be an active member of society, by having a job, doing sports or practice their hobbies. Findings from qualitative interviews with wheelchair users (Appendix A) and a qualitative survey among wheelchair users (Appendix B) are used to understand the context and complete the insights.

Education

The interest and abilities of the person, determine what kind of education is possible. The number of students with disabilities is under-represented, but the difference with able-bodied people is decreasing, said the Organisation for Economic Co-operation and Development (OECD) (Rothman, J., 2018). In the USA 11.2% of people in wheelchairs graduate from college, compared to the 21.6% of the general adult population (Bakhshi, J, 2015).

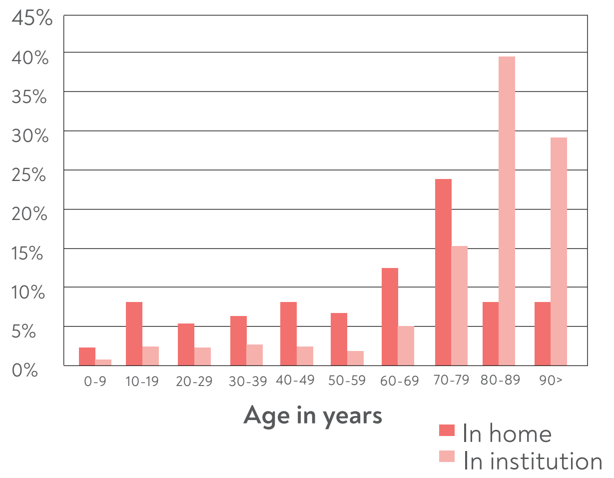


Figure 16 Distribution of wheelchair users by age, at home and in institutions in France (Vignier et al., 2008)

The accessibility of the education building is also important for wheelchair users, since they will need to be able to access all necessary facilities.

Working life

The degree of disability determines whether people are able to participate at work. Even though many people in wheelchairs want to have a job, they are underrepresented on the job market: In the UK the employment rate is 74.4% (OECD, 2018) and that of disabled people is 48%(Scope, 2018). In the Netherlands the employment rate is 77.5% (OECD, 2018), and that of disabled people is 42%.(CBS, 2018). In the US the employment rate is 70.7% (OECD, 2018) and that of working-age wheelchair users is only 17.4%(Bakhshi, J, 2015). With the current developments in policy and regulation, these differences are expected to decline in the future (Patrick, R.,, 2018).

Ideally, people in a wheelchair choose a job that is suitable with their disability. Most jobs for wheelchair users are jobs that can be done behind a desk, since physical work is harder to do in a wheelchair. The working environment should also be accessible for the wheelchair.

(In)active life

Most of their time wheelchair users are in sedentary position. Their disability determines whether they are able to be physically active. But, it is also depending on the type of person, like with able-bodied people, whether they are active or not.

In a statistical review of Sport England (2017), it is said that 51% of those with three or more impairments are inactive compared with 21% of those without a disability. Only 36% of those with three or more impairments are active compared with 65% of those without a disability. It can be concluded that wheelchair users are less active than able-bodied people. Where active means more than 150 minutes and inactive means less than 30 minutes of engaging in sports or physical activity in a week.

Activity for wheelchair users can consist of different forms. From wheeling to your job, doing strength exercises in the gym up till participating in wheelchair rugby. As long as the person is using his body for energy expenditure.

Painpoint

The fact that more wheelchair users will participate in high focussed activities, like work and study, will most probably lead to more time being physically inactive. Together with the fact that wheelchair users participate in sports activities less than able-bodied people, this results in a very unhealthy lifestyle. With wheelchair users being in sedentary for long periods, the effects of a sedentary lifestyle are even worse for the people already experiencing discomfort from their disability.

Social

Wheelchair users are in contact with the people around them. From experience, in comparison to able-bodied people, wheelchair users are more likely to know more fellow wheelchair users, like living in institutions or wheelchair accessible buildings.

Also, they often have more experience with contact with medics, mostly through their medical experiences. This is expected to come with a higher understanding of medical conditions and terms.

Causes of wheelchair dependence

There are a lot of different reasons why people need a wheelchair. Some people are unable to walk comfortably, others are born with disabilities. In most situations, mobilizing the person can help them achieve things that otherwise were not possible. Wheelchairs are generally advised when a person has difficulties or is unable to walk (comfortably for a longer distance).

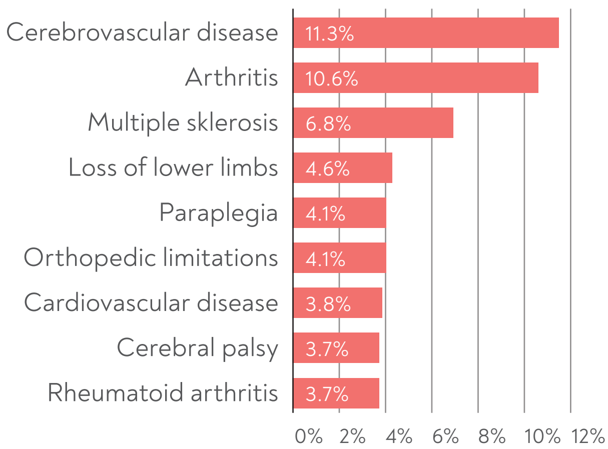


Figure 17 Nine of the most occuring reasons of wheelchair dependence (Statista, 2013)

Wheelchair dependency can come from illness, disability and injury and can occur by due to unhealthy lifestyles, accidents, naturally and can be genetically. In a data research on the major reasons for wheelchair use of Statistica (2013) a info-graphic is made. Nine of the most common reasons for using a wheelchair world wide can be seen in Figure 17.

In a Canadian study (Shields, 2004) people of all ages were asked what their reason of wheelchair dependency is. Four categories are used to distinguish different wheelchair need causes:

- Disability from birth
- Disability due to natural aging
- Disease or illness
- Injury

It is stated (Figure 18) that disease and illness in almost half of all cases is the reason of the use of a wheelchair. In approximately 20 percent of the cases it is because of injury. A quarter of the total wheelchair users is in a wheelchair because of age-related problems. A very small percentage is in a wheelchair from birth. When looking at different ages the percentages of the causes change (Figure 19).

Type of wheelchair users

Different types of dependance, result in different type of users. Some users need their wheelchair only for certain activities, other for all their mobility. Others only rely on a wheelchair for a few weeks, while again others depend on their wheelchair for their entire life.

Temporary wheelchair use

When a person undergoes surgery or has had an injury (like broken bones), a doctor or therapist determines whether the person needs help with mobility. When the certain trauma is prohibiting the person to walk comfortably for a longer period of time, the choice is made for a wheelchair. Depending on age and fitness, the person is advised to rest for a few weeks to let the wound or bone heal, but after the advised period is pushed to do exercises to be able to walk as quickly as possible.

People who will use a wheelchair for a short period of time, often rent a wheelchair for the necessary time. This is a simple and standard wheelchair that can be modified

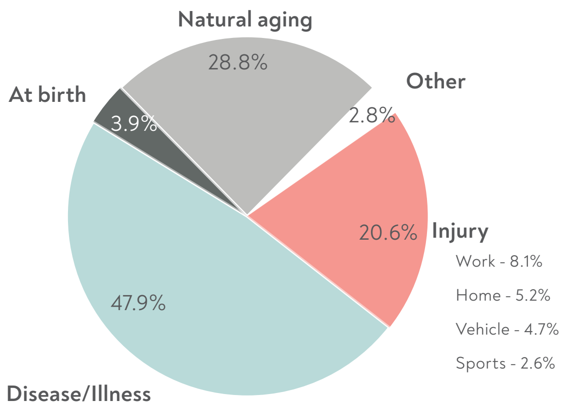
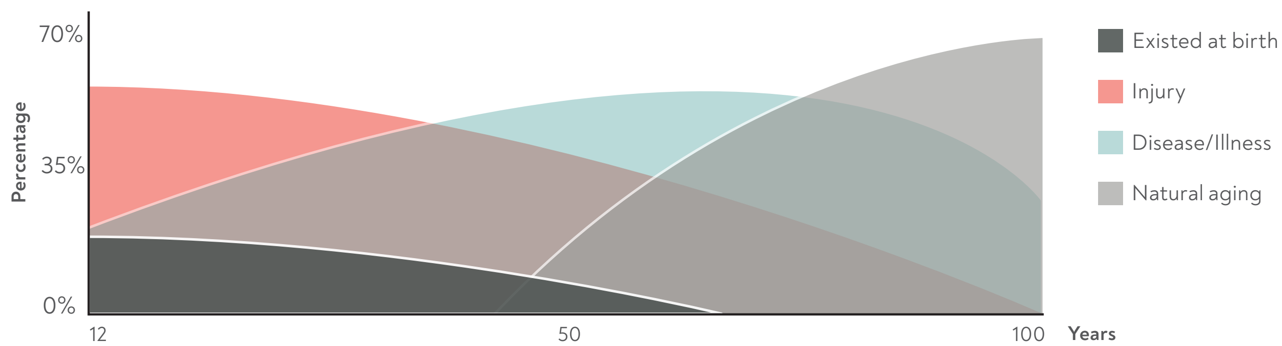


Figure 18 Percentage causes of wheelchair dependance (retrieved from research of Margot Shields, 2004)

Figure 19 Percentage causes of wheelchair dependance over age (trendlines based on research of Margot Shields, 2004)



to approach the person dimensions, but is often not ideal. Poor wheelchair use has effect on the body of the user. Especially people at an older age have risk to be wheelchair bound for a longer period than actually planned due to secondary injuries due to poor wheelchair use.

Permanent wheelchair use
Long term wheelchair use is often due to illness, disabilities or deformities. The main goal of the wheelchair is to gain mobility. Because of the length of dependency, permanent wheelchair users often own a more expensive and personalized wheelchair.

The wheelchairs of permanent users are designed for ideal fit and comfort. This is achieved by designing the wheelchair with personal dimensions for proper posture and personal cushioning for better pressure distribution. If discomfort is experienced over a long period of time, this could result in deformities and trauma of the body. It is extremely important to decrease discomfort as much as possible, to increase the quality of life for long term users, but this often comes at a higher cost.

Daily duration of use
Wheelchairs are used to improve mobility for people who are less mobile. Some people only use their wheelchair when a longer distance needs to be covered (part-time wheelchair users), for others it is their only way to be mobile (full-time wheelchair users). When analysing the average duration of wheelchair use in a day, researchers found that the average duration in a wheelchair is 11 hours per day (Sonenblum, Sprigle and Lopez, 2012). Some full-time wheelchair users remain sedentary for the whole time, except for sanitary visits or sleep. In a research with participants with spinal cord injuries, Sonenblum, Springle and Lopez concluded that measurements of seated behavior suggested that individuals who use a wheelchair full time typically did not perform frequent pressure relief. They did perform more frequent weight-shifts, often consistent with clinical guidelines, but without any routine to the timing. Thus, reminding the wheelchair user to perform frequent pressure relief of weight-shift could improve sitting behavior. The long wheelchair occupancy means that activities in the wheelchair have a high impact of the life of wheelchair users.

Technology use
From the survey and observations during the interviews can be concluded that wheelchair users make use of their smartphone. Even people with decreased functionality in their hands and fingers make use of an smartphone. Differences between able-bodied people is not expected. 'Despite stereotypes indicating that elderly are not well suited or interested in technology usage, research shows that they indeed perceive the benefits of its use to outweigh the cost of such use. *Inconvenience* (for example: unwanted interactions, costs, mental effort to use mobile devices), *complexity of features design* (for example: numbers of options and settings on mobile devices) and *security and reliability* (for example: lack of trust with the use of personal data, positioning technology not functioning when in the need) are considered the major dislikes from older adults to technology. Two main barriers to technology adoption are suggested: *Low computer self-efficacy* and *performance anxiety connected with computer use*. Finally, in addition to the points above, *ergonomic impediments* is suggested as a barrier for technology adoption by elderly. These barriers have similarities with the ones observed in younger adults (for example: quality/quantity of the data provided by the service, interaction design of the service not corresponding to user needs.)' (Villalobos-Zuniga and Cherubini, 2017)

Types of tracking technology users
In a research about the relation between prior motivation and affordances from tracking technology use, Jahiri and Shin (2017) distinguished 5 types of users which receive different affordances from tracking technology use: curious immobile, aspiring starters, motivation seekers, quantified selfers and persistent roamers (Figure 20). They researched the use of the Fitbit activity tracker, but similar types of users are expected be found in other tracking devices.

Informational affordances of the device can be perceived useful in the short term, but they are unlikely to justify and encourage long-term use in the absence of motivational affordances (with the exception of 'quantified selfers'). This is because, without motivated interest, both the novelty of the device and the uniformity of the information it may provide are likely to wear off over time.

	Physically active	Motivated to improve	Informational affordance	Motivational affordance
Curious immobiles	Not active	Lack existing motivation	Yes	No
Aspiring starters	Not active	Motivated to be more active	Yes	Yes
Motivation seekers	Active	Want to maintain or increase activity level	Yes	Yes
Quantified selfers	Active	Want consistent information about personal performance	Yes	No
Persisitent roamers	Active	Satisfied with activity level	Yes	No

Figure 20 Five types of users of tracking technology based on the research of Jahiri and Shin (2017). The diameter of the colored circle indicated the amount of motivation to increase activity and the amount of desirability of informational and motivational affordances.

Information from the Fitbit device became less meaningful or less relevant for many users, as its representations became routine, and lacked sufficient novelty to maintain their interest. Once the information had lost its novelty and meaning, the 'Curious Immobiles' and 'Persistent Roamers' behavior began weakening perception of its long-term benefit. This is in contrast with claims that access to better data sources, or better presentation of information from activity tracking devices, motivates user behavior change (Cotgreave, 2015).

For most 'Curious Immobiles' and 'Persistent Roamers', tracking device use does not lead to significant motivational affordances. The 'Curious Immobiles' are dissatisfied with their activity levels, but they are not sufficiently motivated to engage in further activity in the near future. This is borne out by findings in the literature, suggesting that readiness to change behavior is one of the factors that influences the way individuals interact with and take advantage of information for behavioral change (Bar-Ilan et al., 2006). 'Persistent Roamers' already have solid motivation structures outside of a tracking device.

All types gain informational affordances, like data visualisation and self-monitoring, but the long-term effects are questionable. Groups that are prone to motivational elements (aspiring starters and motivation seekers), like: goal-setting, rewards, visualisation, coaching and social interaction, or groups with insintric motivation (quantifies selfers) are more likely to become long-term users of tracking technologies.

The hypothesis is made that the use of technology among wheelchair users is not significantly different than that of able-bodied people.

Project stategy
This project will incorporate both informational display and motivational strategies to improve the behavior of the groups that need most support (curious immobiles, aspiring starters and motivation seekers). Wheelchair behavior data should be available, since it is used by all types of users. Motivational elements, will be optional and advised to be used, but should be able to be ignored. In this way, all types of users will gain value from the product.

Target group
There are a lot of different types of wheelchair users, with each their own lives and lifestyles. With all the different causes and disabilities, come all kinds of different requirements for wheelchairs. This project will primarily focus on the average wheelchair user with normal sedentary posture and average cognitive, upper body and upper extremity functionality. Special cases, like deformed bodies and differences in body functions, will not be included in the ideation of this project. Eventually, each case will require a personal approach.

People of all ages experience problems from wheelchair use. It is important to design an inclusive product that can be valuable for a large range of society. For this project it is chosen to focus on adults and elderly, who are expected to understand the physical consequences of their actions better than children.
The target group for this project will be adults and elderly (18-80 years old). These curious immobiles, aspiring starters, motivation seekers and quantified selfers, already have prior motivation to change their behavior to improve their health and reduce their physical problems. People below and above the target group age can also use the product, but will be left out of the ideation for solutions in this project.

It is hard to determine the size of the target group, since there are no official numbers on manual wheelchair users. In the Netherlands, which has a population of 17 million people, it is stated that there are 0.5 million people aged between 12 and 64 with a medium to severe motor impairment, of which 17% relies on a wheelchair (CBS, 2008). The estimation is that there are approximately 70 thousand wheelchair users. Based on Figure 21, it is estimated that 50% of this group is a manual wheelchair user of which a guess is made that 50% is an autonomous wheelchair user. This makes the target group for the Netherlands around 17500 potential users, which is approximately 0,1% of the total population.

Project focus

Wheelchair use can have many different causes. Depending on the disability, fitting wheelchairs are advised for permanent, full-time wheelchair users. People using powered wheelchairs or scooters are not using their body strength to propel their wheelchair. Since this project is about sedentary behavior and physical activity, the focus will be on the popular manual wheelchairs primarily.

Key take-aways

The product would not be used if the benefits are not meaningful to the user. Simplicity and clarity of actions would improve the experience of users of all ages. Users want to know their information is secure. The product should give informational and motivational affordances to the user.

It is most valuable to focus on manual wheelchair users, who are permanent and full-time users of their wheelchair for mobility and who are independent from caretakers.

Image 23 First foldable tubular wheelchair designed in 1933 by Harry Jennings. (Zimmerman et al., 2004)

Image 24 iBot wheelchair balancing on two wheels. This wheelchair is able to stand up, increasing the height of the user, and drive up stairs. Retrieved from: https://www.designlisticle.com/

2.3.4. Manual wheelchairs

Everyone has seen a wheelchair once in their lifetime. A wheelchair is a wheeled mobility device in which the user sits. Wheelchairs are used by people for whom walking is difficult or impossible due to illness (physiological or physical), injury or disability. For this chapter, desk research and semi-structured qualitative interviews with wheelchair users and a therapist is done to gain insight (Appendix B). The interviews are used to map out the context around the wheelchair user and to understand their problems. In this chapter, you will read about the history, current developments and different types of wheelchairs and see an overview on the main physical problems due to wheelchair use.

Brief history

Wheelchairs have helped people for centuries. The first known wheelchair purposely designed for disability and mobility was called an “invalid’s chair”. It was invented in 1595 specifically for King Phillip II of Spain (Kamenetz, 1969). This was in fact a chair with small wheels attached to the legs of the chair. In this time, only the wealthy could afford to buy a wheelchair. So, there is a high possibility that these people were pushed in their devices by servants.

The first independently propelled wheelchair was developed by a german watchmaker in the mid 1700s. Recognisably modern designs with wheels, in which users could propel themselves, appeared in the late 19th century. The American Civil War and the later world wars all served as spurs to invention; powered chairs appeared in Britain as early as 1916. In 1933, Harry Jennings, an engineer, invented the first foldable tubular steel wheelchair as we know today (Bellis, 2018).

Modern day wheelchairs are comparable to the models named in this paragraph, they are just further developed products by improving usability, comfort, ergonomics and functionality.

Future of wheelchairs

There are lots of high-tech solutions being developed for wheelchair user’s problems. The development and integration of technology, results in advanced wheelchair design and functionality. Researches on comfort and safety, are contributing to improving personal comfort and wheelchair fitting (Sprigle, 2014; Mikolajewska, 2010).

In the context of manual wheelchairs the main developments are in the direction of lightweight and

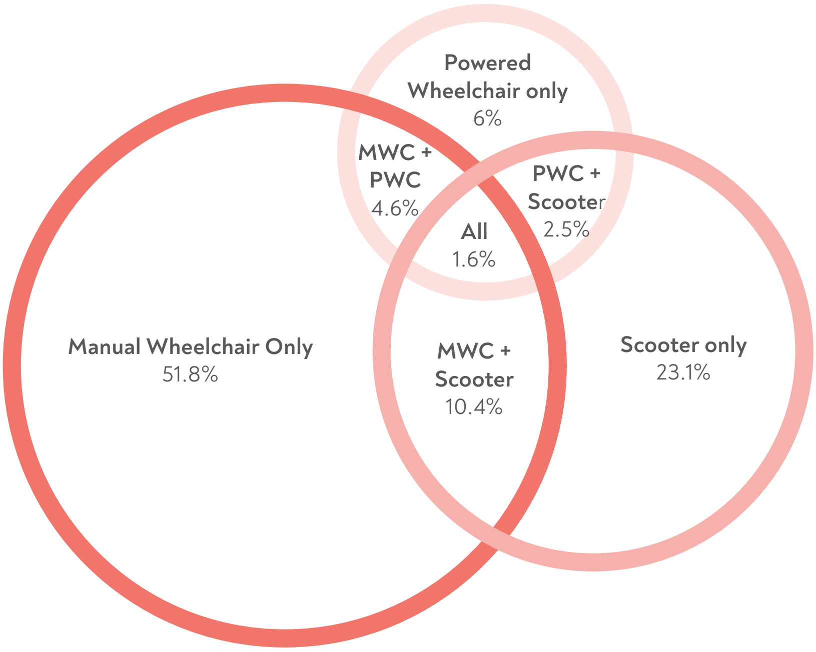


Figure 21 A visualization of the combinations of use from research of Smith et al. (2016) in Canada. More than half of the cases use only manual wheelchairs. MWC = Manual wheelchair PWC = Powered wheelchair

compact devices which are easy to fold and/or transport. Most current developments can be found for motorized wheelchairs, by integrating even more functionality and technology. Developments can be seen for people who need constant care. New wheelchairs are being designed that take over responsibility of the carers, making caring more efficient. For example, wheelchairs that are able to make the user stand up easier, wheelchair that drive up stairs (Image 24), wheelchair that follow each other and wheelchairs that use advanced AI to avoid the collisions. For the future, researchers are even doing research around brain-computer interfaces, making it able to control wheelchairs with thoughts (Mikołajewska, 2010). Freewheel even jumped on the big data bandwagon, attaching sensors to wheelchairs to register mobility and make accessibility city maps (Techcrunch.com, 2015).

Market

The global wheelchair market is expected to reach an estimated $6.1 billion by 2022. The market of wheelchairs is expected to be growing 5% every year (Growth Opportunities in the Global Wheelchair Market, 2017) and will be developing as long as there are people who need such devices. It is unclear how large the market for manual wheelchairs alone is. The hypothesis is that a high percentage is in the development and sales of powered wheelchairs. In Figure 21, an infographic can be seen on the use of manual and powered wheelchairs and scooters. More than 50 percent of all users depend solely on manual wheelchairs for their daily activities.

Manual wheelchairs

There are many different types of wheelchairs that enable people to do things they are unable to do by themselves. Such as transporting themselves, reach high shelves and drive up stairs. But, the most common wheelchairs are manual. Some examples of types of manual wheelchairs are:

- **Standard manual wheelchairs**
- **Bariatric manual wheelchairs.** Wheelchairs for heavy and large people.
- **Active manual wheelchairs.** Wheelchair for active people and sports (often without armrests).
- **Transit/transport wheelchairs**. Wheelchair to be pushed by a carer, often seen in hospitals.

The archetype of all these wheelchairs look alike and can be compared with the archetype example in Image 25.

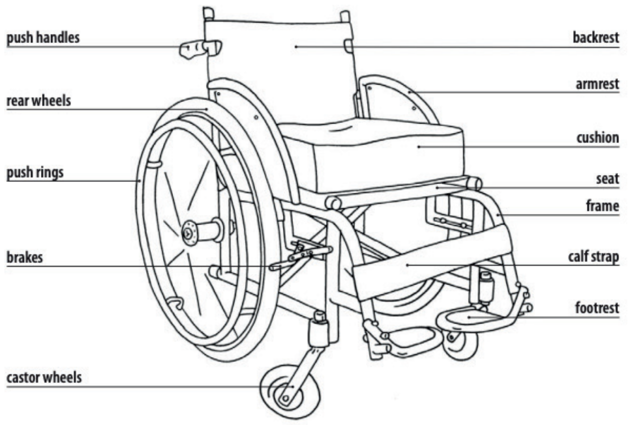


Image 25 Archetype of a manual wheelchair with named components

Image 26 Example of a standard manual foldable wheelchair

Image 27 Example of an light active manual wheelchair

Many users choose for a foldable or compact wheelchair, or a one that can be reassembled for easy transporting by personal car.

Main differences in manual wheelchairs

As can be seen in the images on the left, there is a high consistency in lay-out of the wheelchairs. The main differences are in the personal requirements and preferences that determine what kind of wheelchair features suit the user best. This results in different kinds of dimensions, cushioning, support and wheel protector or armrest.

Depending on the user's needs and preferences the wheelchair is chosen. Less active wheelchair users often require a wheelchair that distributes their weight as much as possible to increase comfort and reduce the risk of over-pressuring the skin. Properly fitting the dimensions of the seat, armrests, footrests and cushioning is important to achieve this.

However comfort is also important, practical use is more important for active wheelchair users. They often choose for a more compact sitting posture, to increase their wheelchair manoeuvrability, agility and speed. They often choose to leave out the armrest. This makes it easier to fit under tables, but makes it harder to in- and egress a wheelchair. Leaving them with solely a wheel protector, to reduce the risk of touching the wheel while it is spinning.

Project focus

In this project the focus will be on a design that can be integrated in a standard manual wheelchair, where the user is self-propelling. The expectancy is that most inactive individuals own a standard manual wheelchair and will gain more from behavior improvement. The archetype of the manual wheelchair will be used as a base to integrate technology for the sensing and actuation of behavior. The design should have no effect on the primary use of a wheelchair.

Key take-aways

Armrest is the most visible part of the standard manual wheelchair to its user.

Image 28 Example of a concept of an active manual wheelchair designed in a competition of Toyota
Retrieved from : https://mobilityunlimited.org/ (2019)

2.3.5. Use environments

This chapter will focus on the use and functionality of a wheelchair in use. By describing various scenarios, the purpose and meaning of the wheelchair will become more clear. In Figure 22 an abstract journey through use environments is shown. A visualisation of the use journey is shown in Figure 23 on page 62. In this chapter an analysis is done of the use of a wheelchair during the most common activities and In the most common use environments.

Sitting

First of all the wheelchair is used to be seated. The user places his buttocks on the seating pan, back on the backrest and his feet on the footrests. The moment of ingress takes up a lot of energy, since, in the case of a user that is unable to walk, the user needs to lift their body and places themselves in the chair using their upper extremities. At the end of the day or during sanitary breaks the user needs to pull themselves out of the chair and transport themselves.

The wheelchair user often sits in their wheelchair for long continuous hours, without sufficient pressure relief. Some interviewees have said that they only perform pressure relief or posture adjustment when they experience discomfort. One participant stated that he would likes to receive guidance in sedentary posture, since he sometimes experiences discomfort from postural dis-balance.

Rolling

The wheelchair user sits in the chair and places his hands on the hand rims. By turning the wheels forwards or backwards, the user manages to propel and navigate themselves through their journey. The intensity of the push translates in an acceleration of the wheelchair.

The weight of the person and wheelchair, the surface floor type and inclination have a high effect on the resistance of the wheelchair. The resistance of the surface floor is always in the opposite direction of the movement. When a wheelchair user is moving uphill the force is also in the opposite direction, resulting in a need to exert more energy at a more frequent pace. The physical equations will be elaborated in the chapter “Technology analysis”.

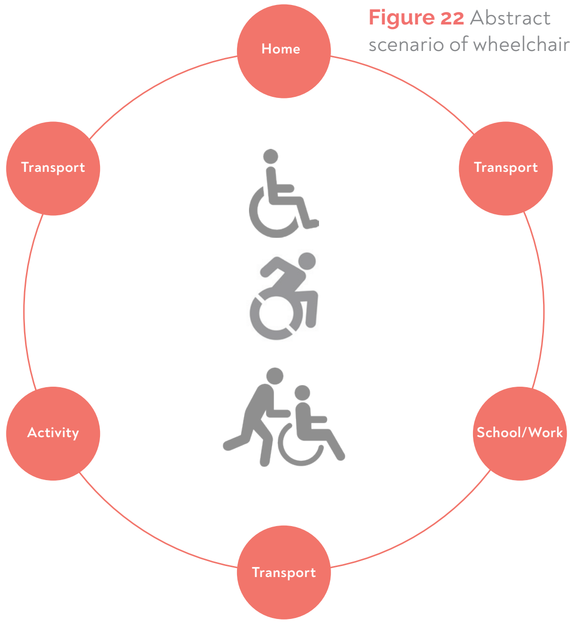


Figure 22 Abstract use scenario of wheelchair use

Daily activities

School/work

By doing high focussed work, even able-bodied people tend to sit still for a very long time. This, together with reaching towards the keyboard and looking at a computer screen often has a negative effect on your sedentary behavior. In these kind of environments often other colleagues or fellow students are also present, who do not want to get distracted from their work.

Sports/Recreation

Wheelchair users also practice their hobbies. Whether its sports or recreational games, most of them require to be at a specific location. Recreational locations can be very loud (sportshall) or very quiet (during a chess-match). These environments each have their own requirements for distraction of the user and their surroundings. In some cases, for example in sports, the user has to use another type of wheelchair to participate in sports.

Sanitation

During the sanitary visits, the user needs to egress out of the wheelchair and onto the toilet. During this moment, the wheelchair is on a brake. After the visit, the user ingresses into the chair again and leaves the sanitation room.

Resting

Next to the activities named above, the user also waits and rests in its wheelchair. This moment is comparable to standing or sitting down for able-bodied people.

Smartphone use
The wheelchair users have similar smartphone behavior as able-bodied people. Using their device as a way to plan their travels, inform on news and connect with friends. This can be that they take short moments for themselves every once in a while to update their knowledge.

Transport
Public transport
When a wheelchair user wants to use public transport, it requires some organizational planning. It is necessary to find out whether the station, bus or train is accessible for wheelchairs. After entering public transport, this is a fairly passive way of transport.

Passive personal transport
Some wheelchair users are legally allowed to drive and own a personal vehicle. Of course there are multiple scenarios, but an example is: If a user is able to lift their body, they egress their chair, fold it and put it on the backseat and take place in the driver's seat themselves. In other cases, the vehicle is modified and the user is able to roll into the car and stay seated in their wheelchair while operating the vehicle. During driving the user is highly focussed on traffic.

Active personal transport
Like able-bodied people can walk or ride a bike to their destination, wheelchair users roll or handbike. This requires high physical effort, thus it is the most active way of transportation. This type of activities burn many calories and are preferred to reach the goal of daily activity. The amount of energy needed to transport is dependent on the weight of the wheelchair and its user and the resistance of friction and inclination.

Environments
Indoor/outdoor
The wheelchair will be used in both indoor as outdoor environments. The users will be using their wheelchair during everyday activities. This requires the product to be intimate by not disturbing surrounding people as much as possible. It is necessary to use technology which is capable of measuring physical activity both in indoor and outdoor environments. Outdoors, it is important that the product withstands the weather conditions, but also remains usable in these conditions. For example, sunlight for readability and rain for interacting and waterproof requirements.

Intimate / Public
The wheelchair is also used in different types of environments where other requirements are more important. For example, there are situations where the user is doing something in an environment with other people who are highly focussed, for example: library or working floor. With the new design, interaction between people should not change in these kind of environments. There is also a chance that wheelchair user want to keep their wheelchair interaction intimate. There should always be an option to 'mute' the interaction. Intimate environments, like at home, are more free and personal.

Adaptive behavioral interventions
Different environments ask for changes in interaction. Therefore, it is important to understand location-based interaction requirements. Interactions should be timed carefully for the user to be received as valuable and meaningful. By learning the routine of the wheelchair user, like waking up, transport, working time and arriving home, it will be possible to make fitting settings or information flow.

Project focus

Since the focus is on permanent, full-time wheelchair users, the product should be able to be used in all environments unobtrusively. A private interaction is preferred and will be default. Consequently, the interaction settings should be able to be personalized.

Key take-aways

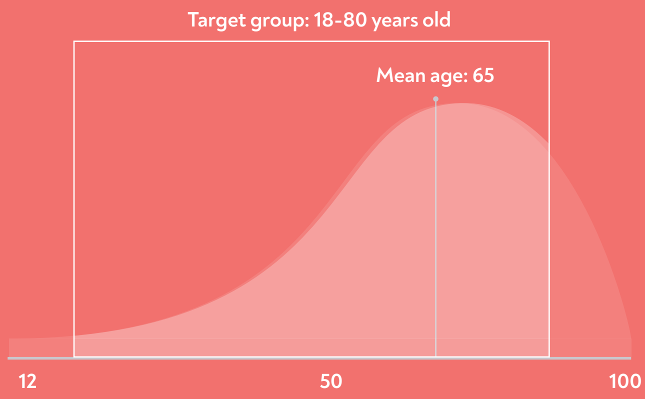
Posture guidance should be available. The interaction should be private. There should be an option to turn on a 'silent-modus'. Technology should work in- and outdoors.

Figure 23 Use scenario containing phases, types of environments, steps, duration, estimated current wheelchair behavior, emotional state and technology use

Phase	Waking up at home	Transport	
Type of activity	Leaving home	Active personal transport	Passive personal transport
Description and steps in activity	Morning routine Wake up Enter wheelchair Sanitation Breakfast Pack bag Leave home	Rolling/Handbiking Propel/Handbike Participate in traffic Arrive at destination Remove handbike	Driving car Propel to car Ingress car Lock wheelchair Participate in traffic Arrive Unlock wheelchair Egress car
Duration of activity	~1 hour	2x ~30 mins	2x ~1 hour
Type and level of sitting activity	Ingress wheelchair Dynamic	Propelling Very dynamic	In&Egress / Driving Static
Type and level of mobility activity	Ingress wheelchair Moderate	Propelling Very high	In&Egress / Driving Low - moderate
Emotion / Mindstate	Curious Active Hurry	Active Focussed on surroundings	Focussed on surroundings
Receptive for intervention	High/Moderately	No	High
Smartphone	Take out of charger Morning routing: Check news/ socials/agenda	Navigation No use	Navigation No use

	Daily activities			Arrive at home
Public transport	School / Work	Recreation / Sports	Restroom visits	Arriving home
Driven by car/ bus/train Propel to stop Ingress Lock wheelchair Moment of inactivity Arrive Unlock wheelchair Egress	Public environment Arrive at location Quiet public environment Loud public environment Moments of focus Leave location	High acitivity activities Arrive at location Change clothing (and gear) Activity in (other) wheelchair Change clothing Leave location	Sanitary activity Arrive at location Egress wheelchair Toilet Ingress wheelchair Wash hands Leave location	Evening routine Arrive at home Enter home Dine (Egress WC) Relax Sanitation Exit WC Lay in bed
2x ~1 hour	~8 hour	~1.5 hour	~3x ~15 mins	~1,5 hour
In&Egress / Sitting Static	Sitting Static	Recreational acivity Very dynamic	In&Egress No - Dynamic	Egress / Rolling to location Dynamic
In&Egress / Sitting Low - moderate	Rolling to location / Sitting Low	Recreational acivity High - Very high	In&Egress No - Low	Egress / Rolling to location Low
Calm Planning ahead	Focussed on school/work	Focussed on activity	Bored Reflective	Calm Curious Reflective
High	Moderately	No	No	High
Check news/ socials/agenda Use for entertainment	Use for work/school: Searching/planning Use for distraction	No use	Use for distraction/ entertainment	Evening routine Use for distraction/ entertainment

Summary, conclusion and requirements internal analysis



The analysis of the user and context generated insights in the situation of the wheelchair user. The main choices, conclusion and findings are presented in this summary.

Stakeholders
All stakeholders could gain from insights in wheelchair behavior. Here, the main focus is on wheelchair users.

Wheelchair users
An estimation is made that 0.1% of the population needs a manual wheelchair for mobility. Wheelchair use increases with age, resulting in a mean user age of around 65 years.

Wheelchair users are under-represented in education and the work-field. Wheelchair users do not meet the guidelines for physical activity and pressure relief.

Different type of activity tracking users were identified in prior research, which concluded in the effects of informational and motivational affordances. Users who have low activity but aspire to improve or seek motivation, make use of the motivational elements mostly, increasing the probability for long-term product use. The hypothesis is made that wheelchair users have similar understanding of technology compared to able-bodied.

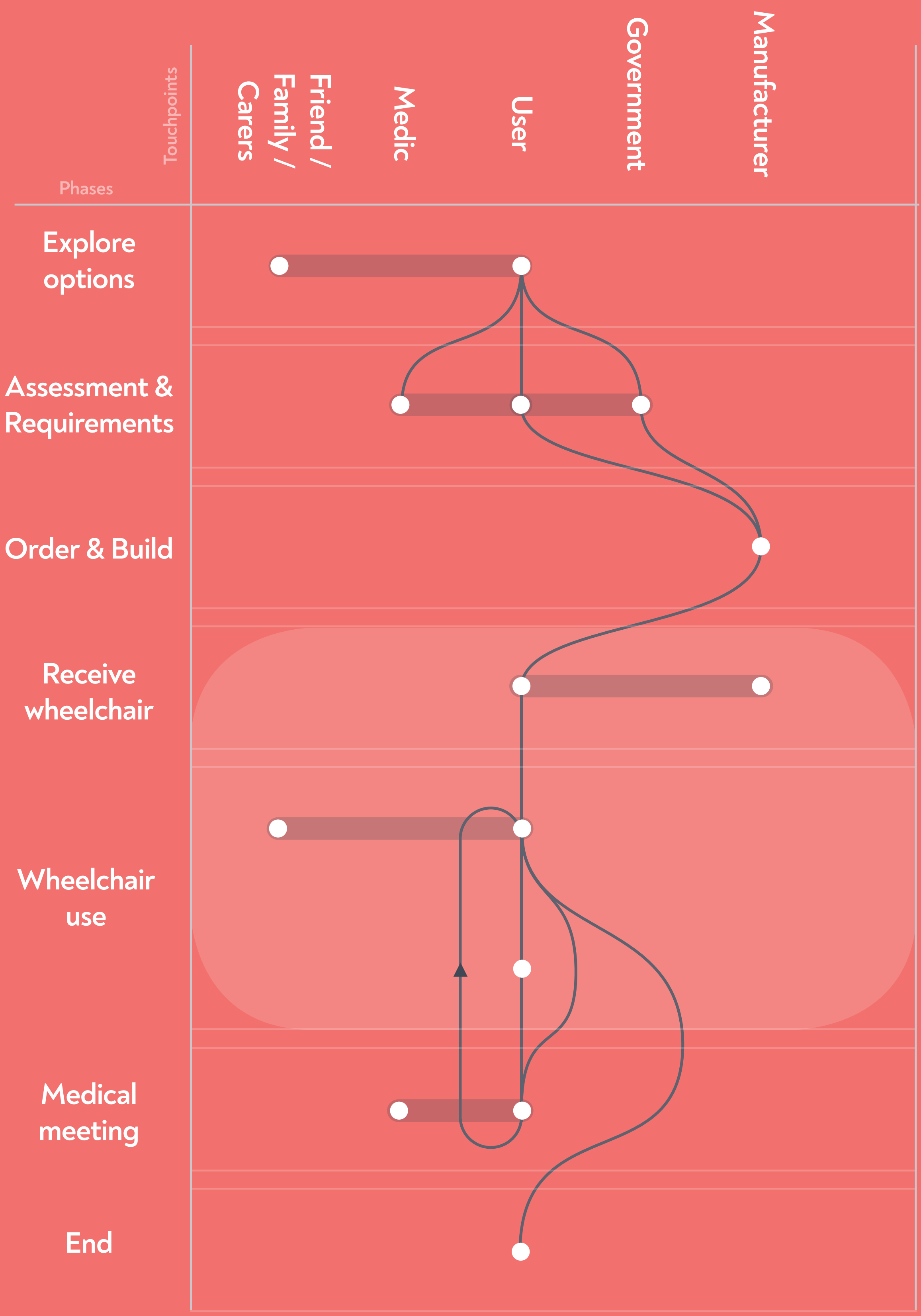
User journey
Analysing the user journey concluded in an overview of current interactions and flow. The focus for this project will be on the wheelchair use. Providing wheelchair users with insight, information and behavioral interventions is expected to improve wheelchair behavior and affect the consequences of poor behavior.

Wheelchair
Users of standard manual wheelchairs are expected to be less mobile and active than users of active wheelchairs. Standard manual wheelchairs are more focussed on comfort and have armrests. The design solution should be integrated in the existing archetype and not intervene with wheelchair functionality.

Use environments
Different environments come with different interaction requirements. The interaction must feel intimate and not distract the others as much as possible and not distract the user during high risk activities like active personal transport.

Main requirements:

- Interaction should be intimate, easy, clear, meaningful and safe. (2.3.3.)
- User should be able to activate silent-mode and posture guidance. (2.3.5.)
- Design should be integrated in an archetype standard manual wheelchair. (2.3.4)
- Visual component should be embedded in armrest. (2.3.4)
- Design should function in- and outdoors. (2.3.5.)
- Design should make clear what happens to their data (transparancy). (2.3.3.)


Touchpoints
Phases
Friend / Family / Carers
Medic
User
Government
Manufacturer
Explore options
Assessment & Requirements
Order & Build
Receive wheelchair
Wheelchair use
Medical meeting
End

2.4. External analysis

2.4.1. Trend analysis

By using the trend analysis method as described in the Delft Design Guide, an overview is made of the most important trends, related to wheelchair use, that have been found during the DEPEST analysis. In this analysis demographic, economic, political, ecological, social and technological can be seen. The trends in wheelchairs and behavioral monitoring are added to complete the picture.

Demographic trends

The population of Europe is expected to be 5% larger in 2040 and 2050 respectively (Foster, 2014), next to the growth the mean population age is also rising, resulting in the phenomenon of the graying population of Europe. Because of this, the population is expected to experience more age-related diseases (Heisel, 2015) and thus an increase in the amount of wheelchair users can be expected.

Economic trends

As an effect of the graying population, the medical costs are rising and there is a decline in the ratio between working to beneficiary. Which means less money for patients, insurance companies are challenged to come with new models (Goforth, 2016). This results in higher investments in maintaining health and injury prevention (Morisson, 2014). The wheelchair market is growing by 5% each year globally (Growth Opportunities in the Global Wheelchair Market, 2017).

Politic trends

Independence of wheelchair users increases due to accessibility laws for buildings (European council, 2018). The policies to facilitate working possible for wheelchair users is expected to increase the gross domestic product. In Canada, the GDP is expected to gain $17B by 2030 by improving disability access (Vomiero, 2018).

Demographic

Growing society
Aging society
Rise of age-related injuries

Economic

Growing medical costs
Insurance companies re-strategize
Wheelchair market growing

Politic

Accessibility laws
for buildings
Increase independence and
work force wheelchair users
eHealth

Ecologic

Zero waste
Closed loop
Longer lifetime

In its e-health Action Plan 2012–2020, the European Commission (2012) explicitly mentions that, "e-health – when applied effectively– delivers more personalized 'citizen-centric' healthcare, which is more targeted, effective and efficient and helps reduce errors, as well as the length of hospitalization. It facilitates socio-economic inclusion and equality, quality of life and patient empowerment through greater transparency, access to services and information and the use of social media for health." (Bol, Helberger and Weert, 2018)

Ecological trends

There is an evolving trend in the production of products with zero waste. This is done by using recycled materials or closed-loop manufacturing, where product parts are reused in new assemblies when these are sufficient enough (Fairware, 2016). The goal is to reduce the impact on the planet.

Social trends

There is an increase in participation in education (Bahksi, 2015), work life and sports by wheelchair users. Wheelchair sports are more known and accepted due to exposure of the paralympics (GBWBA, 2013). This contributes to the acceptation of wheelchair users in society. Also, next to the rising obesity rates (The State of Obesity, 2019) there is an counter-trend, where people tend to live healthier (Market research blog, 2019).

Technologic trends

With the coming of cheaper (MacDonald, 2019) and more advanced technology, like wearable fitness trackers (MBI, 2016), low energy data transmission (Garcia et al, 2016) and the 'Internet of Things', there is an increasing datafication of the lives of people (Forbes, 2017). Together with artificial intelligence, this improves the way data is processed and used.

Consumers want the abundance of data to become more digitally centralized, according to DeMers (2019), Founder & CEO of AudienceBloom. This means that they are looking for convenient ways to manage basically everything from a minimal amount of devices.

Smart sensors and the Internet of Medical Things (IoMT) opens up the possibility of remote or home healthcare becoming mainstream in the future (Martin, 2019).

Social

Wheelchair sports gain popularity
Increased participation in education, worklife and sports
More people live healthier lifestyles

Technologic

Internet of Things
Big data
Smart products and services
Digital centralization
Low energy data transmission
First fitness monitors for disabled

Wheelchair

Lightweight wheelchairs
Sleek design
Increase in functionality

Behavioral

Activity monitoring popular
People prefer multi functional devices
More research in mobility performance in wheelchair sports

Products become customizable and are able to be 3D-printed on a larger scale. Data visualization is becoming mobile friendly, interactive and also available for non-scientists(Carto, 2018). The progression in touch screens is increasing in quality and decreasing in costs.

Wheelchair trends

There is a two-way trend in the wheelchair market. On the one hand it becomes technology driven when looked at electrically powered wheelchair. Especially in the context of patient care. On the other hand, manual wheelchairs are being optimized to ergonomics and are being designed to be lightweight and easily transportable (Ellapen et al., 2017). Wheelchair manufacturers use textures, materials and colors to follow fashion trends to suit the taste of the consumers. Trends for 2019 are expected have a sleek and minimalistic design (Trendhunter, 2019) and contrasting natural colours (O4, 2018).

Behavioral monitoring of wheelchair users

The monitoring of wheelchair users is becoming more popular in the context of patient care. The first prototypes are being developed that make it easier to monitor sedentary behavior of elderly in powered wheelchairs (Mobility, 2019). More research is being done in this field and also in wheelchair sports (Cooper, 2012).

Project focus

With the expected rise of the amount of wheelchair users, it becomes more important to focus on the injury reduction to avoid even more rising medical costs. The rise of wheelchair users in education, workplace and sports is a positive progression, but results in new contexts and behavior development. It is expected that there are demographics who will less become active and some will become more active, influencing health and obesity in wheelchair users. Technological developments in eHealth can help with the datafication of this change of lifestyle and health patterns. AI and personal customization will create opportunities in making the wheelchair more personal and provide the user with meaningful data, presented in a centralized device, which in the current age is considered to be the smartphone.

Key take-aways

eHealth and IoMT are important trends of which this product will be part of, with a mission to improve the quality of care. Data is prefered to be centralized in one personal device.

2.4.2. Competitor analysis

Looking at current developed products from competitors can give insight in their approach and create inspiration for this project.

This project is about a smart wheelchair. With a focus on sitting position and activity there are multiple markets to analyse. The markets that are interesting to look at is posture control and insights, activity monitoring and other smart wheelchairs.

Sedentary behavior monitoring

Posture control is a growing market since a lot people work in while in sedentary position and experience problems over time. Most office jobs require a lot of sedentary time, which is comparable to wheelchair users. At the time of this market research, only one product has been found that is specific for wheelchair users that was related to posture control.

Sedentary behavior monitoring in wheelchair

The concept for a powered wheelchair by Life & Mobility and SAP (Mobility, 2019) was the only posture monitoring product specifically for wheelchair users. The product was focussed on measuring the sedentary behavior of elderly. This wheelchair was capable of monitoring postures and sedentary time using load sensors in the seating pan and backrest and temperature and humidity of the seating pan, since these factors are also factors of ulcer development. This concept was no consumer product, so there is no price indication.

This concept has a goal close to the this project. The main difference is in the way the data is used. The prototype software shows hard data in the shape of data points, graphs over time and percentages from analysis. It looks like it is used by data scientists and the manufacturer to learn about wheelchair use behavior.

Sedentary behavior monitoring in office chairs

There are multiple products on the market that focus on the sedentary behavior in office chairs. From wearables (Lumo lift, Upright), cushions (Darma smart) and smart office chairs (Axia Smart Active). Most wearables, whether they are worn on the skin or as a belt, make use of the inclination of the sensor to estimate the position of the upper part of the spine. This way they can determine the slouched or forward lean. The cushion and smart office chair measures pressure in specific areas of the seating pan and optionally backrest, to estimate the posture above based on pressure distribution.

All products make use of a simple notification, in the shape of vibrations or sound, to let the user know that something should change. Deeper insights can always be seen in the connected application. Different visualizations are used for presenting information.

The chair is a good example of a product that is comparable to the wheelchair for this project. The product makes use of three levels of information. Direct feedback (level 1) with vibration and visual presentation of where the pressure is abnormal on a plastic label

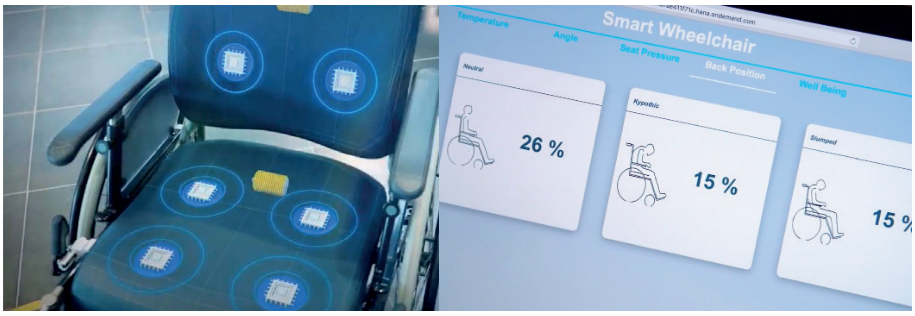


Image 29 Life & Mobility prototype. Sensors in the seating pan and back rest and visualizations of measured sedentary postures.. Screenshot taken from promotional video

Image 30 Application screens of Upright Go. A wearable gyroscope sensor to measure posture.

on the side of the seat. The smartphone application generates insights in behavior by presenting previous activity (level 2) and the possibility to gain knowledge on the correct sitting behavior and the consequences of poor sedentary behavior (level 3).

The chair has default settings that should work for everyone, but can be adjusted if needed using the application. The battery is said to have enough capacity for 7 years of use, which is the average lifespan of an office chair. The company even facilitates an extra touchpoint in their service, if questions rise about chair use or other technical questions.

Key take-aways

- Vibration and Application. The smart wheelchair of Life & Mobility uses sensors to measure the sitting position of the user, but does not give real life user feedback. The office posture devices (Lift, Upright and Axia Smart) use vibration as an actuator to notify the user of their poor behavior. More information can be found in the application. The multi-level information will be used to complete the information circle.
- Silent mode. The option to track posture activity without actuation should be present for when the user does not want to be distracted.
- Proactive coaching. Proactively reacting to behavior like seen in Darma is also a nice feature to have. When a person is in a certain position or inactive for too long, the product should attend the user to their behaviour.
- Bluetooth 4.0 connectivity is the most common facilitator of connected products with smartphone interface.

Image 31 Promotional image for Axia smart. A smart office chair with sensors to measure sedentary behavior.

Activity behavior monitoring

The monitoring of people's activity has grown in popularity due to the use of technology incorporated in smartphones and smartwatches. Products from this market are used to gain insight in activity behavior. The reason of use is often gaining insight in fitness and health of the user by counting steps, calories burned, inactivity and more. In this chapter, the focus will be on widely used and popular activity monitors (Fitbit and Apple's activity and health application).

For every price range a suitable activity monitor can be found. The sensors are not expensive or even built in a personal device, but the true value can be found in the way the data is used to interact with the user.

Fitbit tracking technology

The fitbit has been tested and does not give valuable data for wheelchair users (Liu, 2018). These activity monitors are able to track, distance travelled, altitude change, heart rate monitoring, step count, and sleep and activity detection, which are displayed in the application.

Heart rate enables the Fitbit to measure intensity of the activity, which helps calculating the calorie burn and measurement of sleep patterns.

The dashboard of the application shows a summary of all the data information in visualized icons. These icons are radial charts which show the data or the amount of the goal reached. To see more detailed information, the user can tap on the icon and see its development over time. Data visualization is done in multiple ways. Most daily data is detailed and can be shown as a line or a simplified visualization as seen in the sleep monitor screen in Image 32, weekly and monthly data is in bar charts.

The Fitbit technology provides further extrinsic features to motivate people to become more active, such as goal-setting, rewards, sharing, comparing and competing over activity data with contacts. Extrinsic capabilities and affordances are:

- **Goal-setting**. the device's default settings allocate users with a 10,000-step goal and a 30-minute activity period, with progress display, and a vibration alert when a goal is reached.

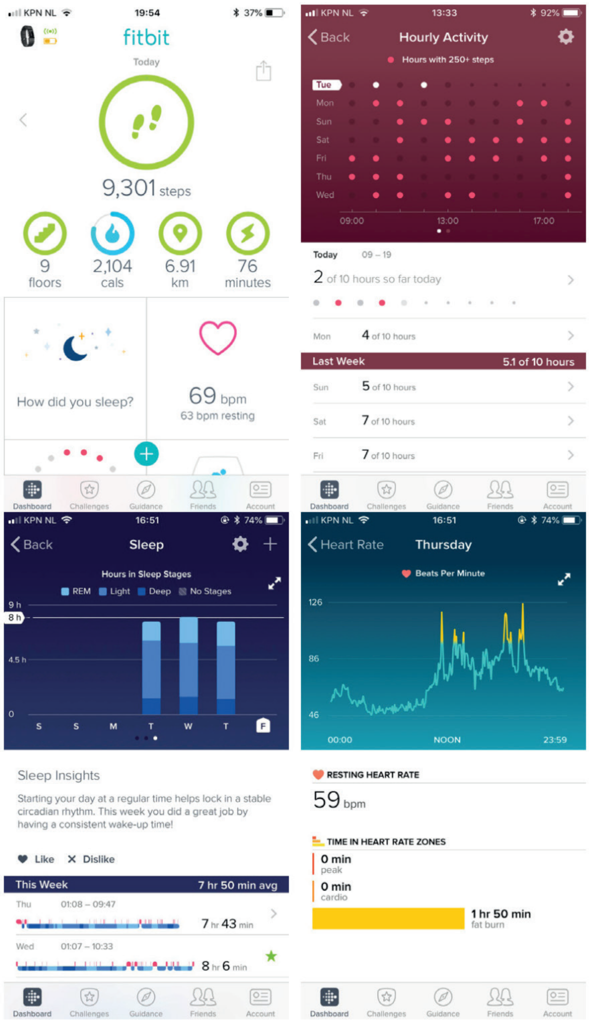


Image 32 Smartphone interfaces Fitbit.
Retrieved from: www.fitbit.com

- **Rewards**. the 'One' model, displays a virtual flower that 'grows' to indicate a user's recent activity level and badges for achieving goals or step count milestones, 'Flex' issues vibrating and flashing LED light alerts
- **Social sharing and competing.** Fitbit's user website enables social motivation by allowing user groups to compare and compete on displays of data achievements. It connects users to their existing social network sites such as Twitter and Facebook. The 'Flex' device allows many of these features in real time (Jarrahi, 2017).

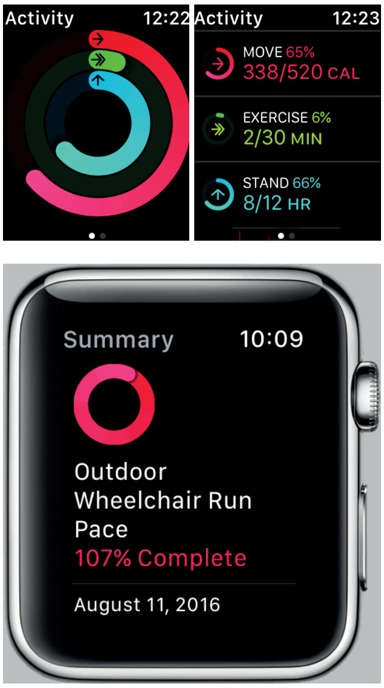


Image 33 Smartwatch interface Apple watch.
Retrieved from: www.apple.com

Image 34 Smartphone interface Activity app.
Retrieved from: www.apple.com

Apple watch & Activity app
The Apple watch measures activity and heart rate. With this data it follows your daily activities and shows a simplified version of your daily goals in a radial bar chart on the smart watch (Image 33). Radial charts have the advantage to show progress even when the goal is reached and give the user a quick overview on their personal daily goals. The user can navigate through the watch interface to overview data by numbers and over time, add exercises and connect with other people. By tapping that data the user will see a history of 12 hours of that element.

If the user wants to review the data on a bigger screen with more data, the user can open the app on the iPhone (Image 34). Here the radial bar charts of every day can be reviewed and explored. This application has the option to change the settings into wheelchair users. This gives slight changes in the interface, like instead of the notification to stand up, it says: 'Time to roll!' and shows amount of push activity instead of walking activity.

- **Goal setting**. The design uses two fixed target goals. One is for 30 minutes of exercise, which is defined as the intensity of brisk walk and equivalent to moderate intensity activity, the other is for standing or rolling for at least one minute every hour for 12 hours. The third goal can be set personally and it uses burned calories.
- **Rewards**. The design shows an animation when the user closes a ring. Other badges can be collected from doing exercises.
- **Social sharing and competing**. The user is able to add contacts and see their progress. They can also invite eachother for a challenge or send eachother a cheer.

Apple health app
Apple's health app collects all collectable data into one application. Internal IMU, apple watch and third party products can be connected to the iPhone and added to the dashboard (Image 35). More detailed information can be looked into when tapping on the element. It

Image 35 Smartphone interface Health app.
Retrieved from: www.apple.com

is possible to view data in daily, weekly, monthly and yearly view. For each type of data a fitting visualization is chosen.

Limitations
Although it can give valuable insights in physical activity, it misses insights in sedentary behavior. Posture and sedentary time are not targetted, while this is also a risk behavior of wheelchair users.

In the default settings, the 'stand'-goal measures whether the person is non-sedentary for at least 1 minute every hour. This is meant to motivate the user to become active more often to reach their goals more easily. The targetted behavior is Inactivity. But, it also has the side effect of the user perfoming pressure relief. For wheelchair users 'stand' is replaced by 'roll'. This has the same effect for physical activity data, but misses the nudge to perform pressure relief.

Key take-aways

- Dashboard overview of all collected information. This way the opening screen of the application contains all possible explorable data. This should be a simplified overview.
- Exploring deeper levels of information for deeper insight in history of behavior.
- Each type of data has its own visualization in detailed mode. Radial charts, bar charts or line diagrams are often used visualisations. Every type of information visualization should be designed to be clear.
- Abstracting visualization of meeting the activity goals
- Intensity in zones can be used to visualize very active moments. Possibly it can be used to estimate power expenditure and calorie burn. Although, this will need further study due to wheelchair users not using their entire body and the outcome can differ for certain disabilities.

2.4.3 Technology analysis

To understand what is technologically feasible, it is important to know the functionality and limitations of technology. From previous analysis, it became clear that activity and sedentary behavior insights will be needed. Regarding the activity of the user, the insights in physical activity (energy expenditure) and injury risk are needed. Regarding sedentary behavior, insights in sedentary time, pressure relief and posture are needed.

Calculating physical activity

In the field of human dynamics (or kinetics), physics is used to calculate movements and required forces. In this field, the system of an object and human is simplified into physical terms of body, forces, distances and moments. A force-body diagram of the situation of a wheelchair on a slope can be seen in Figure 25.

To move, a wheelchair user needs to exert some kind of force. The force needed to move the wheelchair forward can be found by using the formula F=m*a. The required force exerted by the arm of the wheelchair user can be seen as a function of the acceleration, the mass of the wheelchair and user, all the resistance forces and the dimensions of the wheelchair. The resistance force is the sum of the frictional resistance of the bearings, friction of the surface and potential slope (Figure 25).

While in motion, the wheelchair and the user have kinetic energy, which is calculated with the formula $\frac{1}{2} m v^2$. In this formula the quantities mass and velocity are used. This energy keeps the wheelchair in motion until the resistant forces reduce the energy to zero.

The formula of potential energy, which is E=m*g*h, calculates the amount of energy needed to make an object displace in height.

An overview of needed data and formulas can be seen in Figure 24.

Initial input

To be able to calculate with algorithms some values are needed as initial input:

Quantity	Symbol	SI Unit
mass	m	kg
force	F	N
moment	M	N*m
height	h	m
gravity	g	9.81 m/s^2
acceleration	a	m/s^2
velocity	v	m/s
displacement	s	m
ang. acc.	α	rad/s^2
ang. vel.	ω	rad/s
ang. dis	θ	rad

Formulas

First law of Newton	F=m*a
Kinetic energy	E= $\frac{1}{2}$*m*v^2
Potential energy	E=m*g*h

Integration

$$v_{current} = v_{initial} + a_{current} * t$$
$$s_{current} = s_{initial} + v_{current} * t + \tfrac{1}{2} * a_{current} * t^2$$

$$\omega_{current} = \omega_{initial} + \alpha_{current} * t$$
$$\theta_{current} = \theta_{initial} + \omega_{current} * t + \tfrac{1}{2} * \alpha_{current} * t^2$$

Figure 24 Basic kinematic equations; differentiations of the acceleration result in the velocity and displacement

User data

- Mass (of the wheelchair and user)
- Body dimensions (arm length)

Wheelchair properties

- Placement wheels
- Diameter of the wheel
- Diameter of the pushrim
- Friction coefficient of wheels

Estimating mobility data

At the base of all calculations are the estimates of travelled distance, velocity and acceleration. If one knows only one value of the displacement, speed or acceleration, using integration, the other quantities can be calculated. Analyzing this data can be used to count pushes, calculate the energy needed to accelerate and the moment of force on the joints.

In Figure 26 a plot of the speed is shown while propelling a wheelchair. What can be seen is that the velocity has a small peak at the moment of a push. Since a force is needed from the user to accelerate the wheelchair, the hypothesis is made that by calculating all accelerations forward while pushing can be counted as energy expenditure. Thus, pushes and acceleration need to be measured.

To incline, the wheelchair user needs to exert more energy. The algorithm would need to estimation of the necessary energy to climb the height, which could be done using the potenial energy formula. Thus, data on the inclination and/or difference in height is needed.

At decline, the wheelchair user will use less energy, since potential energy will accelerate the wheelchair when on a slope, thus it should not be counted as exerted energy.

In this project, the focus will not be on developing an optimized algorithm, but on solely understanding the algorithm and on how its functionality needs to be proven.

Activity monitors

Physical activity has been defined as any bodily movement produced by skeletal muscles that requires energy expenditure. Energy expenditure (EE) is often calculated using metabolic equivalent of a task (MET). To calculate energy expenditure the type, intensity and the duration of the activity has to be known.

Most pedometers and activity monitors make use of an accelerometer sensor or inertial measurement unit. An inertial measurement unit (IMU) is a sensor that incorporates three accelerometers, three gyroscopes and three magnetometers, all three in the three cartesian axes (X,Y and Z).

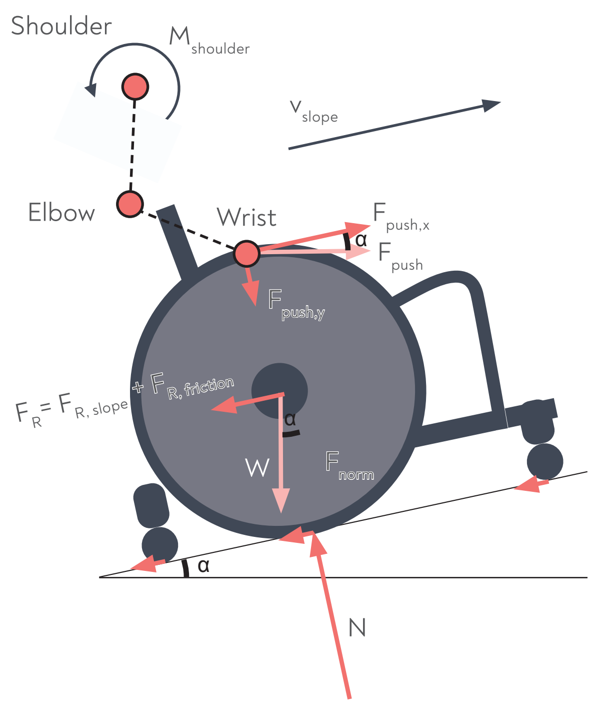


Figure 25 The forces from gravity of the user and the wheelchair result in forces of resistance due to friction with the floor (depending on floor type and N) and inclination.

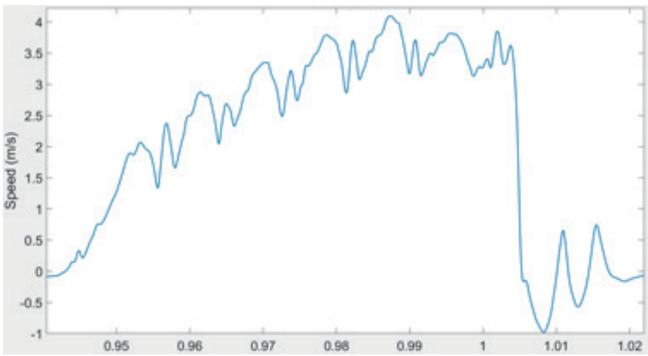


Figure 26 Partial plot of the speed of a 12 meter of an athlete sprint ingusing an accelerometer setup like in the research of Van der Slikke (2015)

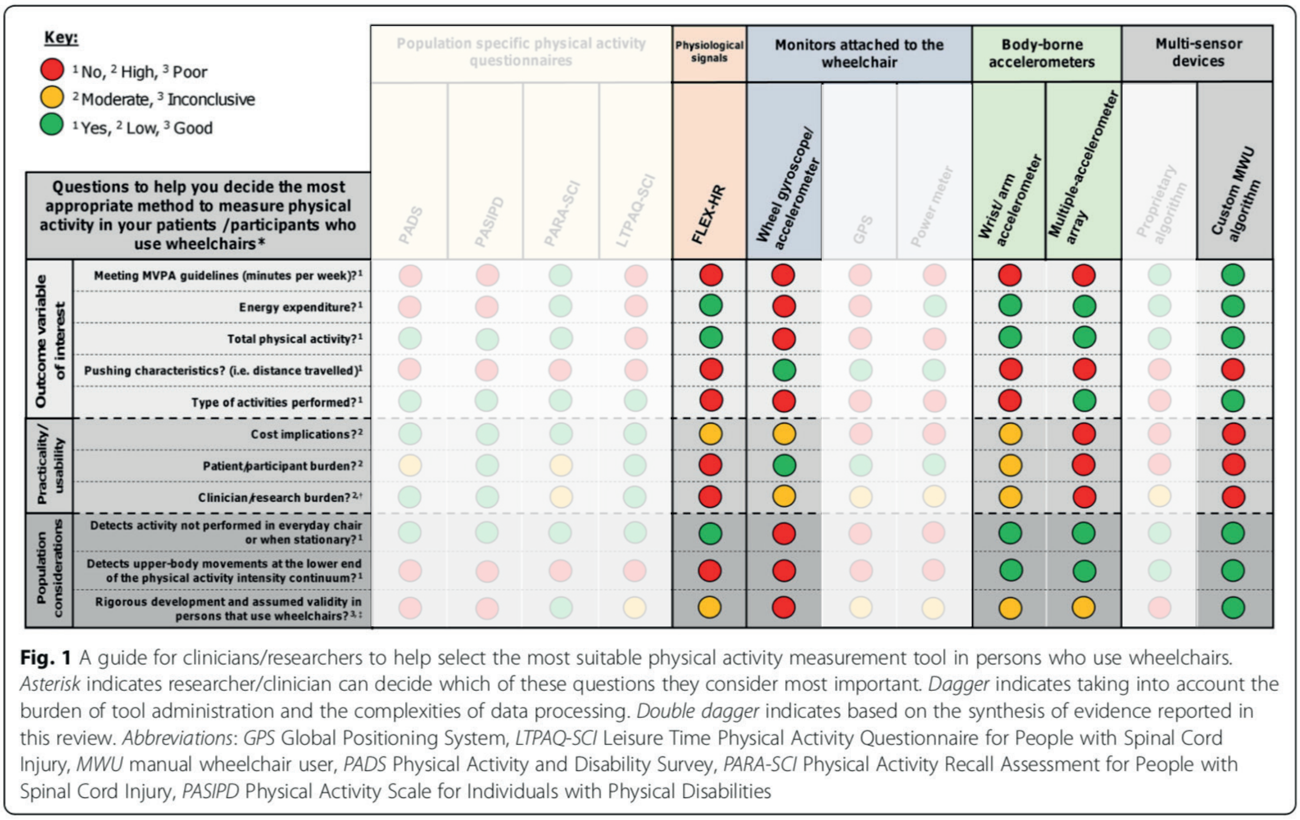


Image 36 An overview for selection of measurement tools for physical activity of wheelchair users. A custom manual wheelchair user (MWU) algorithm using accelerometer and physiological data would provide most valuable insights. (Nightingale et al., 2017)

Many pedometers for able-bodied people, which are used for estimating physical activity, are attached to the body of the user. Using research data on MET for certain activities (walking speeds) and the calculated steps, using accelerometers and an algorithm, will estimate the EE. These devices have difficulties in predicting the intensity of the activity (many small steps are counted similarly to the same amount of steps during running).

New-age activity monitors use additional body function data, like heart rate and oxygen levels in the blood to estimate intensity, which is added to the formula in the algorithm, to improve the estimation of the intensity of the activity. Improved estimations of intensity enables the algorithm to estimate EE more accurately. The algorithm determines the accuracy of the estimated EE.

Activity monitors for wheelchair users

Solely wheelchair bound mobility data makes it difficult to accurately estimate EE and intensities. Solely a physiological sensor data makes it able to estimate EE easier but has a harder time estimating mobility data. A combination of the two would give most accurate estimations of both type of activity and intensity (Image 36). The option for connecting a third-party heart rate sensor should be held open.

Walking is seen as the activity that has most influence on energy expenditure. Of course, this is different for wheelchair users. Apple is one of the first companies to introduce a feature for wheelchair users based on research. In this case, the accelerometer and heart rate monitor of the Apple Watch is used to estimate the physical activity intensity and energy expenditure of the user. To make a new algorithm specifically for wheelchair users they had to start from scratch and start researching, which made it possible to estimate the energy expenditure of wheelchair users.

Increasing speed and slope while propelling a wheelchair increases VO2. The intensity of an activity can be predicted to some extent by measuring speeds and slopes during wheelchair propulsion. (Gauthier et al., 2017)

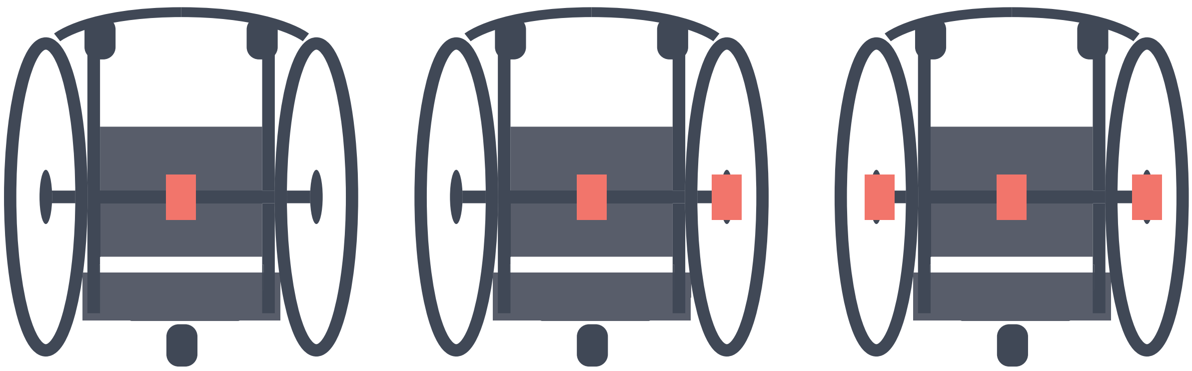


Image 37 Placing of the IMUs in the research of Van der Slikke et al. (2015) - More sensors result in more accurate data and possible insights

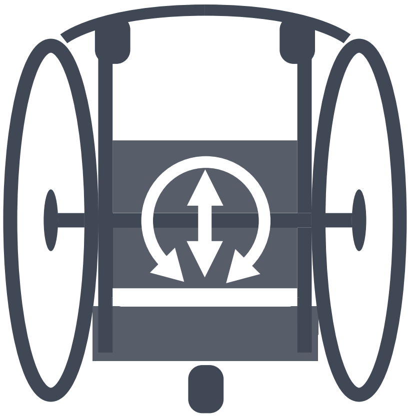


Image 38 IMU in the wheelchair frame has to be able to measure the acceleration in one axis and rotation in one axis to give insights in translation and rotation of the wheelchair

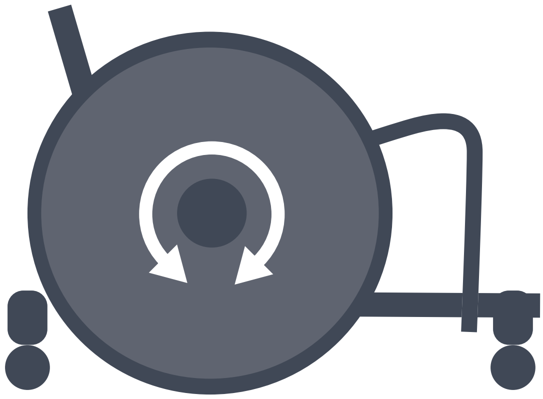


Image 39 IMU in the wheelchair frame has to be able to measure the rotation of the wheel to have a reference of speed

Mobility tracking in wheelchairs

A wheelchair is used indoors as well as outdoors. This makes it unable to use GPS as a localization technology to measure mobility (Gps.gov, 2019). In the requirements of the project it says that the design should be able to function without the need of additional devices next to the smartphone. Thus, it is necessary to use wheelchair-bound technology.

Researchers, who were interested in measuring mobility performance of individual wheelchair athletes, used wheelchair bound systems. With a miniature data logger, explorations of distances travelled and speeds achieved during wheelchair basketball and rugby matches (Sporner et al., 2009) and forward speed (Tolerico et al., 2007) were done. Other researchers used potentiometers (Moss et al., 2003) or inertial measurement units (IMU) (Usma et al., 2010 ;Fuss et al., 2012 ;Pansiot et al., 2011;van der Slikke et al., 2015)

The Hague University IMU research

The research of the The Hague University (THU) (van der Slikke, et al., 2015) used IMU sensors in the wheelchair frame and wheels. The placing and amount of IMU sensors influence the reliability and accuracy of the data. In Image 37 three configurations can be seen, which are explained below.

A simple configuration with only one frame sensor, would allow displacement estimation (van der Slikke et al., 2015). However, the considerable integration drift (the increase of errors due to integration of the acceleration data over a long time) makes this option of limited practical use. This could mean that the system thinks it is moving, while it is standing still.

One IMU on the wheel is not prefered, because the wheel is connected to the frame with an axis, which makes it more inefficient for charging and connecting with the other technologies in the seat.

In a configuration of two IMUs (where two IMUs are attached to the wheelchair: one on a wheel's axis and one in the middle of the frame near the rear wheel axis), it is possible to register all wheelchair mobility performance outcomes (van der Slikke et al., 2015). It uses the data from the frame IMU and calculates the rotation of the wheel with the wheel IMU.

In a combined configuration (where three Shimmer IMUs are attached to the wheelchair: one on both of the wheel's axes and one in the middle of the frame near the rear wheel axis), forward frame acceleration can be used to get more accurate data and it will be able to detect skidding wheels (van der Slikke et al., 2015).

An algorithm uses the data from the accelerometer and gyroscope in the frame and the gyroscope from the wheels to calculate the acceleration and rotation of the wheelchair in the horizontal plane (Image 38 and Image 39).

Elements to use in this project

To be able to give insights in mobility activity the system should be able to estimate and record the displacement, speed or acceleration. It is expected that one frame IMU will give insufficient accuracy due to drift.

A minimal configuration to measure accurate wheelchair mobility data consists of the measurement of an accelerometer and gyroscope in the frame and the rotation of one of the wheels. This way, the wheelchair will be able to do high frequency measurements to be able to calculate pushes and acceleration, but will experience no drift, due to referencing the speed with one of the wheels.

Key take-aways

With research and development a fitting algorithm could be developed to measure activity from wheelchair bound technology. Age, dimensions and weight are needed as initial input. Heart rate would give more accurate estimations.

In the THU research the IMUs in the wheels were attached to the axis of the wheel. The sensors needed to be charged and read after every measurement. The axis of the wheel is difficult to reach, so a better solution is needed to measure rotation of the wheel. Because of the need for charging the accelerometer, it would be more practical to use a frame-bound system to measure rotation of the wheel.

Predicting injury risk

Injury can occur due to sudden overloading of the upper extremity joint (high force) or by doing loading the muscles and joint by doing repetitive motions for a longer duration than the person is used to (duration). High forces could be calculated by measuring very high accelerations or measuring a situation (for example an extreme inclination). In both situations the resistance force should be calculated or estimated. Using sensors which make it able to measure inclination and an algorithm these situations are expected to be able to be recognized.

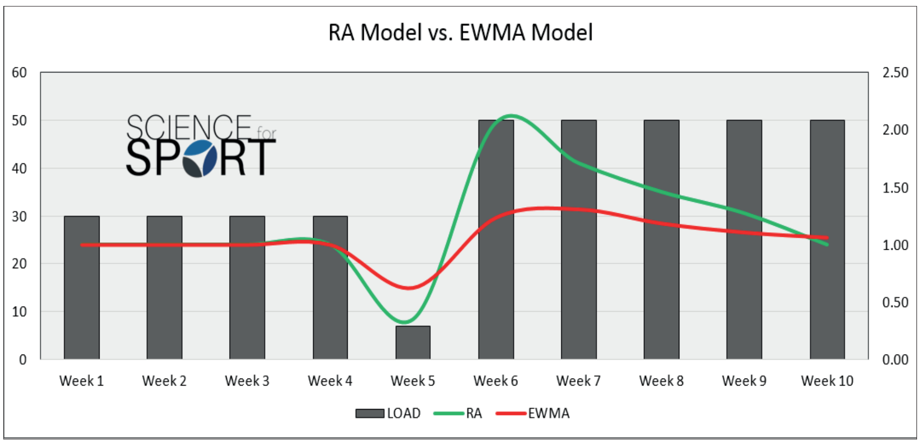


Image 40 Comparison of the effects of temporarily reduced load followed by an increase. Retrieved from: Scienceforsport.com

Acute:chronic workload ratio

One of the methods that can predict injury risk is the acute:chronic workload ratio. With this ratio it is possible to gain insight on the progress of your training and reduce the risk of injury due to under or over training. It divides the acute physical activity load by the average load of the previous weeks to predict the preparedness of an individual. The load is calculated using the duration and intensity of a session.

The session is graded with an intensity score and this is multiplied by the duration of the session, resulting in arbitrary units (AU). These AUs are scientifically used as a unit to calculate, but in fact are comparable to multiplying MET values with a duration.

There are two models that can be used to conclude body fatigue: the rolling average model and the exponentially weighted moving average model:

The Rolling Average (RA) model is obtained by dividing the AU by the average of the previous 3 or 4 weeks, resulting in a ratio (White, 2019). The EWMA model places a greater emphasis on the most recent workload an athlete has performed by assigning a decreasing weighting for each older workload value. Additionally, variations in the manner in which loads are accumulated are better represented.

When the athlete's ratio is between 0.8 and 1.3 the risk for an injury is low (Image 41). When higher or lower, there is higher chance for overload or a decrease in fitness resulting in possible overload in the next session.

Intensity can be graded using an self assessment or measured by heart rate or activity. Large to very large relationships between self assessment and heart rate are found (Paulson et al., 2015).

By using the travelled distance, speed and acceleration, researched energy value categories and anaerobe limits for wheelchair users, the duration and intensity, it is possible to create an overview on aerobic and anaerobic muscle activity (Apanasenko, 2010).

After developing a model focussed on wheelchair users, it could be able to measure the AU or MET without the need of manual grading.

Key take-aways

With research and development a fitting algorithm could be developed to measure injury risk from activity using wheelchair bound technology.

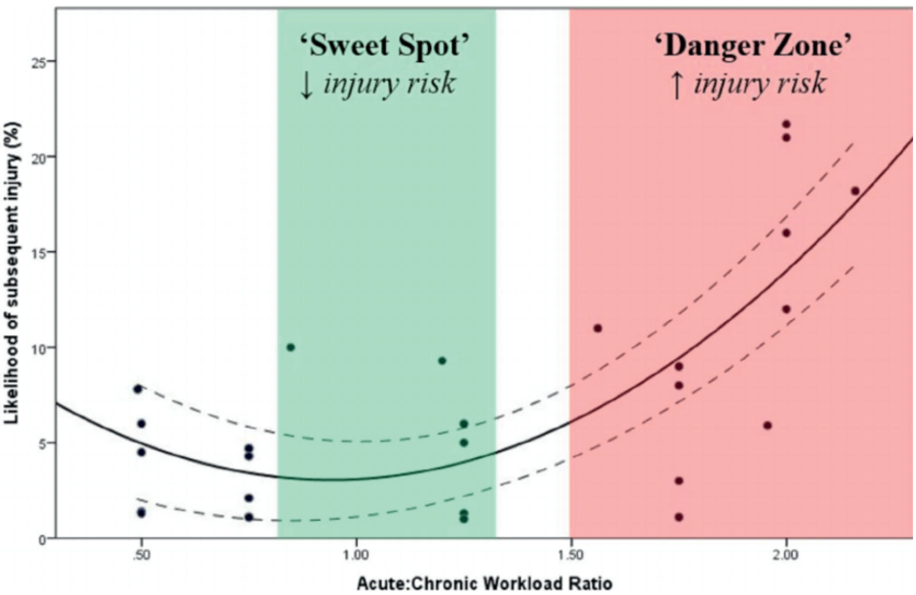


Image 41 The acute:chronic-ratio for workload gives an indication for injury risk.

Sensing sedentary behavior
The design should be able to estimate posture and measure sedentary time and relief time without the need of other devices. This can be done placing pressure sensors in the interface (contact area between the person and wheelchair).

From research is determined that focussing solely on the seat and backrest is sufficiently accurate to distinguish changes in posture. Liu has done research on literature about sensing postures in his graduation report (Liu, 2018). This project will build upon his findings.

In the prototype seven force sensing resistors (FSR 402) were used to measure the pressure exerted on the seat and five FSR 402s in the backrest (Image 43). They were distributed as seen in Image 42. The data was processed using an Arduino Mega and later an Raspberry Pi. To be able to measure exercises that involve pushing the body above the seating pan, two FSR 408s were placed on the armrests. For more detailed upper body exercise data the concept contained an accelerometer on the wrist resembling an activity monitor. This activity monitor will not be added to the concept of this project, because the focus is on the wheelchair-bound technology.

When the user leans forward the top of the backrest experiences less pressure and the pressure centrepoint in the seating surface moves forward. when slouching, the buttocks move forward and the lower area of the backrest experiences less pressure. Leaning to the side results in high values on the side leaning and low on the other side. This way the system could recognize posture changes.

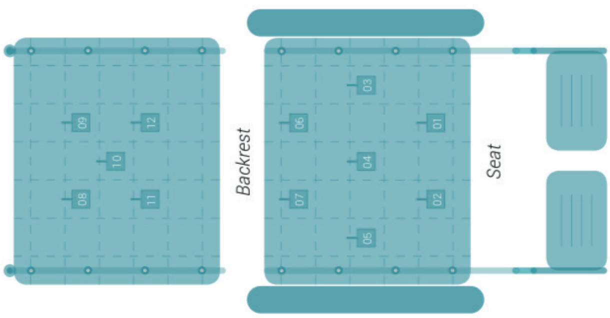


Image 42 Poitioning of force sensing resistors, indicated by the numbers, in the seating pan and backrest of the prototype from the graduation project of Liu (2018)

This distribution of FSR 402s and 408s contributed to a functional prototype being able to detect leaning forward, slouching, leaning left and right and lifting the body of the seating surface as exercise.

With the same technology it is also possible to measure sedentary time.

Zenk (2008) did research on ideal pressure distributions. What can be concluded is that ratios of pressure distribution can be used to easily detect a good/ comfortable posture. This insight can be used for the development of an algorithm.

The prototype of Liu, and previous research proved the feasibility of the sensing technology. This project will not optimize this technology, but will use the knowledge of its feasibility to develop an interface to make the measurements valuable for wheelchair users.

The technical feasibility of the wanted data can be seen in Appendix E.

Key take-aways

With research and development a fitting algorithm could be developed to measure sedentary behavior using wheelchair-bound technology.

Image 43 Poitioning of force sensing resistors in the prototype from the graduation project of Liu (2018)

Project focus

Technology has been proven to be feasible. The focus in this project is on the interfaces and integrating the technology in a novel wheelchair design. For convenience reasons the two prototypes in this chapter are used as a starting point.

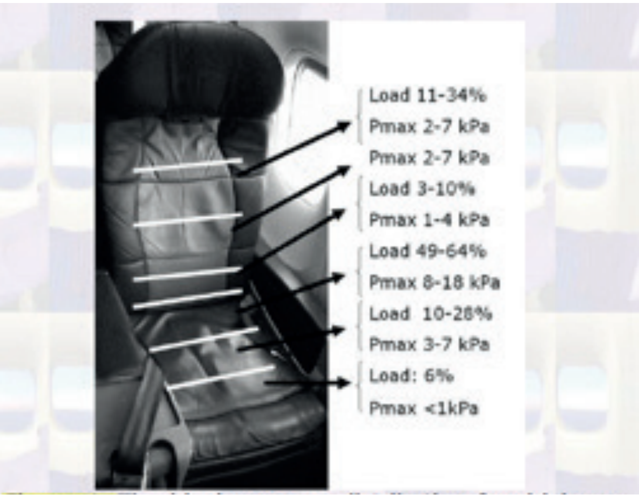


Image 44 The ideal pressure distribution for aircraft seats according to Zenk (2008) and Mergl (2006). Retrieved from presentation slides of Vink, 2010

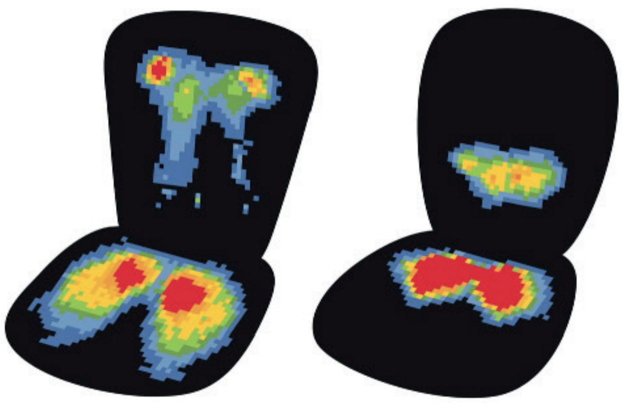


Image 45 Left: Good pressure distribution in a chair focusses peak pressure under the sitting bones and in the lumbar and thoracic areas in upright posture, (Miller, 2013)
Image 46 Right: Sitting in a sling-type chair puts pressure on the gluteus maximus muscles at the sides of the buttocks as wel as on the heads of the upper leg bones and sciatic nerves. (Miller, 2013)

Summary, conclusion and requirements external analysis

Trend analysis

With the expected rise of the amount of wheelchair users, it becomes more important to focus on the injury prevention to avoid even more rising medical costs.

The rise of wheelchair users in education, workplace and sports is a positive progression, but results in new contexts and behavior development. Sedentary lifestyles and obesity are expected to occur more often in the future. Increasing the need of motivating people, and also wheelchair user, to become more physically active.

Technological developments in eHealth can help with the datafication of this change of lifestyle and health patterns. AI and personal customization will create opportunities in making the wheelchair more personal and provide the user with meaningful data, presented in a centralized device, which in the current age is considered to be the smartphone.

Competitor analysis

Since there is no smart manual wheelchair measuring sedentary behavior and physical activity in existence, the market is open. Insights from competitor products will be used as inspiration for designing a new solution for wheelchair users.

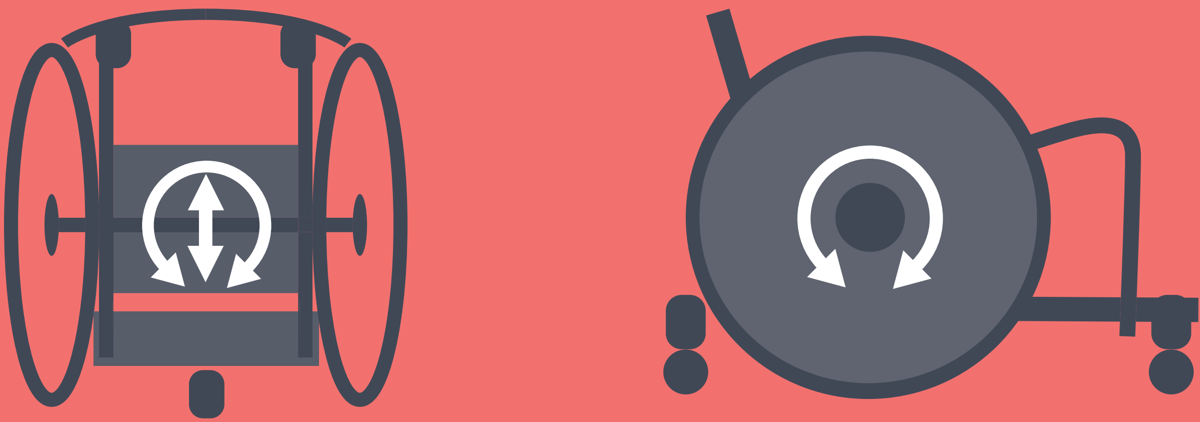
Technology analysis

Using formulas from human dynamics (kinetics) it is possible to calculate the forces and energies needed to displace a wheelchair. As initial input the model of the wheelchair, initial resistant forces and optimized energy expenditure estimation will need to be researched and integrated into the algorithm. This will however not be the in the scope of this project. The functionality of the algorithm is proven to be feasible. Third-party connection with fitness and heart rate monitors could be used to increase the accuracy of the estimations.

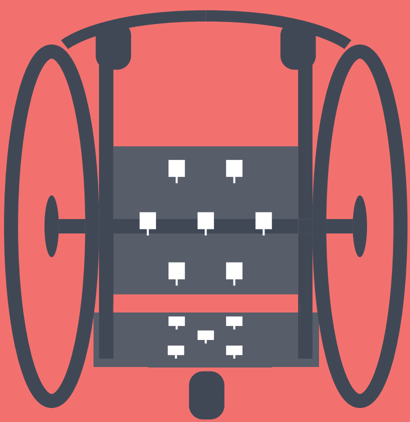
Pressure sensors in the seating surface and backrest make it able to measure sedentary time and behavior.

Requirements:

- Smartphone interface should be used as an interface for communicating larger amounts of data and information and change settings. (2.4.2)
- Weight, body dimensions, age and disability type are required as initial input for the algorithm. (2.4.3)
- The design should be able to estimate energy expenditure and calorie burn. (2.4.3)
- Activity sensing technology should measure acceleration, rotation and inclination of the frame and the rotation of at least one wheel as a reference against drift. (2.4.3)
- Pressure sensors in the seat, backrest and arm rests are needed to be able to measure posture, sedentary time and pressure relief. (2.4.3)
- Design should be able to be connected with a external device for heartrate data, for more accurate estimations. (2.4.3)



Mobility sensing technology



Sedentary behavior sensing technology

Processing and data analysis

2.5. Requirements and design criteria

In this chapter an overview of all the requirements for the new product are shown. From this list, the criteria for the product, interventions and interaction are combined into a design checklist (Figure 27). All insights from the analysis phase can be reviewed in Appendix G.

Project
- Design should improve physical activity and sedentary behavior of wheelchair users (1.2.2.)
- Design should use behavioral change theories and intervention principles (1.2.4.)
- Design should use technology to measure sedentary behavior and physical activity of wheelchair users using integrated technology (1.2.3.)
- Design should be able to be used standalone (without external devices) (1.2.3.)

Target group
- Target group for this project is autonomous manual wheelchair users aged 18-80 with normal cognitive functionality (2.3.3.)
- Potential target group size is estimated to be 0,1% of the total population of a western country (2.3.3.)
- Design should make clear what happens to their data (transparancy). (2.3.3.)

Physical activity
- The design should persuade the user to increase the volume of physical activity (2.2.2.)
- The design should aim to motivate the user to transcend physical activity guidelines (2.2.2.)
- The product should inform the user about possible injury risk (2.2.3.)

Technology for measuring activity
- The design should be able generate estimated data on energy expenditure and calorie burn (2.4.3.)
- Design should be able to generate data on type of activity, intensity and duration (2.4.3.)
- Activity sensing technology should measure acceleration, rotation and inclination of the frame and the rotation of at least one wheel as a reference against drift. (2.4.3.)
- The design should measure the surface types and inclination (2.4.3.)
- The design should be able to generate data for physical activity visualisation understandable for the target group: distance travelled and amount of pushes (2.4.3.)
- Design should be able to be connected with a external device for heartrate data, for more accurate estimations. (2.4.3.)

Sedentary behavior
- The design should persuade the user to sit with good posture (2.2.5.)
- The design should persuade the user to perform pressure relief with a duration of 30 seconds after a sedentary bout of 30 minutes (2.2.4.)
- The design should persuade the user to do stretch exercises (2.2.5.)

Technology for measuring sedentary behavior
- Pressure sensors in the seat, backrest and arm rests are needed to be able to measure posture, sedentary time and pressure relief. (2.4.3.)
- The design should be able to identify poor posture(2.4.3.)

Behavioral interventions
- The design should persuade the user to improve wheelchair behavior using behavioral interventions: nudging, providing information, self-monitoring, data visualisation, goal-setting, rewards, gamification, coaching and social interaction (2.2.6.)
- The task to achieve target behavior should be as easy as possible (2.2.6.)
- Design should provide insights, knowledge and guidance on improving wheelchair behavior. (2.2.6.)
- Design should make use of a GROW approach and SMARTER goal-setting. (2.2.6.)
- Design strategy should use a positive, non-authorizative approach (gain-frame). (2.2.6.)
- Nudging strategy should be timely, open, clear and unobtrusive. (2.2.6.)
- Insight, knowledge and nudging should be personal, clear, simple and meaningful. (2.2.6.)
- Interaction should not distract in potentially dangerous situations (2.3.4.)
- Interaction should not distract others in the environment (2.3.4.)

Product
- Design should be useful and easy to use (2.2.6.)
- The design should not interfere with normal wheelchair functionality (wheeling)
- Weight, body dimensions, age and disability type are required as initial input for the algorithm. (2.4.3.)
- The design should be able to estimate energy expenditure . (2.4.3.)
- The design should use integrated technology for sedentary behavior and physical activity measurement in the archetype of a wheelchair (2.3.4.)
- The design should use integrated interface in the wheelchair to interact with the user during wheelchair use (2.4.2.)
- Visual component should be embedded in armrest. (2.3.4.)
- Interaction should be intimate, easy, clear, meaningful, reliable and safe. (2.3.3.)
- The design should be able to connect to a smartphone device (2.4.2.)
- Smartphone interface should be used as an interface for communicating larger amounts of data and information and change settings. (2.4.2.)
- Design should function in- and outdoors. (2.3.5.)
- User should be able to activate silent-mode and posture guidance. (2.3.5.)

Design checklist

Is the idea..

Figure 27 Design checklist. The main criteria are useful, easy to use and unobtrusive. Ideas for behavior interventions can be tested on the criteria, and double checked with the words underneath.

3. Synthesis

In this chapter, the findings, insights and requirements from the analysis phase will be used to shape the design objectives. You will be able to find the product direction, a new user journey with the integration of behavioral change theories and a new information flow. This chapter will conclude in a design brief and requirements.

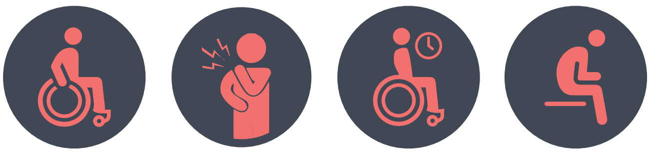
88 3.1. Opportunities from analysis
90 3.2. Personas
92 3.3. Product strategy vision
98 3.4. Design brief

3.1. Opportunities from analysis

3.1.1. Reducing injury risk

Secondary physical problems due to wheelchair use occur because of improper wheelchair behavior; posture, sedentary time and pressure relief, physical inactivity and body overload. The effects can vary from muscle stiffness and decreased skin quality, but can evolve into various diseases, pressure ulcers, body deformity and overall decreasing health.

The wheelchair user needs to become more aware of its behavior. Increasing activity by simply rolling more or doing exercises can help the user increase health benefits and skin quality. Reducing poor sedentary behavior, by maintaining a proper posture, tracking sedentary time and performing frequent pressure relief, is expected to affect pressure distribution, comfort and eventually the reduction of risk for pressure ulcers.



3.1.2. Behavioral interventions

It is expected that behavior change is more effective when all the elements within behavior are adressed. Changing behavior can be done by applying behavioral interventions to the design. The choice architect, in this case the designer, is responsible for using smart solutions to guide the behavior of the user into improved wheelchair behavior.

The design should provide informational and motivational affordances to its users. The product is expected to have higher chance for success with aspiring starters and motivation seekers, since these have prior motivation. The challenge is in motivating curious immobiles, who are inactive but also lack motivation.

Next to providing the users with informational data visualisation on their wheelchair behavior, motivational affordances should be reached. Users should be persuaded to use the product. Potentially effective principles to motivate users are data visualisation, goal-setting, rewards, coaching, social interaction and gamification.

Persuasive system principles can be used to build a strategy and product using existing and proven elements. The guidelines of the EAST-method will be used for ideation of behavioral nudges. Make it easy, attractive, social and timely. In this project, the behavioral intervention tool of Anne van Lieren will be used. This tool includes principles from many known behavioral science methods for facilitating ideation.

3.1.3. Product architecture

The design should measure wheelchair behavior using integrated technology in the wheelchair. It should be able to function without a smartphone. For sedentary behavior it is chosen to integrate force sensitive resistors in the seating pan and back rest. For mobility activity it is chosen to use IMU in the frame and a more suitable sensor could be chosen for the rotation of the wheel. Preferably, this technology is fully integrated into the frame, for easy disassembling and charging of the wheelchair.

The wheelchair will need to provide the user with direct feedback. This could be visual, tactile and auditory feedback integrated in the seating surface or frame and, for example, visual feedback integrated in the armrest. To be able to function, the wheelchair will need to be able to process data by itself and it requires some source of power.

To increase informational and motivational affordances the design will use a smartphone application for behavioral interventions. Smartphones can be used to centralize personal data, increase the connectivity and localization of the system, making it able to share data and provide the user with time-based and location-based notifications/nudges.

Behavioral interventions using visual, tactile and auditory feedback in the wheelchair and personal smartphone

3.2. Personas

The analysis in the user context, gives insights in potential users. Considering there is a broad range of causes of wheelchair dependence, disability, age and lifestyle goals, three personas were made spread over the target group range (Figure 28).

The three personas are made after three types of users: new users, experienced users and elderly. In Figure 29 it is able to briefly get to know the personas. It is able to see their life situation, personality, goals and quotes they could have said (inspired by interviews and ideation).

This tool will make it easier to design a future scenario and behavioral interventions.

William (quantify selfer)
To represent the younger target group, who is new to wheelchair usage, William is introduced as one of the personas. This 20 year old student experienced an accident which made him a full-time wheelchair user. He has to learn how to use a wheelchair from the start. Before his accident he was a very active person and used to track his fitness progress on his smartphone.

Claudia (motivation seeker)
Claudia is a friendly middle-aged woman of 46 years old, who is full-timely wheelchair-bound due to a spinal cord injury from her youth. Recovery made it difficult to study, but she managed to finish an administrative course. She uses her smartphone for everything, from staying in touch with friends, to searching things on the web, to navigating to places she has never been before. Now she works as a secretary at a tech firm and has a rich social life. Sometimes, after a day at work, she feels stiffness in her back muscles. She wants to become more active, since she feels like she could do more. Claudia cares about her looks, fitness and health.

Peter (aspiring starter)
Elderly people in institutions are known for lacking physical activity and having sedentary behavior for most of the time. Peter is one of those people, who could use a little motivation to become more active, since he wants to see his grandchildren grow up and already secretly knows that his wheelchair behavior has a negative effect on his health. He just learned to video-call with his kids.

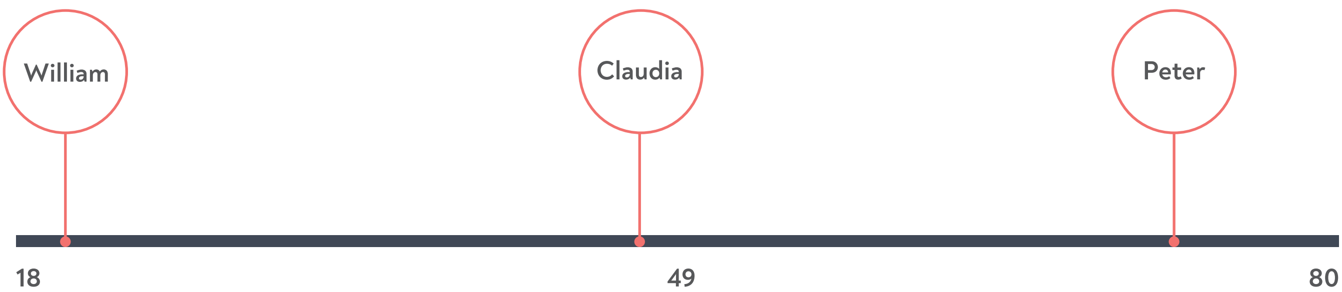


Figure 28 Personas in the spectrum of the target group

William

Age 20
Work Student/unemployed
Living in Haarlem
Hobbies Used to surf, Surfing for funny pictures

New to wheelchair use - Addicted to his smartphone - Clever guy

Personality

Introvert – Extrovert
Intuitive – Rational
Analytical – Creative
Passive – Active
Unmotivated – Motivated

Goals

- Learn how to live with a wheelchair
- Find an activity that sparks his joy just as surfing did.
- Enjoy life, feeling as healthy as possible

Quotes

“I never had to sit for such a long time in my life, I am not used to this”

“I used to be very active, but I do not know what to do now.”

“School just started again, I am glad that it is just a 10 minute walk away.”

Claudia

Age 46
Work Receptionist at a tech firm
Living in Utrecht
Hobbies Wheelchair tennis, Hanging with friends

Wants some help being more active - Cares about her appearance

Personality

Introvert – Extrovert
Intuitive – Rational
Analytical – Creative
Passive – Active
Unmotivated – Motivated

Goals

- Lose a few pounds
- Become an active person
- Live without the back pains

Quotes

“I gained a few pounds in the past years, I would like to challenge myself to be more active.”

“A few weeks after I received my first wheelchair, I got sores. Never again!”

“I have a friend with whom I try to be active and eat healthy. “

“My work is half an hour drive, it is too far to just roll.”

Peter

Age 73
Work Retired (was a mechanic)
Living in Arnhem - in an institution
Hobbies Wheelchair tennis, Hanging with friends

Spends most days in the institution - Feels like he could use some assistance

Personality

Introvert – Extrovert
Intuitive – Rational
Analytical – Creative
Passive – Active
Unmotivated – Motivated

Goals

- Reduce the risk of degrading health
- Increase the length of his life

Quotes

“Back in the old days, I was an active guy. I cannot do much in this wheelchair”

“I would like to see my grandchildren grow up.”

“My therapist gives me exercises, but most days I do not feel like doing them”

Figure 29 Personas: William, Claudia and Peter

3.3. Product strategy vision

3.3.1. Behavioral change strategy

Most fitness trackers make use of a sensing device with integrated visual, tactile and/or auditory feedback interface. Take for example a smartwatch, which uses an easy accessible interface for direct feedback. Those trackers also make use of a screen of a personal smartphone device to visualize data. In the application, behavioral intervention principles are used to motivate and persuade the user into setting goals and achieve those goals by acting out to target behavior. In the smartwatch interface the small and easy nudges are prompting the user to change current behavior, which in their case is increasing physical activity or improving sedentary behavior. In this project, both target behaviors are relevant and a similar approach will be used.

Product architecture

The information will flow through a double loop feedback system (Figure 30), in which there is a feedback interface embedded in the wheelchair design and feedback is given through an application on a smartphone device.

Wheelchair

During wheelchair use, the wheelchair will use a visual, tactile and/or auditory feedback interface, to communicate to the wheelchair user. This interface will be integrated in the wheelchair design. The visual component will be integrated in the armrest of the wheelchair, the tactile vibration in the seating surface and a convenient place for the auditory feedback system should be decided later. The user will be able to interact

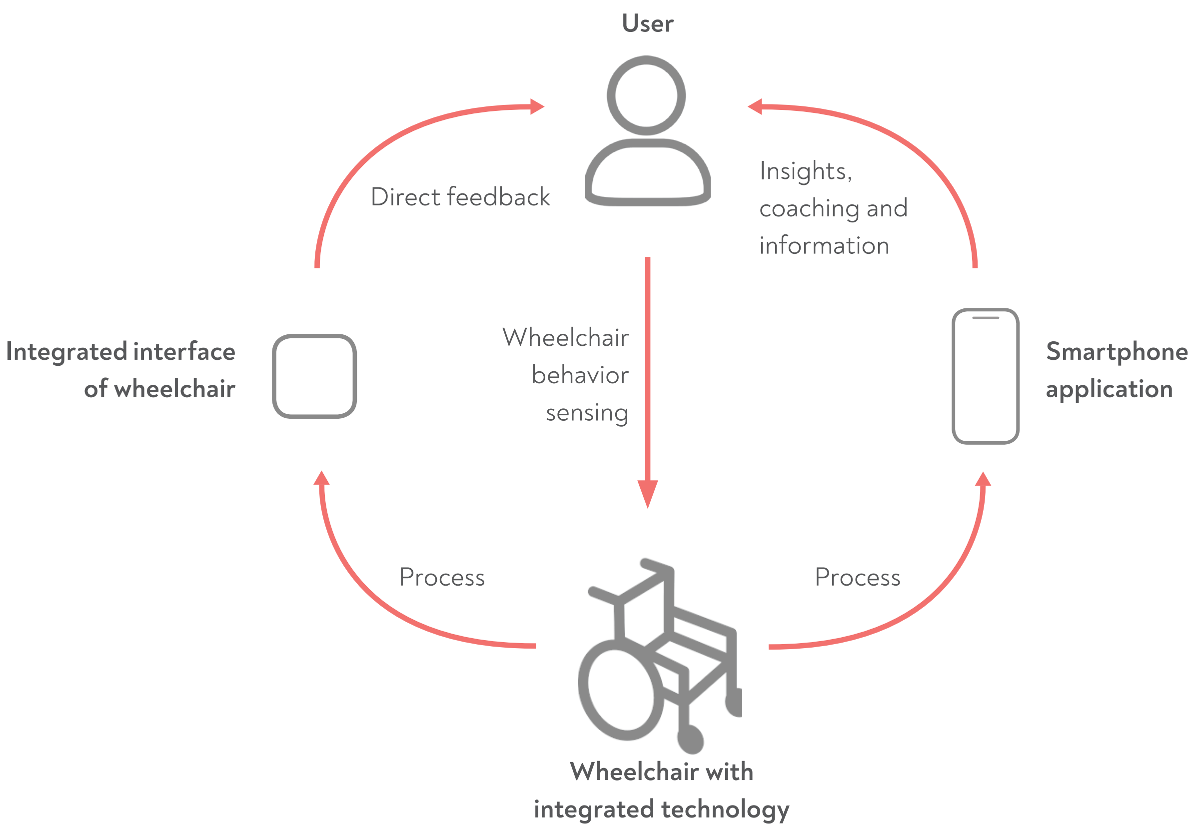


Figure 30 Double feedback loop. The user will be nudged to change behavior by the wheelchair while using it. The application will give feedback on goal achievement, insights in behavior and guidance for achieving next goals.

with the system to turn on 'silent-mode', overview data and activate posture guidance. Therefor, a button will be integrated in the design.

Application
The data, extracted by the wheelchair, will be transmitted to the smartphone application, where the user will be able to see insights in behavior and progress. The application will make use of persuasive technology and behavioral intervention principles to persuade or nudge the user into setting personal goals, gain insights or information, be coached, motivated and collect their rewards for proper behavior.

Data flow
The collected data is temporarily stored in the wheelchair. When the connection with the smartphone is made, the data is transmitted and stored on the personal device and sent to the cloud as backup. With permission from the user, it should be able to share the data with their social networks or medics (Figure 31). In absence of the smartphone the wheelchair notifies the user and saves the data until a connection with a smartphone is made.

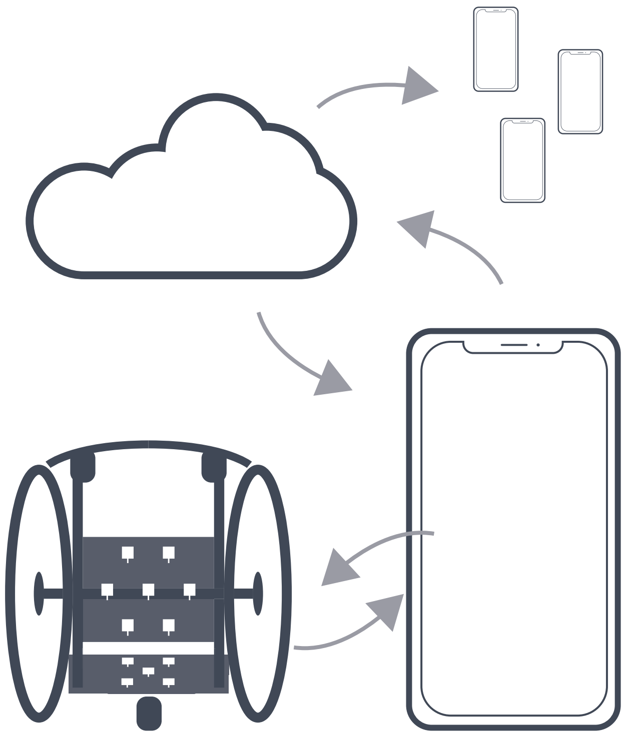


Figure 31 Data flow

Targeted behaviors
The design will focus on improving two types of wheelchair behavior: physical activity and sedentary behavior.

Physical activity
Being physically active has many benefits for the health of wheelchair users. People eat food to have energy for their body to work. All activities the body does results in energy expenditure, popularly also known as burning calories. Diet and physical activity go hand-in-hand and determine a person's weight, mood and risk of diseases.

The guidelines for physical activity are to be as active as possible, but ideally at least 150 minutes of moderate intensity physical activity (>3 MET) or 75 minutes of vigorous intensity physical activity (>6 MET), where more activity results in more health benefits. Preferably, activity is spread out over multiple activity bouts per day. Unusual amounts or intensities of activity increase injury risk of the muscles and joints in the upper extremity.

Sedentary behavior
Wheelchair users unwillingly are in a sedentary position for the largest part of the day. Next to resulting in low physical activity, it also increases the risk body pains and in some cases even lead to pressure ulcers.

Those reduce these problems and risks, wheelchair users should sit in a good posture and frequently relief pressure to allow blood flow. Good posture can be defined by distributing the pressure of the body over the seat surface and backrest. Pressure relief is advised to do as often as possible, but guidelines tell that after a sedentary bout of 30 minutes, 30 seconds of pressure relief should be performed.

Measure behavior
The wheelchair will monitor all physical activity and sedentary behavior, while in a wheelchair. It will use the integrated activity sensors to estimate energy expenditure, which is used to calculate burned calories and all activities above 3 MET. Sensors in the seat will

monitor the sedentary time and posture of the user. Based on this data, the product will provide the user with guidance to improve their wheelchair behavior.

Nudging strategy

Every aspect in the user experience can be designed to have an element of nudging. The nudging strategy is to make the target behavior more attractive than the alternative. The important rules are that nudging should always be in the favor of the one being nudged and that it is without coercion.

The design will approach the user with a non-authoritative style, persuading the user through a neutral voice, like a friend would. The strategy will integrate positive reinforcement and rewarding for good behavior and suggest alternative behavior during periods of poor behavior. The user should not feel 'punished' for poor behavior.

Suggestions for alternatives should require low ability, so that they can be done even when motivation is low. To not become obtrusive, the nudging should only happen when it is needed. It should be easy to understand, subtle and easy to ignore. The nudging will take place during wheelchair use and during moments of reflection.

The design will make use of the motivation principles: nudging, data visualisation, goal-setting, gamification, rewards, coaching and social interaction. The first four are in effect in both the wheelchair and application. The last two will only be available in the application, since it requires more information and connectivity.

Nudging

The strategy is to nudge the user at their most receptive moment, which can be a during certain behavior, in the absence of certain behavior, at a certain time or at a location. Nudges will be used in the wheelchair to maintain good wheelchair behavior and focus on goals. Nudges in the application will be used to set new goals and use the other motivational features available.

Data visualisation

Showing the user their behavior and progress or decline of activity will create understanding and hopefully motivate the user to change.

Goal-setting

By setting achievable and safe goals, using the SMARTER rules, the user will be motivated to achieve them. The goals will grow incrementally, challenging the user.

Gamification

Using game elements for specific tasks will make tasks more fun to do. This way people are expected to do it more likely.

Rewards

Using extrinsic motivators, like rewards, will be used to make people feel good about reaching goals. This is expected to motivate them to see what the next goal is, and try to achieve that one as well. People will also receive subtle praise for good behavior, like setting up a goal, as confirmation for doing the right thing. Rewards will be received for positive development or achievements. In the beginning these challenges will be easy to achieve, but these will grow incrementally motivating the user to improve. Examples for challenges are: daily/weekly/monthly records, traveled distance milestones and completion of personal physical activity goals.

Coaching

The coaching function can be seen as a virtual coach, trying to help their client. It will provide the user with:

- **Information.** Knowledge about proper behavior and understanding of potential consequences of poor behavior.
- **Insights**. Teaching the user how to read the data and give data analysis insights.
- **Suggestions**. Showing the options for physical activity and stretching exercises.
- **Guidance**. Nudging suggestions for alternative behaviors.

Social interaction

Connecting to socials for extra motivation. Making the commitment towards others will increase the motivation for good behavior.

3.3.2. Envisioned user scenarios

To understand how this could help people. Written scenarios are created for all three personas from chapter 3.3.

William

As active as he was, he now has to get used to his life in a wheelchair. A friend he made in the hospital told him about a wheelchair that tracked his activity. This was new to William, so he decided to look into it. He likes the idea of being able to track his own activity, to see his actions. Just like he did on his smartphone when he was able to walk. He decides to choose it for his new wheelchair.

The simplified setup makes it easy for him to understand the product. He attentively looked at the information about sedentary posture and the risk of pressure ulcers, which he never even thought about.

During use, he does not get reminders often, because he is unable to be inactive. Once in a while he gets a notification that he is sitting for too long and needs to release some pressure. He now knows why he needs to do that, so he starts doing it automatically.

After a few weeks of use, he sees himself progressing in his activity levels. He starts to feel fitter as well. He even got the idea to register for wheelchair basketball, since he wants to challenge himself to be even more active than he already is.

He continues to use the wheelchair, with occasional notifications, but he knows the purpose and feels okay with it.

Claudia

Claudia can finally apply for a new wheelchair. She asks her medic if he knows a way to become more active, without the need for a therapist or gym. The medic suggests this new product.

After receiving her product, she goes through the onboarding process and receives her rewards. Now she knows that she is able to collect rewards for certain goals. This makes her explore the other functionalities of the application and which goals and notifications settings she can personalize to her preference.

She makes long hours in the office, so she often gets the reminder to be more active, but it is not always possible to do this. The application suggests active sitting exercises she could do in the office, to improve blood flow and release pressure.

By accepting the localization function of the application, the app is able to detect popular locations. When she arrives at work, she receives a notification on her smartphone motivating her to work hard, but to not forget to drink enough water, which is a factor that reduces the risk on pressure ulcers, plus the trip to the office kitchen also increases the physical activity.

In the application she is able to see how active she was that day and at what time of the day she is most and least active. She connected her app to a colleague, who is also in a wheelchair. This way they can get a suggestion to invite each other for a roll during break hour.

Peter

The medic has seen Peters health decline over the past years and she suggests that he should take the new product. By choosing the new product, Peter commits to a new goal to increase his physical activity to the medic. They decide that they will use the data from the wheelchair in future meetings, to see what can be improved and how things are progressing.

In the institution where Peter lives, multiple people own such a product. Together with a few people he knows, they start a group. This group is able to see each others activity levels and compare. This way there is social control and they are able to motivate each other to go for a roll or do something else active. The approach of the app is always very positive and gives Peter much praise and rewards for his behavior.

After a few months the application sees that the activity levels of Peter are declining. The app asks for the reason of the declining activity levels. Peter has had a lung infection and was not able to be very active. The application adjusts to the new situation and suggest a new smaller goal, but which is a little higher than his current activity level and easier to achieve. Incrementally the goals will increase to higher levels.

Peter feels personally understood and connected to the product.

3.3.3. User experience

The product will be used by a broad target group. All users should feel comfortable with the product and its interaction.

Using a new product or learning a new thing can make people uncertain. It is important to provide the user with guidance and confirmation, so the product should give the user confidence to achieve their goals. After seeing the information and receiving meaningful insights, the user should feel like they have the energy to take on the world. By provoking curiosity the user is expected to become more motivated to learn and improve.

While using the product the user should feel confident, energized and curious (Image 47). An analogy of the experience of using the new product should feel like:

"A friend who watches your back"

He will give you a nudge when he feels like you need one. He motivates you to achieve your goals, helps you with reflecting on previous behavior and shares his knowledge and advice with you.

The product qualities resemble the way the interaction with the product should look and feel.

For this product it is chosen that the product should be casual, playful and natural. Keeping the design casual and natural, but with a touch of playfulness, putting more focus on the value from the product (Image 48).

Image 47 Qualities of interaction. Image retrieved from: https://intentionalworkplace.com/

Image 48 Product qualities. Image retrieved from: https://vanmoof.com/

3.4. Design brief

3.4.1. What is the problem?

The amount of wheelchair users is expanding due to the greying population and the increase in injuries. This not only increases the wheelchair market, but also the medical bill.

Wheelchair users experience secondary physical problems due to wheelchair use. Risk behaviors are:

- Insufficient physical activity.
- Sudden peaks of muscle overload.
- Long sedentary time and insufficient pressure relief.
- Poor pressure distribution due to poor posture.

Currently, there is no product for manual wheelchair users to receive insights in wheelchair behavior and facilitate guidance in improving behavior during use.

3.4.2. Who has the problem?

The main problem owners are wheelchair users. From a user's perspective, it is important to improve the user experience of the wheelchair. The physical problems are experienced by the user and result in their discomfort or pain. The focus in this project will be on people who are have prior motivation to improve their wheelchair behavior. The target group is adults and elderly autonomous self-propelling standard manual wheelchair users (aged 18-80), who own and are able to use a personal smarthone device. The estimation is made that 0,1% of the population is a possible user. In this project, the idea is to start in the countries of the Netherlands and the UK and scale up by introducing the product in other countries. The quantity will be set for 10.000 units, with expansion in the future.

3.4.3. What is the goal?

The goal is to design a feasible novel concept, which consists out of a wheelchair interface and application, that integrates behavioral intervention principles to improve wheelchair behavior, and thus reduces injury risk due to wheelchair use and increases health benefits.

3.4.4. What is within the scope?

- Focus on the experience on product use: starting from receiving the product, product use and using the application.
- Wheelchair-user interaction that uses behavioral interventions to change the behavior of the wheelchair user.
- Smartphone-user interaction to create insights in and behavioral interventions that result in improvement of wheelchair behavior.
- Feasibility of technology.
- Novel wheelchair concept with integrated technology.

3.4.5. What is out of the scope?

- Optimizing and functional technology
- Optimization and manufacturing of the products
- Design of a ergonomic wheelchair

3.4.6. Objectives

The project consists out of two products that work together to deliver a behavior change strategy. The idea is that the products will improve the wheelchair behavior of the user. To facilitate these functions, wheelchair interface and smartphone interface with integrated behavioral interventions need to be developed.

The first objective will be to develop a fitting strategy and design the solution for every risk behavior. Secondly, to develop the interaction needed to achieve the strategy. And lastly, the technical feasibility of the solution will be elaborated.

Objective 1

Develop a behavioral intervention strategy to improve wheelchair behavior.

Wanted outcome 1

A design for wheelchair and smartphone interfaces and strategy to increase physical activity, reduce injury risk due to physical activity, increase frequency of pressure relief and maintain good posture.

Objective 2

Develop the interaction and interfaces of the product.

Wanted outcome 2

A prototype of the wheelchair and smartphone interaction to test with real people.

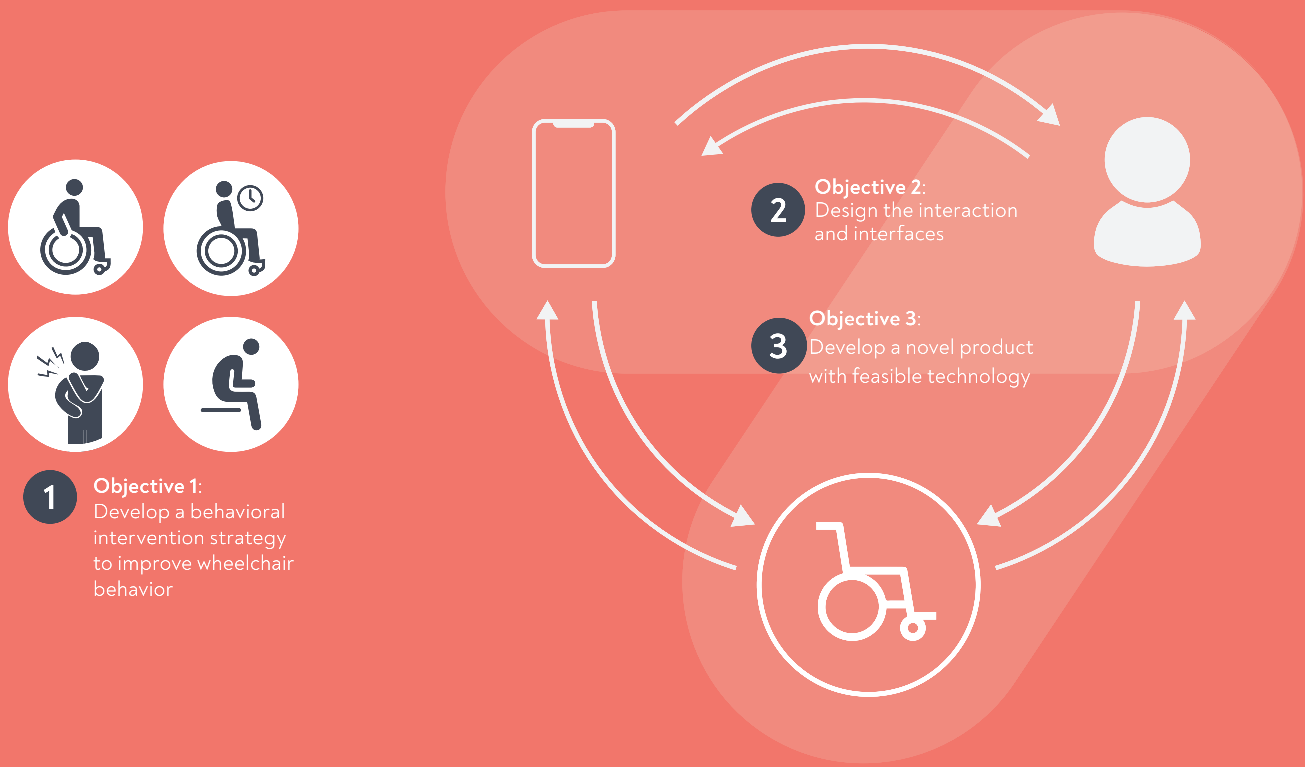
Objective 3

Develop a novel product with feasible technology.

Wanted outcome 3

A novel wheelchair design, application design and back-end technology.

Figure 32 Overview of objectives. The product-service-system (PSS) consists of a product (wheelchair interaction integration and smartphone application) and a service (insights and behavioral change strategy). The service is experienced in two interfaces: wheelchair interface and smartphone interface



4. Simulation

The focus from the design brief will be used for the ideation and developments of the future interaction. In this chapter, the strategy and two product around the interaction will be developed using the requirements and criteria from the previous chapters.

102 4.1. Objective 1: Behavioral intervention strategy
112 4.2. Objective 2: Design the interaction and interfaces for the product
130 4.3. Objective 3: Feasible technology

4.1. Objective 1: Behavioral intervention strategy

4.1.1. Preliminary ideation of behavioral interventions based on theory

To design a new user journey, first is looked at the current user journey of the wheelchair user (2.3.3.). After analysing the user journey, moments of opportunity are defined where interventions should be added to improve the experience: moment of receiving wheelchair and the use of wheelchair. One extra moment is added to the ideation of the journey, since the choice for the product is seen as the first behavioral intervention.

The behavioral intervention cards, together with the EAST cards and persuasive technology principles were used as inspiration for solving the problems during these moments.

User journey improvement

Focussing on one part of the situation and using an behavioral journey map for that specific situation, creates insights in what is missing and how this could be improved using behavioral interventions. An overview of the analysis of all moments can be seen in Figure 35.

Below, the problems and the ideation of solutions per moment are explained. The behavioral interventions and persuasion principles in the text are noted in *italic*.

Moment of choice

To apply for a wheelchair, the wheelchair user needs to send an application with all preferences, measurements and choices to the social system. The wheelchair user is searching their sources to determine a wheelchair that will suit their preferences. This can be on the web, in magazines or in a conversation with the medic. During the conversation between the medic and the user, the life goals and preferences are made into requirements for the wheelchair. At this moment, the user chooses a type of wheelchair.

Assuming that this product is in the favor of the society, government and the medic, since it improves health and reduces medical costs, it is important that the attention is drawn towards the new product. By making the choice for this product, the user is already making a *commitment* towards themselves, society and the medic. This already can be seen as the first intervention. It creates a *foot-in-the-door* to change their health and gain insight in their behavior.

Persuading to choose this product should be done in a positive way, so the user is most likely to choose this wheelchair. One of the ways to do this is to use *credible messengers,* which are people or sources that are considered reliable. Medics, medical offices and wheelchair associations are examples of credible messengers, which are respected by most wheelchair users.

Posters and advertisement could be used to *attract* the attention of the potential new users. Most people are more receptive to positive approaches. By using a *gain frame* approach, the user's attention can be drawn using a positive slogan, for example: "Feel better with ..." ,or "Live a more enjoyable active life" instead of "Low activity kills".

Receiving wheelchair and setting up application

Most of the time the user receives their new wheelchair from the manufacturer or the medic, with minimal information about proper wheelchair use.

In the new situation the experience should feel like a warm welcome (*peak-and-effect*). One intervention is to *reduce uncertainty* of the user, by informing them with *credible* information about proper behavior. A way to improve the understanding of the wanted behavior, for example posture, it would be nice to *rehearse* the behavior and receive *feedback* from the product.

The wheelchair and application from now on are in the possesion of the wheelchair user. The product should look attractive (*increase salience*) and *easy to use*. It is good to *emphasize owning* to increase motivation of use. Setting up the account efficiently by *reducing* needed steps and *tunneling* to make the process faster, making the product *personal* and *tailored* to their preferences.

The product should be able to be used right away and work with *default* settings, that are pre-set. These setting should be realistic and achievable, and should be able to be adapted in a way that the user will be nudged to be more active than before. Setting up first goals and making the commitments to others (friends, social media or medic) will increase the probability that people will put in work for their goals.

During the set up of the application, the product should always give *suggestions*, in order to facilitate a faster process and create a personal connection. Every achieved step should show some kind of *praise* or *reward*. Rewarding for setting up, actually can be seen as a *headstart* in achieving the first goals, increasing momentum and motivation.

Wheelchair use
Use will be devided into four phases: seeing the wheelchair, sitting down, sitting and wheeling and application use.

See wheelchair
People tend to continue use and do more for a product that they find *attractive*. By designing a wheelchair that looks active and makes it clear it senses the user, it is expected to already unconsciously *prime* the user into better behavior.

Sit down
The real use of the wheelchair starts when the user sits down. *Real-time feedback* will *remind* the user that the wheelchair has started *monitoring*. The product will give *real-time feedback* over the posture their sitting in and guide into an acceptable pressure distribution and give *suggestions* for what is a better posture.

Sitting and wheeling
The wheelchair will be used like a normal wheelchair but will continuously *monitor* the user. The interaction will be hidden at moments that behavior is performed well. When poor behavior is being performed for a longer period, the wheelchair will *prompt* the user. This should be done in a positive, *attractive, timed* and subtle way, so that the environment is not distracted, but the nudge is made clear to the user. The target behavior will be simple to act up on and made more pleasant by susing *gamification*. By constantly alerting the user during moment of poor behavior, the user is *conditioned* into changing of behavior.

Scrolling (Application use)
The application will contain the visual information about the behavior done in the wheelchair by the user. *Owner emphasis* and *personal* nudging will be used to attract the user towards the app and feel more connected. It will show real-time feedback on behavior in a *salient/ attractive* way.

The user will be nudged to look at their previous behavior, progress or set new goals. At first all the settings will work through a set of *default* goals and setting, but these can be changes to *tailor* to the user. It is important to set goals that are not too easy, but also not too hard. Using a *door-in-the-face technique*, the user will be shown a goal that is above their ability, but this goal will be chopped into smaller chunks. The user will see these smaller goals as much more achievable and is expected to be more motivated to achieve those.

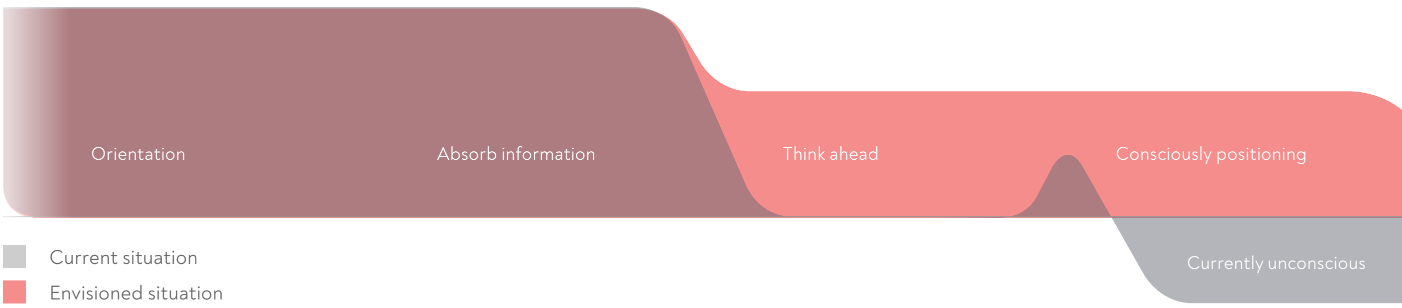
Whenever the user is having trouble with achieving activity goals, the application shall go in a *coaching* modus. The use of a *gain frame* approach will positively motivate the user, in order to increase activity or give *suggestions* for activities that the user can do as an *alternative*.

The user will receive *incremental virtual rewards* and *praise* for every goal achieved, from changing setting, hitting the physical activity goal, active sitting goals up to sharing their *commitment to others*.

Leaving wheelchair
The wheelchair will automatically send all data to the personal device for reviewing and will go in energy saving mode, so that less charging is needed. Ideally, the wheelchair should last one week without charging.

	Moment of choice	Receiving	Use	
Phase	Orientation & Wheelchair choice	Explanation for use	See wheelchair	Sit down in wheelchair
Steps	• Orientation in possibilities • Interview with medic • Requirements for wheelchair • Apply for wheelchair	• Inspect wheelchair • Receive information for use • Receive information in proper behavior • Receive information in health risks • Configurate product	• Pull towards yourself • See seating surface	• Sitting in seat • Adjust posture

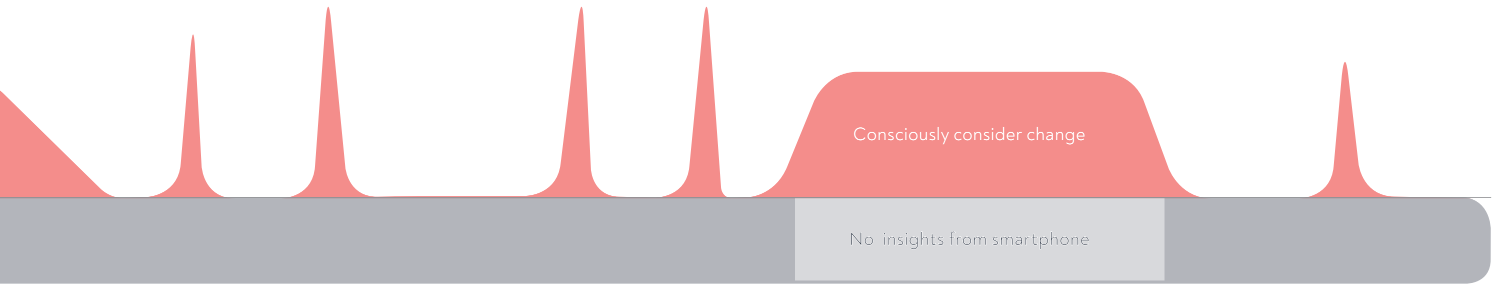
Current and target consciousness level



Available touchpoints	• Advertisment (Internet, tv, ..) • Public buildings • Medical building • Medic • Friends, family (word of mouth)	• Medic • Wheelchair technician • Internet • Wheelchair • Smartphone app	• Wheelchair	• Wheelchair • Smartphone app • (Smartwatch)
Behavioral interventions ideation	• Advertisement (Social/Public) • Recommendation from medic (Known figure)	• Information with references to the network of the user (Social reference)	• Visual on the seat - Nudging into thinking about (future) posture	• Activation of the wheelchair (Default) • Nudge that sitting and activity behavior is measured (Reminder) • Guiding into good posture (Personal)

After use

Sitting	Rolling	Scrolling	Leaving wheelchair
• Poor/proper posture • Static/dynamic posture • Prolonged sitting • Exercise	• (In)active • Injury risk • Activity/Energy expenditure	• Moment for yourself • See statistics • Explore data • Set goals • Review history behavior	• Lift body out of wheelchair • Transplace to bed/couch • Moment for yourself
Consciously repositiong	Consciously become active	Reviewing previous behavior	Reviewing previous behavior



Sitting	Rolling	Scrolling	Leaving wheelchair
• Wheelchair • Smartphone app • (Smartwatch)	• Wheelchair • Smartphone app • (Smartwatch)	• Wheelchair • Smartphone app • (Smartwatch)	• Wheelchair • Smartphone app • (Smartwatch)
• Guiding into good posture (Personal/Default) • Nudge to change posture every 30 minutes (Personal/ Timely/Default) • Nudge to exercise (Personal) - refer to application for exercise examples	• Nudge to move more (Personal/Default) • Notify when activity levels are potentionally harmful (Personal) • Overview of daily activity and goals (Personal) • Location-based settings (Timely) • Wheelchair is constantly charging (Default)	• Visualize in a way that compares to previous achievements (Loss aversion) • Fast overview of daily activity and stats (Easy & Attractive) • Share goals with medic/friends (Social) • Prompt to set new goals (Timely)	• Shut off wheelchair (Default) • Weekly notification to review overview of behavior (Personal reference)

Figure 35 Behavioral interventions ideation for the user journey phases

4.1.2. Survey: Testing intervention ideas

A survey was done to check what people would think of some ideas for the preliminary behavioral intervention ideation (Appendix C)

Method

A google forms survey was made for an easy scalable research. The insights from this research were used as qualitative insights to develop the strategy. The main question was which ideas were perceived as valuable for potential users.

To get to know the participants some questions were asked about their lifestyle and prior experiences with physical problems due to inactivity, poor sedentary behavior and technology use, and motivation to maintain proper behavior.

Both wheelchair and long day office chair users were invited to do the survey. Eventually 22 participants filled out the survey, of which 7 were wheelchair users.

Results

People were quite interested in using a product that would increase their activity (All: 4.7/6, WCU: 4,2/6), improves their sedentary behavior (All: 4.6/6, WCU: 4,4/6) and reduces physical problems (All: 4.9/6, WCU: 4,4/6).

Participants were also quite positive about the intevention ideas: direct feedback on sedentary behavior (All: 4.6/6, WCU: 4,2/6), direct feedback on activity behavior (All: 4.4/6, WCU: 4,2/6), notification to do exercises (All: 4/6, WCU: 3,8/6, view previous activity (All: 5/6, WCU: 4.1/6), receiving exercises based on previous activity (All: 4.3/6, WCU: 4,2/6) and receiving a weekly overview of behavior (All: 4.3/6, WCU: 4,2/6)

What kind of commitment increases the probabilty of achieving: saying it out loud (All: 3.7/6, WCU: 3.2/6), sharing it on social media (All: 2.5/6, WCU: 2.8/6), telling a friend (All: 4/6, WCU: 5/6) and telling a medic (All: 3,9/6, WCU: 4.2/6).

If the data is shared with friends, the participants would want to use it most for motivating each other(84.2%), then compare (38.8%) and lastly compete (21%)

Data is allowed to be shared in the situations of medical insights and anonymous national research in 68% of all cases and with a medic for personalized insights in 86%.

A product would be chosen more often when it looks attractive (All: 90.9%, WCU: 100%). A wheelchair that looks active is expected to motivate the user to become more active (All: 59.1%, WCU: 28%). And people are willing to pay more for a product with the stated functionalities (All: 68%, WCU: 58%).

Conclusion

There is a positive attitude towards the ideation of the functionality, direct feedback, data overviewing and notification by all participants. Making a commitment on a social basis with friends or credible people like a medic, is expected to have a larger effect on the motivation of the users. Sharing data is accepted in situations that is seen as valuable but should be secure. The product should look attractive, but an active look is not necessary for wheelchair users. Most people are willing to pay extra for extra functionality.

4.1.3. Intervention strategy ideation

The strategy will use the behavioral intervention principles defined to be most effective for the whole target group. It will make use of data visualisation, coaching, goal-setting, rewards, gamification and social interaction. The principles from the EAST-method of the BIT will be used to explain the strategy.

First of all, the design will only try to improve the behavior of the user when it is needed. If the person is perfoming proper physical activity behavior, the product will not draw the person's attention and distract. Starting from first use, the user should be attended that they have a daily goal. Eventually, the less persuasion is needed, the more effective the product is.

Motivation of users for physical activity behavior

Two possible prior motivations of the user for increasing overall activity levels can be weight-loss and increasing activity for health benefits. The aim of the intervention is to help the wheelchair user increase their physical activity and achieve their personal goals.

People who want to loose weight are advised to monitor their caloric intake and burn. The body burns calories all the time, but this increases during physical activity. The calories burned during physical activity are often called 'active calories'. These units can be estimated with the use of technology and can be defined as all activities with an intensity above 1.1 MET.

To gain health benefits, wheelchair users are advised to be as active as they can, with guidelines to have 150 moderate intensity physical activity minutes or 75 vigorous intensity physical activity minutes in one week. Adding more physical activity gives extra health benefits. Moderate intensity can be estimated with the use of technology and can be defined as all activities with an intensity above 3 MET.

These two types of insights should be available by default, since these provide the user with a meaningful insight in their performed activity behavior. It is expected that people are interested in numeric insights in distance traveled and amount of pushes, but these do not indicate the intensity this was performed in and do not show the true benefits from the activity. These insights will be available, but not presented by default.

Motivation of users for sedentary behavior

Two possible prior motivations of the user for improving sedentary behavior can be to improve posture to reduce body pains and to increase the frequency and duration of pressure relief for injury risk prevention. The aim of the intervention is to help the wheelchair user improve posture and to improve pressure relief behavior.

For sedentary behavior the two target behaviors are the same for everyone. People need to maintain a healthy posture as much as possible and perform relieve pressure frequently, 30 seconds every 30 minutes. Pressure relief needs to be performed for a longer duration if the sedentary bout was longer. The more often it happens, the better. The system will measure the sedentary behavior and register all postures and every type of pressure relief continuously.

Data visualisation

The user chooses the product to help him achieve personal goals in improving wheelchair behavior. To make them understand their progress, their monitored activity needs to be presented in a clear way, to understand their current behavior. If the user can see previous behavior, they will be able to compare the effects of daily life decisions on their wheelchair behavior.

During wheelchair use

The user will be presented with their progress of that specific day. This way, the user should create an understanding of what the effect of certain activities is on reaching their goals. If, during the day, the user notices that they are far from their goal, they can decide to do some extra exercises.

When starting the interaction, the wheelchair will guide the user in a good initial posture. If the user sits with potential harmful posture (lean forward/slouch/lean left/right) for 5 minutes, the system will see this as a trigger to notify the user. Visualising the posture of the user will give them an understanding of their current behavior, but the visualisation should guide the user into good behavior. If the user cannot or does not want to act upon the interaction, the visualisation will disappear in 15 seconds or it can be hidden by the user. The posture guidance feature should always be activated by the user when wanted.

The user will be able to choose to see their goal progress for pressure relief whenever they want. Seeing the progress should remind and motivate the user to perform pressure relief.

During smartphone use
The expectation is made that people can be interested in comparing daily activity to understand their daily routines and become motivated to improve activity behavior after discovering moments of opportunity. Weekly and monthly comparison could be used to gain insights in progress over a longer period, motivating the user stay active or become more active.

The user will be able to review their daily, weekly and monthly progress of postural behavior and goal achievement, to gain insights in personal behavior.

The user will also be able to review their daily, weekly and monthly progress of pressure relief behavior and goal achievement, to gain insights in personal behavior.

E A

Goal-setting
Wheelchair users are expected to mainly perform light and moderate intensity activity in their wheelchair. Dividing the weekly goal of 150 minutes over 7 days, gives approximately 21 minutes of moderate physical activity per day.

To motivate the user from the beginning the current situation and abilities of the user are unknown. So an approach is to start with an easy to achieve goal for daily physical activity and increase the goal by 50 active calories or 5 minutes of moderate intensity activity after being achieved. In the beginning this increase will happen daily. Activity increase is expected to decrease over time, so the goals will be achieved less frequently incrementally (Figure 37). Eventually, the user will have a daily goal that will be above their normal daily activity, motivating them to increase their daily activity. From that moment, the goal increase will be suggested after reaching a goal for three days in a row.

If the user has abnormal low activity for three days, the application will question the user for the reason, and suggest to (temporarily) lower the goal and change

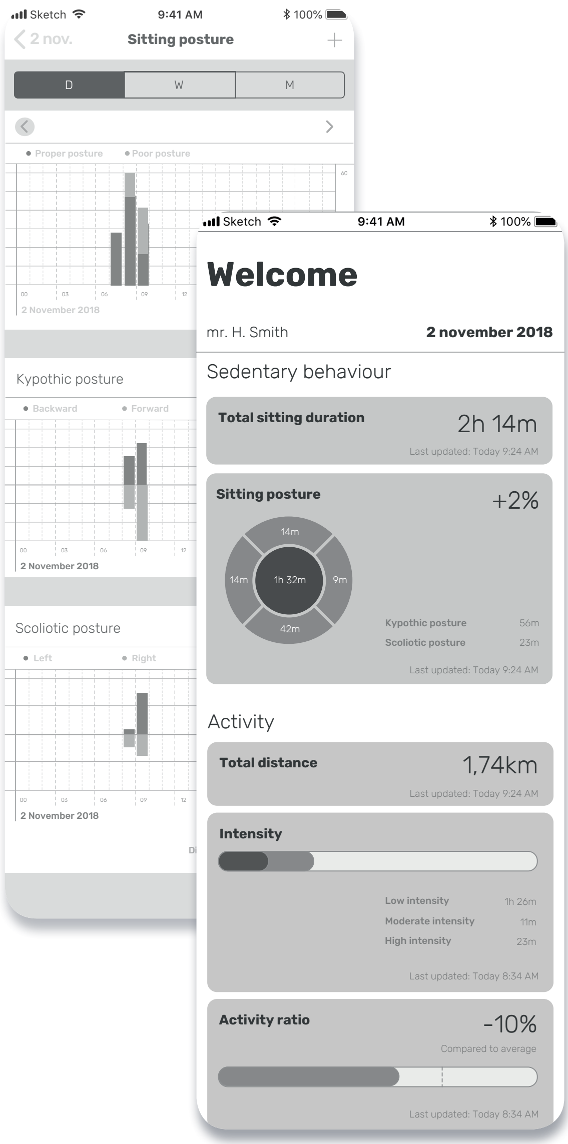


Figure 36 Wireframe ideas for overview page

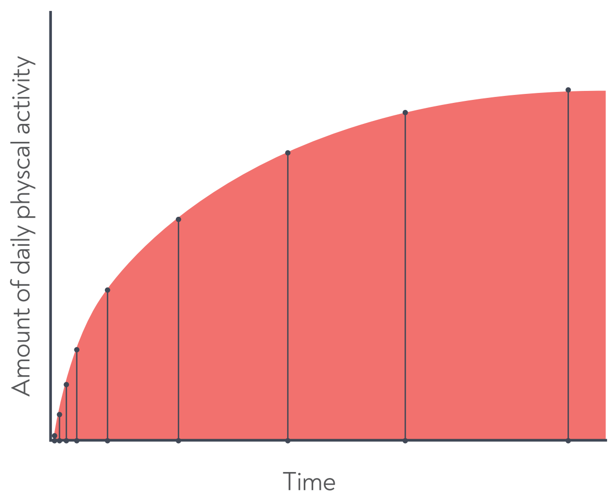


Figure 37 Goals become incremental. Frequency declines while goal is harder to reach

motivation notification frequency depending on their answer.

A strategy for helping the user achieve their daily activity goal easier is to nudge the user to become active when they have not performed any kind of physical activity for the duration of one hour.

Setting goals for posture can be done by rating the posture quality with a percentage, indicating the amount of time in good posture.

Pressure relief is measurable and has guidelines. The user should perform 30 seconds of pressure relief after 30 minutes of sedentary time. If the person acts correctly, that means that every hour the user should do at least 1 minute of pressure relief. Making this the default hourly goal and making it visual, could motivate people. By default, the goal will be to complete 6 hours of at least one minute of pressure relief. Which will be incrementally increased, to motivate progression.

During wheelchair use
The user should be able to quickly review their daily progress overview to see, become motivated or reassure themselves on their daily activity progress.

By default, the user will receive persuasive nudges to become more active after one hour of inactivity. This setup should have the ability to be altered by its user.

The user should be able to quickly review their progress of reaching the daily goal and their hourly progress. This should motivate them to perform more pressure relief.

During smartphone use
In the smartphone application the user can see progress and adjust goals. The user is able to add personal goals that were not turned on by default, like distance, pushes or weekly goals.

E A T

Rewards
Good decisions and proper behavior should be celebrated, rewarded and praised to motivate the user to keep going and feel supported. This could be done by using a point system or something more abstract like collecting badges or medaillons for certain behaviors. The challenge to achieve the reward should become incrementally more difficult to achieve, to motivate the user to continue improving or maintaining good behavior.

Some examples for rewarded challenges are:
- Setting up your first goal
- Reaching all your goals 3 days in a row
- Achieving a milestone (50km of manual propulsion)
- Connecting with 5 friends

During wheelchair use
A subtle celebration to notify the user of their achievement can be experienced in the wheelchair interface.

During smartphone use
The user receives a notification of the achievement and at opening of the application an attractive animation will show up attracting the attention towards the daily goal or reward the user has earned.

In the application the user should be able to see their achieved rewards and what needs to be done to achieve the next reward.

A T

Coaching
By default, at the beginning of product use, the product will send daily motivational messages to the user, like a virtual coach. The frequency of these messages can be adjusted to the preference of the user, but the option to adjust notification settings in the application should be made available right away to avoid notification disabling in the settings of the smartphone.

The coaching feature will analyze the current wheelchair behavior patterns of the user and pro-actively suggest alternative behaviors. Like, notifying that it is nice weather to go for a roll in the park, suggest contacting a friend to go for a roll or notify the user that his current behavior has potentially high injury risk.

If the user enabled frequent coaching and the product measures that the activity of the user is low for a duration of a week, it will suggest to increase the frequency of coaching. If this suggestion is declined it will be tried again in one month.

During wheelchair use
While using the wheelchair the product will only try to interact with the user if actually harmful behavior is performed. Examples can be: unusual long vigorous intensity activity bouts, unusual long inactivity bouts, long sedentary bouts or prolonged poor posture.

The user will receive a nudge to persuade them to relief pressure when they have not performed any form of pressure relief for 45 minutes. By default, the nudge will be set after 5 minutes of poor posture, which should be made clear that it could be changed in the application. After unusually high intensity activity for longer than 5 minutes, the system will nudge the user to warm for injury risk.

If the user performs good behavior after a period of poor behavior, but within the time of activation of the nudge, the system confirms the good behavior with a subtle confirmation nudge (Figure 39).

During smartphone use
The rest of the strategy explained above takes place in the smartphone application. Also, an overview of possible physical activity and stretching exercises should be available, for the user to gain inspiration and easily act upon.

E A S T

Social interaction
Making a commitment to others has a high effect on motivation for maintaining good behavior. Users will be persuaded to add personal contacts, with whom they will be able to share their daily progress, compare and challenge for competition.

Users will be able to join a team, which will enable them to achieve team goals, motivate and supervise each other to become more active. They will also have the ability to notify the team that they are going for a roll or exercise, which makes the activity more fun. It is also possible to share progress with a personal medic. This option enables the medic to review progress and give compliments or advice.

During wheelchair use
No social interaction will be available through the wheelchair.

During smartphone use
All other functionalities named above are integrated in the smartphone application.

S T

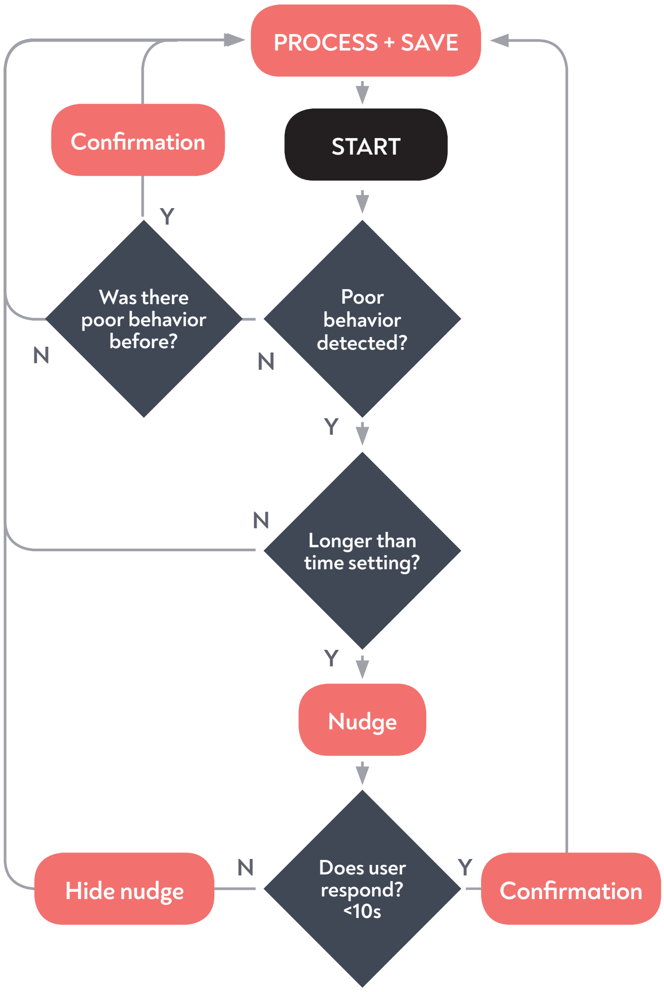


Figure 39 System flow diagram of the process of analyzing behavior, nudge and confirmation of good behavior.

4.1.4. Required ideation from strategy

The strategy ideation resulted in a list of necessary screens. These were used for ideation and the development of the final concept.

Wheelchair interface:

Feedback

- Visualisation daily activity goal active calories
- Visualisation daily activity goal moderate intensity physical activity
- Visualisation daily pressure relief goal
- Visualisation of pressure relief guidance
- Visualisation of posture guidance

User interactions

- System should automatically detect user and start measuring
- User should be able to quickly view their progress of goals
- User should be able to activate posture guidance
- System should automatically detect pressure relief

Notifications / nudges

- Nudge to become active after one hour
- Nudge to improve posture after 5 minutes of poor posture
- Nudge for pressure relief after one hour sedentary bout
- Notify user for achieving a goal
- Notify of potenial harmful behavior
- Notify of invitation to roll

Confirmation

- Confirm pressure relief
- Confirm good posture

Smartphone interface

Data visualisation

- See progress of daily goals
- Daily/weekly/monthly overview of activity history
- Daily/weekly/monthly overview of sedentary history

Goal-setting

- Default goals for calories, moderate activity and pressure relief
- Guide goal setting following SMARTER rules
- Give the ability to set personal goals

Rewards

- Celebration of goal achievement at opening
- Collect rewards
- See achieved rewards
- See what to do for next reward

Coaching

- Pro-active location/time/behavior based suggestions
- Provide information about proper behavior
- Provide with examples of activity and stretching exercises

Social

- Persuade to add peers
- Persuade to join a team
- Share data with medic
- Compare/compete/motivate peers

Notifications / nudges

- Informational messages from virtual coach
- Motivational messages from virtual coach
- Persuade to increase coaching
- Persuade to connect with peers
- Persuade to meet goals after low activity
- Persuade to set goals
- Persuade to increase goal after achievement
- Receive a message from the medic
- Notify of goal achievement

Settings

- Default setting: maximum coaching, option to change to lower levels
- Default setting: visual and tactile feedback, option to (dis)able tactile and auditory feedback

4.2. Objective 2: Design the interaction and interfaces for the product

4.2.1. Wheelchair interface interaction

This chapter will be presenting the decisions of the development of the wheelchair interface and interaction. The questions answered are:

- How will the interaction attract the attention of the user?
- How will the user interact with the system?
- What are the technical requirements for the interaction?
- What information should be displayed?
- How could this information look?

To come to these decisions, user testing was performed to test ideas using a survey (Appendix C) and the final concept using a prototype.

Criteria

From the criteria design checklist (2.5), the criteria meaningful, clear, intimate and subtle were used for the ideation of the wheelchair-to-user interaction. For the user-to-wheelchair interaction the criteria meaningful, clear, simple and easy to act on were used. Thereby should the product look casual, playful and natural.

Wheelchair-to-user interaction

The three senses, vision, feeling and hearing, could be used to attract the attention of the user, but this should be done in an effective way. Since the interaction will be for the nudging strategy, it should attract the attention of the user in a way that is clear, meaningful, but also easy to ignore in unwanted moments, that is why it should also be intimate and subtle.

Using only one sense has its limitations. Users would only notice a visual signal if it were directly in their line of sight. Using only tactile or auditory feedback would notify the user, but would require different kinds of interactions, which will make the product loose subtleness and clarity.

A combination of visual feedback combined with tactile or auditory feedback is expected to be most effective. The primary tactile or auditory feedback would notify the user that something needs to happen and the secondary visual component would make clear what that something is.

Tactile feedback

The sense of touch can be used to draw attention to change. Most products, like smartwatches and smartphones, use vibration motors or haptic motors to re-enforce or replace visual and auditory signals. The qualities of tactile feedback is that they are only felt by the user and attract attention. Limitations are that it is only felt during contact with the body and clarity can be missing when the user is in an environment or situation where other vibrations can be felt.

Technical requirements for tactile feedback

The tactile feedback elements should be placed strategically and used during moment of low environment vibrations to increase the effectiveness and clarity.

Auditory feedback

The brain can recognize sounds in just 0.05 seconds. A quality of using auditory feedback is that it is possible to have many variations in signals, however it has many limitations. It depends on sound frequency, amplitude, environment noise and the hearing ability of the person. Compared to tactile feedback, sound is a very public way of interaction, since, depending on the volume of the sound, the attention of everyone in range of the source hearing it is attracted.

Technical requirements for auditory feedback

Auditory feedback will not be turned on by default since it is obtrusive for the environment. For the people relying on sound as main primary feedback element, the sound should be designed in such a way that it is clear to the user, but least distracting for surrounding people. In a silent environment the sound of the vibration motors could also be seen as a form of auditory feedback.

Visual feedback
The visual feedback should clearly communicate to the user what needs to be done. So, the question is: What amount of information is considered clear, but simple enough to be unobtrusive?

In Figure 40 a comparison is made of multiple levels of visual feedback. With the target group in mind, information should be clear and easy to understand for everyone. A user test supported the conclusion that an animation of the target behavior is necessary to make it more clear. Minimal supportive text should be used to increase clarity.

Technical requirements for visual feedback
The visualisation of the information should be easily understandable from the perspective of the wheelchair user.

User-to-wheelchair interaction
People should be able to navigate through the overview of daily goals and activate features, like posture guidance and pressure relief guidance, in their wheelchair interface. They also should be able to hide visualisation or temporarily silence the interaction. These interactions should be clear, simple and subtle.

Interactive systems often use the input of touch or speech. Speech is no option for this project, since the product could be perceived as obtrusive when used in silent environments. To navigate, the product often uses buttons for subtle interaction or touchscreens for more complex interactions. The downside of touch-screens is that it makes a product more expensive and vulnerable, since the display will be integrated in the armrest, which will be loaded by the weight of the human body during in- and egress. From ideation is determined that pressure relief guidance should be detected while the user is performing pressure relief, making use of the sensors in the seating surface interface.

The amount of visible screens is limited to 3 screens. During the ideation of the screens and interaction, the amount of buttons is reduced to one button.

Visual feedback information level

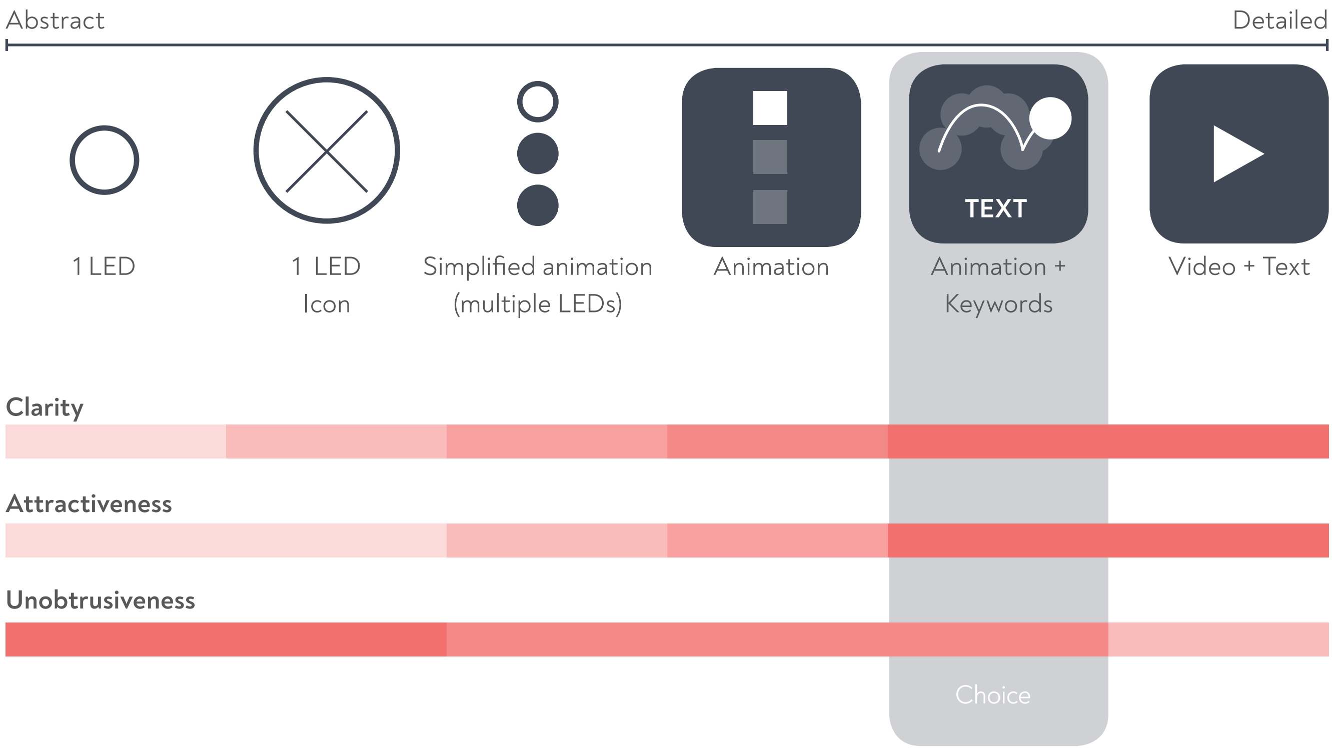


Figure 40 Informative display scale and choice

Survey strategy of animation

Because of the limited availability of wheelchair users, office chair users were also used in the process to score the concepts, since they perform sort-like behavior during office hours. The main goal of the first user test is to understand which visualizations and interaction ideas are prefered by people who sit for a large part of their day.

Method

Chosen was the do a survey in Dutch, to quickly get insights without the need to be physically present. The survey was not big enough to be used as quantative insights, but were used as inspiration for further development. In total 22 responses came in (of which 7 were wheelchair users).

There were three categories: activity, posture guidance a breaking sedentary time. For each category, three types of animation were created: a simple alert, a guiding animation and an loss-aversion visualisation.

The survey was set up in such a way that the demographics and history of sedentary behavior problems were asked and what they would think about certain behavioral insights. After that, three animations per category were shown and the participants were asked to score them on clarity, attractiveness, easy to ignore and which was the personal favorite. After each category the participant was asked if the animation should be enriched with tactile (vibration) or auditory feedback and in which kind of environment what kind of interaction is accepted (intimate, public, high focus and transport (wheelchair users only))

Results

In Figure 41 the designs scoring the highest scores overall for wheelchair users and all participants.

Conclusion

What can be concluded is that both groups chose the same abstract visualization for activity.

For guidance more wheelchair users chose for the design that guided them into a better posture. The choice overall was for a guiding animation, showing that back pain can occur. In this case, the choice is made to follow the wheelchair users. The sitting behavior of office chair users has a smaller impact on the body than that of wheelchair users, who are considered sedentary the entire day. Guidance in posture will be more valuable, since this creates a fast overview in what should change in their posture.

The difference was very small in the breaking sedentary time choices. The choice is made to go with the guiding animation that was chosen by most wheelchair users. This design is perceived as clear and can be combined with the guidance of the posture animation.

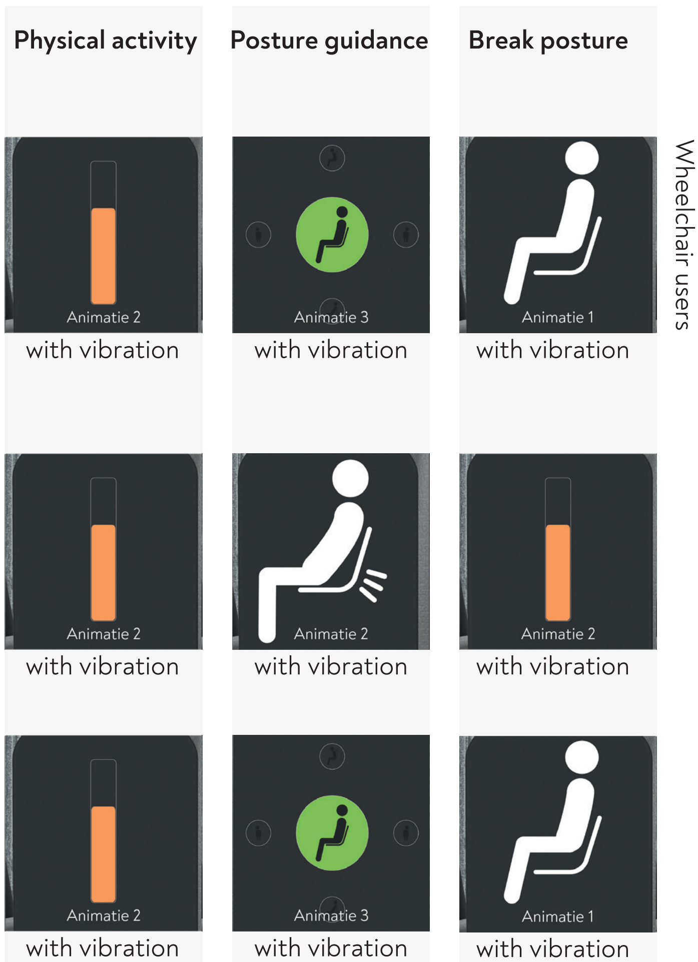


Figure 41 Most chosen outcomes from research

Wheelchair interface interaction strategy
In the default case, when the user would receive a nudge, the vibration motors will signal the brain that something is happening. This will be the cue for the user to consciously think about what they think might have been the reason of the nudge. If the person understands, they can quickly act and change their behavior or at least think about it. If they do not understand, they can look at the visual feedback display to find information about the target behavior, and thus about what they did wrong. If the user has acted, the visual display will confirm and turn off again. If the user does not act, the visual will stay on for 10 seconds and then turn off. Auditory feedback should be activated in the application if necessary.

In Figure 42 a system flow diagram can be seen on how the system reacts to the button and reacts. One short push on the button will have the function of activating and navigating overview screens of daily and hourly goals, posture guidance and hiding nudges. Hourly goals, for pressure relief and physical activity, are added for quick viewing to nudge the user about the importance of those behaviors. A long push will temporarily silence the interaction for 2 hours. When the 2 hours are over, a subtle nudge will notify the user that the nudging system is activated. To enable silence-mode prematurely a long push will be required. Two hours is chosen, since this feature is expected to be used during longer periods of entertainment time, like watching a movie. Silence settings should be able to be changed in the application as well. Also, setting goals and changing settings for nudging in the application should be automatically updated to the wheelchair interface,

If no nudging or visualisation is displayed, the display is off. If the person is not seated in the wheelchair, the whole system goes in energy saving mode. Elaborated system flow in Figure 49.

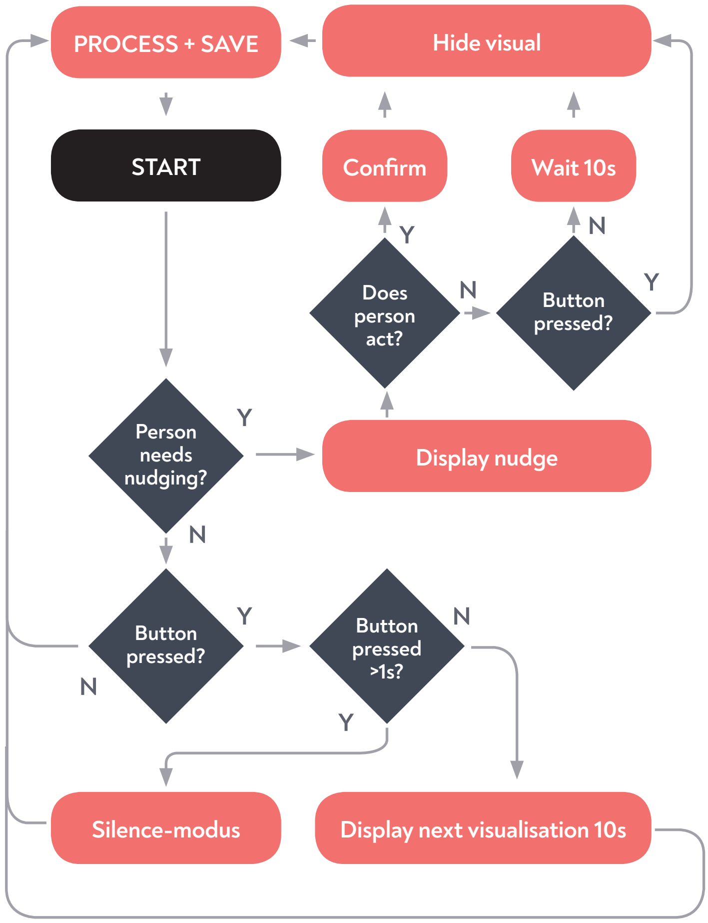
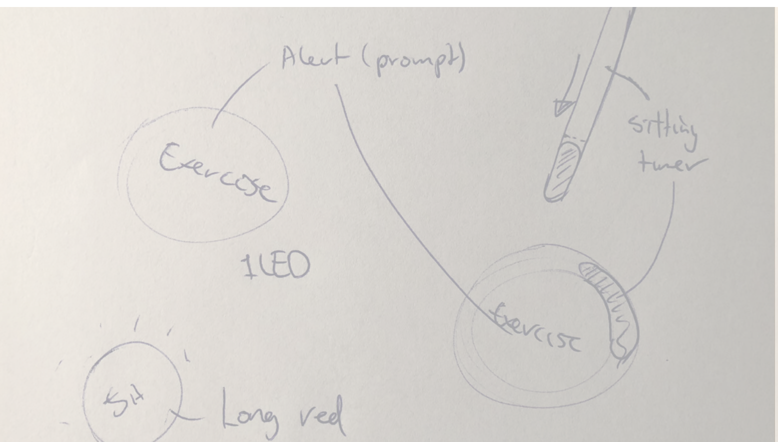


Figure 42 System flow diagram of how the system the button

Concept of the visual interface
On the right page the visualisations concept for the user test can be seen.

In the daily goal visualisation, the three goals as named in the required screens (4.2.2.) are combined into one quick overview (Figure 43). It is chosen to not show detailed numerical data, but focus on a seeing the progress of the goal quickly. Since the visual display will be integrated in the armrest, the reading distance is approximately 40 centimetres. The user should be able to quickly overview



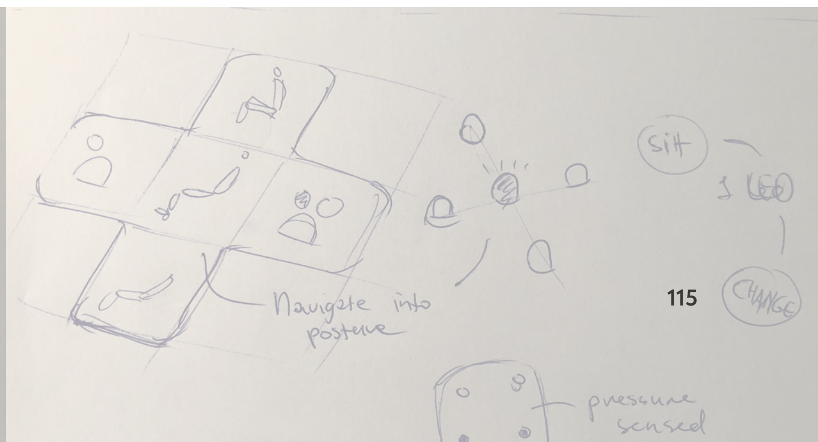


Figure 43 Daily goal overview

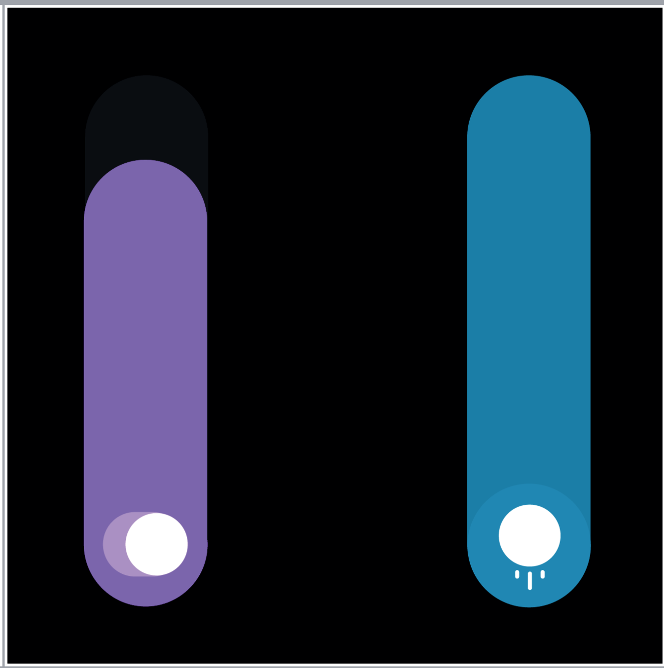


Figure 44 Hourly goal overview

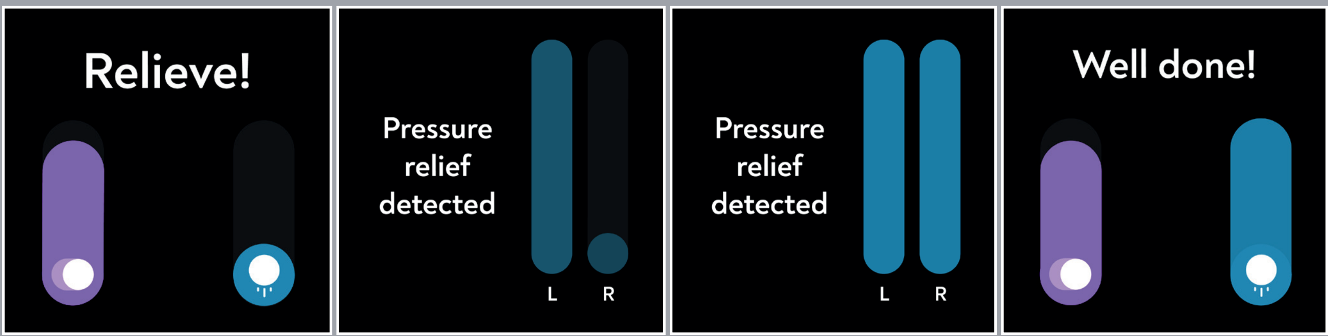


Figure 45 Process of nudging, detecting pressure relief performance and confirmation

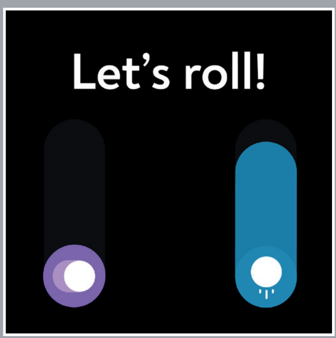


Figure 46 Nudging for physical activity

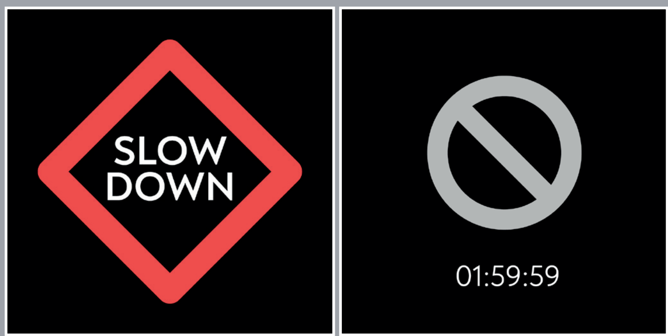


Figure 47 Alert for possible injury risk and visual of activation silent-modus

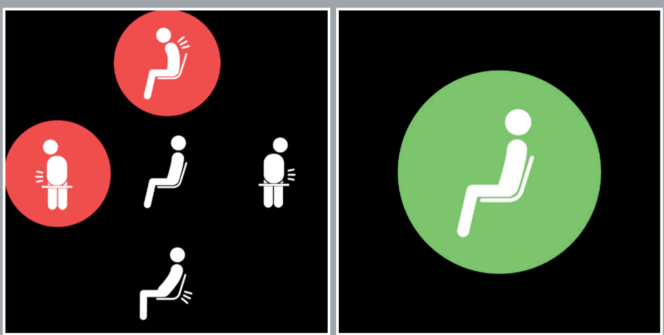


Figure 48 Interactive nudge and posture guidance

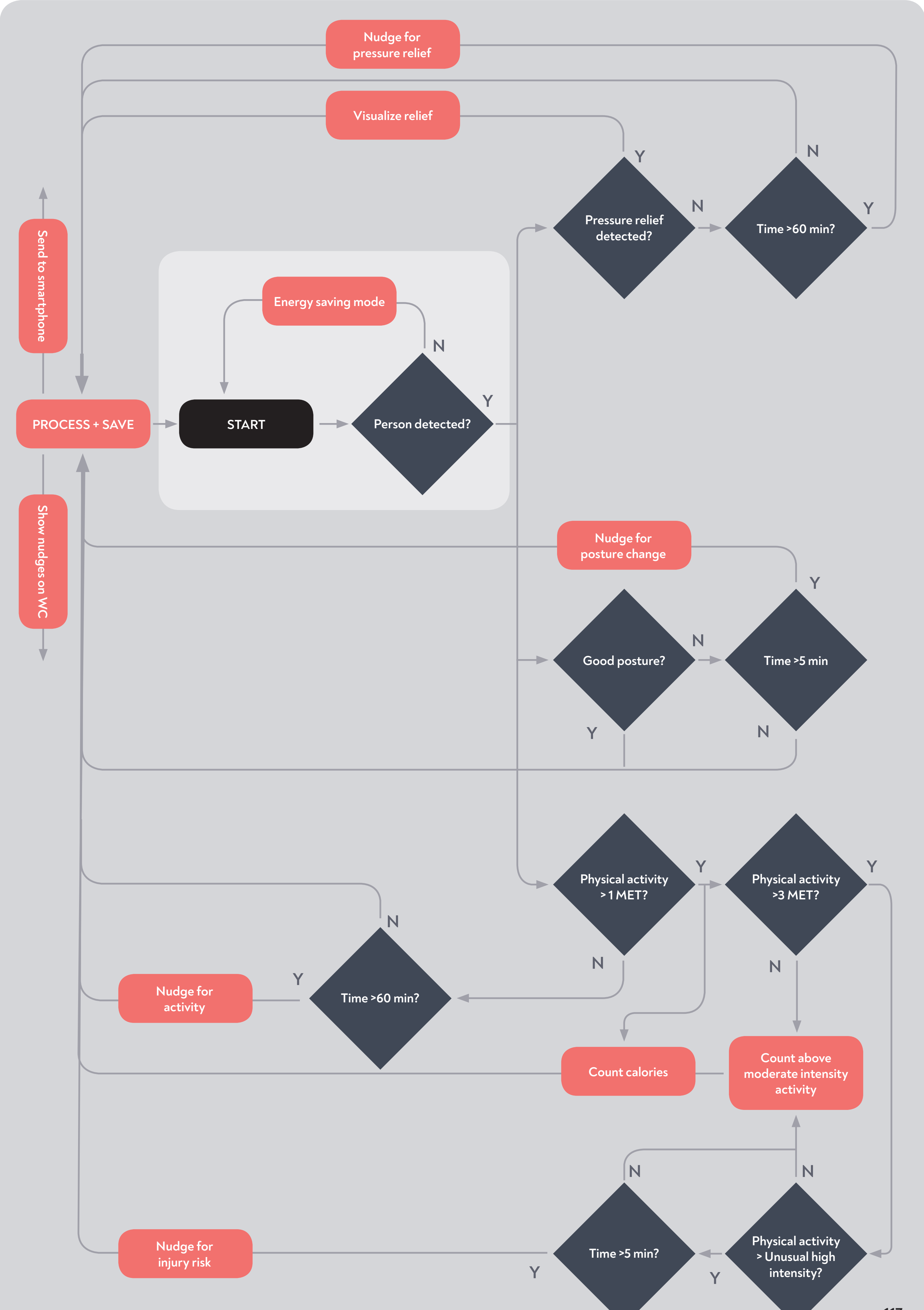


Figure 49 System flow diagram of nudging strategy

the information from this distance. Only explanatory text is used to explain the meaning of the visualisation. Strategically, radial charts are chosen, because they are clear and have no ending, thus progress can be shown even when the goal is reached. The goal is to make all circles complete.

The goals of hourly activity and pressure relief should be completed every hour, that is why a bar-chart is used that 'counts down', when not performing the target behavior and 'counts up' when one has been active or has performed pressure relief (Figure 44). This screen has an element of gamification. It uses the loss aversion, the feeling of them losing 'point', to motivate them to fill the bar up.

The nudge to perform hourly activity or pressure relief, uses the visualisation of the hourly goals to notify the user that 'the bar is empy'. With one word, the visual communicates what needs to be done to fill up the bar, 'Let's roll' or 'Relief' are used in the design. At the same time the user also sees the other bar, for which they can decide whether to fill up that bar as well. When the behavior is performed the visual shows a confirmation of the behavior and disappears (Figure 46).

Pressure relief guidance comes up if the system detects the performance of some kind of weight shifting or full pressure relief. It challenges the user to fill up the bars, which can be filled simultaneously when performing full pressure relief, or one by one when performing weight shifting. The performance is confirmed and visualized by an animation of the filling of the bar (Figure 45).

The nudge for posture improvement, is starting up the posture guidance feature. This feature shows what posture the user is performing at the moment, indicating that something needs to change (Figure 48). When activated the feature gives direct feedback on its estimation of the posture of the user, which they can use to sit in a better posture. This is confirmed by an animation and the visual disappears. This feature can always be activated by the user using the button.

The warning alert will only appear in very rare cases, when there is a high risk of injury due to unusually intense physical activity. A bright red colored 'SLOW DOWN' 'sign' is shown, to notify the user. This is the only situation where a nudge is given while the wheelchair is in motion. If the silent-mode is activated a visual is shown that indicates that something is off and a count-down of the time until deactivation is displayed (Figure 47).

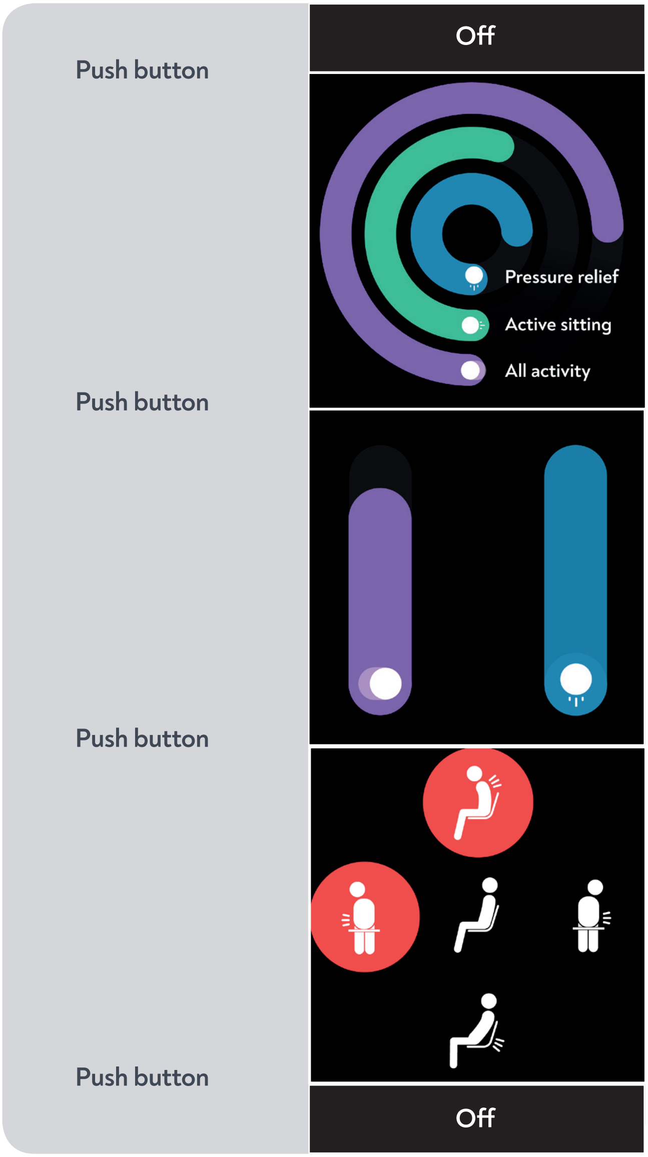
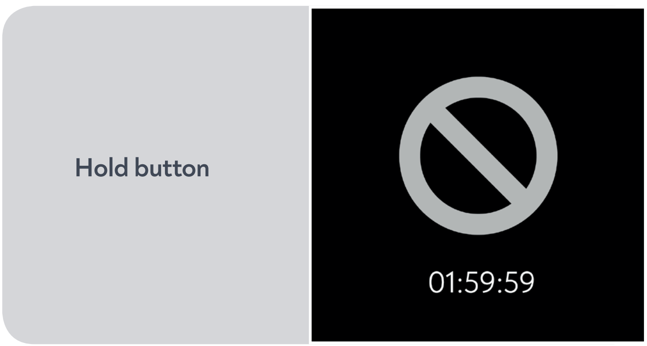


Figure 50 Interaction of reviewing of screen
Figure 51 Activating silent-mode



4.2.2. Application interface interaction

This chapter will be presenting the functionality and ideas behind the concept prototype of the smartphone application and interface. The questions answered are:

- What should be presented on the required screens?
- How will the user navigate through the application?
- How could the application look?

In chapter 4.1.3. the strategy of the application and its features is already explained. The ideas were tested is tested and the main findings from that research can be found in chapter 4.1.2.. The set up of the research in can be found in Appendix H.

Criteria

The criteria meaningful, simple, clear, and personal are used to develop screen for the application. The looks of the application should match the criteria casual, playful and natural.

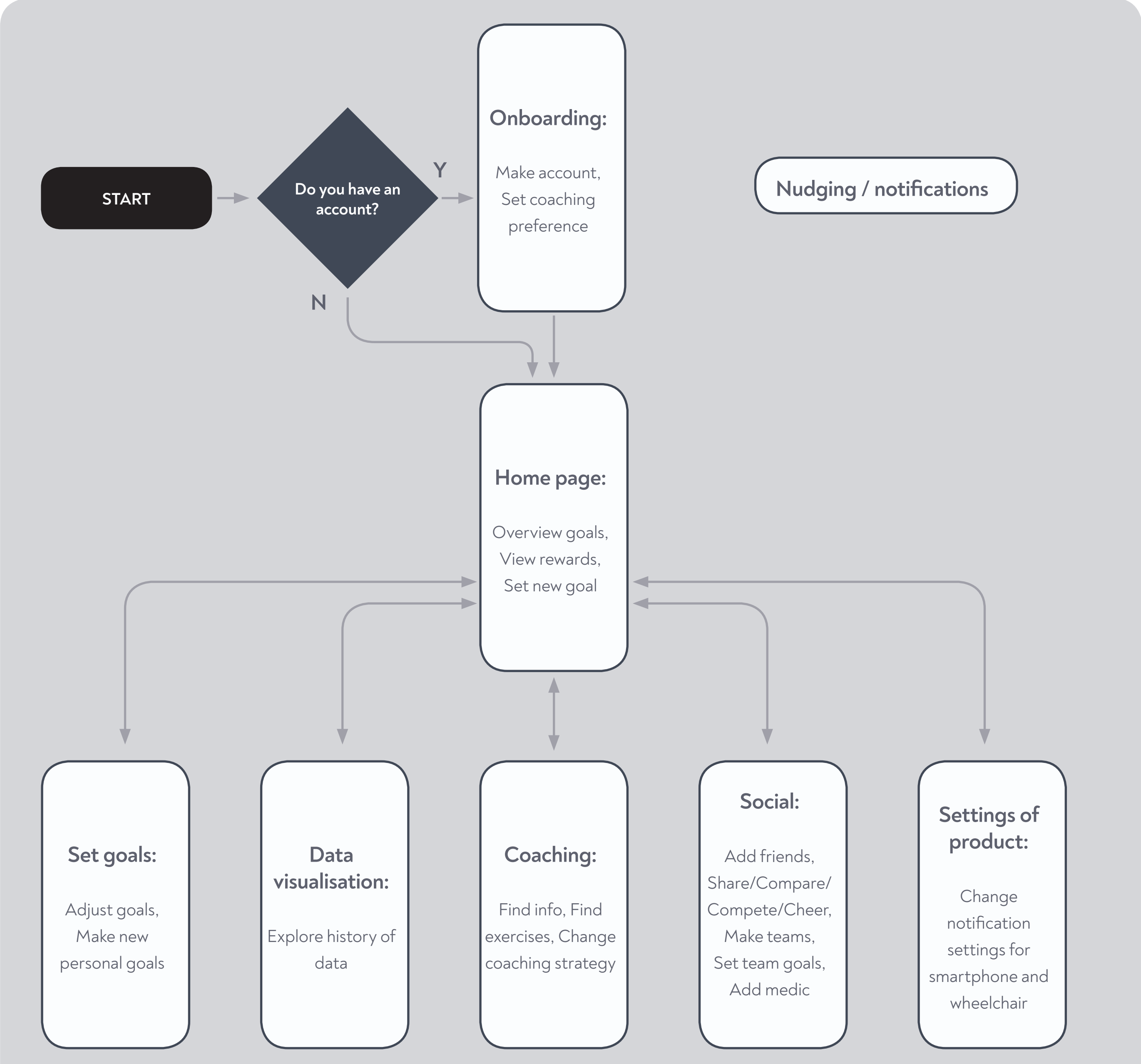


Figure 52 Flow chart of the application with screens and integrated features

A global overview of the required screens and the flow chart of the app can be seen in Figure 52. Wireframes of the screens are made to test the strategy with users. For the lay-out information is placed on so-called 'cards'. Every functional element has its own card, and every type of category has its own color. For example, everything in a red card is related to the virtual coach, the social feature is yellow, and the three goal types each have their own color: burning calories is purple, active sitting is green and sedentary behavior is blue.

Onboarding

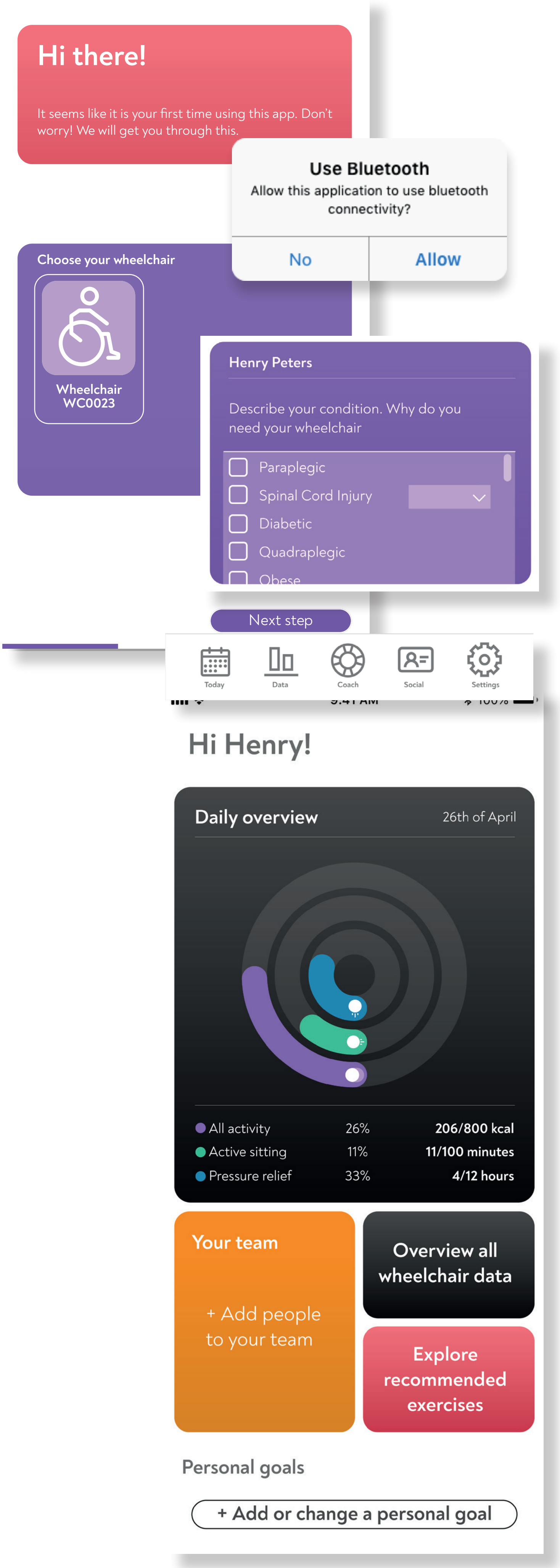
During the onboarding the user sets up their application for the first time. They need to go through system protocol to allow connectivity, location and notification. They will have to make an account, connect the wheelchair to the app and set the wanted amount of coaching. This onboarding is done by a so called wizard, who simplifies the steps and makes it easier to go through. In the bottom of the screen there is a progress bar, so the user is made clear how much steps they still need to complete. Onboarding can be done in 3 steps: connecting the wheelchair, setting up a personal account, choose coaching strategy and setting initial values about disability and metrics for algorithm optimization.

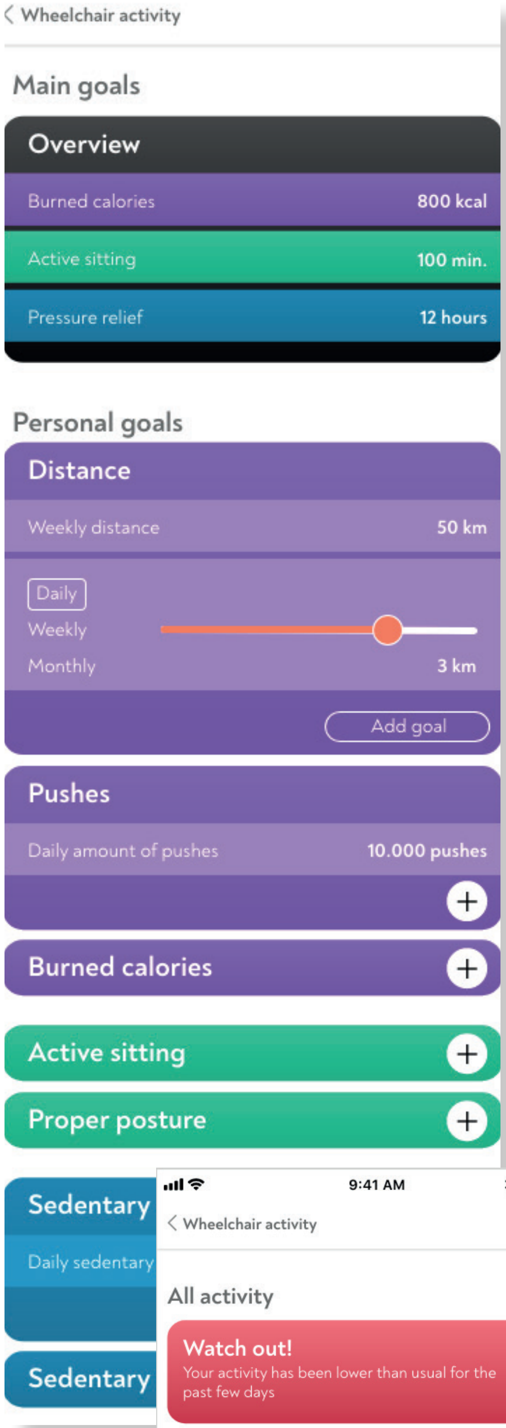
Overview

The goals visualisation is the first thing the user will notice. It is the same visualisation as in the wheelchair interface, but in this screen more numerical information is provided. Quick actions to motivational strategy features are placed directly under the overview, to make it easy to use the social and coaching features. Next to the three main goals the app persuades the user to add a new personal goal at the bottom of the page. Using the navigation menu, all the features of the app can be easily found.

Set goals

The application begins with a preset of the three easily achievable daily goals for all activity, active sitting and pressure relief. The option for adjusting these goals or adding new personal goals is always available on the overview screen and data visualisation screens, making it easier to do while in a moment of high motivation.



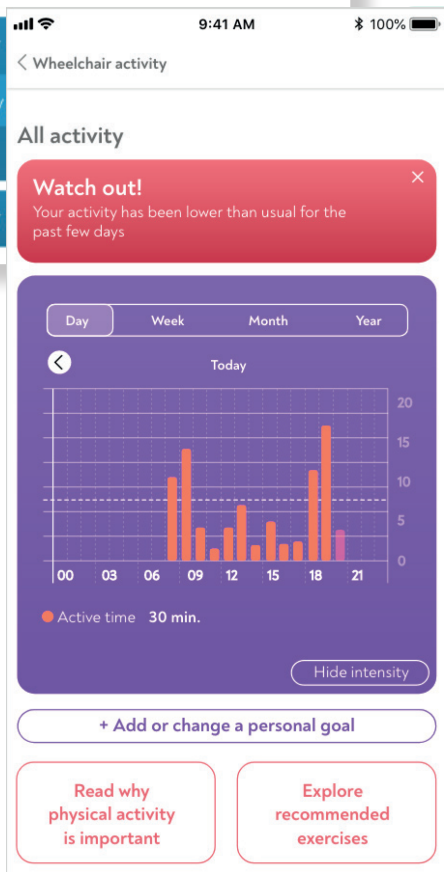


The SMARTER goal setting is integrated by making the goal specific, measurable, attainable, realistic, time-bound, exciting and recorded. Setting up a goal is made easy by using a slider for the amount and a quick option to set a time wherein the goal has to be achieved. The application will pre-set an attainable incremented goal, based on the analysis of everyday recorded behavior. It is up to the user to see whether this goal is realistic and exciting. These personal goals will be visible on the overview page, so the user will be able to see them directly everytime they use the app.

Data visualisation

In the data visualisation, all recorded data is presented in the shape of graphs and can be reviewed. It separates all different behavior measurements and uses bar charts to present the data. This data can be reviewed by the user as input for their personal reflection.

Under the data visualisations, the user can quickly act to set a new goal, read information about the specific behavior or find recommended exercises that are related to that specific behavior.



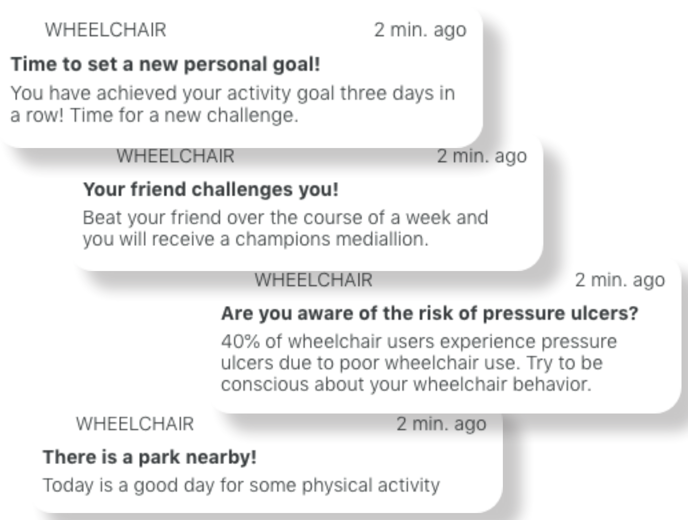
Coaching
Everything that is red is some way of coaching. This virtual coach is helping to set up the application, gives compliments, suggestions and warnings, but also provides the user with strategy for achieving goals, knowledge about wheelchair behavior and examples of exercises. The coaching cards are strategically placed on pages where it is most believed to be effective.

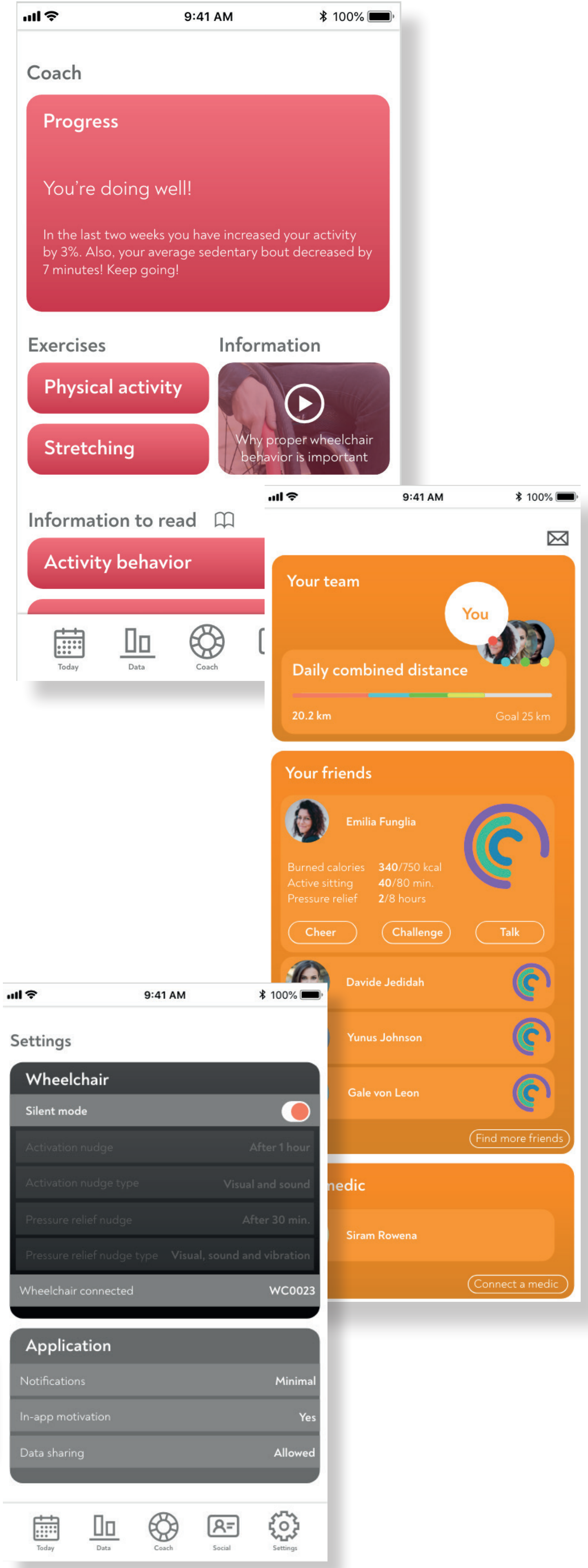
Social
The user is being nudged to explore the social page by seeing the element on their overview screen. This invites them to easily add friends who also own such device. By doing so they can keep an eye on each other's progress, send a cheer, challenge for a competition and invite each other for an activity using the talk function.

It is also possible to connect with a medic, therapist or others, like for example, sports coach, which gives the user the choice to easily share their progress.

Settings
To change the settings for the application and feedback system of the wheelchair, the user can go to the settings page, where they can adjust timing and signal type, but also enable silent mode manually for the rest of the day.

Notifications
The nudging strategy will make use of sending behavior-based, time-based and location-based notifications. The amount and content of these notifications depends on strategy and performed behavior.





4.2.3. User research

A user research was conducted to gain insights on the experience from product use.

The questions that needed to be answered in the user research were:

- How does the user react to the interaction/screen?
- Is it experienced as useful/clear/obtrusive?
- Do participants expect this to help them with their goals? How would they use it?
- What can be improved?

Method

The wheelchair interface has multiple features: nudging, guidance and overviewing. Building a fully functional prototype was not within the abilities of the author. That is why a test was done using simulation prototypes. Testing these screens was done with the use of a working principle prototype of the posture guidance and wizard-of-oz simulation of the display and interaction using an interactive screen model.

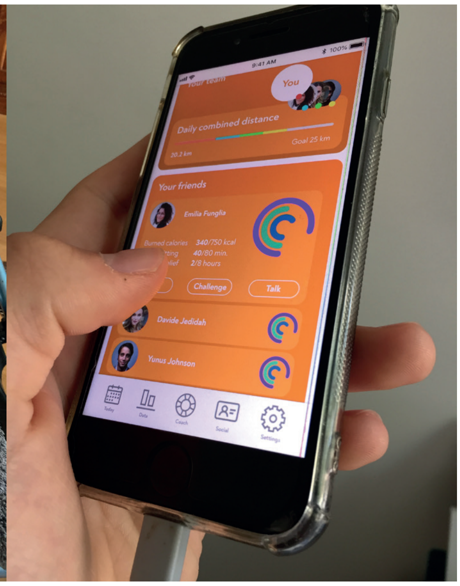
Both the wheelchair interaction as well as the application were tested with three participants, 1 wheelchair user (P1: male 26 years old) and two able-bodied (P2: female 21 years old and P3: male 38 years old). They were invited for a qualitative user testing research to experience the product and prototype. Conclusions are drawn from observations and interviewing of the participant.

A working principle prototype was made of the posture guidance interaction. Using force sensitive pressure sensors, Arduino UNO, vibrator motors and light emitting diodes (NeoPixel), a simulation was made of the functionality of the sedentary sensing system. After a few iterations, four pressure sensitive sensors were placed on the seating pan and two on the backrest, the prototype was able to estimate the four poor postures defined in the problem analysis: leaning forward, slouch, leaning left and right. The interface of posture guidance was simulated using 5 LEDs lighting up underneath a prototype screen of the visualisation. The prototype architecture can be seen in Appendix F.

A wizard-of-oz prototype was developed of the wheelchair interface and application using a computer application design program Adobe XD, which enables to animate and trigger animations from a personal computer. A smartphone display was attached to the armrest of the wheelchair to simulate the integrated screen of the concept. The same smartphone display was de-attached from the armrest to be used in the application testing.

Research procedure

At first, the user test started with a few questions over the participant and their experience and abilities in technology use, physical activity and consciousness of sedentary behavior.



Secondly, the procedure of the research was explained and a keynote presentation was shown with the main information that would be known to the user if they would have decided to choose this product. It explains proper wheelchair behaviors and the concept of the product and basic functionality.

The participant is asked to sit down in the wheelchair, of which the posture guidance prototype is activated. The participant is observed to see their behavior. Afterwards the participant was questioned with the questions which are asked after every feature tested.

- Explain what you think that the visualisation means?
- What do you feel/think about this idea?
- When/why would you expect this visualisation to appear?
- What can be improved?

The other visualisations were triggered to appear on the wheelchair display prototype. Observation and questioning is continued.

For the application research the prototype of the application was uploaded to the smartphone. The participant was given 1 minute to explore the application, after which a few scenarios to find specific functions were done using trapped door testing. The navigation was observed and after finding the feature the questions were asked as in the wheelchair interface testing.

Lastly, several notifications examples were presented to the user, to start discussion and answer the questions:

- How do you feel about these notifications?
- How high is the probability of you acting upon them?

Results

Some interesting quotes from the research can be seen in Figure 53. Using quotes from the research and clustering them per subjects, an understanding was created on what are positive and negative elements of the design. The full research set-up can be found in the appendix H.

Discussion

Overall the user testing created more understanding of the perception of the product and the interaction. The fact that the wheelchair user was an active wheelchair user, resulted in a reduced interest in the motivational affordances from product use. He was classified as a 'Quantified-selfer', who wants to review his personal stats and goals, who focusses more on the informational affordances. The two other participant were classified as 'Motivation seekers', they see more potential value in the motivational elements of the design.

Wheelchair interface

Posture guidance

Starting with the posture guidance, all participants understood what it did and found it useful. For the research the prototype was set to have a direct feedback, meaning it would react directly if poor posture was detected. This, as expected, resulted in the opinion that it responded too fast. In the concept this time is set for 5 minutes by default. It should be researched what a suitable time is.

Relief and activity nudge

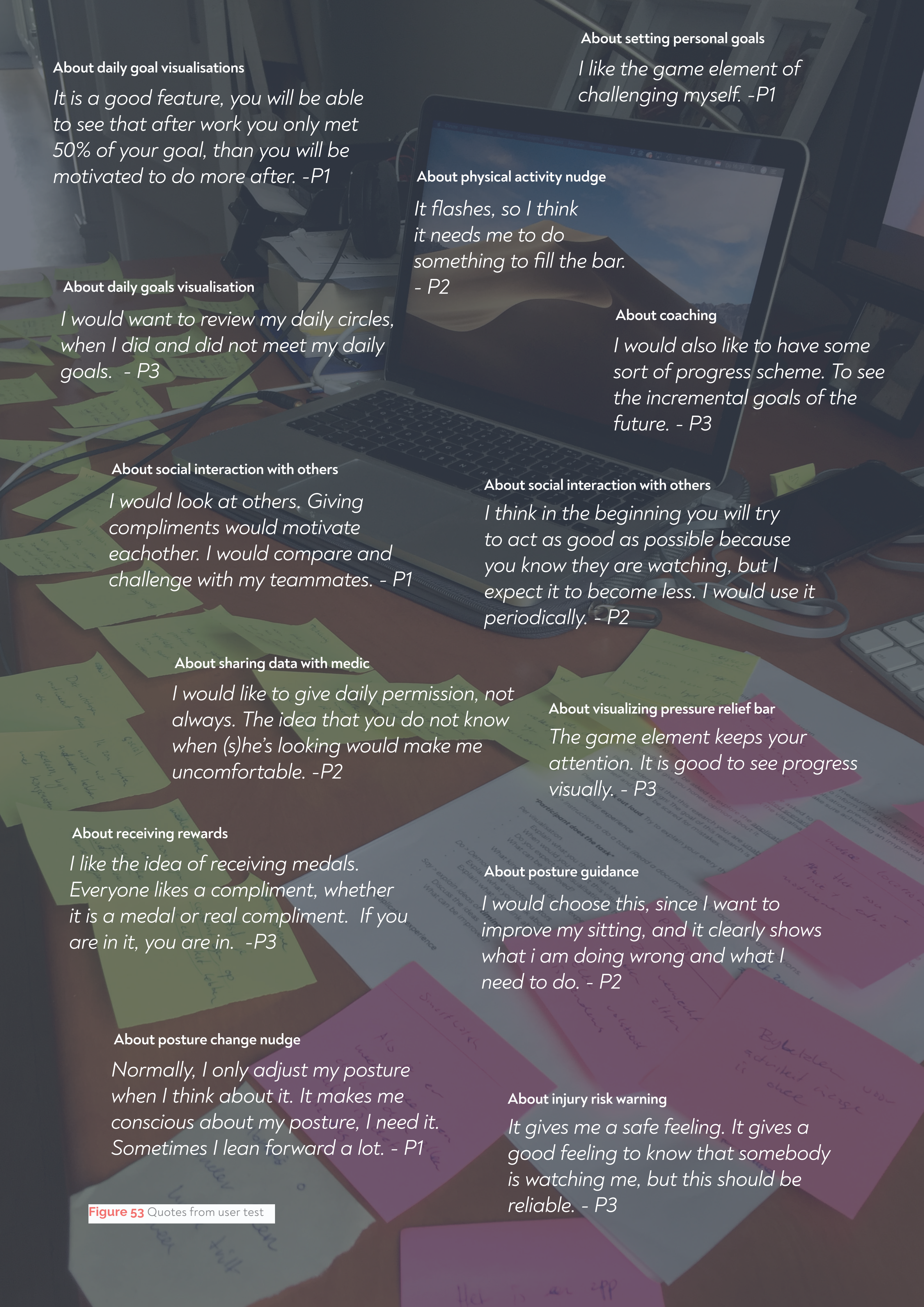
P3 thought that the icons were not clear enough to indicate the meaning directly, later he recognized the color relation with the visualisation of the daily goals. Improving the clarity of the visualisation would make this a more promising solution.

Pressure relief guidance

The counting bar chart has a motivational effect for all participants. It is experienced like a game. Participant 3 has said: *'I have to see something happening, it seems frustrating if you're doing something and it does not show.'* Which is understandable, since it was a simulated animation while no behavior was performed. Future research should have a reliable functioning prototype to test the usability.

Injury risk warning

'I think that when you were active and you receive such a warning it will demotivate.' - P1. Participant 1 and 2 found the message demotivating or scary, while participant 3 felt more safe. 'It gives a good feeling to know that somebody is watching me, but this should be reliable.' - P3. The warning should only be visible if the situation



About setting personal goals

I like the game element of challenging myself. -P1

About daily goal visualisations

It is a good feature, you will be able to see that after work you only met 50% of your goal, than you will be motivated to do more after. -P1

About physical activity nudge

It flashes, so I think it needs me to do something to fill the bar. - P2

About daily goals visualisation

I would want to review my daily circles, when I did and did not meet my daily goals. - P3

About coaching

I would also like to have some sort of progress scheme. To see the incremental goals of the future. - P3

About social interaction with others

I would look at others. Giving compliments would motivate eachother. I would compare and challenge with my teammates. - P1

About social interaction with others

I think in the beginning you will try to act as good as possible because you know they are watching, but I expect it to become less. I would use it periodically. - P2

About sharing data with medic

I would like to give daily permission, not always. The idea that you do not know when (s)he's looking would make me uncomfortable. -P2

About visualizing pressure relief bar

The game element keeps your attention. It is good to see progress visually. - P3

About receiving rewards

I like the idea of receiving medals. Everyone likes a compliment, whether it is a medal or real compliment. If you are in it, you are in. -P3

About posture guidance

I would choose this, since I want to improve my sitting, and it clearly shows what i am doing wrong and what I need to do. - P2

About posture change nudge

Normally, I only adjust my posture when I think about it. It makes me conscious about my posture, I need it. Sometimes I lean forward a lot. - P1

About injury risk warning

It gives me a safe feeling. It gives a good feeling to know that somebody is watching me, but this should be reliable. - P3

Figure 53 Quotes from user test

is really harmful. The wheelchair user indicated that he listens to the feeling in his body to determine whether he needs to calm down or not.

Visualisations

For the navigation of the user-wheelchair-interaction, the button functionality should be made clear. This was not always the case, since in the prototype the button was virtually displayed on the screen. It is expected that use over time would learn the user to understand the navigation functionality with more ease. Though, long press functionality for silent-mode should be made clear.

Seeing the daily and hourly goals, was seen as a valuable quick review to overview progress. But, the term active sitting sounded as a contradiction to participant 2. Users are not familiar with the term. A term should be used which is more clear.

The current time should be added to remind the user of how much time is left in this day to achieve the goal and as an extra feature to tell the time and simultaneously see the daily goals.

Silent-modus was seen as a valuable feature for private moments, like with friends or during a movie.

Application

Onboarding

The onboarding of the application was understood, but should be made even simpler to increase the speed. An option would be to give the user less choices at the beginning and move strategy choice to a later moment in time.

Overview

The overview successfully informed the participants for the integration of the data overview, social element and coach page, since they tried to navigate in the right away. Participant 2 found the black 'overview all wheelchair data' unnecessary and expected it to appear as she would press on the daily goal visualisation. These two cards could be combined to make the design more streamlined.

Data visualisation

The participants expected to use this as a way to learn about their behavior. Activity data was easy to understand, but the sedentary behavior overview had many categories that people found difficult to read and understand. Also the red color was misinterpreted for a poor behavior. Data visualisation was found really useful, but could be more clear, by explaining the labels and choosing a more neutral color.

Goal-setting

This page could be found by going to all data visualitions and going to the bottom or at the bottom of the overview page. Participant 3 could not navigate efficiently to the goal-setting page. He was expecting the goal-setting feature to be in the coach section. Which did not include a link to the goal-setting, but should be integrated as well.

Coaching

Participants would use the page to find more inspiration for exercises. *"If this shows how I can improve, I would use it. I do not know many exercises."*-P1. *"I will look through all the exercises to see if I see something new. I would like to see explanatory animations."* - P2. The coaching feature needs development of valuable content and exercises. After which it would be a feature that users can rely on for advice and information.

Social

The social feature would be used to compare and motivate each other more than competing. *'Good to see that you're not alone. It brings a feeling of togetherness.'* - P2. This could help people engage in conversation via the app or in real life, motivating each other to improve their behaviors. Also a problem was adressed. *'I think most wheelchair users have a limited friendships. What if I do not have friends in wheelchairs.'*- P3. In the conversation, an idea arose for a platform, where people would be divided into groups of a similar demographic and disability to compare with. These users could anonymously cheer, motivate each other, and if they would accept each other as contact the chat function will be enabled. This could also have a cultural value by decreasing the loneliness in elderly and meeting new people.

Settings

People found it hard to tell something about the settings without experiencing the full product. Many opinions about disabling the sound were similar to silent-mode.

Notification
Like expected, notifications would only be accepted and enabled if they would give them immediate value. The variation of coaching, social, suggestive and location-based notifications were tested of which they responded with what it would mean and why.

The 'increase goal after achieving three time'- goal is a very motivating notification. It shows the competence of the user, gives a compliment and gives a feeling of leveling up.

The challenge invitation of a friend received positively, but the persuasion for a reward was not necessary for participant 2. The interaction with the other person alone is enough. Though, the reward element will not be excluded, since it gives the user a form of reminder and some bragging points. The name of the challenger defines whether participant 3 would accept the challenge, or not.

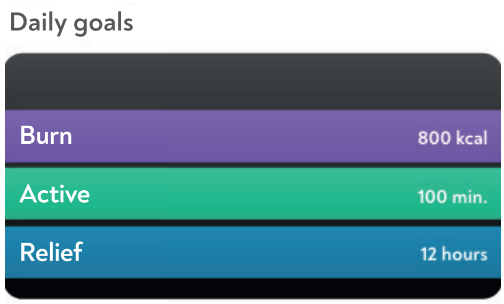
An activity suggestion about the park nearby could motivate, but the participant did not see it as very valuable, since they would like to decide whether they are going for a ride in the park. Though, is was seen as a reminder to be active in which case it would have been valuable. But it was also mentioned that the participant would not accept location sharing with the application if this was the use of it.

Compliments from a medic have been perceived positively by two participants and negatively by one. This last participant was also against sharing data with the medic. The other two liked the idea of receiving acknowledgement from someone.

Occasional information and exercise suggestions are accepted as long as they do not happen often. They should make the user aware about important things otherwise they would turn them off. It could make the user more conscious about their future behavior.

Conclusion
Most motivational strategy features are received

Figure 54 Redesign and renaming of the daily goals



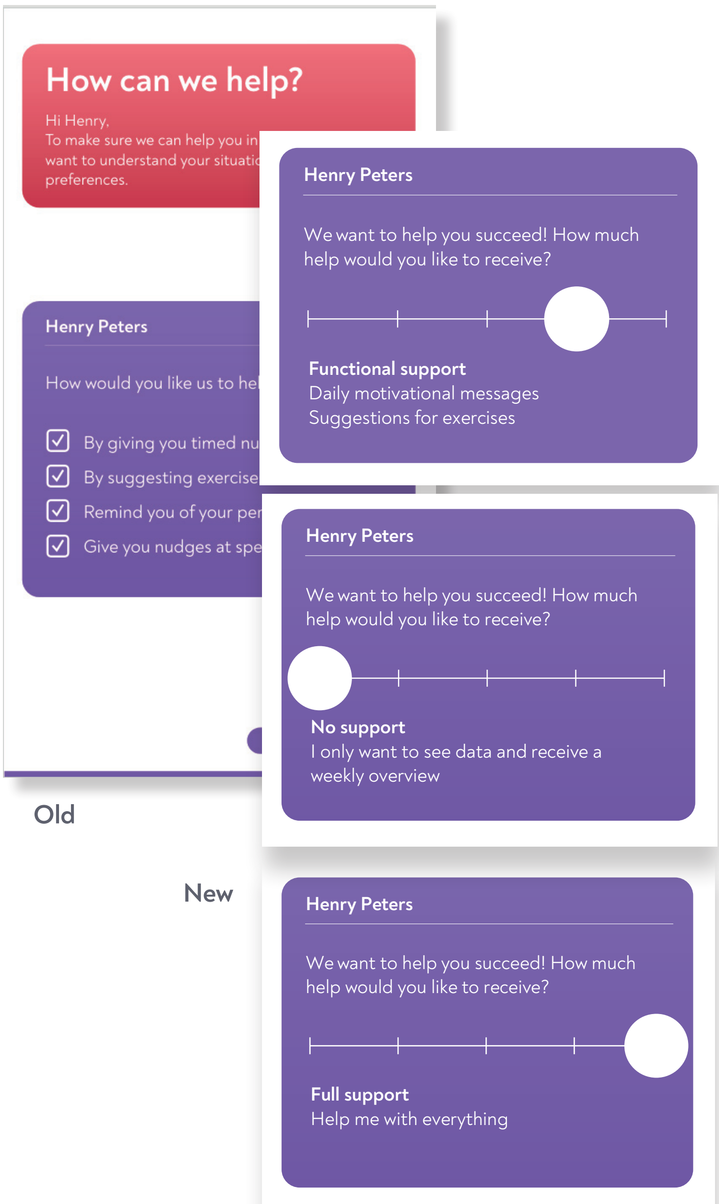


Figure 55 During ideation some steps were redesigned to make them even more simple for a faster onboarding process.

positively by the participants. Future research should improve the user interface design and fine-tune the strategy to be considered fitting for all users.

A short list of the main things to improve based on the research:

Wheelchair interface

- Posture guidance starts up too soon
- Icons and terms of behaviors are not clear enough, they confuse the user
- Add titles to the overviews to remind the purpose of the animation
- Button functionality should get an introduction
- Add navigation visualisation in overview interaction
- Add current time

App

Navigation

- Streamline onboarding
- Combine daily goal overview with black card to overview all data
- Add review of history of daily goals in one overview
- Show achievement and adjustment of daily goal over data visualisation history
- Add goal-setting links to coaching

Unclear elements

- Icons and terms of behaviors are not clear enough, they confuse the user
- Explain postures data more clearly

Strategy

- The injury warning should only come up when it is really valuable.

Interaction should feel casual, playful and natural. People should easily navigate through the interfaces and find what they expect to be there. The use of the product should continuously be researched to be refined.

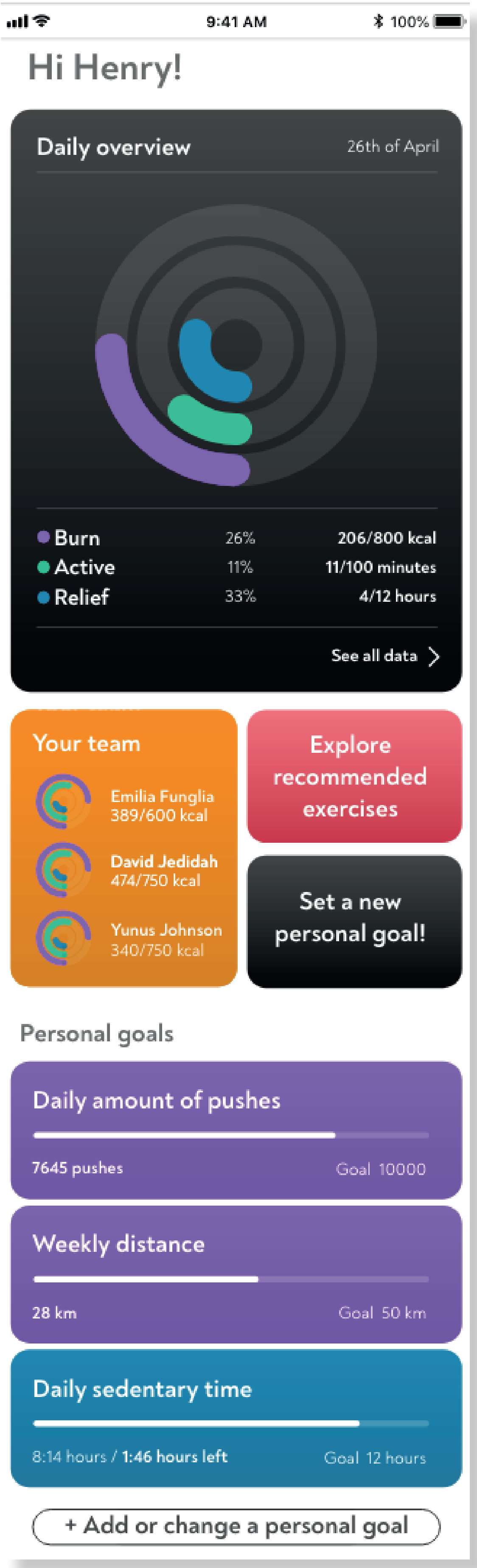
The findings are used for suggestions for a redesign. A few suggestions are presented in Figure 54-58.

Limitations of the research

The research is done with a limited amount of participants. Future research should be done using wheelchair users from the entire spectrum of the target group. It should be done using a functional prototype that is able to process data into real visualisations and coaching strategy messages. Reliable data is needed to research the real meaningfulness of the concept. In this way more insights are expected to be gained and better improvements can be made. When a working prototype is developed it could be used to research the use over time and the changes in use and perceived value.

Another limitation to the prototype was the experiencing of a functional wheelchair interface button. The simulating button in digital prototype gives a wrong impression of it being a physical button and confused the participant.

Figure 56 Redesign of the wheelchair interface daily goal overview navigation screen, simplifying the design and terms, adding time, title and navigation.



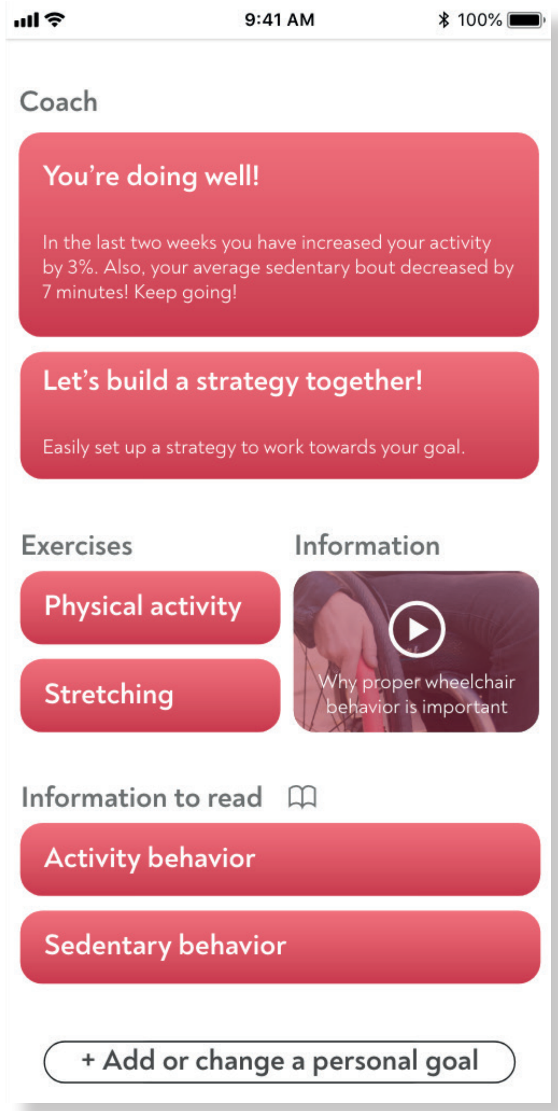


Figure 57 Redesign of the coach screen. Adding ability to set up a long term goal strategy and ability to add personal goals

Figure 58 Redesign of the overview screen. Referencing to all data in the daily goal overview and extra emphasis on setting personal goals on first view.

4.3. Objective 3: Feasible technology

4.3.1. Conceptual design

In Figure 60-65 a conceptual design can be seen of a wheelchair with integrated technology. The wheelchair was designed on the dimensions and comfortable seating position for P50 female 60+. Dimensions are found on Dined (TUDelft, 2019). Seating position is determined by using the 95 degree angle for the back rest and 100 degrees for the foot rest. The seating pan is inclined with 10 degrees for more better pressure distribution on the legs. The wheelchair is designed to showcase the functionality of technology and interfaces. Usability and ergonomics of the wheelchair were not in the scope of this project.

The design of the armrest concept was done using insights from research. The design is made with the words casual, playful and natural in mind. The list of requirement can be found in Appendix.

Dimensions

An armrest for wheelchair users should support the full length of the lower arm. The average length of the elbow to grip (centre of the hand) is approximately 335mm (Dined-TU DELFT M+F P50). Measured wheelchair armrests were approximately 50mm in width. It could be wider, but certainly not narrower.

Placement of the visual display

In the synthesis of this project was decided that the visual display would be placed in the armrest. This location provides good visibility during everyday wheelchair use. The wheelchair user rests their elbow on the 'beginning' of the arm rest and lays their lower arms forward. The visual display is placed at the 'end' of the armrest, so that the user will only need to lift their arm to be able to see the visualisations.

During in- and egress the user uses this part as support, so the display should be integrated in a way that it would withstand the forces.

Placement tactile feedback

The placement of the vibrotactile actuators in the wheelchair should be chosen to have maximum effect. In the research of Vink and Lips (2017), the most significantly different less sensitive and more sensitive areas of the human back and buttocks were found (Figure 59).

The challenge with vibrotactile actuators in a wheelchair seating surface is that people wear clothing and use cushioning and support, which could decrease the effectiveness of this signal. One solution would be to use vibrators that will be felt through cushioning, another solution would be to attach the actuators on top of the cushioning.

A small user test using a vibromotor and participants wearing everyday clothing concluded that the vibration is felt best in the front of the seating surface, comparable to the findings from the research of Vink and Lips mentioned before. Vibration in the backrest was experienced less pleasant, but could be a solution for people with decreased sensibility in the lower extremities. For these people this feature could be re-enforced or replaced with sound. Placing the vibrator motors in a cushion with high density or on the hard bottom plate, could make the whole cushion vibrate. This should be researched.

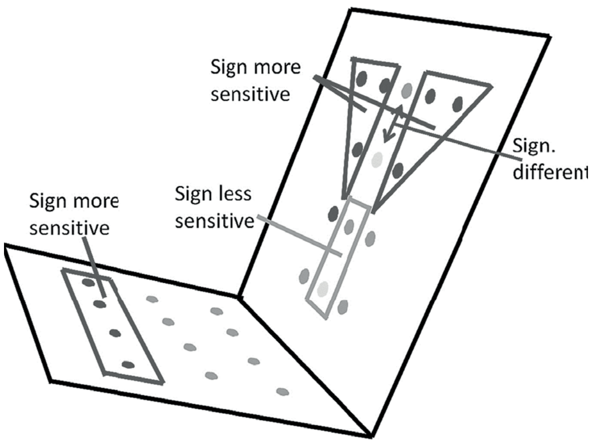


Figure 59 Research findings for sensitivity of the buttocks and back (Vink and Lips, 2017)

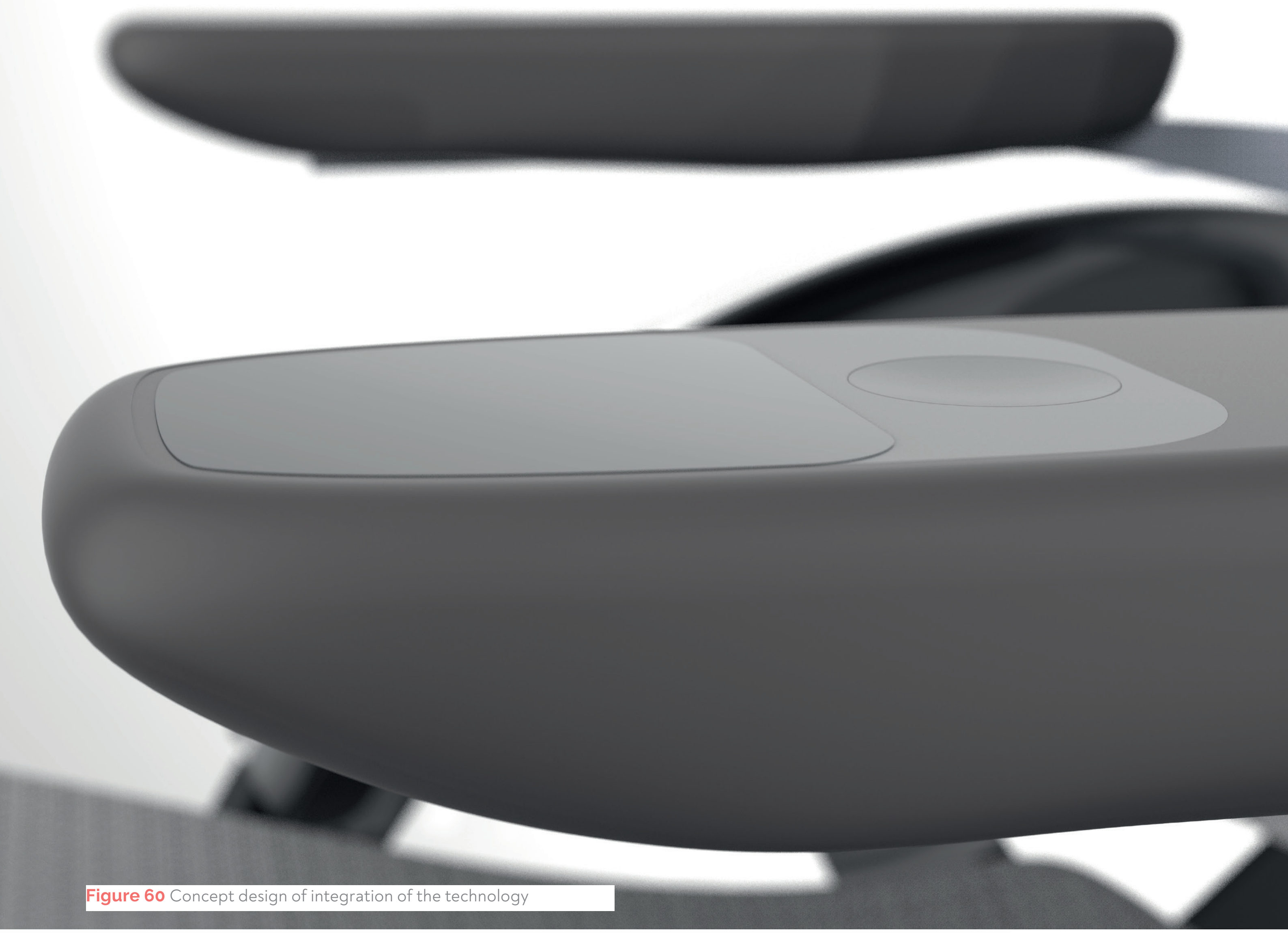
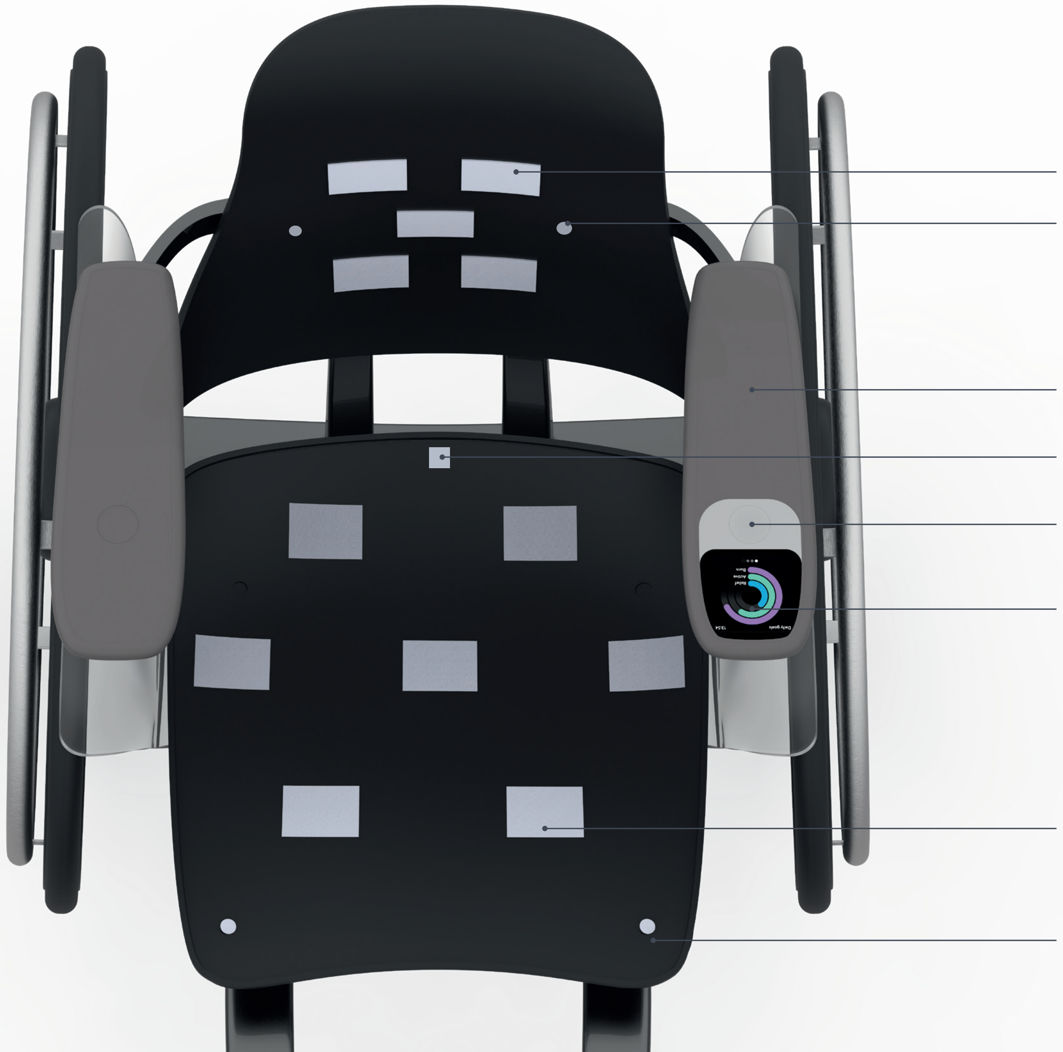


Figure 60 Concept design of integration of the technology

Figure 61 Overview of technology components (1/2)



Placement of the auditory feedback

A speaker is needed to play a sound at the moment of triggering. To be as unobtrusive as possible, the speaker has to play the sound in the direction of the user. One of the best options is to place the speaker in the armrest. This way it is also integrated in a part that already has technology built in, which make the distance shorter.

Placement of the button

The button is placed under the visual display for easy control. Other locations were considered, but proved to be evenly risky for accidental activation.

The size of the button is chosen to be 20mm, 2mm wider than the average finger breadth (Dined, 2014). The button is slightly incaved to be able to feel the placing of the button, but also decrease the chance for accidental pressing while using the armrest.

4.3.2. Technology

Activitity measuring technology

To measure the pressure distribution of the wheelchair user, sensors are needed that can measure applied forces. A selection of options is elaborated.

Force sensing resistors

Like in the prototype of Liu, FSR can be used. These resistors are made out of two electrodes and often a polymer in between. By applying a force or pressure the polymer deforms resulting in a smaller distance between the electrodes and a reduction in contact resistance. This way more current flows through and an analog signal can be converted into usable values. These FSRs can be used on the seating surface both on top and under the cushioning.

Load sensors

The basic principle makes use of the relation between the deformation and the resistance. The deformation because of strain results in a proportional change in the resistance of a metal. These sensors can be used in many configurations. In the current, these sensors could be placed on the attachment of the seat and backrest to the frame. However, this will limit the amount of measuring points to the amount of attachment points.

Fibre optical pressure sensor

This sensor uses light to measure pressure by calculating the time difference between sending and receiving a light pulse. It is very accurate, but also more expensive than the sensors above.

Pressure measurement technology choice

The choice for force sensing resistors, like in the prototype of Li, is the best option. These sensors have a long durability when chosen for the right mechanical properties. It is also able to place these sensors in all wanted locations. The placement of the sensors is based on prior research of Liu, but it should be researched further to minimize sensors and optimize accuracy.

Wheel rotation measurement technology

Measuring the rotation of the wheel is needed to decrease the drift. By knowing the circumference of the wheel an estimate of the traveled distance can be made and compared to the calculation of traveled distance of the accelerometer in the frame.

Gyroscope

The sensor like used in the research of THU measures the rotation of the body it is attached to. It uses battery power and saves the data on a memory card. If this type of sensor should be inseperable, it would require some kind of connectivity.

The sensor can give continuous data in both directions, but is limited by battery power. It will not be disturbed by interference of dirt, water, light or shocks.

The functionality is comparable with the Garmin cadence sensor discussed in chapter 6.2.1. Bike activity trackers. This device costs 40€ in retail, which could be around 5€ production.

A gyroscope would need to be on the wheel to be able to be used. Attachment could be on the spokes of the wheels, but this would still require recharging.

Hall effect sensor

This sensor measures the presence of a magnet by measuring the pushed voltage. This technique is used in a lot of speedometers for bikes. By calculating the time between each rotation and the circumference of the

Figure 62 Overview of technology components (2/2)

Figure 63 Render of wheelchair design

wheel, the speed can be calculated. To increase accuracy, multiple magnets can be placed on the wheel, this can result in higher frequency of measurements. The sensor can give data in timestamps in both directions. It will not be disturbed by interference of dirt, water, light or shocks. A solution is to place the sensors in the frame and the magnets in the wheel. Hall effect sensors can be found cheaper than €0.02 small magnets can be bought for €0,40.

Reed switch
Like in a hall effect sensor a magnet triggers the sensor. The magnet pulls two wires against each other, resulting in an electronic pulse. While the speed can be calculated with the same logic as with hall sensors. The sensor can give data in timestamps, but is unable to detect direction. It is also vulnerable in circumstances where there are a lot of shocks. The two wires can touch, resulting in a pulse not triggered by the magnet.

Optical sensor
Optical sensors are used in industrial machines to measure high frequency rotation. It sends a beam of light into a sensor and when the light stream is broken it measures difference. The sensor can give data in timestamps, but is unable to detect direction. It is also vulnerable in circumstances where there is other light and dirt can break the light beam resulting in no data. LDR sensors can be found for less than €0,28.

Variable reluctance sensor
The analog sensor uses a magnet in the sensor to measure the presence of metal objects. If a tooth of a gear comes close the sensors measures high values. This way, the rotating wheel just needs a shaped metal ring. The sensor can give data in timestamps in no directions. It will not be disturbed by interference of dirt, water, light or shocks. A solution is to place the sensors in the frame and the shaped metal ring on the wheel. VR sensors can be found cheaper than €10.

Choice wheel rotation measurement
Gyroscope, hall effect sensor and variable reluctance are the best options for this project. If very accurate data is needed, the choice should go to the gyroscope. However, for the insights of this project less accurate data will be sufficient. Considering the price, hall sensors with magnets is the cheapest method to gain data on speed.

The system will be able to calculate all data named in Appendix E, however the accuracy will go down due to

	Type of data	Measurement	Withstands use environment (Rain, Dirt, Light, Shocks)	Price	Suitable
Gyroscope	Constant data	Bidirectional	Yes	~€5	+
Hall sensor + magnets	Timestamp	Bidirectional	Yes	€1 + x*€0,08	++
Reed switch + magnets	Timestamp	No direction	No	€0,20 + x*€0,08	-
Optical	Timestamp	No direction	No	€0,28	-
VR	Timestamp	No direction	Yes	€5	+

Figure 64 Wheel measurement technology comparison

non-continuous data stream. Detailed distance, speed and acceleration data will not be possible based on wheel measurement. More complex data like rotation speed, rotation acceleration and analysis of push behaviour will be inaccurate as well, however it is expected to be estimated by the IMU in the frame.

Display

For this project a visual display is needed, without touch sensitivity. A measurement of a few wheelchair armrests and consideration about readability and looks resulted in a choice for a visual display with a width of approximately 50mm.

Most common smartphone displays have a pixel density between 300 and 400 pixels per inch (wikipedia.org, 2019), which is considered high resolution. This resolution gives precise visualisations, but could even be lower if needed. More pixels mean more power consumption for processing and functionality.

A smartphone display is used as an example for calculations. A 7-inch 800x480 pixel LCD screen (AT070TN92 from Innolux Display Corporation) uses a voltage of 16V on average when activated. The LCD uses 25mA for visualisation but 170-200mA for the backlight. An optional screen for this project could be the 176 by 220 pixels, 2 inch monitor lcd display (alibaba.com, 2019). It has a size of 51.30 by 37.68mm and a price for $3 when many are purchased. No datasheet is available, but the assumption is made that it has a lower power consumption than the previous example. For the calculation, an estimated 15 mA for visualisation and 100 mA for backlight will be used.

Data processing architecture

Wheelchair processing

All sensor inputs and calculations for behavior estimation need to be internally processed to be able to visualise on a display without the need of a smartphone computing power. The processor will need to be able to compile visual data for the screen, process measurement data and communication technology data. The expectation is that the graphics of the display will not need much, but some processing. A fitting processor and Graphics Processing Unit (GPU) will need to be chosen. An estimated current of 100 mA is used for calculations, comparable to the LCD screen, since a Model A Raspberry Pi uses 140 mAh current and is able to show resolutions of 1920x1200pixels.

With internal processing and smart saving, the hypothesis is made that day of measurements could be reduced to a less than 1 megabyte of data. With sizes this small a 512mb flash drive could store more than a years worth of data. The price and current of a flash will be neglected, since these can be bought for a few cents (alibaba.com, 2019) and require no power for storage, only for writing.

Smartphone processing and actuation

The smartphone will receive its information from the wheelchair device. The internal processing power is used to generate the insights and strategy for behavioral change.

Connectivity

In chapter 3.3.1. a decision was made for the data flow in the system. The user is expected to have a personal smartphone device. These devices are equipped with bluetooth connectivity as a technology to connect to other products. The smartphone will use bluetooth connectivity to connect to the wheelchair.

Bluetooth Low Energy (BLE) is an exceptionally successful wireless technology. It's hard to find a smartphone or tablet which doesn't support it, and it's a key ingredient in the rise of wearable technology (Wooley, 2017). The most actual version at the time of writing this thesis is 4.2.. The development of bluetooth connectivity makes it possible to become faster, give it more capacity, safety and while using low energy. BLE 5.0 is already in the market an allows mesh networking of bluetooth devices. This is considered not yet relevant for this project, but should be looked at for future development. It also is able to transfer data at a speed of 1.4 megabytes per second.

Dialog Semiconductor released wireless sensor module (SmartBond™ DA14583 IoT Sensor Development Kit) which measures 12 degrees of freedom (IMU+ Environmental sensors) that works with a 100 hz frequency for calibration. In connected state it uses less than 1.3 mA, while advertising (a state where it offers

Figure 65 Render of the wheelchair

data to another device to be received) less than 110 μA and while in power save mode less than 11 μA. This could mean that with proper strategy and coding the communication would hardly use any energy. Separate BLE modules can be found for $3,50 (Alibaba, 2019).

Data transfer strategy

The system of this concept does not need to continuously update live data to the smartphone. It would not give extra value if the user would be able to see the daily goal visualisation grow in front of their eyes. If the system would advertise the data every 15 minutes and taken the assumption that the size of the data from measurement is no more than 1 MB per day, it would mean that the system would be in connected state for a duration of a less than one second per day to transfer all data.

Power supply

In Figure 66 a calculation can be seen of the amount of energy use on a day with extreme use (16 hours of use and total 2 minutes of LCD use per hour). It is estimated that per day 147.58 mAh is needed to power the system. If a battery with 1200 mAh storage would be used, the wheelchair should only be charged once a week.

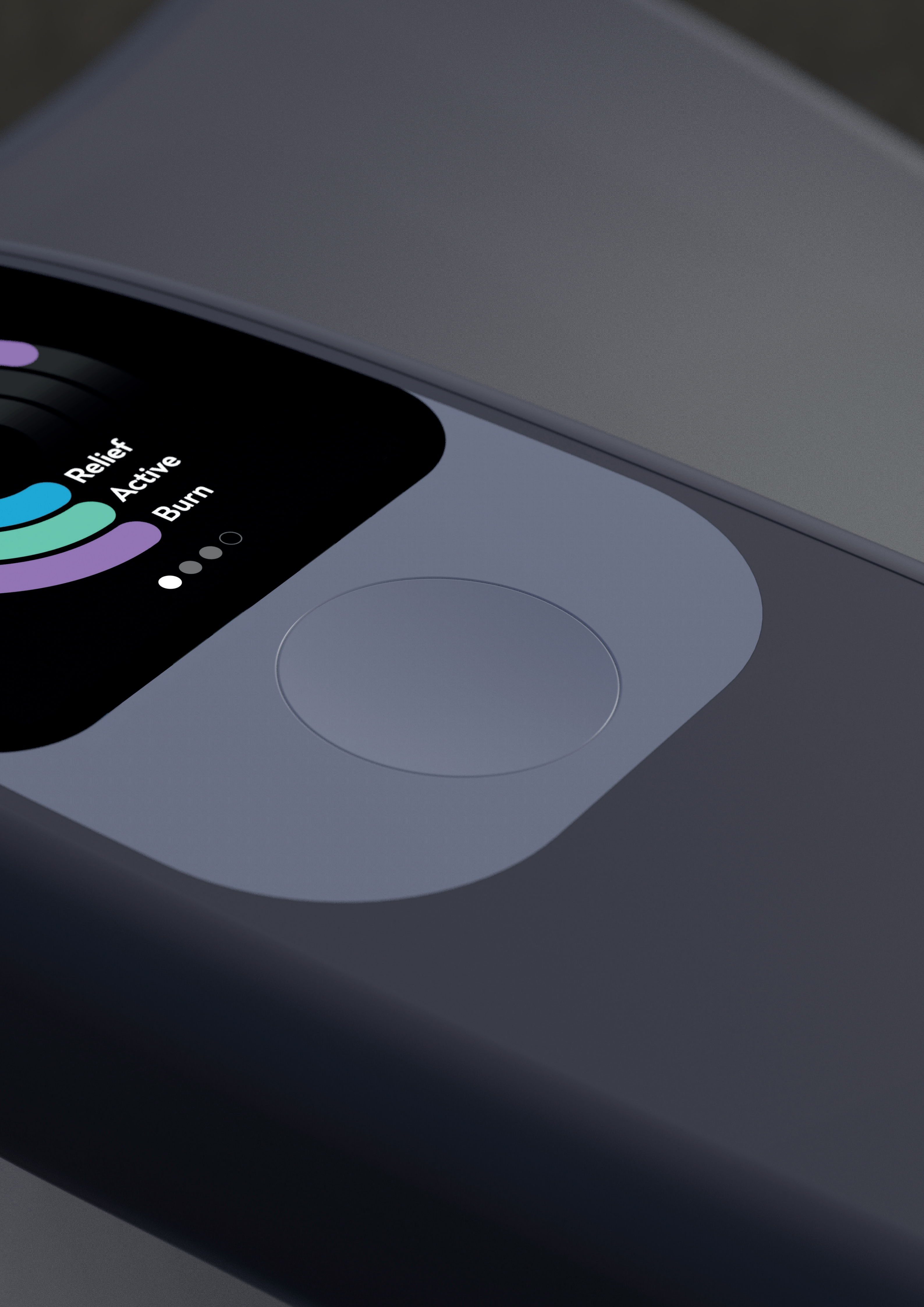
Electronics price

The price of all extra components combined is estimated to be around €170 (Figure 66). The main costs influencer are the pressure sensitive resistors, which are €15 per unit. By reducing the amount of necessary sensors, the price will decrease a lot. The rest of the components are relatively cheap. Combined, these are estimated to cost approximately €25.

LCD Screen					
ON	10V	115 mA	32 min/d	61.33 mAh	€3
Bluetooth LE + Accelerometer					
Con.	1.5V	1.3 mA,	1 sec/d	0,00036 mAh	€3.50
Adv.	1.5V	110 μA	64 sec/d	0.0015 mAh	
Pow-S.	1.5V	11 μA	15.9h/d	0.17 mAh	
Hall sensor					
Active	3V	5 mA	10s/d	0.013 mAh	€0.02
Magnets (3x)					€0.90
Pressure sensors					
10x	3V	~0.20 mA	16h/d	32 mAh	€150
Vibrator motors					
4x	3V	65 mA	10sec/d	0.72 mAh	€12
Processing					
High	9V	100 mA	32min/d	53.33 mAh	€5
				147.58 mAh	€174,42

Figure 66 Calculations for energy use and cost of all electrical components

Hi Henry!
Daily overview
26th of April
Burn
26%
206/800 kcal
Active
11%
11/100 minutes
Relief
33%
4/12 hours
See all data
Your team
Emilia Funglia
389/600 kcal
David Jedidah
474/750 kcal
Yunus Johnson
Explore recommended exercises
Set a new personal goal!
Today
Data
Coach
Social
Settings
Daily goals
13:54


Relief
Active
Burn

5. Evaluation

In this chapter you are able to find the discussion, conclusion, recommendations and a personal reflection

142 5.1. Discussion
143 5.2. Conclusion and recommendations
144 5.3. Personal reflection

5.1. Discussion

The purpose of this graduation report is to design a solution that decreases the physical problems of wheelchair users by using persuasive technology interventions.

The research starts with identifying the most common physical problems and their causes. This is followed by the exploring of theories of persuasive technology, behavioral science and decision-making. Interviewing wheelchair users and therapists creates a deeper understanding of the context of the wheelchair user and their problems concerning wheelchair use. However, this group of interviewees is limited to fully understand the situation of older wheelchair users.

The developed solution integrates behavioral science principles and methods into prototypes. Testing the prototypes is really valuable to gain insight in how people think and react. Participants are positive about the main motivational principles. They also experience many features of the prototype as useful. However, there could be some improvement on the criteria 'easy-to-use'. Some strategies, like location-based suggestion notification nudges, are not seen as less meaningful during the research. To define the real value of the interventions wider and longer research would be necessary. It is difficult to research a nudging strategy during a short period, as well as to research multiple varying factors at once. Future research should pinpoint functionalities to research and focus on optimizing the approach.

The insights from the user research are used to develop a redesign and implement it in a concept for a novel product. This product would have to be designed together with a manufacturer of wheelchairs, to be compatible with existing wheelchairs, or it could be integrated in a new design. The findings of this research can however be used as a starting point for development of future prototypes regarding behavioral change of wheelchair users.

There is no existing product specifically for wheelchair users on the market, yet. Survey and interviews suggests that there is a desire for such a product coming from the context of wheelchair users. This project and prior research shows the feasibility of the technology, but future optimization and development is definitely needed. The viability of the concept will have to show over the course of time. It is expected to become a valuable product for wheelchair users, as long as the right developments are made.

5.2. Conclusion and recommendations

Since this project was unable to cover the full development of a complex product, recommendations are done for necessary future development.

First of all, research needs to be performed with the a larger and more diverse group. In this project were no participants from the upper half of the target group. Those potential users are expected to receive most value from a product motivating to improve wheelchair behavior, since they experience most of the problems. The product design should be optimized for their use.

The motivational strategy should be integrated with elements of the behavioral intervention principles: self-monitoring, datavisualisation, goal-setting, coaching, rewarding and social interaction.

Further research on the strategy should be done, in order to improve the strategy and fine-tune the features. A prototype with functional technology is expected to give meaningful insights in the behavior of the users towards the product. Additionally, use over time could possibly be researched. This will create an understanding of the effectiveness of the intervention.

Notification nudging strategy must be introduced carefully, since users are prone to disabling notifications when those are experienced as useless and obtrusive.

For the concept, the primarily focus should be on making a functional prototype that is able to give data on sedentary behavior while using less force sensitive resistors. The price of these sensors is disproportionally higher than the rest of the required technology.

Also, research should be done to develop researched values for determining energy expenditure, which is based on wheelchair inclination and mobility data. Combining the data of the wheelchair with heart-rate monitors could give a more accurate estimation of the energy expenditure of the wheelchair user.

If there is a possibility to solely use the accelerometer for activity measurement, it would be unnecessary for the hall sensor to go through the frame of the wheelchair. Within this, all technology could be integrated in the armrest and seat. This could be achieved by finding a solution to reduce drift and easy calibration of initial state (not moving).

To successfully enter the market, a marketing introduction plan needs to be developed. The current price is €170 for the electrical components, without counting the development cost of the algorithms and strategy. The eventual retail price would be around €1000. In this case, the concept should be proven to reduce physical problems effectively before it would be supported by governments and medics. It should be worth to spend the extra money for a more expensive wheelchair with the features mentioned above. People, businesses and the government need to see the value of the product.

The integration of the measuring technology creates new opportunities for other contexts. An example is how mobility and activity data could be used to map out accessible streets and buildings for wheelchair users. Medical services could be directly linked to the wheelchair data to gain insights for national research. Furthermore, manufacturers could gain insights in the use of their product, enabling them to innovate their products based on data.

5.3. Personal reflection

A long journey has come to an end. When I started to search for a graduation project, I looked for a project that would fit my idea of combining both product design and interface design. Finding a graduation project for a 'smart wheelchair' looked like a nice challenge, since I was not too familiar with the context.

The introduction into the world of wheelchair rugby was a very extraordinary encounter. It was fun to watch and I was impressed by their tactical gameplay. The project, however, took longer than expected, due to personal and practical reasons. So, in September 2018 we reshaped the project in such a way that the subject was still about wheelchairs, but now the main focus group was changed to the daily wheelchair user instead of wheelchair athletes. Consequently, I had to start from the bottom and perform a new analysis of the target group, which concluded in this totally new project.

I had some trouble narrowing down what theory was necessary for this project. A gentle 'nudge' in the direction of behavioral science by my supervisors has opened a new world. This project has given me the opportunity to acquire a lot of new knowledge on human behavior and nudging. A subject that I expect to use more often in my future as a designer. In the beginning, I had difficulties to systematically document my findings from literature research. This resulted in a delay, which affected my progress.

I would not lie if I said that I found it challenging to finish this project. My idea of being a designer is that one person can design a good solution, but a team does it better. In my journey as a industrial design student, I experienced an intrinsic drive when cooperating in teams. Now I can tell that I prefer to not work alone. Using each others strengths and enthousiasm has been motivating me during my studies at the TU Delft. I missed that kind of energy during this project.

In conclusion, I found it challenging to do a full project by myself, but eventually all the work has paid off. I learned a lot about the subjects, but also about myself.

6. References and glossary

150 References
152 Glossary

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Glossary

Wheelchair
A chair fitted with wheels for use as a means of transport by a person who is unable to walk as a result of illness, injury, or disability.

- **Manual wheelchair (MWC):** A wheelchair that is propelled by the user or pushed by another person. Often used because of insufficient lower extremity functionality or insufficient stamina.
- **Motorized wheelchair or Powered wheelchair (PWC):** A wheelchair that is partially or fully propelled by a motor, operated by the user. Often used because of insufficient upper body functionality for propelling.
- **(Mobility) Scooter:** A motorized mobility aid for people with insufficient lower body functionality or insufficient stamina. Has longer range and higher speeds than PWC.

Wheelchair mobility
The ability to move or be moved freely and easily in a wheelchair.

Bouts
A short period of intense activity of a specified kind.

Metabolic equivalent (MET)
MET refers to metabolic equivalent, and 1 MET is the rate of energy expenditure while sitting at rest. It is taken by convention to be an oxygen uptake of 3.5 milliliters per kilogram of body weight per minute. Physical activities frequently are classified by their intensity using the MET as a reference.

- **Light-intensity activities** are defined as 1.1 MET to 2.9 METs.
- **Moderate-intensity activities** are defined as 3.0 to 5.9 METs. Wheeling at 2.0 miles per hour requires 3.3 METs of energy expenditure (Conger&Bassett, 2011) and is therefore considered a moderate-intensity activity.
- **Vigorous-intensity activities** are defined as 6.0 METs or more. Handcycling at 10 miles per hour requires 7.5 METs of energy expenditure (Conger&Bassett, 2011) and is therefore classified as vigorous intensity.

Physical activity
Any bodily movement produced by skeletal muscles that requires energy expenditure.

- **Inactive:** No activity beyond baseline activities of daily living.
- **Low activity:** Activity beyond baseline but fewer than 150 minutes (2 hours and 30 minutes) of moderate-intensity physical activity a week or the equivalent amount (75 minutes, or 1 hour and 15 minutes) of vigorous-intensity activity**.**
- **Medium activity:** 150 minutes to 300 (5 hours) minutes of moderate-intensity activity a week (or 75 to 150 minutes of vigorous-intensity physical activity a week). In scientific terms, this range is approximately equivalent to 500 to 1,000 metabolic equivalent (MET) minutes a week.
- **High activity:** More than the equivalent of 300 minutes of moderate-intensity physical activity a week.

Physical inactivity
An insufficient physical activity level to meet present physical activity recommendations. For adults (≥ 18 years) this is seen as not achieving 150 min of moderate-to-vigorous-intensity physical activity per week or 75 minutes of vigorous-intensity physical activity per week or an equivalent combination of moderate- and vigorous intensity activity.

Exercise
Physical activity that is planned, structured, repetitive, and designed to improve or maintain physical fitness, physical performance, or health.

- **Aerobic physical activity:** Forms of activity that are intense enough and performed long enough to maintain or improve an individual's cardiorespiratory fitness. Such as wheeling or walking.
- **Anaerobic physical activity:** High-intensity activity that exceeds the capacity of the cardiovascular

system to provide oxygen to muscle cells for the usual oxygen consuming metabolic pathways.
- **Muscle-strengthening activities:** Maintain or improve muscular strength, endurance, or power.

Sedentary behavior
Any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture.
- **Sedentary time:** The time spent for any duration (e.g., minutes per day) or in any context (e.g., at school or work) in sedentary behaviors.
- **Sedentary bout:** A period of uninterrupted sedentary time.
- **Sedentary interruptions/breaks:** A non-sedentary bout in between two sedentary bouts.

Posture
The position in which someone holds their body when standing or sitting.
- **Kypothic posture:** A posture wherein the person's back has a abnormally excessive convex curvature. Examples of postures are slouching and leaning forward, which are described as improper postures. (See examples in chapter 2.1)
- **Lordotic posture:** A posture wherein the person's back has a abnormally excessive concave curvature. (See examples in chapter 2.1)
- **Scoliotic posture:** Sitting posture where the person's pelvis is unaligned and results in a spine that is not vertical when seen from the back. (See examples in chapter 2.1)

Pressure sores / Ulcers
Pressure sores due to prolonged sitting or, also known as bedsores, pressure ulcers or decubitus ulcers on the skin.

Behavioral science
explore the cognitive processes within organisms and the behavioural interactions between organisms in the natural world.

Behavioral economics
studies the effects of psychological, cognitive, emotional, cultural and social factors on the economic decisions of individuals

Nudging
A concept in behavioral science, political theory and behavioral economics which proposes positive reinforcement and indirect suggestions as ways to influence the behavior and decision making of groups or individuals.

Persuasive technology
Technology that is designed to change attitudes or behaviors of the users through persuasion and social influence, but not through coercion

Appendices

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A | Interview: Wheelchair users

Deepening knowledge on wheelchair users and their problems

Main subjects: Wheelchair use, Wheelchair problems, Situation understanding,

Introduction

Wheelchairs are used all over the globe. These devices not only enhance the independence and mobility of wheelchair users, but also open the possibilities to have education, work and a social life. While being helpful in many situations, people also experience 'unnecessary' problems.

Poor sitting position and insufficient activity are seen as factors that influence the health of wheelchair users in a bad way. These users not often share their story on their experiences with wheelchairs. So, this research is set up to get to know the story of the wheelchair experience.

Method

This research will focus on the experiences, opinions and views of the ordinary everyday wheelchair users. Starting with the moment they received the wheelchair up till how they use it and what problems occur along the way. This will be used as insight in the lifestyle and experiences of the wheelchair user

This research will was done by interviewing with тшо wheelchair users (age 27 and 34) in a semi-structured interview (Last page).

The main questions are:

- How do they get the wheelchair? Who pays?
- How were they instructed to use it? And are they checked up?
- When do they use the wheelchair?
- How do they use it? Explain a day in a wheelchair.
    - Roadmap of use
    - What kind of activities
- What problems do they experience while using it?
- Are they aware of their sitting positions?
    - Do they have knowledge about good sitting positions?
    - Do they do exercises?
- How active are wheelchair users?
    - Is there an urge to be more active?
- Technology use?
- Would they like to be reminded about their sitting and activity behaviour?

Interview set up

Introduction

Interview for educational purposes. Only be used in graduation report. Are you consent to record the audio of this interview for personal use. 45 mins?

It will be personal questions, when you are not comfortable, please say so.

Questions

Name / Age / Profession / Hobbies...

What is the reason of your need for a wheelchair? Can you walk?

Is your wheelchair personalized? Are the settings set for your abilities and body dimensions?

When did you get your wheelchair? How did you get it? (Company/Insurance/..)

Did you get an instruction of some sort? What can you remember of the instruction?
(Device/Wheeling/Strapping/Sitting/..)

How often are you revised on your wheelchair use?

Please explain your day (in a wheelchair) (name many activities?)
>......................

What kind of problems do you experience with your wheelchair?

How do you solve these? Is there someone to help you with your experienced problem?

What kind of physical problems do you experience?

Are you aware of your sitting position? Do you know what a proper sitting position is?

Do you do exercises?

Do you find yourself an active wheelchair user? Do you participate in sports?

Any more problems to discuss?
Thank you! Possible to participate in future research?

Answers

Interview 1

Age / Profession / Hobbies
27 - Finance advisor at Shell TapUp - Used to do wheelchair basketball

What is the reason of your need for a wheelchair? Can you walk?
Spina bifida, Used to walk, not able anymore due to brain surgery

Is your wheelchair personalized?
Yes

When did you get your wheelchair? How did you get it?
When I was 12 I got my first wheelchair. WMO.

Did you get an instruction of some sort? What can you remember of the instruction?
I cannot really remember.

How often are you revised on your wheelchair use?
Every year I visit the ergotherapist for a check-up. For problems with my wheelchair I go to the manufacturer repair service.

Please explain your day (in a wheelchair) (name many activities?)
Wake up - Sit in wheelchair - morning routine - Wheel to train - train to working city - Wheel to work - work - toilet - leave work - transport - chilling at home - watch netflix

What kind of problems do you experience with your wheelchair?
Curbs - transport

How do you solve these? Is there someone to help you with your experienced problem?
Trainpersonell helps with in- and egress in trains

What kind of physical problems do you experience?
Occasionally back pains - History of ulcers because of new wheelchair

Are you aware of your sitting position? Do you know what a proper sitting position is?
I am, but I not always sit in this way. Sometimes you forget.

Do you do exercises?
I used to do wheelchair basketball, but now I only wheel to the train. This is more than 3kilometres so it is quite a lot.

Do you find yourself an active wheelchair user? Do you participate in sports?
I used to do wheelchair basketball, but now I only wheel to the train. This is more than 3kilometres so it is quite a lot.

Are you interested in a product that communicates whether you sit proper and move enough?
I believe I am active enough to be considered active. But it would certainly help to monitor my sitting. I would check it often due to curiosity.

Interview 2

Age / Profession / Hobbies
32 - TWREX Total Wheelchair Rugby Experience - Wheelchair rugby

What is the reason of your need for a wheelchair? Can you walk?
Paraplegic, after accident. Unable to walk due to inability to use legs

Is your wheelchair personalized?
Yes, it is made to my dimensions and the strapping I needed. My sports wheelchair is completely made from scratch.

When did you get your wheelchair? How did you get it?
When I was 19 I got my first wheelchair. WMO.

Did you get an instruction of some sort? What can you remember of the instruction?
I had a long period of learning to be mobile again. I was advised to sit upright, but I often do not feel whether everything is right, since do not feel my lower half of my body

How often are you revised on your wheelchair use?
Every year I visit the ergotherapist for a check-up. And there is always someone who can help me with my wheelchair at Reade. Most of the time I change my wheelchair to what feels most comfortable for me.

Please explain your day (in a wheelchair) (name many activities?)
Wake up - Sit in wheelchair - morning routine - enter car - drive to work - work - toilet - leave work - Drive - Prepare training - coach and train - drive to home

What kind of problems do you experience with your wheelchair?
Not real problems I cannot overcome. Just some places are hard to visit.

How do you solve these? Is there someone to help you with your experienced problem?
I do it myself or ask bystanders to help me a hand.

What kind of physical problems do you experience?
Occasionally back pains - History of ulcers because of new wheelchair

Are you aware of your sitting position? Do you know what a proper sitting position is?
I try to sit as good as possible, but I do not have sensitivity in my legs, so sometimes it is difficult to determine a good posture. Sometimes you forget.

Do you do exercises?
I am a professional wheelchair rugby player, so I train 4 days per week and play matches in the weekend. For training I go to practice and I also go to the gym.

Do you find yourself an active wheelchair user? Do you participate in sports?
Yes, sometimes even too much.

Are you interested in a product that communicates whether you sit proper and move enough?
Yes I would use it for documenting my activity. And it may help me with sitting as well.

Conclusion
These two wheelchair users both got their wheelchair through the social act (WMO). It provides them with comfort and transportation to participate in everyday activities. The participants are considered to be active since they both participate(d) in sports and transportation by manually propelling. Back pains and are a common physical problem they experience and also a history in pressure ulcers has been occuring with both.

B | Interview: Medic

Deepening knowledge on physical problems of wheelchair users and the solutions

Main subjects: Wheelchair use, Physical problems due to wheelchair use, Solving physical problems.

Introduction

Wheelchairs are used all over the globe. These devices not only enhance the independence and mobility of wheelchair users, but also open the possibilities to have education, work and a social life. While being helpful in many situations, people also experience 'unnecessary' secondary problems.

Poor sitting position and insufficient activity are seen as factors that influence the health of wheelchair users in a bad way. These users not often share their story on their experiences with wheelchairs. So, this research is set up to get to know the story of the wheelchair experience.

Method

This research will focus on the different problems, their causes and solutions, experienced by wheelchair users and the current procedure.

This research will be done by doing a semi-structured interview with an occupational therapist, who is in the seating advice team at the Reade centre of rehabilitation medicine and rheumatology in Amsterdam, the Netherlands.

The prepared questions and topics can be seen at the end of this research.

Results

Martine Beurskens is an occupational therapist, who are in the seating advice team at the Reade centre of rehabilitation medicine and rheumatology in Amsterdam. This team, consisting of a PA, occupational therapist, physical therapist and a rehabilitation technician.

People in wheelchairs sometimes have complaints about their chair, or get complaints after years of use. If one of the therapists cannot identify the problem individually, the team gets together to come up with a solution for the patient, by doing a thorough sitting analysis. In this analysis, they analyze the body of the patient and look at the current way of sitting and finding the real cause of the sitting problem.

Given answers are from her experience at the rehabilitation centre.

When do you prescribe a wheelchair?

Every patient is unique. There are many reasons to prescribe a wheelchair, but overall these are to giving them the possibility to be individually mobile. Some reasons are, muscle diseases, paraplegia and age.

How do they get the wheelchair?

The patients are facilitated with a wheelchair to use, together with an occupational therapist is looked if the chair is suitable for the patient. It could be that parts need to be adjusted or replaced.

In the rehabilitation centre they get a wheelchair from the centre. This wheelchair they can use as long as they are treated in the centre, but outside there are multiple ways to obtain a wheelchair. Sometimes a patient needs a temporary wheelchair for a few weeks, sometimes a half year and sometimes it is for always.

Short term: People are able to rent a wheelchair from thuiszorg via their insurance. This can be done twice for three months.

Working setting: If people need a wheelchair to be able to function and work, they can contact the UWV (Employee Insurance Agency) to get a wheelchair.

Long term: WMO is a law that says that local authorities in the Netherlands needs to help people finance a wheelchair. The patient needs to apply by writing a personal plan, with the reasons to obtain and requirements for the wheelchair.

Personal: If a patient is able to finance the wheelchair themselves, they can buy one from a wheelchair manufacturer.

How do you measure and customize a wheelchair?
It is important that one therapists visits the patient to measure the main dimensions of the body. The dimensions and the patient's personal goals and preferences are used to find a suiting wheelchair. The therapist analyzes the patient's body and wheelchair to determine where the patient lacks and needs support and what settings need to be changed. These can be dimensions, sitting position, seating cushioning and back support.

The wheelchair is modified to be acceptable for the patient, but if the patient experiences discomfort they revisit the therapist to see if a solution can be found.

Due to behaviour outside of the wheelchair, like disease, sleeping behaviour and (in)activity, the body of the patient can change over time and also the requirements and ideal settings of the wheelchair can change. When a patient is using the wheelchair over a longer period of time, the body can change in shape and need other kind of sitting position, cushioning or back support. A therapist re-analyzes the situation and makes adjustments to the wheelchair.

If the patient is able to self-propel a wheelchair, the preference of choice always goes to a manual wheelchair. If this is not the case, another solution is tried to be found, like a motorized wheelchair or scooter.

The patients is positioned in such a way that he or she is able to look forward.

There is no such thing as a standard ideal sitting position. Every patient is unique.

Current technology use?
If the individual therapist cannot come up with the perfect setting to solve discomfort the seating team is gathered. They do more thorough analysis of the body, sitting pressure, sitting position and wheelchair.

During the measuring of pressure distribution to reduce discomfort and the possibility of ulcers, the therapists use a pressure mat to test different types of cushioning and the effect on the skin of the patients. The distribution and the sitting position are used to choose the right solution for the patient.

Outside the practitioners office no technology is used to track the behaviour of the patients.

Do you give instructions with the prescription?
The patients are given an instruction at reception of the wheelchair. The advice is on use and sitting.

What kind of physical problems occur most often with patients due to wheelchair use?
The occupational therapist named body pains due to improper sitting position, overuse of the shoulder muscle, insufficient activity and decubitus ulcers due to long term sitting as the main measurable problems during wheelchair use.

Further she thought of other problems related to wheelchair use, like transportation in vehicles and transition from bed to chair and vice versa.

What do you prescribe to solve these problems?
Improper sitting position
People come to the therapist with a feeling of discomfort or pain. The therapist looks at the (changes in the) body of the patient and the wheelchair if it is possible to reduce the discomfort. Often the changes are done to the wheelchair, like changing sitting position, change/add cushioning or change/add back support.

Overuse shoulder muscle
Usually the therapist only can give advice on push technique and settings of the seat. It is advised to make long stokes instead of short hard pushes.

Insufficient activity
The therapist mentions that wheelchair users, like everybody else, should partake in physical activity. It is needed to maintain a healthy cardiovascular conditions and battling obesity.
However this is not always possible due to illness or disability. It was said that the body shows signs of the want to move, but for example people with paraplegia are unable to feel these signals.

For patients who are not active, it is advised to move more. Do more activities and exercises, in and outside of the wheelchair.

Prolonged sitting

The pressure on the skin of sitting for a long time, results in decubitus ulcers They are caused when the blood supply is cut off from a particular area of the skin. If the skin is under pressure because of continuous sitting on the wheelchair in one specific position, it results into such sores. It might result into severe consequences with respect to hygiene, diet and health.

It is tried to distribute the pressure as good as possible to minimize peaks in pressure. This is done by applying custom cushioning and/or back support.

What is a proper seating position?

It is impossible to set a standard in ideal seating position, because everyone's body is different. First it is looked at what does the patient want to do in life and what is possible. If one is active in life and for example goes to work, an active position is chosen to be able to do all activities that the user wants to do. If a patient is more passive a more laid back relaxed position is chosen to decrease pressure on the body and more comfort.

How often does an abnormal situation occur?

Almost every time. Every wheelchair needs to be customized to fit the person and the needs

What is normal mobility activity for different age groups?

No clear answer was given for this question, since every person is different and it is advised to be (healthy) active as much as possible.

Discussion

From this research it is found what to focus on best, what can be better in the process of fitting a wheelchair and staying comfortable and gives ideas for possible solutions.

Focussing on designing a perfect wheelchair is impossible, because of the inexistence of a perfect wheelchair. With every user's body being unique and every user having differences in wants and needs, it is good to look at how these difference can be measured and adapted.

When the patient receives the wheelchair it often takes a few visits to the therapist to get with the best acceptable settings for the wheelchair. This process takes longer than it should.

Changes in the body and behaviour of the wheelchair user can result in discomfort and over time. This problem should be resolved by informing the user and the therapist about what kind of changes occur and when using simple and cheap technology.

However full pressure mat data would be unnecessary much to constantly process, a simplified system could provide the insights in sitting behaviour for therapists and users. This way the measurement are not only made in laboratory environments, but also in the field.

Set up:

Interviewee Martine Beurskens - occupational therapist part of the sittin advise team at rehabilitation centre Reade in Amsterdam.

The main questions are:

- When do you prescribe a wheelchair?
- How do they get the wheelchair?
- How do you measure and customize a wheelchair?
- Current technology use?
- Do you give instructions with the prescription?
- What kind of physical problems occur most often with wheelchair users?
    - Body pains
    - Ulcers
    - Insufficient activity
    - Other
- What do you prescribe to solve these problems?
- What is a proper seating position?
- How often does an abnormal situation occur?
- What is normal mobility activity for different age groups?

C | Survey

Introduction

In this project, the goal is to decrease the discomfort of the wheelchair users by improving their sitting and activity behavior. The next step is to try to understand how this will be done, what works and what does not. In the concept, there is a multi-level information hierarchy, consisting of direct feedback in the wheelchair, behavioral insights in the application and information/knowledge transmission.

Method

The wanted outcome of this research is a quantified view and understanding on the preferences of the potentional users. This research will be done with an internet survey, using google forms.

In the survey first the participants are asked to share some demographics, wheelchair use, technology use and their view on their current sitting and activity behavior (understanding their situation). Than, questions about their experience with discomfort and pain due to sitting and their consciousness with their posture (understanding their experiences). After this, it is asked how much they would prefer a chair that would influence their discomforts and behavior (acceptance of concept). All information up to here will be used to classify and compare.

Next, three concepts per topic are graded on clarity, attractiveness, ease of ignoring and personal favorite and the wantedness of other stimuli, like vibration and sound (grading of ideas). Three scales for interaction qualities are added: informing-motivating, formal-fun and modest-outrageous (interaction qualities)

Some ideas for nudging principles are tested to find the best approach, like for product recommendation and information presentation (testing nudging during product use). Also, the acceptance of the features of the application is tested.

'Commiting to a goal'-ideas are added to the list to see what will be most effective. Also, how progress should be celebrated, shared and what their data may be used for (application ideas)

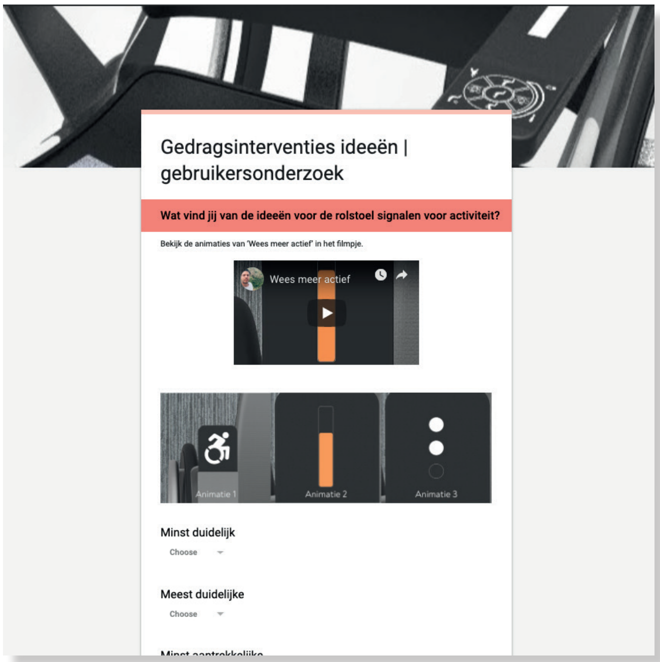
Lastly, the participants will be asked whether aesthetics, function and price have influence on their choice for a new chair.

The results will be processed inside the google forms website and in Apple's numbers software.

Participants

For the survey the choice was made to use wheelchair users and other people with office jobs, who sit for a large part of their day. In total, 21 participants contributed to the survey, of which 7 were wheelchair users.

Results



Conclusion

Only 50% of wheelchair users (WCU) are consciously sitting
Only 26% of all participants are consciously sitting

70% of WCU experienced discomfort or pain from sitting
84% of all participants experienced discomfort or pain from sitting

Most occured discomfort: Stifness in the lower back and neck (Oftenly caused by slouching, reaching and prolonged sitting)

50% of participants never had a proper instruction on sitting

Visual interaction is most accepted in all environments

Vibration is slightly more accepted than visual interaction in intimate and public environments

Notifications mostly wanted on chair and smartphone

Interaction should feel more motivating than informing
Interaction should feel more fun than formal
Interaction should feel modest

Ideation for direct feedback is mostly wanted

Wheelchair use instruction prefered by doctor/therapist/expert or video instruction.

Wheelchair users who have experiences discomfort or pain with sitting are more drawn to a product that improves their behavior

Sharing personal goals with friends/relatives or doctor increases the probability of commitment to goal

Motivation by collecting points for good behavior

Most want to share data for personalized advice and medical research

Data sharing with friends to motivate eachother

D | User journey | Medical

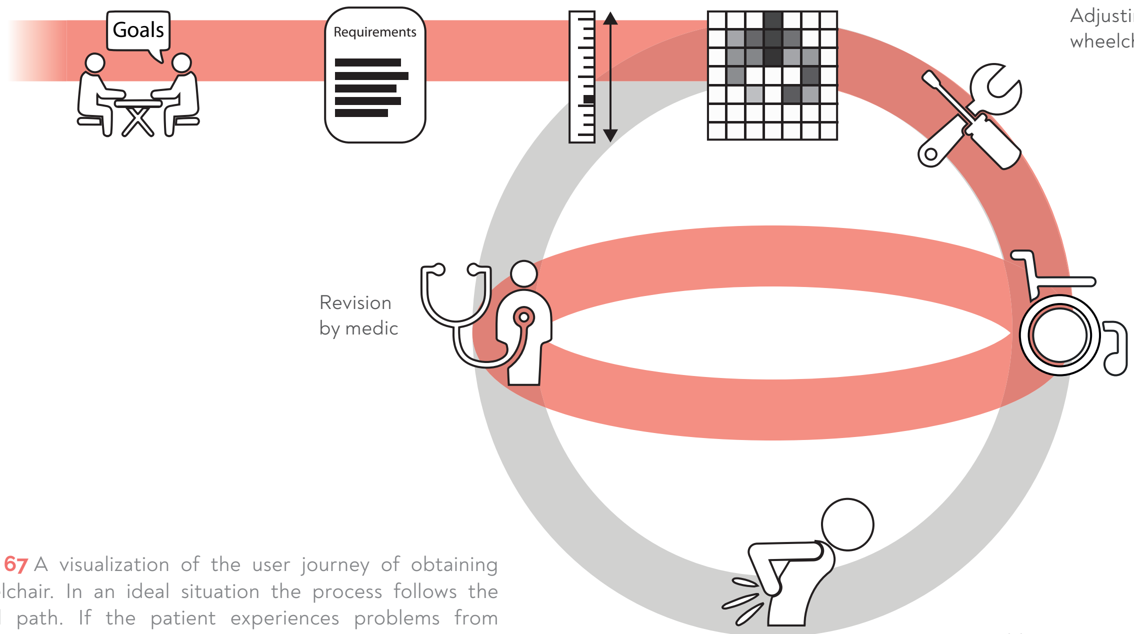


Figure 67 A visualization of the user journey of obtaining a wheelchair. In an ideal situation the process follows the colored path. If the patient experiences problems from wheelchair use the grey circle is repeated.

2.3.3. User journey

In this chapter, the goal is to understand the current user journey of the service of obtaining a wheelchair in the Netherlands. To gain knowledge about the current procedure and the missing information for medics, a qualitative interview has been done with an occupational therapist at Reade Rehabilitation and Rheumatology Centre in Amsterdam (Appendix B). Additional internet research is used to complement the analysis. This research concludes ideas for optimizing the fitting procedure of wheelchair and the missing insights in wheelchair use behaviour.

User journey of obtaining an wheelchair

A simplified visualization of the journey can be seen in Figure 20. In the journey the medic can be a doctor or occupational therapist.

Determining personal life goals and preferences

The medic and patient have a conversation on what the life goals of the patient are and how to achieve these. Important factors are living environment and circumstances. An active and working patient requires an active position and agility, while for patients who are in institutions seating comfort is most important. These requirements are then used to apply for a new wheelchair at the WMO or UWV. These will then determine whether the asked wheelchair will be accepted and will arrange financial payment. A patient is also able to finance their own wheelchair, but this does not happen a lot in practice.

Measuring body dimensions

The measuring of the patient by the medic or wheelchair manufacturer is done by measuring the extremities and the dimensions in specific locations to determine the ideal width and depth of the seating surface, the settings for the footrest and the ideal angle and height of the back support. This is done by a set of rules and experience of the wheelchair expert, rehabilitation technician or manufacturer.

Analysing patient discomfort

If complications arise with the patient with the wheelchair, a more thorough analysis is done of the patient's sitting position and behavior. Discomfort can occur due to multiple reasons. In the experience of the wheelchair, there are two main factors: the patient and the wheelchair.

The differences in body shape of the patients and the position they are sitting in determines the effects of the wheelchair on the body. The sitting position determines possible friction, shear forces and high pressure on the skin. What is often seen is that wheelchair dimensions are not ideal for a patient. This can results in change in sitting position and on its turn in an unbalanced pressure distribution. Poor pressure distribution can result in pressure ulcers.

For this analysis of the patient's body and seating posture, the medic can use technology to find the cause of their discomforts. Some examples of technology and their uses are named below.

Pressure mat

A pressure mat (Figure Image 52) can be used to analyse the pressure distribution of the patient. By enlarging the interface surface, the surface between the person and the wheelchair, the pressure distributes better and improves blood flow reducing discomfort. Behaviour is difficult to analyse since the laboratory environment is asking the patient to sit in an ideal situation. This behaviour is often not the behaviour of the patient outside the laboratory.

Changing wheelchair settings

The medic and technician change the settings of the wheelchair based on the analysis. The patient can now leave and will be revised during the annual check-up or when the patient makes an appointment because of discomfort.

X-ray

If specific problems are seen with the skeleton or spine in particular, an X-ray can be made of the patient to find abnormalities. This information can give insights for potential future developments of the body. Also, it can be seen where more support of the body is needed.

Receiving and use of the wheelchair

Contradicting answers were found for this step from interviews and survey (Appendices A,B&C). The occupational therapist said that at reception of the wheelchair, the patient receives explanation about wheelchair use. Though, in many cases, the patient receives their wheelchair from their manufacturer without the presence of a medic. After that they are allowed to take the wheelchair home and use it. Depending of the person exercises are advices by a physical therapist. From survey it was concluded that 50% of wheelchair users never have received a proper instruction on sitting.

(Re)Visiting the medic

Annually or biannually, the wheelchair user revisits the medic for a check-up. In some cases, when discomfort is high, people make an appointment before their check-up. The medic re-analyse the situation of the patient and decide whether changes are needed in therapy, settings or user behaviour. An occupational therapist can advise

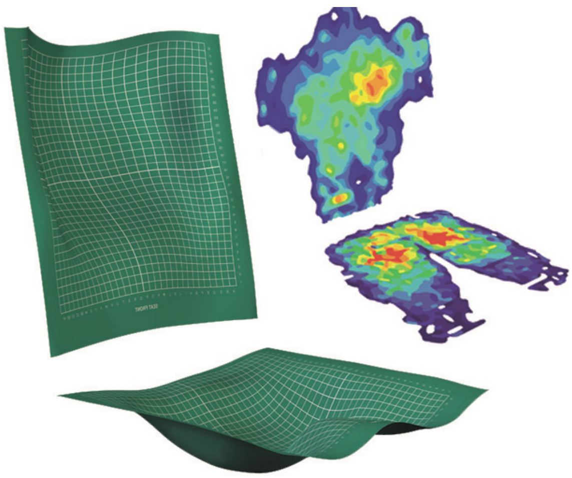


Image 52 An example of a pressure mat (green) and the pressure distribution data visualized on a computer (colored). The data is used to distinguish needed changes to the wheelchair dimensions, seating surface, support or posture.Image retrieved from: https://www.biosensemedical.com/SeatedPressureMeasurement

some exercises or activities to the patient to improve their health and reduce discomfort, but this often relies on the dedication of the patient to be executed. If needed a thorough analysis is done. The methods as named before can be used again to find the real cause.

Early revisits

Wheelchairs are obtained directly from the manufacturer or institution after measuring the dimensions of the patient. If problems occur, medics re-analyse the patient and wheelchair by expertise, measurement and adjustment of the wheelchair.

A lot of patients revisit to the medic with inconveniences, remarks about their wheelchair or even body pains. In the wheelchair user interview (Appendix A) the participant experienced some kind of problem after receiving a new wheelchair. In another interview, the medic said that most of these problems are due to research in a controlled environment, but the patient's behaviour in daily life is different. Poor sitting position is often a reason for their problems. Age, gender and physical health of the patient are factors that affect the reasons and consequences of poor posture.

Choosing right wheelchair adjustments

To choose the right adjustments to the wheelchair the analysis as can be read above needs to be done. Adjustments are often changes in dimension settings of the wheelchair, support by cushioning and support by strapping.

Dimensions

An easy adjustment, but sometimes requires the rehabilitation technician, are the dimensions of some parts of the wheelchair. With many wheelchairs the width is a dimension that is unable to adjust, and requires another wheelchair choice.

Cushioning

In the market of cushioning there is a wide variety of choice. The shape of the cushion determines the support, but is influenced by the type of wheelchair and the shape of the patient. To determine the best type of cushioning often pressure mat analysis is used.

Strapping

Some wheelchair users are unable to maintain a proper sitting position without the aid of special support or strapping. If necessary, the user should use these. Strapping should be done correctly to maintain stability, but not affect other body functions like intestines (Rader, Jones and Miller, 1999).

Missing information from wheelchair use

The meeting with the patient is only a short snapshot of the total situation of the patient. The majority of the time the patient is using the wheelchair. Due to behaviour and small insufficiencies in the wheelchair, over time, secondary physical problems occur. These problems are often discussed with the medic, but the quality of the analysis is dependant on the situation at that specific moment in time and the word of the patient.

Quantifiable data

The medic is said to be interested in data that can show the behavior of the patient during daily use. The discussed topics of sitting position and physical activity.

Insight in posture

Determining issues in sedentary behavior during daily use could result in the possibility to give better recommendations for wheelchair use and diagnose problems quicker. By seeing patterns in behaviour, current problems can be helped, but also future physical problems can be foreseen. Patterns can change over the period of week or days, but also different behaviour in the morning compared to late in the evening. It is also possible to offer exercises, which are personalized to the behaviour of the person.

Insight in activity

The overall health of a patient is important. One of the factors that keeps the body is shape is physical activity. People who tend to do insufficient activity suffer from longer rehabilitation, poor skin quality, worse blood flow and reduced quality of overall life due to lack of energy. Medics often advise their patient to do exercises and to keep themselves active during the day. By being active, physical problems decrease and the patient is in a better state of mind.

Wanted data

Research says that it is useful to increase patients engagement and accountability to document and share long term activity with medics. Dr. Lajam from the American Academy of Orthopaedic Surgeons (AAOS, 2016) gives an example of the importance of monitoring for different groups of orthopaedic patients.

Data generated by fitness monitoring devices can be applied across different levels of orthopaedic care:

- Non-surgical patients can track behavior, activity levels and medication use and alter these factors to lose weight and maintain the best possible function in their extremities.
- Pre-operative patients can reduce risk for postoperative complications by reducing their weight, preventing diabetes through glucose monitoring, and identifying sleep disorders.
- Post-operative patients can evaluate rehabilitation progress and surgical outcomes by measuring mobility activity, and alter physical therapy for better recovery.

The monitoring of wheelchair mobility behaviour could be used by all three groups for the same purposes as stated above. They will be able to maintaining the best possible function in their (upper) extremities, lose weight due to overall activity and monitoring activity progress.

E | Technological feasibility of wanted data

	Technologically possible	Wanted from research	Use in display	Use in app
Travelled distance	Yes	Yes	Simplified	Yes
Pace	Yes	Not discussed More interesting for athletes	No	Should be possible
Speed (zones)	Yes	Yes (Not discussed Can be used for energy expenditure)	No It is not a competition	Yes Review previous mobility intensity
Acceleration	Yes	No	No	No
Rotations	Yes	No	No	Not interesting
Rotation speed	Yes, not very accurate	No	No	Not interesting
(average) Rotation acceleration	Yes, not very accurate	No	No	Not interesting
Muscle overload	Yes, possible (see: 11.1.4)	Yes	Yes, Alert	Yes, review previous mobility intensity
Amount of pushes	Yes, not accurate enough	Not discussed, could be interesting for optimizing pushing technique	No	No, push technique should be done by therapist

	Technologically possible	Wanted from research	Use in display	Use in app
Peak force	Yes, but acceleration can be due to other factor	Yes	Yes, alert	Yes, moments of occurrence
Overuse	Yes, but mobility can be due to other factors	Yes	Yes, alert	Yes, history of activity

	Technologically possible	Wanted from research	Use in display	Use in app
Posture goals	Yes	Yes	No, but can be notified	Yes
Mobility goals	Yes	Yes	No, but can be notified	Yes
Personal goals	Yes	Yes	No, but can be notified	Yes
Achievements	Yes	Yes	No, but can be notified	Yes

F | Posture guidance prototype

Posture guidance is one of the interventions designed to persuade the user to change their behavior. Based on the current posture of the user, the display shows the detected poor posture and guides them into a proper posture.

The prototype of Liu (2018), analysis of postures and the theorie for ideal pressure distribution in percentages of Zenk (2008) were used as inspiration for the development of the prototype.

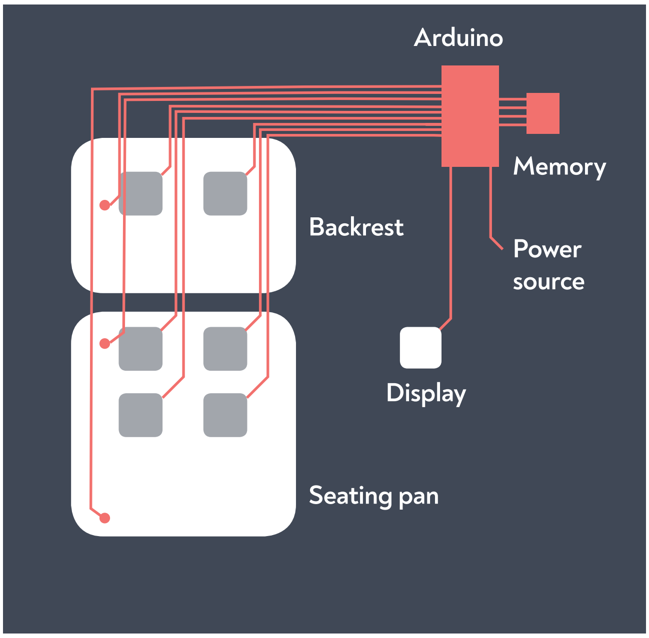
The prototype uses force sensitive resistors (FSR) on the seating surface and backrest, an Arduino UNO, NeoPixel light emitting diodes (LED) and a vibrator motor.

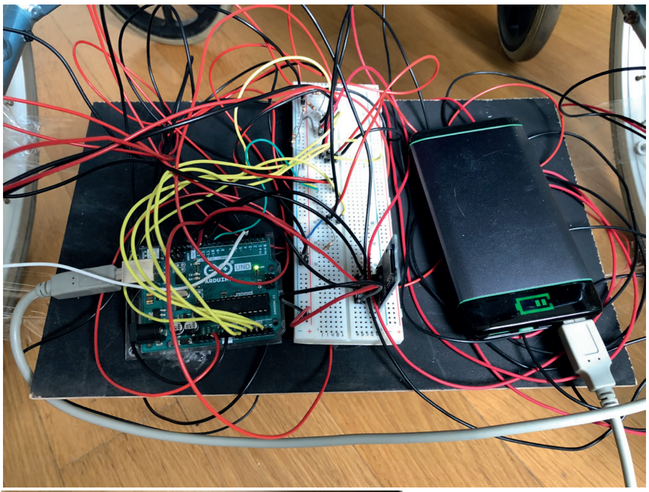
The taped and distribution of the FSRs was as seen in the picture. Two in the middle of the seat, two deep in the seat and two in the upper back. This way when a person would slouch, the deep FSRs would give a low signal, while when leaning forward, the back rest gives low signal. To determine disbalence between left and right the signals are divided, and if the ratio surpases a researched value it is identify as leaning left or right.

In the beginning only the bottom sensors were used, but this gave wrong estimations. When the person leans on the right side of the backrest, the pressure on the left side of the seating pan increases. As a solution, the two FSRs in the backrest were also divided and a ratio is used to identify leaning behavior.

A case was 3D printed, wherein a grid of soldered LEDs was placed. Vibrator motors were taped to the seat and backrest. One vibrator motor was used as fast researching of placing of the tactile feedback.

The prototype was not perfect, but worked sufficiently enough to do research with.





G | Insights from chapters

2.6.1. Physical problems

Insights

- Most secondary physical problems occur due to poor sedentary behavior and physical activity.
- In sedentary behavior, the two main factors for discomfort and possible secondary physical problems is due to poor posture and prolonged sedentary time.
- 1:Poor posture is one of the reasons for high pressure on the skin increasing the chance for pressure ulcers.
- 2:Prolonged sedentary time restricts the blood flow in the skin, increasing the chance for pressure ulcers.
- 3:Insufficient activity results in degradation of the muscles and skin, and reduced cardiopulmonary fitness, decreasing the blood flow and quality of the skin and increasing the chance for pressure ulcers.
- 4:Sudden peaks in activity increase the chance on injury of the shoulder, potentially in its turn decreasing the ability to do physical activity in the future.

Opportunities

- Motivating the wheelchair users to increase their physical activity (up till target guidelines) will increase their physical, mental and social health and quality of life.
- Motivating the wheelchair user to release pressure from the buttocks by doing exercises will decrease their perceived discomfort and chance for pressure ulcers.
- Motivating the wheelchair user consciously think about their posture is expected to improve their posture and reduce pressure ulcer risk.

2.6.2. Behavioral interventions

Insights

- If a product makes use of research on behavioral interventions, it will most likely be more successful in changing the behavior and improve the experience of the user.
- The behavior can be changed by influencing the elements that shape behavior as seen in the planned behavior theory.
- Tasks should be designed to be as simple as possible, so that they can be done with minimal abilities.
- Users are most receptive to prompting or notifying when it is perceived as valuable.
- Different types of prompts can be used at different moments and situations
- People's choices are often predictably irrationally, the use of behavioral science theory can help predict their behavior.
- The biases and heuristics can be used to nudge the user into doing something while in their automatic system.
- During the need of conscious decisions the product can use a mindful nudge to rationally override.
- The designer of the product is the choice architect and should design the nudges and alternative choices of the product.
- The behavioral intervention design tools can be used to ideate for solutions.
- The persuasive technology principles can be used as inspiration for developing persuasive product
- There are multiple persuasive strategies to choose from.
- Making it able to set goals is important to affect the performance of the user.

Opportunities

- Behavioral interventions should be used in the product to succesfully influence the behavior of the user.
- The behavioral interventiol design toolkit of Anne van Lieren (2018) can be used to quickly ideate for solutions using the theory of multiple behavioral science theories.
  Persuasive technology principles can be used as inspiration for solutions of common problems.

2.6.3. User

Insights

Stakeholders

- Wheelchair users, medics, manufacturers, government and social systems and many others can benefit from a product that provides insight in wheelchair use.

- Wheelchair users want to reduce their problems
- Medics want to gain insight in their patients behavior
- Manufacturers want to gain insight on wheelchair use
- Government and social systems want to reduce the medical bill

Users

- 0,1 % of the world population needs the aid of a wheelchair
- Wheelchair users can be of any age, gender, disability and lifestyle.
- Causes change over age
- The mean age of wheelchair users is 65 years old.
- Many wheelchair users live a inactive lifestyle
- Wheelchair users have higher understanding about their medical condition
- Smartphone use will be considered the same as for able-bodied people for this project
- The entire population of wheelchair users could gain from a increased activity, but the focus will be on adults and elderly

2.6.4. Wheelchair

Insights

- It is impossible to design a one-design-fitting-all wheelchair.
- Most manual wheelchairs look like the archetype.

Opportunities

- Visual feedback could be integrated in the archetype: armrest, seating surfaces or wheel protector.
- Sedentary sensing technology could be integrated in the seat pan and back rest
- Activity sensing technology could be attached on the frame, wheels and seat.
- Wiring could be integrated in the frame of the tubular wheelchair

2.6.5. User journey

Insights

- An application for a wheelchair needs to be made with the goals, measurements and preferences of the wheelchair user
- Patients receive their wheelchair with often insufficient information about behavior
- Therapists give exercises to do at home
- Medics only see their patients in the lab, missing insights in behavior outside of the lab.
- Monitoring can be important for all kinds patients

Opportunities

- The option for a smart wheelchair should be introduced during conversation.
- Information about proper wheelchair use should be easier available

  Coaching during wheelchair use could benefit the patient
- Data can be used during meet ups to gain insight in wheelchair behavior

2.6.6. Use environment

Insights

- Environment has influence on the interaction between the user and wheelchair, but also the user and others in the same environment.
- Use environment gives requirements for the product.

Opportunities

- During moments of high activity and high focus, notification should be low.
- Interactions should be intimate
- Long periods of inactivity should motivate to become more active

2.6.5. Trends

Insight

- Population and wheelchair users amount is growing
- Medical costs are rising, investments in maintaining health and injury prevention are higher
- Wheelchair market is growing
- Citizen-centric health care is wanted
- Inactivity problem is worldwide
- Technology is more becoming cheaper and IoT has more influence in the medical world.
- People are demanding data centrification
- Colorful wheelchair are being made to suit the taste of people

Opportunities

- Provide insights and motivation to maintain health and prevent future injury
- Make use of existing devices to minimize amount of devices needed

2.6.6. Competitors

Insights

- There is no wheelchair in existence that provides the user with wheelchair behavior insights
- Apple watch is the first to give behavioral interventions regarding activity
- Interface determines the usability of the product
- Heart rate gives deeper insight in intensity
- Product should use valuable interventions to be perceived valuable

Opportunities

- Using personal smartphone as informational screen
- Using multi-level information flow, for live feedback to nudge user, insights in behavior and knowledge about wanted behavior
- Make use of overviews for centralized information
- Using daily and long-term goals
- Using default goals
- Using colorful animations for salience

2.6.7. Technology

Insights

- Wheelchair bound technology makes it able to measure wheelchair mobility and sedentary behavior.
- Wheelchair mobility could be more accurate, if body functions, like heart rate, would be incorporated in the algorithm.
- Thorough research to optimize the algorithm is needed
- Thorough research is needed to determine MET values for use in the algorithm

Opportunities

- Measurements in mobility can be used to estimate energy expenditure
- Measurements in sedentary posture can be used to give guidance in posture
- Measurements in sedentary posture can be used to for advice in timely sedentary time break.

H | Prototype user testing

Research script

Say > Ask whether the research may be recorded for personal review and anonymous documentation.

Do > start video recording facing the participant. Start step 1. Understand the person.

1.Understand the person

Age:		.... years old
Profession		....
Wheelchair user	O no	O yes, for .... years

Tech savviness

- How do you use your phone? notes/calendar/social?
- What kind of devices do you connect to your phone? How/Why?
- What kind of notifications do you allow? How often do you change the settings?

Physical activity behavior

- How physically active are you on a daily basis? How/When/Where?
- Do you keep a diary of your sports activity? How/When?
- Do you use your phone for tracking your activity? How/When?

Sedentary

- How many hours per day are you sedentary? Why/where?
- How conscious are you about your sitting behavior? How does this show?
- How often do you re-adjust your posture or do pressure relief?

Overall

- How motivated are you to improve physical activity and sedentary behavior?

2. Introduction to the design

Instruction keynote

The design in this project is a wheelchair that is measuring your sedentary and activity behavior. Using a visual interface, the wheelchair wants to inform you about your behavior or suggest an activity based on previous behavior. In the application previous behavior can be reviewed, goals can be set and social sharing is enabled to make sure achieving an improved wheelchair behavior is more probable.

In the first part of the research, you will be asked to experience the wheelchair and its interface. The participant will walk through a scripted scenario and will see visualizations on the visual display. Please try to do what you think the visualisation is asking from you. After this, you will be asked to answer a few questions.

Secondly, you will be asked to explore the application. After that a few ideas will be presented to you. You may give you honest opinion about it.

Please understand that this research your are unable to make mistakes, since there can only be mistakes in the design! The goal of this research is to test the design, not you. Try to do the tasks yourself and do not be scared for mistakes.

Please, **think out loud.** Try to explain your every thought and move.

3. Wheelchair experience

Say > Instruction to do a task (Read a document) and to act on the animations.

Participant does the task

Per visualisation
- Explain what you think that the visualisation means?
- When would you expect this visualisation to appear? When is it desirable?
- Do you expect this visualisation to help you improve your behavior?
- What can be improved?

What kind of signals do you expect from the wheelchair (next to visual)?

Do > Demonstrate vibrator motors
- Explain what you think about the idea of vibration as a signal.
- Explain what you think about sound as a signal.

Say > explain ideas of timing of the visualisations
- Discuss the ideas
- What can be improved?

4. Application experience

Do > startup application in Adobe XD, give smartphone to participant

Say > Participant is allowed to explore the application for 1 minute

After every scenario
- Explain your steps / what you see
- What do you think is meant by this?
- (How, when) would you use this? Explain
- What can be improved?

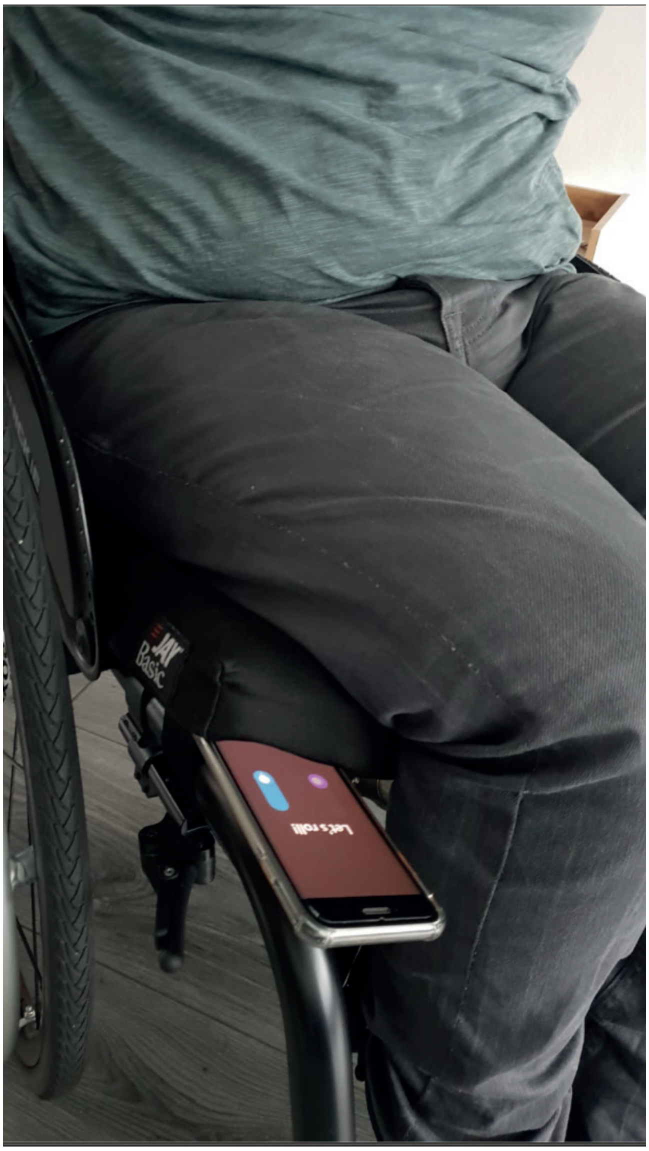
Scenario 1 > Review past sedentary data
Scenario 2 > Set a goal
Scenario 3 > Challenge Emilia to increase physical activity
Scenario 4 > Change the settings for the (wheel)chair notifications
Scenario 5 > Find the information about physical activity

Show ideation for nudging notifications to make conscious, for setting new goals and to increase physical activity. Explain the timing of this notifications

- What do you think about these kind of notifications?
- How do you feel about these notifications?
- How high is the probability of you acting upon them?

5. Overall discussion

- What do users find good about the design? What changes do users suggest?
- What do you think about the overall experience?
- What do you think about the position of the visual interface? What is your preference?



Participant 1

26 Male - Counter at hospital - Wheelchair user

Tech savvy

Relatively Posture conscious

Moderately active at work - compensates with Wheelchair Rugby

Motivated to improve

1. Posture guidance interactive

This is clear. I would not use it very often, but it makes me conscious about my posture. It makes it easy to change posture.

2. Starting visualization

It means that it starts measuring

3. Let's roll

It means that you need to become more active, because you are sitting still for too long. At work, you need to do your chores, so you are not able to always be active. It would be good to see your activity on daily basis, so you will be able see and do more activity after work for example. It would make you more conscious that you need to do something. If I would receive such a notification, I would feel pushed in my face. If it requires a small activity, it is easier to do. Notification make you think of your goals.

4. Posture guidance

Normally, I only adjust my posture when I think about it. It makes me conscious about my posture, I need it. Sometimes I lean forward a lot, I sit close to my bureau but it feel stiff. Especially after sports, I tend to sit poorly. I like to be reminded.

5. Relieve

I think this is a good notification, for the people who need it. It makes you conscious that something is measuring and that it is important.

6. Relieve guidance

It makes it like a game, I like that. I think it will motivate more.

7. Warning

I think that when you were active and you receive such a warning it will demotivate. I think that someone will physically feel if you do that. If it comes up at moments when it is really harmful it would be handy.

8. Interface

1. Button

-

2. Function

I like the mute function, I would only turn it on when I need it.

3. Concept

I would only turn it on when I need it. I like the fact that I can check it quickly. It is a good one, you will be able to see that after work you only met for example 50% of your goal, than you will be able to do more after. I would like to have a sort of pedometer, that measures pushes. I think I will only use it for 6 months.

9. App - Data review

It needs more explanation for all categories. I would like to see the time of amount of good posture. It is a lot easier to grasp if you see what you have done or what you should do.

10. Goal setting

I like the game element of challenging myself. Having a scheme and monitoring helps with achieving goals

11. Social

I would look at others. Giving compliments would motivate eachother. I would compare and challenge with teammates.

I would not always share my data with my medical(al staff). It is valuable in specific periods, with personal permission. It feels like there eyes are burning in my back.

12. Coach

If this show how I can improve, I would use it. I do not know many exercises.

13. Settings

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14. Notification 1: next goal

It depends on what way I reached the goal. If it was easy, I would increase the goal. if I would receive a notification' You have to do … to reach your goal' It would motivate me.

15. Notification 2: Challenge

I like this!

16. Notification 3: Park

I think I will ignore this one. If you want to do something like this, you will need to have time.

17. Notification 4: Medic

Compliments would motivate me.

18. Notification 5: Info

If you read something like this, you will be more thoughtful about it.

19. Notification 6: Location

It would not give me extra motivation.

20. Overall

I would turn off sound, since you never know where you are. Vibration is more subtle. I would like to have the activity functionality more than the sitting. It is an app that makes you more conscious. Paying (100€) extra is accepted. Placing is difficult, since every wheelchair is different. It needs to be integrated.

21. Vibration

Leg. Back is disturbing/itching.

Participant 2

24 Female - Student - non-wheelchair user

Tech savvy

Relatively Posture conscious

Moderately active

Moderately motivated

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1. Posture guidance interactive
The interaction is clear, and it responds really quick. But it comes up fast.

2. Starting visualization
The welcome does not matter to me, but it gives me a personal feeling.

3. Let's roll
Icons are unclear. It flashes, so I think it needs me to do something to fill the bar.

4. Posture guidance
Icons are clear, it guides me into proper posture. I already chose this product, so I would want this guidance. I would choose this, since I want to improve my sitting, and it clearly shows what i am doing wrong and what I need to do. It's a subtle warning

5. Relieve
It is clear that I need to do some relief.

6. Relieve guidance
I think the filling of the bar gives enough satisfaction.

7. Warning
I would stop and feel scared. I would also feel offended, since i am trying something good.

8. Interface
    1. Button
    Short/Long press in unclear
    2. Function
    Active sitting should be explained, it sounds contradictive.
    3. Concept
    It looks like a total overview of the status of your activity - Overview

9. App - Data review
If I would have back aches, i would look for why it could appear or if I can see improvements.
Explaination for the graph/colors.

10. Goal setting
Change name to Daily goals

11. Social
Good to see that you're not alone. It brings a feeling of togetherness. I think in the beginning you will try to act as good as possible because you know they are watching, but I expect it to become less. I would use it periodically. I don't see it as a challenge.
Group goal is a nice idea, but I think i will not use it.
Medic- I would like to give daily permission, not always. The idea that you do not know when (s)he's looking is annoying. I would like to be able to contact my medic, when I see that something changes over time.

12. Coach
I chose this product, so I would like to improve something. So i will look through all the exercises to see if I see something new. I would like to see explanatory animations.

13. Settings
I would want to turn the notifications off while looking a movie for example. It does not matter during some moments that you're not sitting perfectly, you want to be social. I would trigger this through my wheelchair.

14. Notification 1: next goal
I would open and watch. I would expect a celebration for achieving the streak.

15. Notification 2: Challenge
I would accept the challenge, but the reward is not that interesting.

16. Notification 3: Park
I want to decide myself when I want to do more activity.

17. Notification 4: Medic
Leave me alone! I want him to look only when I give permission.

18. Notification 5: Info
If it is often I would find it annoying, but my brother looks at all of them. I would like to set the quantity of these kind of notification, like 1 per day.

19. Notification 6: Location
I do not like the idea that they know I am at work.

20. Overall
Link to data with press on three circles

15. Vibration
Most sensitive in the legs.

Participant 3

38 Male - Marketeer - non-wheelchair user

Moderately tech savvy

Relatively Posture conscious due to lower back pains, long car rides, 4h office sitting

relatively active, sports. cant sit for longer than 40 mins.

Moderately motivated

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1. Posture guidance interactive
Great, but it comes up really quick.

2. Starting visualization

It's accessible and personal. I would assume it would trigger me to be more motivated.

3. Let's roll
What do the colors mean? It is not clear what I need to do. Icons unclear.

4. Posture guidance
These icons are clear. This is really clear.

5. Relieve
Also really clear. The game element keeps your attention. It is good to see progress visually..

6. Relieve guidance
I have to see something happening, is seems frustrating if you're doing something and it does not show

7. Warning
It gives me a safe feeling. It gives a good feeling to know that somebody is watching me, but this should be reliable. (ex. Heart rate). It would great if i could enter a personal setting for these kind of warnings based on my needs, this way I will rely even more on this feature.

8. Interface
1. Button
The text is too small, I cannot read it. It would frustrate me if I can not read it.
2. Function
The long press is not clear. Instruction should be clear.
3. Concept
Idea is great. add 000, push text hold text

9. App - Data review
Enlarge font size
Takes long to find data overview
Labels are too small
I would want to review my daily circles, when I did and did not meet my daily goals.
Colors are confusing, red seems negative. I expect blue as positive

10. Goal setting
Searches for goal setting in coach and settings tab.
If I am a starter user, I would like to adjust the goals to my abilities. I would also like to have some sort of progress scheme. (incremental goals). If I would see a a goal that i think I am unable to reach, I would feel unmotivated.

11. Social
I like it. But, I think most wheelchair users have a limited friendships. What if I do not have friends in wheelchairs. Suggests 'platform' with similar disability groups. Add chatting function. Use hide name (mask) option (make it private).

I would share it if I had a good relationship with my therapist.

12. Coach
-

13. Settings
-

14. Notification 1: Next goal
I like the motivational part of saying that I achieved something

15. Notification 2: Challenge
I would like to see the name, to decide who I want to compete with.

16. Notification 3: Park
Change to: There is a park nearby, maybe it is a good moment to do some extra physical activity. Motivational would work, makes me conscious. I would only give my location data if I expect it to give extra value.

17. Notification 4: Medic
I like the idea of receiving medals. Everyone like a compliment, whether it is a medal or real compliment. If you are in it, you are in.

18. Notification 5: Info
Push notifications are okay if they make me conscious, but I should be albe to turn them off.

19. Notification 6: Location
Not so valuable. I would not want to receive notifications during work. After work it would be more valuable.

20. Overall
I would want to know what happens with my data.

Limitation research
Simulating button in digital prototype gives a wrong impression of it being a physical button.

If you feel like talking about this subject or want to ask a question, feel free to contact me.

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