Design, Development and Evaluation of a Power Wheelchair Driving Simulation in Virtual Reality

Master Thesis

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by
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[St. Pölten, 20.05.2021]

Declaration

I declare that I have developed and written the enclosed Master Thesis completely by myself and have not used sources or means without declaration in the text. Any thoughts from others or literal quotations are clearly marked. This work was not used in the same or in a similar version to achieve an academic grading or is being published elsewhere.

St. Pölten, 20.05.2021
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Preface

As an occupational therapist I work with people with special needs on a daily basis. A lot of them need a wheelchair due to impaired mobility. So far, I have not seen a lot of possibilities to support clients with a training for driving a power wheelchair. More specifically there is a lack of computer assisted trainings. Furthermore, it is very hard for the patients to learn how to drive a power wheelchair on their own. For example, due to the fact that clients have no own wheelchair available. Virtual Reality is a possibility for a safe learning environment. Currently clients must learn in the "real world", which means that accidents can happen and have dramatic implication. I wanted to explore possibilities how people with special needs can train wheelchair driving in the future and make their life safer.

Firstly, I want to thank my advisor Jakob Doppler, MSc and Dr. Markus Wagner, BSc MSc for their valuable input and feedback during this thesis.

Additionally, my special thanks go to Stefan Schürz, BSc, DI Michael Gstöttenbauer and Sebastian Mayer, MSc from LIFEtool for their cooperation and support.

Furthermore, I want to thank my survey participants for testing my prototype and contribute decisively to finish writing.

Finally, my special thanks go to my family and my very profound gratitude to my partner Patrick who has always encouraged me and has contributed to the thesis with lots of useful advices.

Abstract

The demographic change of the current society will increase the demand of powered mobility. One of the challenges is to ensure that power wheelchair users can adequately use the power wheelchair without causing accidents leading to injuries. One way to increase the adequate use of power wheelchairs are technology-supported learning environments. One possibility is Virtual Reality (VR), which can provide a safe learning environment for power wheelchair drivers.

The aim of this thesis was to design and further develop an existing application, called WheelSim VR, which is a virtual wheelchair simulator using current VR technology to enable people with disabilities of all ages to learn and train power wheelchair control. The assumption is that a training in VR with specifically selected exercises improve driving performance.

The power wheelchair driving simulation in VR was developed utilizing a user-centered design approach. Functional requirements and the selected exercises in the traffic-free area were developed based on semi-structured expert interviews and a literature research. These requirements aided in the development and usability testing of a working prototype. User tests with quantitative measurements (time and number of collisions) were collected and evaluated. The System Usability Scale (SUS) and semi-structured expert interviews were held to gather qualitative data for the evaluation of the prototype.

A total of six exercises to learn basic mobility skills were filtered and implemented in the prototype. The test users reported both a subjective improvement in driving performance and an improvement in the quantitative parameters as well. This leads to the assumption that the developed exercises in the traffic-free area in VR improved the driving performance.

Future studies should focus on further developing the technical requirements for an automated interpretation of the exercises. Furthermore, wheelchair drivers with special needs should be integrated in future studies and it should be investigated if the training in VR has an impact on driving in the real world.

Keywords: power wheelchair, Virtual Reality, driving simulation

Kurzfassung

Aufgrund des demografischen Wandels der heutigen Gesellschaft wird sich der Bedarf an Elektrorollstühlen und Scootern erhöhen. Eine der Herausforderungen dabei ist die adäquate und unfallfreie Nutzung des Elektrorollstuhls. Neue Technologien, wie Virtual Reality (VR), können eine sichere Lernumgebung für Elektrorollstuhlfahrer bieten.

Ziel dieser Arbeit war die Weiterentwicklung der Anwendung WheelSim VR. Dies ist ein virtueller Rollstuhlsimulator, welcher mittels VR-Technologie Menschen mit Behinderungen jeden Alters das Erlernen und Trainieren der Elektrorollstuhlsteuerung ermöglicht. Die Annahme ist, dass ein Training in VR mit gezielt ausgewählten Übungen die Fahrleistung verbessert.

Die Elektrorollstuhl-Fahrsimulation in VR wurde mit einem nutzerzentrierten Designansatz entwickelt. Auf Basis von halbstrukturierten Experteninterviews und einer Literaturrecherche wurden ausgewählte Übungen im verkehrsfreien Raum entwickelt. Diese Anforderungen unterstützten bei der Entwicklung und dem Usability-Test eines funktionierenden Prototyps. Es wurden Benutzertests mit den quantitativen Parameter Zeit und Anzahl der Kollisionen ausgewertet. Anschließend wurden mit der System Usability Scale (SUS) und Experteninterviews qualitative Daten für die Bewertung des Prototyps erhoben.

Insgesamt wurden sechs Übungen zum Erlernen grundlegenden Mobilitätsfähigkeiten gefiltert und in der Elektrorollstuhl-Fahrsimulation in VR umgesetzt. Die Testnutzer berichteten sowohl von einer subjektiven Verbesserung der Fahrleistung als auch von einer Verbesserung der quantitativen Parameter. Dies lässt die Vermutung zu, dass die entwickelten Übungen im verkehrsfreien Raum in VR die Fahrleistung verbessert haben.

Weiterführende Studien sollten sich auf die Weiterentwicklung der technischen Fahrparameter für eine automatisierte Interpretation der Übungen konzentrieren. Weites sollten Rollstuhlfahrer mit Beeinträchtigung in die zukünftige Entwicklung integriert werden und es sollte untersucht werden, ob das Training in VR einen Einfluss auf das Fahren mit dem Elektrorollstuhl in der realen Welt hat.

Stichworte: Elektrorollstuhl, Virtual Reality, Fahrsimulation

Table of Content

1 Introduction

There is a large number of people using a wheelchair. The U. S. Census Bureau's Economics and Statistics Administration reported 5.5 million wheelchair users in the US in 2014 [1]. Recent estimates indicate that between 17–30% of all wheelchair users use a power wheelchair or a scooter [2]. A statistics of Statista Research Department show that 93,955 power wheelchairs were prescribed in 2015 in Germany [3]. The powered and manual mobility market globally is projected to grow exponentially due to aging baby boomers and increasing longevity [4]. Based on these developments it is very important to gain further insights on how to increase power wheelchair driving safety. There are several reasons for that.

Studies have shown that wheelchair manoeuvres have a much more important role in causing injuries of wheelchair users. Secondly, the number of accidents of power wheelchair users increased significantly. In the collision events cars, trucks or buses were involved in two thirds of the accidents. These occurred predominantly at junctions or intersections (70%) [5]. Thirdly, the possibilities and approaches to provide training environments for manoeuvring power wheelchairs are highly limited. Using powered wheelchair simulation for driving analysis offers flexibility for safely evaluating the individual's driving performance in a variable environment and situations ranging in difficulty. Additionally, it makes it possible to measure numerous variables involved in the driving process [6]. Given these aspects it is highly relevant to develop exercises in VR environments with the aim to improve power wheelchair driving performance during a power wheelchair simulation.

There are multiple benefits that can be gained through this thesis. First of all, the user of the simulation will be structurally guided through the simulation. Proper training programs will contribute to increased safety and mobility for power wheelchair drivers [5].The simulation is a safe learning environment. Thus, accidents and injuries can be avoided in the first learning process. On the other hand, instructors (therapists, orthopaedic technician, etc.) who monitor the users during the simulation can get comparable results and better insights for further therapies and trainings can be derived.

1.1 Research Question

The main goal of this thesis is to design and evaluate a prototype of a VR based wheelchair simulation for power wheelchair training. Through the development and evaluation of this prototype, the following research question and its two sub questions will be answered:

Main Research Question:
Does exercises in a traffic-free area in a VR power wheelchair simulation improve driving performance for a selected group of wheelchair trainers?

Sub Question Two:
Which exercises from manual and power wheelchair training can be found in literature and by expert interviews with wheelchair trainers?

Sub Question One:
How can functional requirements of wheelchair driving performance can be assessed, evaluated, and used in simulative VR power wheelchair training?

1.2 Structure & Methods

This thesis is divided into four chapters. A theoretical background of power wheelchair as a mobility aid is given based on existing literature. In addition, guidelines for learning to drive a power wheelchair are presented. Literature from different fields (virtual reality simulations, assistive technology, occupational therapy, etc.) will be investigated. The literature research for this chapter is comprised of textbooks and scientific publications. To give an insight into current scientific developments regarding VR in training, chapter 2.3 evaluates scientific studies dealing with those topics. To ensure the currency of the information, only articles and studies published in reputable journals after 2016 are used to analyse the current state of the art in the training of VR based wheelchair simulation.

After the literature research the work is structured in a user-centered design (UCD) process [7]. The structure of an UCD process is illustrated in figure 1.

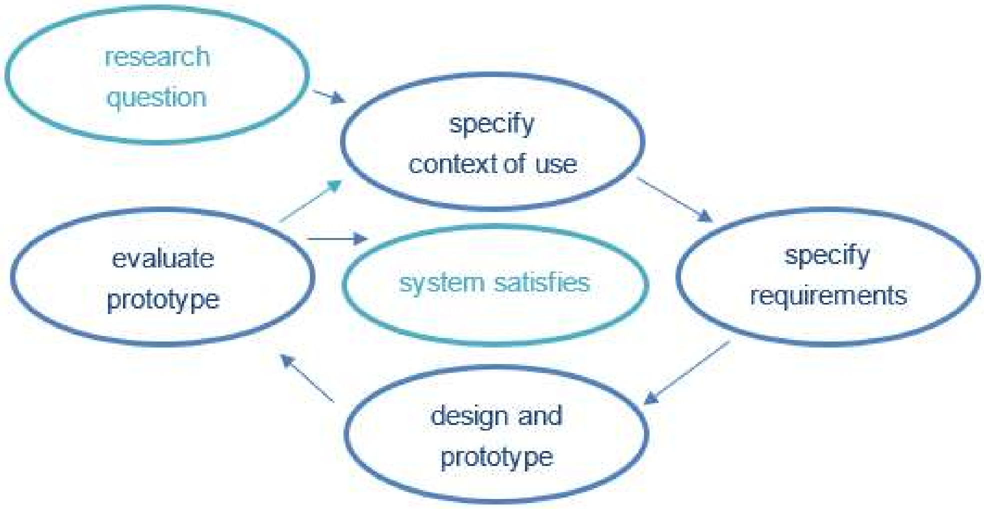

figure 1 Used-centered design process [7].

The second chapter specifies the context of use and the requirements in the requirement and user need for a power wheelchair VR simulation. Therefore, semi-structured expert interviews with occupational therapists were conducted to find out how power wheelchair training is set up in “real word” and which parameters the trainers observe.

The main research question will be answered by evaluating the prototype with usability tests and following System Usability Scale (SUS) questionnaire and semi-structured interviews with five experts. The interviews are held to gather qualitative data for the evaluation of the prototype. Furthermore, in the testing, the quantitative parameters - time and number of collisions - will be collected and evaluated.

This thesis will be done in cooperation with LIFEtool who developed WheelSim VR [8]. The prototype is an ongoing development of the application WheelSim VR, which is a virtual wheelchair simulator using current VR technology to enable people with disabilities of all ages to learn and train power wheelchair control.

2 Theoretical Background

This chapter gives an introduction into the relevant topics of this master thesis. As this thesis deals with the development of a power wheelchair simulation in VR, the goal of this chapter is to discuss power wheelchair and power mobility devices from a theoretical perspective. Furthermore, their role as a mobility aid will be explained. In addition, guidelines for learning to drive a power wheelchair are presented. The chapter concludes with an exploration of the current role of VR in training.

2.1 Power wheelchair as a mobility aid

This chapter presents details regarding a power wheelchair such as: general description of a power wheelchair, use of a power wheelchair in road traffic, accessibility and Power Mobility Devices (PMDs) for people with mobility disability.

A power wheelchair is a mobility aid. It is typically used by individuals who have a medical condition and have difficulty in walking. Furthermore they have a deficit in arm strength and hand mobility and that is why they are unable to use a manual wheelchair [9].However, power wheelchairs are also intended for people who want to increase their mobility or extend their range of motion. This means that there does not always have to be a medical necessity for the acquisition of an electronic means of locomotion. Older people and people with limited walking ability are particularly fond of electric wheelchairs.

There is a large selection of different models, which are divided according to their driving type or driving characteristics. There are power wheelchairs for indoor use or for indoor and outdoor use [9]. In figure 2 a typical power wheelchair for outdoor use is shown. Every power wheelchair has a base, which is equipped with four or more wheels. Power wheelchairs typically have two large drive wheels and two or four smaller wheels called casters for added stability. The drive wheels can be positioned in the front, middle or rear of the power wheelchair seat base. By using a joystick the power wheelchair is driven, which allows for the chair to move forward, backward, left, and right [10].

figure 2 Components of an outdoor power wheelchair [9].

The purchase should be well considered, as the costs can be very high. The cost of a power wheelchair ranges from about 1,500 EUR to 10,000 EUR. The price of a power wheelchair depends on additional individual adaptations [11]. A power wheelchair is an assistive device in Austria. In order to receive a financial support, you need a prescription from the doctor treating you [12]. An assistive device must be prescribed by a doctor and approved by the responsible health insurance institution. The costs are covered by the health insurance institution up to a fixed amount. As there are differences between the health insurance institutions in Austria, you must ask the competent social insurance institution for more detailed information on the assumption of costs [12].

2.1.1 Using a power wheelchair in road traffic

According to Austrian road traffic regulations (§ 2 Abs 1 Z 19 StVO), a wheelchair is not a vehicle. Therefore, it may not be used on the roadway (except when crossing). Wheelchairs are intended to be used on the sidewalk. People in a wheelchair are ultimately placed in the same position as pedestrians from a legal point of view. In this regard no distinctions are made between manual wheelchairs and power wheelchairs. Power wheelchairs should not exceed 10 km/h [13].

Power wheelchairs can be driven without a driving license according the driving license law in Austria [14]. To use a power wheelchair in the road traffic, accessibility is essential. That is why the next sub-chapter is dealing with accessibility.

2.1.2 Accessibility in Austria

Accessibility is given when structural and other facilities, transport, […] are accessible to and usable by persons with disabilities in the generally customary manner, without difficulty and without outside assistance [15].

figure 3 Wheelchair in front of a structural barrier [15].

The previous chapter described that a power wheelchair is a mobility aid for people with disabilities. However, the wheelchair can only be a support if the environment in which the wheelchair user moves is accessible. That is why accessibility in Austria is dealt with in this chapter in more detail.

Accessibility is divided into structural, communicative, intellectual, social, and institutional accessibility [16]. In the following, only structural and institutional accessibility will be discussed in more detail, because these are highly relevant for wheelchair drivers.

When it comes to structural accessibility, possible barriers for the wheelchair are:

- steps (see figure 3), doorsteps, narrow doorways and/or
- barriers in the traffic area like high pavement edges or steps.

The Austrian federal act on the equalization of persons with disabilities regulates to all companies in Austria that all goods, services, and information intended for the public must be offered accessible [17]. Furthermore, since 2019 all buildings must be accessible. In fact, the reality shows a different picture by a study of the ÖZIV Bundesverband regarding accessibility of business premises, like pharmacies, bank, shopping centres, hotels, medical supplies, theatre, etc. for people with walking disabilities in Vienna. The study presents that only 41.7% of the entrances of all premises surveyed in the analysed shopping streets were accessible without steps [18].

One potential reason for this situation is the lack of an authority and/or institution which is responsible whether a facility is accessible or not. Therefore, there are also no penalties. However, if a person with a disability feels discriminated, because there is no accessibility, they can sue the company for damages[19]. Another reason is building regulations. The Austrian Council for People with Disabilities criticises the deterioration of accessibility in Austria. In Austria, the federal states are responsible for legislation in building law. Thus, the building regulations are different in each federal province. The harmonization of the building regulations was developed by means of the OIB (Österreichisches Institut für Bautechnik) Guideline 4. Basically, OIB Guideline 4 was developed without the involvement of persons with disabilities or their representatives and was adopted by all provincial legislators in the respective building regulations. Another standard is ÖNORM B1600, which was developed by Austrian Standards International together with experts with and without disabilities and provides a much higher standard for accessibility than OIB Guideline 4. This ÖNORM B1600 is not legally binding and is presented as a recommendation. This leads to an inadequate representation of interests of people with disabilities in this regard [20].

For people with disabilities, barrier-free public transport is a central factor for being mobile. Only those who are mobile can optimally use their living space, get to work and participate in social life. According to Statistics Austria, 26.3% of persons with disabilities still feel disadvantaged in public transport. Lack of information about the accessibility of transport, problems getting on or off the bus or changing from one mode of transport to another are mentioned by those people. They also find it difficult to get to the bus or train stop and to see or understand signs and notices [21].

In Austria, there is still a lot of work to be done on expanding accessibility so that wheelchair users can move around their surroundings just as independently as pedestrians. No matter how many wheelchair trainings are completed, if there are invincible structural barriers for a wheelchair user, he or she will never be able to use the wheelchair independently.

2.1.3 Power Mobility Devices (PMDs) for people with mobility disability

Power wheelchairs and Power Operated Vehicles (POVs), also known as scooters, are collectively classified as PMDs [22]. In figure 4 you can see a scooter.

figure 4 Scooter [22].

For some older people, PMDs represent the only alternative to independent mobility because 59% to 76% of wheelchair users age above 65 years cannot drive a wheelchair manually [23]. And how important independent mobility is, is shown in the study of Davis et al. that says independence in mobility is one of the most important determinants of quality of life for individuals with disabilities[24]. Quantitative studies have found power wheelchair use is associated with improved mobility, social participation and quality of life, and decreased pain and discomfort [25] [26]. The power wheelchair enables the users to be more productive, enjoy more leisure, and accomplish more self-care. [27].

As one might expect, the use of mobility support devices rises with age [23]. Middle-aged and older people are the most rapidly increasing group of PMD users [28]. With the trend of green energy and an aging population, scooters are becoming an increasingly common sight on many sidewalks. Benefitting from improved design and the decrease in stigma, mobility scooters have become a popular mobility aid. In contrast to power wheelchair users, scooter users can walk a few metres independently. On the one hand a PMD use increases participation in both physical and social activities, but on the other hand the impacts of scooter use on functional health is less clear [29]. Assistive technology devices that are completely passive when the user does have some physical function, run the risk of de-conditioning the users physical functionality and their mobile capabilities at a faster rate than if they had used a more physically active assistive technology [30]. It has been argued that scooters are a lifestyle choice rather than a medical necessity [24].

To ensure a medical necessity and the correct use of an assistive device, an occupational therapist should be involved. Occupational therapists are the only health care professionals who use a client - environment -occupation perspective that considers the interface between these three elements when assessing and recommending complex equipment. Occupational therapists bring depth knowledge of occupational performance and participation, and they provide expertise in human function, human development, and the impact of physical, behavioural, social, and cognitive changes throughout the life cycle of humans. Driving a power wheelchair is complex and requires a variety of skills and abilities from all areas of human functioning and an occupational therapist consider all related skills and abilities. This includes assessing and recommending equipment, technology, and environmental modifications to increase accessibility and align with client's needs, goals, and abilities [31]. The training of mobility and activities of daily living with a wheelchair as an assistive device is part of the work of an occupational therapist [32].

2.2 Guidelines for learning to drive a power wheelchair

There are certain skills for driving a car, a motorcycle, and a bicycle, which you must have. This chapter considers whether there are also guidelines for driving a power wheelchair. The research did not find any evidence-based assessments for learning how to drive a power wheelchair specifically in Austria. Furthermore, no recommendations for necessary mobility skills or driving in traffic with the power wheelchair were found. Therefore, international evidence-based assessments are compared. Additionally, the skills needed to drive a power wheelchair are discussed in chapter 2.2.4 by means of a task analysis.

Currently, there are a few assessment tools available for rehabilitation professionals to evaluate power wheelchair driving capacity, both in the user's natural environment and in the clinic. Three different assessments were chosen for this thesis. Firstly, the Wheelchair Skills Program (WSP) was chosen because it includes basic to advanced power wheelchair skills and the program is built on success of previously learned skills [33]. Secondly, the Obstacle Course Assessment for Wheelchair User Performance (OCAWUP) environmental obstacles that are related to daily wheelchair use is included [34]. And thirdly, the Power Mobility Community Driving Assessment (PCDA) is selected, which was developed by Letts et al. and is a clinical used tool that help identify general areas or tasks for which more training is needed (e.g., "driving on sidewalk") or where modifications to the power wheelchair or the environment are necessary [35].

2.2.1 Wheelchair Skills Program (WSP)

The wheelchair research team at Dalhousie University and Capital Health in Halifax Canada began developing the Wheelchair Skills Program (WSP). The program is using a methodology, which is based on motor-learning literature. The WSP is a set of assessment and training protocols related to wheelchair skills. The WSP includes the Wheelchair Skills Test (WST), the Wheelchair Skills Training Program (WSTP) and related materials. The WSP is intended for manual or powered wheelchairs. The WSP is intended to be as relevant as possible to people of all ages (from young children to elderly people) [36].

The WSP was developed based on the principles of motor skills learning theory [37]. When it comes to measurement of motor learning performance, there exists three distinct ways: acquisition, retention, and transfer of skills. Firstly, acquisition is the initial practice or performance of a new skill. Secondly, retention is the ability to demonstrate attainment of the goal or improvement in some aspect, following a short or long-time delay in which the task is not practiced. And thirdly, transfer requires the performance of a task similar in movement yet different from the original task practiced in the acquisition phase [38, pp. 2–25].

As already mentioned, WSP describes the basic learning process according to motor skills learning theories. Early in the process, success may be partial, inconsistent, or only possible in a familiar setting. As learning progresses, preliminary success is eventually achieved (skill “acquisition”). When training sessions improves, success carries over into subsequent sessions (skill “retention”) and the learner is able to use the skill in more diverse settings (skill “transfer”) [37].

Trainers provided instructions on PWC skills through verbal or visual instruction, based on motor learning principles, and were instructed to progress through 28 discrete PWC skills from basic to advanced. The program is building on success of previously learned skills. Power wheelchair driver were required to consistently demonstrate safe operation of the device in a quiet environment with non-human obstacles prior to proceeding to complex environments where people are present [33]. The Table 1 shows the wheelchair skills test for a power wheelchair.

#	WST skill names
1	Position Controller
2	Turns power on and off
3	Changes program modes
4	Changes speed setting
5	Operates body positioning options
6	Operates access options
7	Rolls forward short distance and stops
8	Rolls longer distance
9	Rolls backward short distance and stops
10	Turns in place
11	Turns while moving forward
12	Turns while moving backward

13	Maneuvers sideways
14	Picks objects from floor
15	Relieves weight from buttocks
16	Performs level transfers
17	Performs ground transfers
18	Gets through hinged door
19	Ascends slight incline
20	Descends slight incline and stops
21	Ascends steep incline
22	Descends steep incline and stops
23	Rolls across side-slope
24	Rolls on soft surface
25	Gets over obstacle
26	Gets over gap
27	Ascends low curb
28	Descends low curb

Table 1 List of individual skills for driving a power wheelchair [33].

2.2.2 Obstacle Course Assessment for Wheelchair User Performance (OCAWUP)

As the second guideline the Obstacle Course Assessment of Wheelchair User Performance (OCAWUP) is represented. It is a tool intended to assess and document manual and power wheelchair user mobility performance in controlled environmental situations which are standardized and potentially difficult. It is created to cover environmental obstacles that are related to daily wheelchair use. To evaluate the assessment a scoring system with qualitative variables ("quality" of the performance) and quantitative variables (time) is specified. Table 2 shows the obstacles used in the assessment.

Environmental situation categories	Obstacles in the course
Driving and manoeuvring while avoiding vertical obstacles	Moving down a narrow corridor, between cones and through a doorway
Getting onto a sidewalk or over a doorstep	Getting over a 2.5 cm doorstep Getting over a 7.5 cm doorstep Getting over a 5 cm sidewalk Getting over a 15 cm sidewalk
Moving on different surfaces	Moving on a carpet (quite thick and soft) Moving on a gravel 6mm to 19 mm
Going up and down incline	Going up and down a 6 m inline of 1:16 Going up and down a 6 m incline of 1:12 Going up and down a 6 m inline of 1:8

Table 2 Obstacles chosen in the Obstacle Course Assessment for Wheelchair User Performance (OCAWUP) [34].

2.2.3 Power Mobility Community Driving Assessment (PCDA)

The Power Mobility Community Driving Assessment (PCDA) is a performance-based measure designed to assess driving performance of individuals using power wheelchairs or scooters in community environments. The assessment uses a rating scale with items scored on a four-point scale, ranging from completely independent to unable to complete task independently. You can also mark if the driving skill is not applicable or assessed [35]. The cognitive and physical abilities are not assessed in the PCDA. This is an issue because if problems in driving a power mobility device are observed, the occupational therapists need to identify underlying causes [39]. In the following Table 3 the general driving skills are listed.

General driving skills	Not applicable	Not assessed	Performance score	**Comments**
Driving on sidewalk				
Driving in parking lot				
Driving on road				
Driving in crowds				
Maintaining a straight course				
Intersection with lights				
Intersection without lights				
Crosswalk				
Accessing crosswalk button				
Crossing streets without lights				

Table 3 General driving skills of the Power Mobility Community Driving Assessment (PCDA) [35].

Of the selected guidelines, all individual exercises were compared with each other. The exercises that appeared in all three guidelines were extracted and used in the expert interview to analyse the mobility skills in practice. The analysis of the mobility skills is done in chapter 3.2 Semi-structured expert interview results. The skills needed to drive a power wheelchair are discussed in the following chapter by means of a task analysis.

2.2.4 Task analysis of driving a power wheelchair

Powered wheelchair use is complex and requires a variety of skills and abilities from all areas of human functioning, in addition to a wide range of knowledge. To identify the needed skills for an activity a task-analysis is a possible reasoning process. It is widely used in rehabilitation sciences, specifically occupational therapy, for skill instruction [40]. The process map in figure 5 s shows how complex for example the task turning 90° while moving forward is. Ovals represent start/end points, rectangles represent steps in the sequence. The driving task is broken into steps, for the driving task turning 90° while moving forward, 7 steps are needed to complete the task [41].

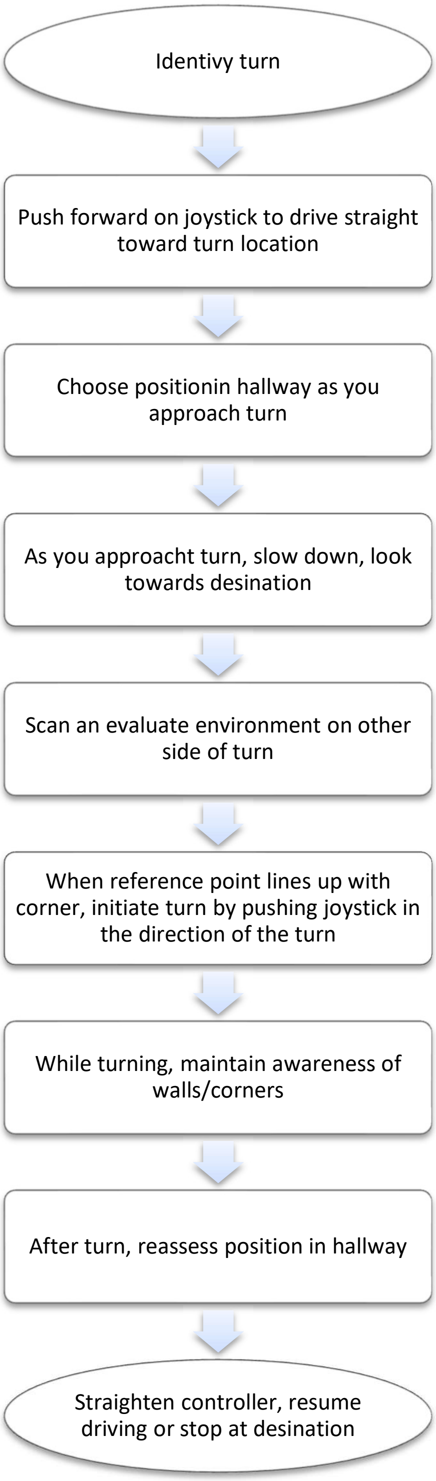

figure 5 Task analysis of the task turning 90° while moving forward [41].

In the task analysis of driving a power wheelchair from E. Smith et al., 110 distinct skills and abilities were identified and were mapped additional to the ICF [41]. The World Health Organization's International Classification of Functioning, Disability and Health (ICF) as an existing conceptual framework for categorizing skills and abilities is used. It is a standardized method for classifying body structures and functions, activities and participation, and environmental factors which may impact an individual's task performance[42].

From the mentioned 110 skills and abilities 80 are in the body structures and functions domain, and 30 in the activities and participation domain. It should be noted that 50% of skills and abilities were mental functions, which are often neglected in the literature of existing power wheelchair training programs. A further important statement is that power wheelchair training programmes should address skills from all domains. Furthermore the knowledge that is used while driving a power wheelchair is broad and this should be considered when developing a power wheelchair training [41]. Therefore, in this thesis the exercises address skills from all domains and the exercises will not be divided in function domains. The exercises will be designed to train both body functions and mental function.

2.3 Virtual Reality (VR) in training

In the previous chapter, wheelchair training in the "real" world was described. The aim of this work is to provide wheelchair training in VR. Therefore, VR will be discussed in more detail in this chapter.

In recent years, VR technology has gained attraction in many different disciplines and there has been made progress and further developments. Exemplary, there are lots of applications in product design, education and training, military, entertainment and leisure fields [43]. This thesis will take a closer look at VR for the purpose of training as the goal of this thesis is to develop exercises in a power wheelchair driving simulation in VR.

2.3.1 Definition of terms

First of all, it is important to clarify what VR is. VR is a computer-generated reality with images (3D) and in many cases also sound [44]. VR creates an artificial and digital environment in which, for example, several people can interact with each other via avatars [45]. To create a feeling of immersion, special output devices called virtual reality headsets, more specifically head-mounted displays are required to represent virtual worlds. Head-mounted display (HMD) devices in the market like Oculus Rift, and HTC Vive are well known [46]. In this thesis the *Oculus Quest 2 from Facebook* will be used, because it is used for the application WheelSim VR. In addition, the term motion sickness should be explained. Virtual reality sickness (VR motion sickness) is the physical discomfort that occurs when an end user's brain receives conflicting signals about self-movement in a digital environment. Like other types of simulator sickness, the symptoms of VR motion sickness can include nausea, dizziness/lack of balance, drowsiness, warmth, sweating, headaches, disorientation, eye strain, and vomiting[47].

figure 6 Head-mounted display and controller of *Oculus Quest 2*.

The following chapters describe VR for the purpose of training in different fields, such as military, healthcare, and driving simulation in more detail.

2.3.2 Use of virtual training

Military is one of the most important application fields of VR. The U.S. Department of Defense listed VR as one of the seven key technologies that will ensure the power of the U.S. forces in the 21st century. The application of VR technology in the military field mainly includes virtual training, virtual battlefield exercises, and virtual weapon manufacturing. The advantage of simulation is that dangerous situations and equipment failures can be trained without putting real people or vehicles at risk[43].

figure 7 Virtual battlefield training in the army [43].

In **healthcare** VR surgical simulators are frequently used. Companies like Osso VR and Immersive Touch offer VR solutions to train surgeons (for example to improve their skills). The training has been proven to be better than traditional training methods. In fact, a recent study from Harvard Business Review showed that VR-trained surgeons had a 230% boost in their overall performance compared to their conventionally trained counterparts. The former were also faster and more accurate in performing surgical procedures [48]. In figure 8 you can see a virtual training surgery on the knee with the training platform Osso VR.

figure 8 Surgery on the knee with surgery training platform Osso VR [48].

Another application of VR is **driving simulation**. Nowadays you can steer a racing car from your living room with VR games, where VR gaming has exploded in popularity. In the world of video game simulation racing popular games like Gran Turismo, Project Cars and Driveclub support VR gaming. VR racing simulators are also used and suitable for the training of professional racers [49].

Furthermore, VR can be used to give insights into the dangers of distracted driving for example with the *ToyotaTeenDrive365* distracted driving simulator of Oculus Rift. During the simulation, you are challenged to drive safely using the car's steering wheel and pedals. While navigating a series of common distractions occur (e.g., traffic noises, the radio, text messages, and virtual friends on the back seats). Nearly 80 percent of the users are saying, that they would reduce and better handle distractions in real world because of the experience in VR [50]. Also, for learning driving skills and before taking a practical test several games in VR are used to provide players the knowledge of driving or getting ready for the basic driving lessons and rules before they drive a real car on the real road. The knowledge from the game increases the awareness and responsibility of the driver to reduce the possibility of having accidents on the road [51].

Another prototype from Austria explores the possibilities of using a VR driving simulator to teach driving a car in a safe environment using cognitive learning methods and gamification. The driving simulator focuses on teaching situational awareness and is designed to be used in addition to classical driving schools [52].

2.3.3 VR simulations for power wheelchairs

This chapter will deal with existing VR simulations for power wheelchair. First of all, the simulation WheelSim VR is dealt with, as this master thesis will be done in cooperation with LIFEtool who developed WheelSim VR.

Similar to driving simulation proper training programs for power wheelchair use will contribute to increased safety and mobility for power wheelchair drivers [5]. VR can be used to simulate critical moments during driving, without harming the user or bystanders [52].

WheelSim VR
WheelSim VR is a virtual wheelchair simulator using current VR technology to enable people with disabilities of all ages to learn and train power wheelchair control. With the simulation the user learns and consolidate the handling of the power wheelchair as well as special requirements and traffic-relevant rules. WheelSim VR runs on a computer and with the VR headset a scene is presented

to the user. The simulation can be controlled by a joystick as you can see in figure 9. The programme offers comprehensive VR training in various situations:

- driving in the home
- driving in the protected area of an outdoor practice park
- driving on the road and in road traffic (Using a crosswalk with or without traffic lights, crossing the road without a crosswalk, paying attention to pedestrians, and vehicle drivers)
- training in everyday situations such as using a lift and public transport
- skill races against the clock on four different tracks

In the definition of the training situations and all aspects relevant to traffic safety as well as the evaluation, the expertise is brought in by the Road Safety Research KFV as project partner.

figure 9 Use of the WheelSim VR application.

McGill immersive wheelchair (miWe) simulator
VR simulators offer a possible alternative for rehabilitation training either at home or in a clinical setting [53]. The McGill Wheelchair Simulator, runs on a regular computer and provides a 3D perspective view, presented on a computer screen in front of the user [54]. It is controlled using a regular joystick, and parameters such as speed and acceleration correspond to a real PW. Several virtual scenarios have been designed, based on an analysis of users' needs, such as entering/exiting an elevator, entering an adapted transport vehicle and street crossing [55].

Wheelchair driving simulator

The VR based simulator was designed in the virtual environments and optics research laboratory of the University of Pannonia. It was primarily designed for people who must learn how to drive a wheelchair due to a recent accident or disease. The application presents an important role in the early phase of preparation of wheelchair driving [56].

Game wheelchair simulator VR

This is a comedic game about a serious issue. You must try to traverse the city by pushing the wheels with your hands and learn the story of a person who does that every day, in VR. This game does not focus on disabled people [57].

The simulations described are mainly used for research purposes at universities. WheelSim VR is the only product that aims to be a training tool for wheelchair users at home or in the clinic. This is one reason why WheelSim VR was chosen for this thesis. Another reason is that WheelSim VR was developed with the inclusion of people with mobility impairments. They also made usability tests with users of power wheelchair and therapists.

3 Requirement and user need for a power wheelchair driving simulation in VR

A power wheelchair simulator in VR is intended to be a safe way for people with disabilities to learn how to drive a power wheelchair. The target audience for power wheelchair VR simulation are people with disabilities who need a power wheelchair as a mobility aid. The second group of users are wheelchair skills trainers like occupational therapists, physiotherapists, etc., who do wheelchair training with their clients. The simulation is an opportunity for experts to make driving performance measurable and comparable. Given these aspects, the main goal is that the power wheelchair VR simulation should improve driving performance. To assist with the design process and to identify the user requirements, qualitative data was gathered through a semi-structured interview with experts.

The primary goal of the expert interviews was to understand the training processes, tools and techniques of a wheelchair training in practice. In addition, they provided proficient expert opinions on the following core topics:

- What learning content does a wheelchair training include?
- What basic mobility skills are used for power wheelchair training?
- Are there measurable parameters that are used in power wheelchair training?

3.1 Semi-structured expert interview setup

As mentioned above semi-structured expert interviews were conducted. In this chapter the setup is described and furthermore the participants, design & procedure and apparatuses & materials of the semi-structured interviews are considered in more detail.

A semi-structured interview is based on a semi-structured interview guide, which can be found in Appendix B. The semi-structured interview is a schematic presentation of questions or topics which are explored by the interviewer [58]. The interview guide is derived from the literature research and includes six closed question with predefined answer options and five open questions.

As interview participants are experts with a domain expertise, this means knowledge of the problems, systems, goals and tools used in specific line of work were selected [59, p. 369]. This means the experts were initially defined as occupational therapists who have professional experience in wheelchair training.

Additionally, experts have technical process orientated and interpretative knowledge on topics relevant to their specific professional activity. Which means that expert knowledge does not only consist of reproduceable and accessible knowledge, but also of practical knowledge acquired by the expert [59, p. 273]. To benefit from the practical knowledge of occupational therapists in instructing power wheelchair training, experts were initially defined as persons with a degree in occupational therapy and with clinical experience as an occupational therapist of at least two years. Prior to the interviews, the interview guide was discussed and adapted with the WheelSim VR project manager.

Participants

A panel of three occupational therapists who have at least two years of professional experience with clients in a wheelchair was chosen. The expert's statements helped to understand the training processes, tools and techniques that are currently used in practice of wheelchair training. A detailed list of all participants and their work experience in years and medical field can be seen in Table 4

Participant	P1	P2	P3
Work experience as occupational therapist	14 years	11 years	6 years
Medical field	neurology and geriatrics	neurology and geriatrics	neurology

Table 4 Participants of the expert interview.

Design & Procedure

As an introduction into the topic and the aim of this master thesis the interviews started with an introduction regarding the principles of VR, followed by an explanation of the driving simulator WheelSim VR. To give the participants a better understanding of the driving simulator a short video about WheelSim VR was also shown. The semi-strucuted interviews were conducted online. Including the introduction, the meeting had a duration of approximately 30-45 min. The interviews were conducted in March 2021.

Apparatus & Materials

For further analysis and to document the interviews, audio of the interviews was recorded, and notes were taken by the interviewer. Supported by the interviewer´s notes, the transcripts were analysed to set the exercises in the traffic-free area for the power wheelchair VR simulation.

3.2 Semi-structured expert interview results

The first question was about whether the experts are using evidence-based training programmes for wheelchair users in their work. All of them answered that they do not use evidence-based training programmes and that they have not faced any in education or practice so far.

The next question deals with the typically included learning content in a wheelchair training. The learning contents were derived from the guidelines of chapter 2.2 Guidelines for learning to drive a power wheelchair. The participants were asked to give answers based on the following scale: always, sometimes, rarely, or never. This is intended to filter out the most frequently used learning contents in a wheelchair training to incorporate them into the wheelchair simulation. The answers were classified differently from the experts, so the categories were analysed later. The responses are presented in Table 5. The values range from 1-3 (0= no response, 1=one response, 2=two responses, 3=three responses).

	always	sometimes	rarely	never
Power wheelchair controls (e.g., turning on/off the wheelchair, tilt/recline functions)	3	0	0	0
Transfers to and from wheelchair	2	1	0	0

Basic mobility skills (manoeuvring around obstacles, turns, ramps)	3	0	0	0
Driving rules (e.g., position in hallways, sidewalks)	1	2	0	0
Speed control (e.g., speed selection)	2	1	0	0
Incorporating powered mobility into basic and instrumental activities of **daily living** (e.g., personal hygiene, dressing, cooking, cleaning)	1	1	1	0
Use of public transportation	1	1	1	0
Navigating in the environment (e.g., route planning, problem solving)	0	2	1	0
Emergency procedures (e.g., obtaining assistance)	1	0	1	1
Traffic rules, behaviour in road traffic	1	2	0	0

Table 5 Responses for typically included learning content in a wheelchair training.

Based on these results the following categorisation of the typically included learning content in a wheelchair training regarding the frequency of responses has been made. As it is shown in Table 6 the categories are “always” and “sometimes”. Whereas the category 1 “always” includes those learning contents which were mentioned by more than one expert. In addition, category 2 “sometimes” also includes the learning contents which were also mentioned by more than by one expert. The answers corresponding to the category have been highlighted in Table 5. The colour green for category one and the colour yellow for category two.

Category 1 “always”	**Category 2 “sometimes”**
Power wheelchair controls	Driving rules
Transfers to and from wheelchair	Navigation in the environment
Basic mobility skills	Traffic rules, behaviour in road traffic
Speed control	

Table 6 Typically learning content in a wheelchair training of category 1 and 2.

Three of the ten items (incorporating powered mobility into basic and instrumental activities of daily living, use of public transport, and emergency procedures) could not be clearly assigned to any category. The answers ranged from always to never.

If a learning content was rated with rarely or never it was additionally asked why the learning content is rarely or never part of the wheelchair training. P1 said: *"In a rehabilitation setting the therapy is often limited by time and therefore it does not happen very often that you can do wheelchair training outdoor".* P1 additionally mentioned*:" Using public transport is also difficult because the buses run rarely in rural areas and you don't have a possibility to train".* P2 describes that if a client is not a beginner and does not have any cognitive limitations, he/she can assess the speed control well himself and therefore no focus is put on it in the training. P2 also said: "*The learning content is very individual as it should be adapted to the client's goals".* For example, if a patient does not want to drive outdoors with the power wheelchair, this will not be part of the wheelchair training. The additional comment to the learning contents of P3 was that mostly the basic skills for wheelchair driving are part of the training. P3 said: *"As a trainer I can assess the most important skills and based on that I can estimate the reaction to different environmental changes, like outdoor driving or driving in traffic".*

Basic mobility skills are the subject of the second question. The experts assigned the individual wheelchair mobility skills to a degree of difficulty. The contents were derived from the guidelines Wheelchair Skills Program, Obstacle Course Assessment for Wheelchair User Performance, and Power Mobility Community Driving Assessment [33] [34] [35]. The exercises from each guideline were compared and merged into one list. The interview is intended to filter out the easy and moderate mobility skills taught in the real world to use them in the wheelchair simulation. In addition, the question which mobility skills are trained by the trainers in wheelchair training in the real world was asked. The responses can be seen in the last column "is used in practice". The responses are presented in figure 10. The values range from 1-3 (0=no response, 1=one response, 2=two responses, 3=three responses).

Basic mobility skills	easy	medium	moderate	difficult	is used in practice
Turns power on and off	3	0	0	0	3
Changes speed setting	1	2	0	0	3
Rolls forward short distance and stops	2	1	0	0	3
Rolls backward short distance and stops	0	1	2	0	3
Turns in place (180°)	0	2	1	0	2
Turns while moving forward	1	2	0	0	3
Turns while moving backward	0	0	1	2	1
Manoeuvres sideways	0	1	2	0	3
Can avoid obstacles while moving	0	3	0	0	3
Ascends slight incline	2	1	0	0	3
Descends slight incline	0	2	1	0	3
Ascends slight incline and stops	2	0	1	0	3
Descends slight incline and stops	2	0	1	0	3
Getting onto a sidewalk	1	2	0	0	3
Going down a sidewalk	0	3	0	0	3
Driving on sidewalk	0	2	1	0	3
Gets through hinged door	0	0	1	2	1
Moving on a carpet	2	1	0	0	0

Moving on a gravel	0	2	1	0	2
Driving in parking lot	0	1	2	0	3
Driving on road	0	1	2	0	1
Driving in crowds	0	0	2	1	2
Intersection with crosswalk	0	1	2	0	1
Intersection without lights	0	0	0	3	1

figure 10 Basic mobility skills of driving a power wheelchair. The values range from 1-3 (1=one response, 2=two responses, 3=three responses).

Based on these results the following categorisation of the basic mobility skills in a wheelchair training regarding the frequency of responses has been made. The mobility skills are presented in the categories easy, medium, moderate, and difficult.

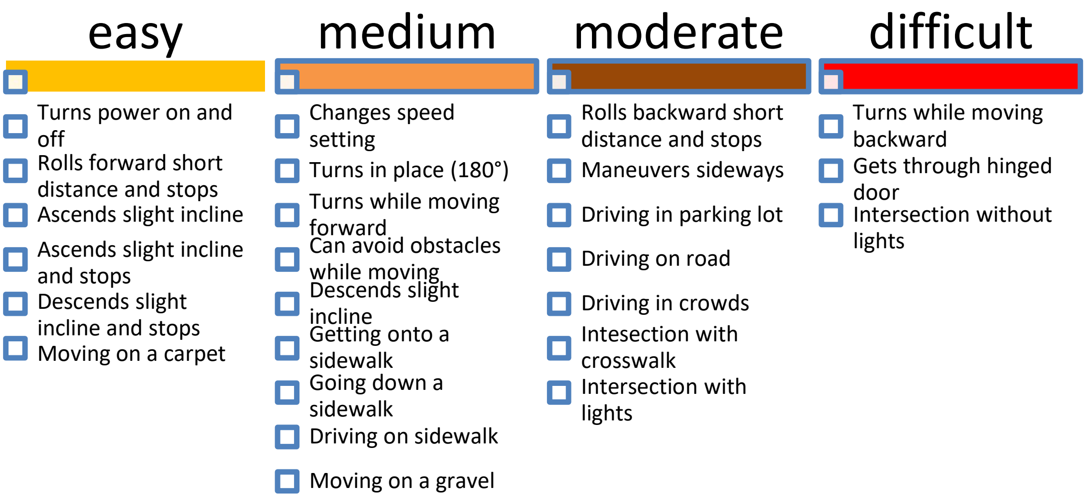

figure 11 Categorisation of the basic mobility skills mentioned in the expert interview.

Out of the 25 basic mobility skills, six are in the category “easy”, nine in the category “medium”, seven in the category “moderate” and three in the category “difficult” as you can see in .

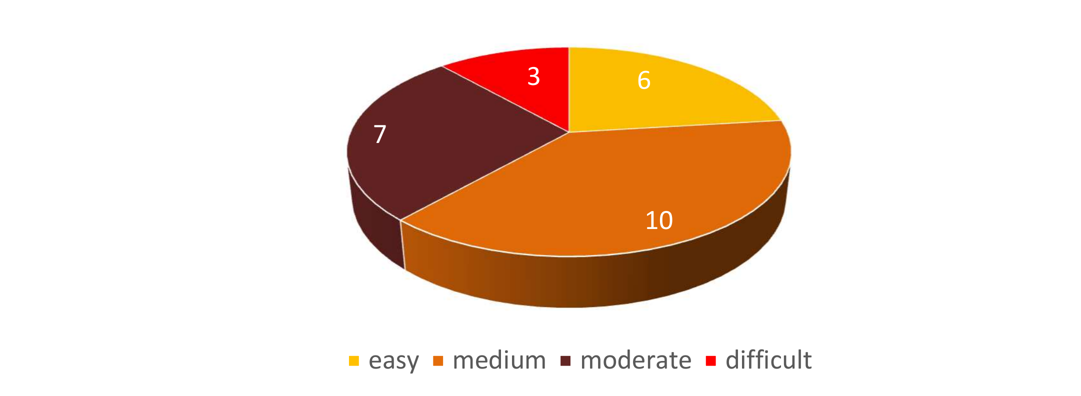

figure 12 Categorisation of the basic mobility skills in the categories easy, medium, moderate and difficult.

In figure 10 in the column “is used in practice” the responses of the experts regarding the used basic mobility skills in their wheelchair training are represented. In total, 19 out of the 25 basic skills were named by more than one expert as skills to be trained during wheelchair training. The following six skills were not mentioned at all or by only one expert:

- Turns while moving backward
- Gets through hinged door
- Moving on a carpet
- Driving on road
- Intersection without lights
- Intersection with lights

As these six skills are not used in practice, they were not included in the subsequent analysis.

Like mentioned in the Wheelchair Skill Program the skills are taught from easy to advanced [33]. For the power wheelchair driving simulation the easy and moderate skills which were mentioned by the experts in the interview which are used in the practice will be highlighted in figure 13. From the category “easy” five basic mobility skills and from the category “medium” nine basic mobility skills are selected. In total 14 basic mobility skills can be used in the power wheelchair driving simulation VR, which can be seen in figure 13.

easy

- Turns power on and off
- Rolls forward short distance and stops
- Ascends slight incline
- Ascends slight incline and stops
- Descends slight incline and stops

medium

- Changes speed setting
- Turns in place (180°)
- Turns while moving forward
- Can avoid obstacles while moving
- Descends slight incline
- Getting onto a sidewalk
- Going down a sidewalk
- Driving on sidewalk
- Moving on a gravel

figure 13 Basic wheelchair skills from the category easy and medium which are also used in practice.

The next question dealt with specific training techniques used in power wheelchair training. The responses are presented in Table 5. The values 1-3 represent the frequency of responses (0=no response, 1=one response, 2=two responses, 3=three responses).

Training technique	yes	no
Verbal cues	3	0
Visual cues	3	0
Trial-and-error	3	0
Demonstration (using the client´s joystick)	3	0
Demonstration (using a second wheelchair)	0	3
Hand over hand guidance	3	0
Games	0	3
Obstacle course	2	1
Group/peer-based training	0	3

Table 7 Specific training techniques in power wheelchair training.

Based on the frequency of the responses, the training techniques that were mentioned by more than one expert are highlighted:

- Verbal cues
- Visual Cues
- Trial-and-error
- Demonstration (using the client´s joystick)
- Hand over hand guidance
- Obstacle course

Next, the experts explained the structure of power wheelchair training which they use. All experts started to explain the power wheelchair controls (joystick, speed controller, on-off button). In addition, all experts began the training in a low-stimulus environment and flat surfaces at low speed. P2 also performed the previously trained exercises at an increased speed so that the wheelchair user noticed the difference.

Basic wheelchair manoeuvres are practised next by all experts such as stopping the wheelchair, driving left and right, and driving backwards. P1 also counted the target braking to the basic wheelchair manoeuvres and trained it for example with acoustic stimuli (when clapping in hand the wheelchair driver stopped). P1 and P2 mentioned turning around in more detail, which was practised when moving in and out of rooms and the elevator. Next, P1 and P2 focused on obstacles, wheelchair user had to avoid obstacles e.g., in an obstacle course. If the client performed the basic mobility manoeuvres, the training continued outdoors by all experts. Outdoor the wheelchair user drove on the sidewalk or in the car park. If the user is confident enough, they drove into town and drove in the pedestrian zone or crossed streets.

On the question how the experts compared the driving performance of power wheelchair training sessions, they were all the same opinion. They used given exercises, observation, and interviews for the comparison. None of them used video or measurable parameters.

In the next question the experts described what they would like to have for power wheelchair training. P1 and P3 would like to have a possibility for the user to train independently at home. P3 said: *"I would like to have a prepared obstacle course that can be used several times and in this way the performance can be compared better."* Also, P3 said: *"A driving simulation would be a great opportunity to train in the beginning before driving with a power wheelchair in the real world."* After the VR training, simulated situations from everyday life would be a very good training opportunity for P3.

Regarding the question if a power wheelchair simulation using VR could be a useful training method for power wheelchair users all the experts said yes. All experts believed that a power wheelchair simulation in VR could be a useful training method for power wheelchair users. P1 emphasised that the training in VR is safe. In practice, difficulties in releasing the joystick in a dangerous situation are observed very often. Dangerous situations had already occurred in practice. In VR the joystick control can be trained more safely in the face of obstacles and dangerous situations. P3 mentioned the advantage of a power wheelchair driving simulation in VR is that different scenarios can be trained, such as road traffic, driving indoors, etc. P2 considered that VR is not suitable for everyone, as older people, for example, might be overchallenged with the technology. Furthermore, cognitive limitations are also a limitation for the application. The experts also noted that a VR driving simulation is a complementary training option and cannot replace wheelchair training in real life.

The final question asked was what additional information about the experience of power wheelchair training would help to understand current practice in this area. P1 said: *"Personally, I miss some kind of driving licence for electric wheelchair users. As no measurable assessments are used in practice, the decision whether a wheelchair user can drive alone varies from therapist to therapist".* P2 mentioned that the use of public transport is very difficult to train. The reason is that many different problems can occur, such as no accessibility of different bus lines with different ramps, where you cannot train all of them. Moreover, accessibility often varies from city to city in Austria. And it also makes a difference whether you live in the city or on the countryside.

3.3 Semi-structured expert interview findings

The interview strengthened the assumption that evidence-based wheelchair training is not used in practice. The background of the categorisation of the learning content was to include the learning content from category 1 “always” in the power wheelchair simulation in VR. The mentioned learning content includes:

- Power wheelchair controls
- Transfers to and from wheelchair
- Basic mobility skills
- Speed control

For the power wheelchair driving the categorization was necessary to filter the “easy” and “moderate” skills and to use them in the power wheelchair driving simulation in VR. In addition, the categories mentioned above have been filtered again by including only exercises used in practice in the VR driving simulation. The results can be seen in figure 13.

One expert mentions that mostly the easy basic mobility skills for wheelchair driving are part of the training. This also becomes apparent when looking more closely at the exercises that are not used or only by one expert in practice. The exercises mentioned are:

- Turns while moving backward
- Gets through hinged door
- Moving on carpet
- Driving on road
- Intersection with crosswalk
- Intersection without lights

The interesting aspect is that the mentioned exercises are all from the category "moderate" and "difficult" except the exercise moving on carpet. Moving on carpet is from the category “easy” and it is the only exercise which is not taught by the experts from the category “easy”. All other exercises from the categories “easy” and “moderate” are used in practice. The exercises are:

- Turns power on and off
- Rolls forward short distance and stops
- Ascends slight incline
- Ascends slight incline and stops
- Descends slight incline and stops
- Changes speed setting

- Turns in place (180°)
- Turns while moving forward
- Can avoid obstacles while moving
- Descends slight incline
- Getting onto a sidewalk
- Going down a sidewalk
- Driving on sidewalk
- Moving on a gravel

The experts recommended following structure of a power wheelchair training. The training should start in a low-stimulus environment and with flat surfaces at low speed. Then the basic wheelchair manoeuvres should be practised indoors. After this, obstacles that the user had to avoid are included. In the interview it became apparent that in practice no measurable parameters are used. However, P1 expressed the wish for a driving licence for electric wheelchair drivers and P2 would like to have a fixed obstacle course which could be used repeatedly to compare the driving performance better.

All experts believed that the power wheelchair driving simulation in VR can be a good training option. On the one hand for training dangerous situations, joystick control and on the other hand for training different scenarios. For future wheelchair training, the experts would like to see a kind of "wheelchair driving licence" and more opportunities to train wheelchair use on public transport.

4 Design and development of a power wheelchair VR simulation

The data collected through the semi-structured expert interview and the literature research allowed the specification of functional requirements for a power wheelchair driving simulation in VR. It is highly relevant to design and develop exercises for basic mobility skills of driving a power wheelchair in VR, because in the literature it is mentioned that wheelchair manoeuvres have an important role in causing injuries of wheelchair users. Secondly, the number of accidents of power wheelchair users increased significantly [5]. Thirdly, the possibilities and approaches to provide training environments for manoeuvring power wheelchairs are highly limited. For example, the experts mentioned that a power wheelchair driving simulation in VR can be a good training option for joystick control and dangerous situations in different scenarios, which they would use in their daily work. Furthermore, it is possible to measure numerous variables involved in the driving process [6]. In the interviews it became apparent that in practice no measurable parameters are collected for wheelchair training, but the need is there. A further reason is that the powered and manual mobility market globally is projected to grow exponentially due to aging baby boomers and increasing longevity [4]. Based on these developments it is very important to develop a power wheelchair driving simulation in VR to increase power wheelchair driving performance.

In the expert interviews it became apparent that mainly the easy and moderate basic mobility skills are trained in the real world. Therefore, the developed exercises in the traffic-free area also focuses on the easy and moderate basic mobility skills. The specific exercises are described in chapter 4.2 in more detail. The exercises are set up in an obstacle course, because in the expert interviews the demand for a comparable obstacle course came up, where in the literature a constant obstacle course is also used in the Wheelchair Skills Program [37].

The exercises in the traffic free are a further development of the WheelSim VR application from LIFEtool. Parts of the source code were provided for this master thesis. For more details see chapter 4.1. In the next chapters, the specification of functional and technical requirements and the selection of the exercises in the traffic-free area and their technical implementation in the existing application Wheelsim VR are presented in more detail.

4.1 Specification of functional and technical requirements

The WheelSim VR application which was initially developed by LIFEtool was further developed with exercises to train for basic mobility skills. The company LIFEtool has provided a branch of WheelSim VR source code. The development platform *Unity 3D* version 2019.2 was necessary for ongoing technical development. In order to clearly represent the ongoing development, it is necessary to mention what the provided WheelSim VR application contains. The general settings are illustrated in figure 14.

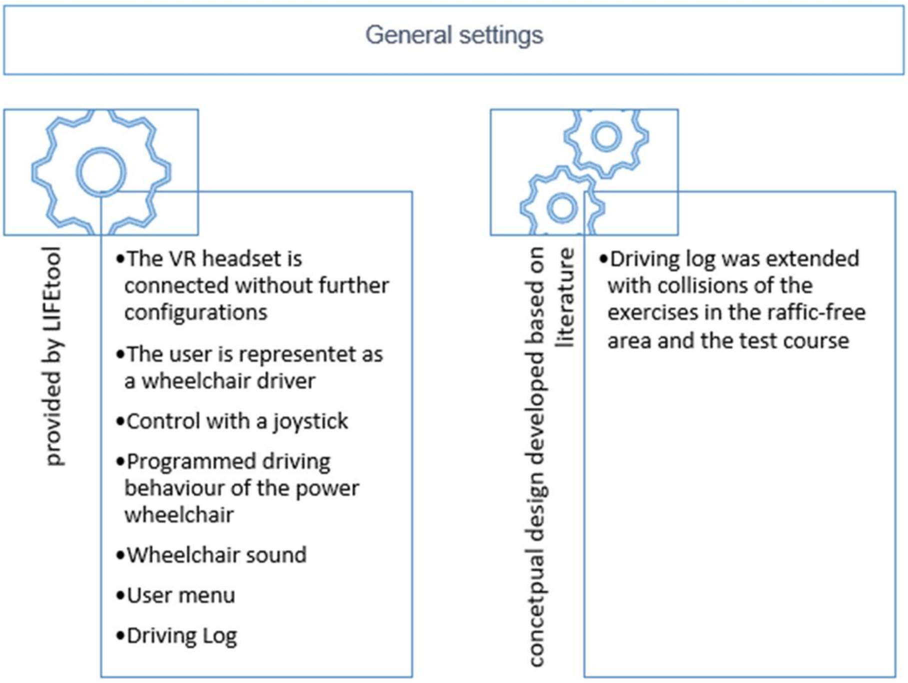

figure 14 Comparison of the general settings provided by LIFEtool and conceptual designed and developed in this thesis.

The exercises in the traffic-free area were implemented in the provided surrounding scene “skill races against the clock”. It contains the existing surrounding like trees, walls, predefined route marked with yellow lines and the features given in figure 15. In this surrounding the selected exercises in the traffic-free area were conceptual designed and implemented. The exercises were selected through the findings of the interviews and the analysis which you can see in chapter 4.2 Selection of the exercises in the traffic-free area. The used assets like traffic cones, barriers were provided in the WheelSim VR project of LIFEtool.

A Unity asset is an object that you can use in the project, like 3D model, an audio file, an image or any other type of file that Unity supports [60].

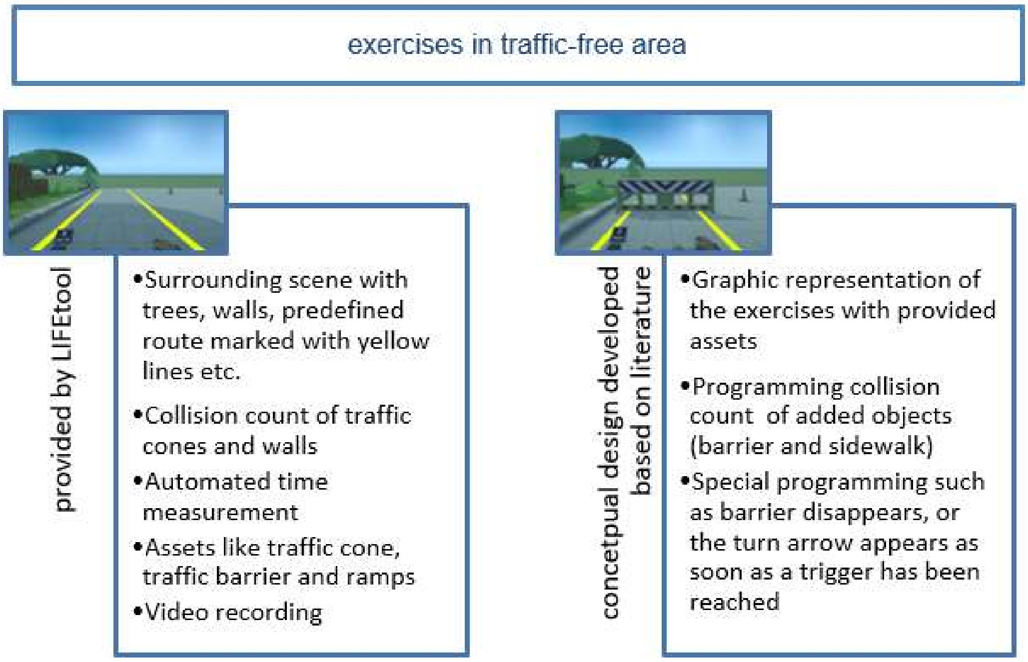

figure 15 Comparison of the exercises in traffic-free area provided by LIFEtool and conceptual designed and developed in this thesis. WheelSim VR Image courtesy of LIFEtool.

In addition, a total new test course was designed in the surrounding “driving in the protected area of outdoor practice park” to measure with the parameters time and number of collisions the change of the driving performance. It contains the existing surrounding like trees and walls and the features given in figure 16. The traffic cones and the walls were rebuilt according to the original *Illinois Agility Test* and the objects were programmed that the collisions and the time were counted.

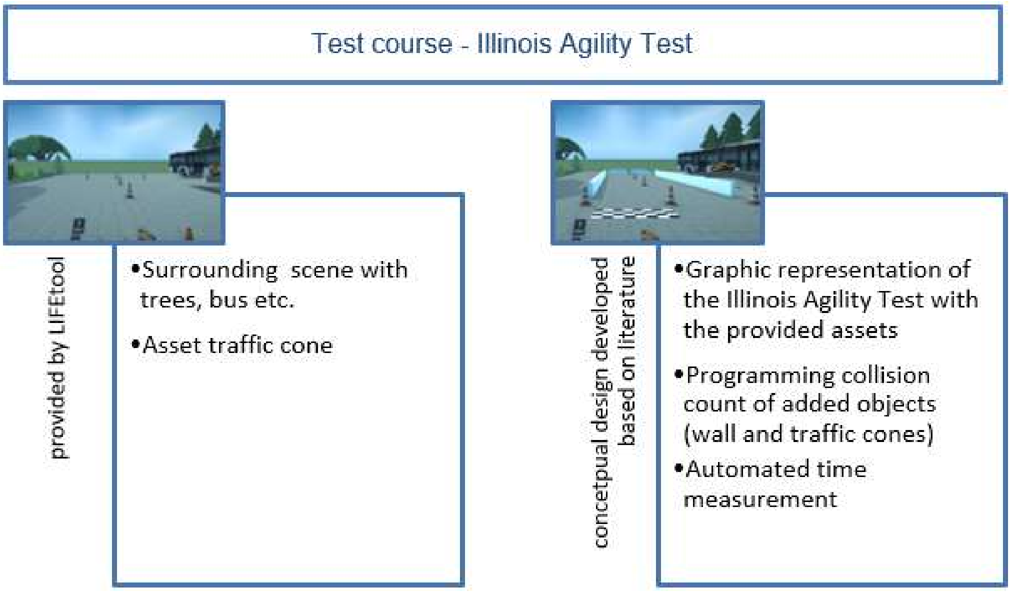

figure 16 Comparison of the test course provided by LIFEtool and conceptual designed and developed in this thesis. WheelSim VR Image courtesy of LIFEtool.

4.1.1 Required hardware

As mentioned, the game engine *Unity 3D* is used. The minimum requirements to run the Unity Editor on a Windows **gaming computer** are Windows 7 or 10 (64 bit), CPU -X64 architecture with SSE2 instruction set support and Graphics API - DX10, DX11, DX12-capable GPUs [61].

VR-headsets are the output devices for VR. For the power wheelchair driving simulation in VR the **VR-Headset** *Oculus Quest 2 from Facebook* was used. The Oculus-App was used to connect to the gaming computer. Furthermore, to control the wheelchair in the application a **joystick** was necessary. In figure 17 you can see the joystick from Optima which was chosen, because the joystick is like the joystick used on a power wheelchair. The joystick works with USB and PS/2 compatible computers of all types [62].

figure 17 Joystick which is used in the power driving simulation in VR.

4.1.2 Required software

For the ongoing technical development of the application WheelSim VR the game engine *Unity 3 D* was used. Unity is a cross-platform game engine developed by Unity Technologies and can be used to create three-dimensional, VR, and Augmented Reality games. The mechanisms built into *Unity* can be supplemented via self-written programmes, so called scripts. Scripts are necessary to describe the game process and logic. The scripting language is C# in the development environment *Visual Studio Code* [60]. To use WheelSim VR on *Oculus Quest 2*, the VR software *Oculus-App* was installed on the gaming computer and the headset was connected to the computer. An overview of the entire software and their versions used during the development is given in Table 8.

Purpose	Software	Version	Platform
Application Development	Unity 3 D	2019.2	Windows 10
Scripting	Visual Studio	16.9.4	Windows 10
Connecting VR headset with PC	Oculus-App-Version	28.0.0.222.469	Windows 10

Table 8 Software used in the development process.

4.1.3 Quantitative driving parameters

In the interview it became apparent that in practice no measurable parameters are used for the comparison of the driving performance. In the expert interview P1 expressed the need for comparable parameters to better compare the driving performance. To quantify the individuals driving performance two of Kamaraj et al. suggested parameters - time and number of collisions with obstacles and boundaries - were chosen, because these are parameters that are easy to determine and which are also understandable for wheelchair users [63].

Time: Time taken to complete the entire run.

Number of collisions with obstacles and task boundaries: the number of collisions the wheelchair drivers crashes in a box collider or in an object counts as a collision. The collisions were divided into collision with traffic cone, collision with barrier, collision with sidewalk edge, collision with wall, and general collision count.

The parameters time and number of collisions are defined in the script drivingLog and can be read from the driving log in a text editor. In figure 18 you can see the representation of time and collision and some more data like date, course name, and maximum speed.

*driving-logs - Editor

Datei Bearbeiten Format Ansicht Hilfe


```
{
    "entries": [
        {
            "Datum": "18.05.2021 21:09:16",
            "Kurs": "Testung",
            "KollisionenMitVerkehrshuetchen": 8,
            "KollisionenMitHindernis1": 0,
            "KollisionenMitGehsteigrand": 0,
            "TestungKollisionenMitWand": 5,
            "collisionCount": 0,
            "time": 158.17767333984376,
            "assignmentCompleted": true,
            "wasDoneOnVR": true,
            "maxSpeed": 10.0,

            ],
            "scene": "Uebungspark",
            "replayFile": "2021-05-18-21-09-16.Uebungspark.8.replay"
        },
```


figure 18 Representation of the driving logs.

The quantitative driving parameters are measured by testing before and after the exercises in the traffic-free area. The applied test, which was used is the existing so-called Illinois Agility Test (IAT) which is explained now in more detail.

Illinois Agility Test (IAT)

The participants perform before and after the exercises in the traffic-free area one round of the Illinois Agility Test (IAT). The IAT is a valid and reliable agility test for wheelchair users [64]. The test is not only used for wheelchair users, but can also be used to assess able-bodied athletes [65]. The test is used in VR in the literature to assess wheelchair manoeuvres [66] [67].

IAT is an obstacle course consisting of eight traffic cones that are positioned as shown in figure 19. Participants were asked to run the path as quickly as they could. For this thesis, a standardized version of IAT was used which is overall a ten by five meters court; the cones on the horizontal lines are placed 2.5 meters in between, and on the vertical line they are positioned 3.3 meters apart[68].

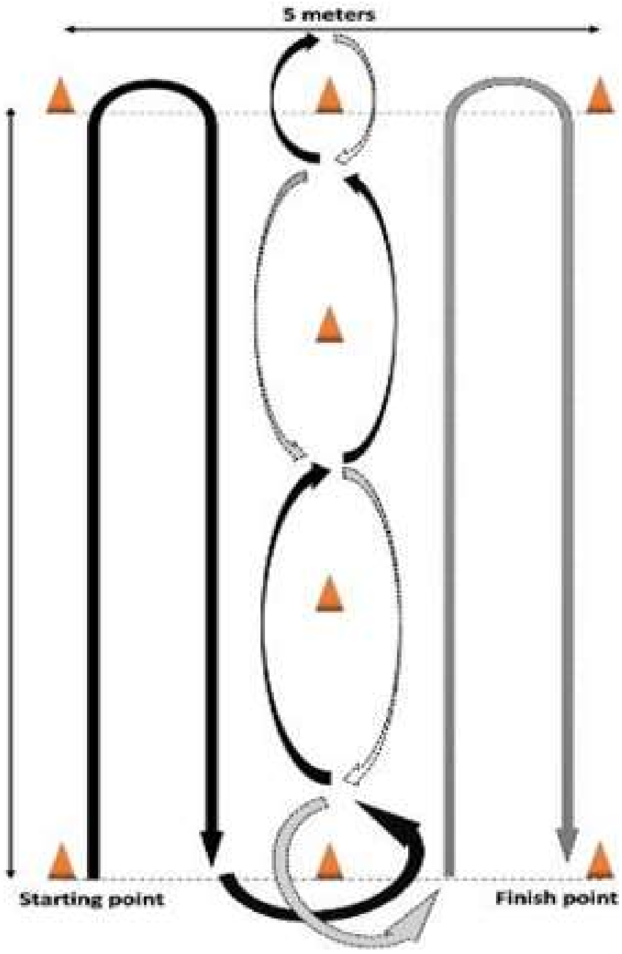

figure 19 The Illinois Agility Test (IAT); participants start by going forward on a straight line and back, then weaving around the center-line cones, and finally, going on a straight line and back again [64].

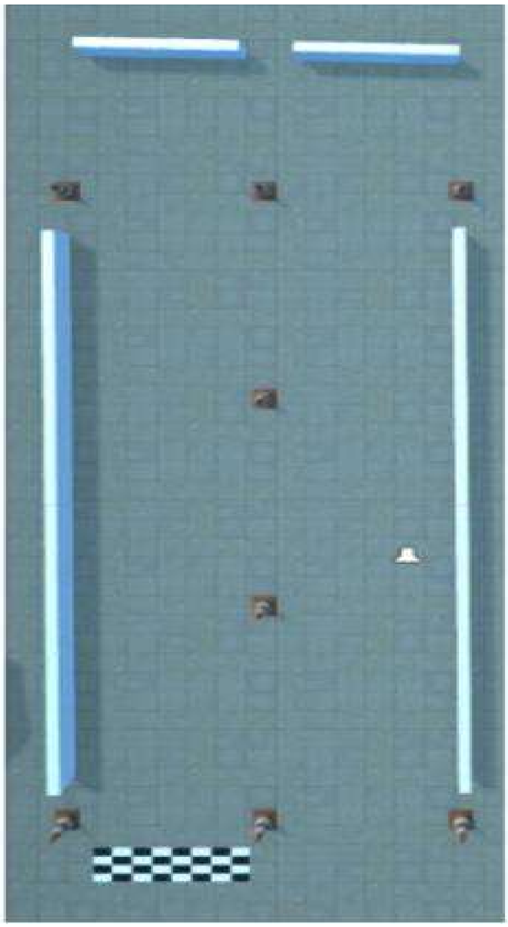

figure 20 Developed test course in the power wheelchair driving simulation in VR, which is based on the Illinois Agility Test.

In the IAT the time taken to complete the run is measured [65]. For the power wheelchair driving simulation in VR the collisions with the traffic cones and the walls are also measured. In figure 20 you can see the developed test course, which is based on the IAT from above.

4.2 Selection of the exercises in the traffic-free area

In the expert interviews the filtered **learning contents** were “power wheelchair controls”, “transfers to and from wheelchair”, “basic mobility skills” and “speed control”. In the power wheelchair driving simulation in VR not all contents can be implemented due to technical limitations. For example, the content “power wheelchair control” is not possible in the current VR application, because the used joystick can no longer be seen when the VR glasses are put on. Thus, the user would have to feel the buttons, and this is not the purpose of the application. Furthermore, the learning content “transfers to and from wheelchair” is not practicable and necessary in the VR environment. In addition, the content “speed control” was not built into the VR environment, because the speed control would have to be via the menu and not via the joystick as in real life. Even if the joystick would have had a speed control it would be the same problem as with the power wheelchair control because the joystick cannot be seen when the VR-headset is on. Indirectly, the content was built in as the driver can influence the speed with the joystick by making large or small joystick movements. But the selection of the speed level is not integrated. These limitations resulted in that the learning content that was included in the power wheelchair driving simulation in VR is “basic mobility skills”.

In figure 13 you can see the filtered **mobility skills** which are used in practice. Not all exercises can be integrated into the power wheelchair driving simulation in VR due to technical limitations. The exercise “turns power on and off” will not be included in the power wheelchair driving simulation, because the button cannot be seen when the VR glasses are put on. As a result, the user would have to feel the button, and this is not the purpose of the application. The same procedure applies to “changes speed setting”. The reason for the exclusion is described in the previous paragraph in the exclusion of the learning content “speed control”. Also, the exercise “moving on a gravel” will not be part of the power wheelchair driving simulation. The driving behaviour on the gravel road cannot be reproduced realistically by the *Unity 3D* programme and therefore the exercise makes little sense in VR. This results in the following 12 exercises in the power wheelchair driving simulation in VR:

- Rolls forward short distance and stops
- Ascends slight incline
- Ascends slight incline and stops
- Descends slight incline and stops
- Changes speed setting

- Turns in place (180°)
- Turns while moving forward
- Can avoid obstacles while moving
- Descends slight incline
- Getting onto a sidewalk
- Going down a sidewalk
- Driving on sidewalk

Like learning to drive with a car, the first practice is in an exercise park before driving in the “real” traffic. Therefore, some of the selected exercises in the traffic-free area are combined with the test protocol of the Austrian Driving Test Ordinance for cars [69]. The exercise “can avoid obstacle while moving” will be developed based on two of the exercises of the test protocol of the Austrian Driving Test Ordinance for cars which you can see in figure 21 and figure 22.

figure 21 Slow slalom includes 6 traffic cones [69].

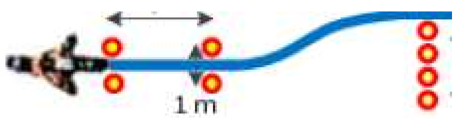

figure 22 Exercise avoiding an obstacle, the traffic cones that are passed through are 1 m apart [69].

The **specific training techniques** for powered wheelchair training used in VR will be verbal cues (semi-supervised instructions, collision noise), visual cues (placed barriers and objects) and the exercises will be developed in an obstacle course. As in the expert interview, one expert expressed the need for a fixed obstacle course which could be used repeatedly to compare the driving performance better. Also, the user can drive through the obstacle course with trial-and-error and if it is necessary the instructor can demonstrate driving with using the client`s joystick or hand over hand guidance.

One finding of the expert interviews was that it is mainly the easy and medium basic mobility skills that are trained in a power wheelchair training. And all experts believed that the power wheelchair driving simulation in VR can be a good training option for training dangerous situations, joystick control, and for training in different scenarios. Therefore, the power wheelchair driving simulation in VR is particularly designed that the joystick control is trained in the basic mobility skills. A non-goal of this thesis is to create an assessment for the driving performance, whereas the aim is to create the exercises in the traffic-free area that way. Thus the exercises are comparable and repeatable.

4.3 Implementation of the exercises in the traffic-free area

The twelve exercises selected from the basic mobility skills are combined and trained in six exercises. For this purpose, the surrounding “skill races against time” of the application WheelSim VR was used to integrate the conceptual designed and developed exercises. The used assets like traffic cones and barriers were provided in the WheelSim VR project of LIFEtool. The collided objects are counted and can be read out after the finished run in the driving logs. The results are only counted because of the comparability to other runs, and they are not analysed in more detail while testing with the test user. For the objects, either colliders or triggers were used, depending on the needs. A collision with a box collider contains information about physics and affects the physics that is why it is not possible to drive through the object. Where an invisible box with a trigger will not affect physics directly and can be handled like an event. Like for exercise four when the driver arrives the arrow the next object is displayed. In figure 23 you can see the surface for these settings in *Unity 3D*.

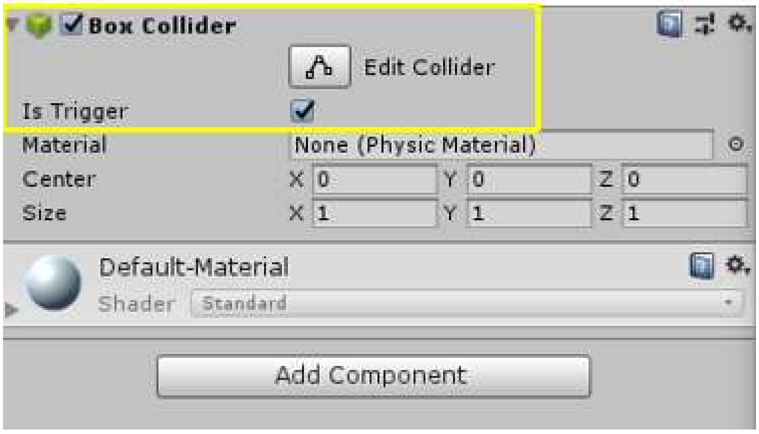

figure 23 Settings in Unity for Box collider and trigger.

The created variables were defined in the public class Gamestatics as a public static GameObject and as a private GameObject. This means that the component can be accessed from any task in *Unity* and then can be added where it is needed. In addition, tags are used for the objects. Tags help to identify GameObjects for scripting purposes. They ensure you don't need to manually add GameObjects to a script's exposed properties using drag and drop [70].

In addition to the collisions presented below in the exercises, collisions with the walls of the track and traffic barriers are also counted as collision count. The driver completes two laps of the obstacle course and gets verbal instructions from the instructor. The driver sees the obstacle course in VR and the instructor sees the same on the screen. The graphical representation and technical implementation of the exercises in the traffic-free area are shown below.

4.3.1 Rolls forward short distance and stops

verbal instruction: drive straight ahead and stop just before the barrier.

Case 1: If you succeed, the barrier will disappear. Then wait until the barrier has disappeared completely and continue driving.

Case 2: You have collided with the barrier. Drive backwards one meter and then drive again straight ahead and stop in front of the barrier. Then wait until the barrier has disappeared and continue driving.

Coding: In Unity an invisible box is created in front of the barrier (see figure 24) with an active trigger and the tag "Hindernis1". If this point is reached, the obstacle disappears, and you can continue driving (see figure 25). Enclosed the code can be found:

```
Private void OnTriggerEnter(Collider other)
{
   var colliderTag = other.gameObject.tag;
   var drivingLog= GameStatics.Player.GetDrivingLog();

   switch (colliderTag)
   {
      case “Hindernis1”:
         removeHindernis1=true;
         break;
```

```
private void Update()
{
   if (removeHindernis1==true)
   {
      var position = GameStatics.Hindernis_1.transform.localPosition;
```

```
      if (position.y > -10)
      {
         position.y -=.2f * Time.deltaTime;
         GameStatics.Hindernis_1.transform.localPosition = position;
      }
   }
}
```

Listing 1 Code for removing the barrier.

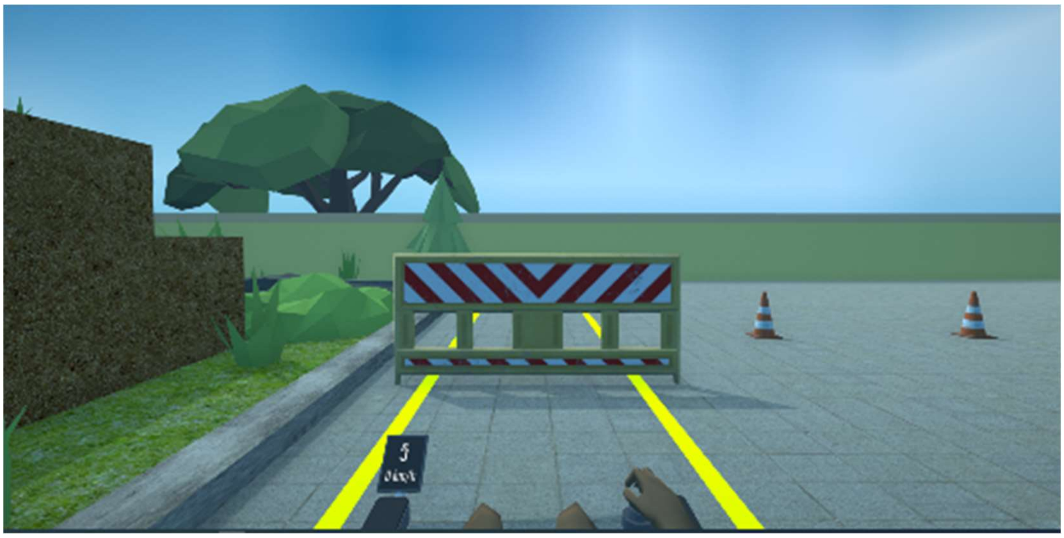

figure 24 Exercise1 - Rolls forward short distance and stops. WheelSim VR Image courtesy of LIFEtool.

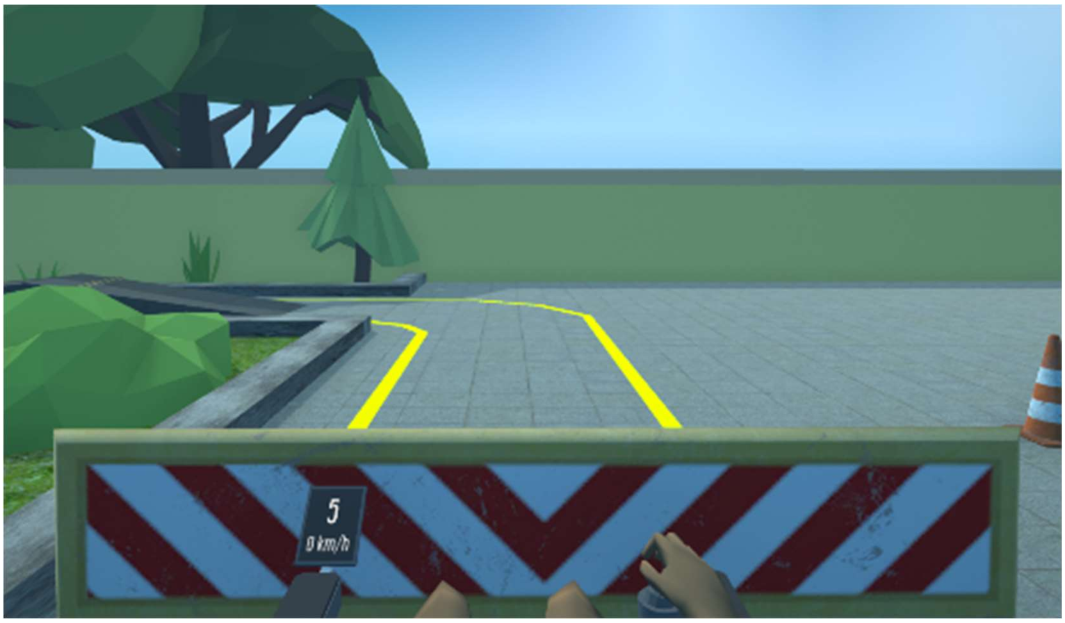

figure 25 Exercise1 - Barrier removes after stopping in front of it. WheelSim VR Image courtesy of LIFEtool.

Case 2: If the driver has a collision with the barrier, it remains in the start position. The driver must drive backwards and try it again. A collision is counted in the driving logs and a collision sound is played. Enclosed the code for case two can be found:

```
voidOnCollisionEnter (Collison collision)
{
   var collisonTag= collision.gameObjekt.tag;
   var drivingLog = Gamestatics.Player.GetDrivingLog();

   switch (collisionTag)
   {
      case"Hindernis1":
         removeHindernis1= false;
         drivingLog.GetLogData().KollisionenMitHindernis1 +=1;
         GamesStatics.Hindernis1.transform.localPosition=
hindernis1StartPos;
         SoundPlayer.Play(Sound.Collision);
         break;
}
```

Listing 2 Code if collision with the barrier happen.

4.3.2 Ascends and descends slight incline and stops two times

Verbal instructions: Drive up the ramp and stop at the first line. Then continue and stop at the second line. After stopping continue driving. In figure 26 the ramp is represented. And in figure 27 a closer shot of the exercise is shown.

figure 26 Exercise 2 - Ascends and descends slight incline and stops two times. WheelSim VR Image courtesy of LIFEtool.

figure 27 Exercise 2 - Closer shot of ascends slight incline and stop. WheelSim VR Image courtesy of LIFEtool.

4.3.3 Turns while moving forward

No verbal instruction is given. The yellow lines should clarify that a turn has to be made as you can see in figure 28.

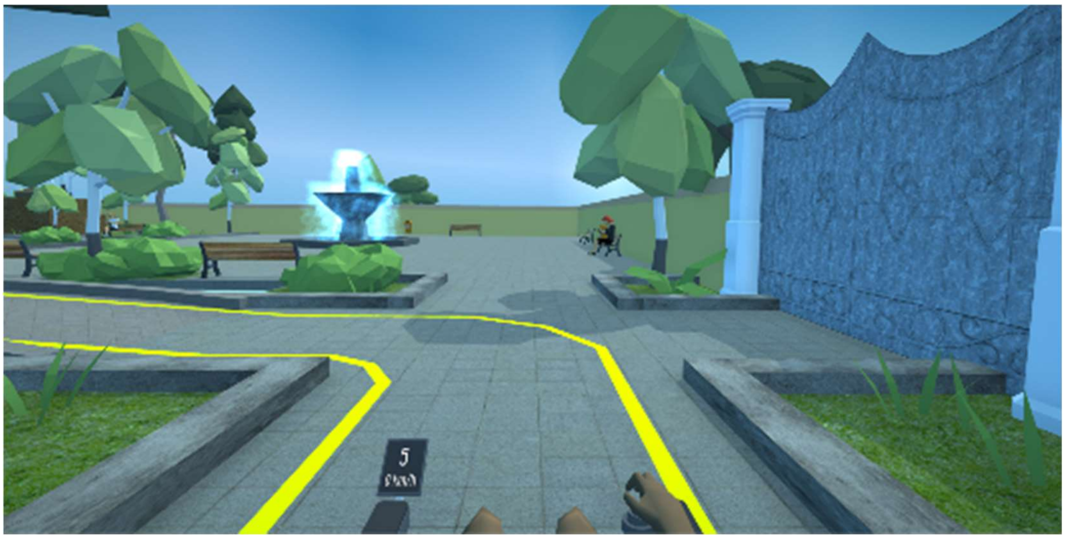

figure 28 Exercise 3 -Turns while moving forward. WheelSim VR Image courtesy of LIFEtool.

4.3.4 Turns in place (180°)

Verbal instructions: An arrow will appear on the ground in front of you. Turn 180° at this point and drive to the next arrow where you turn around again.

figure 29 Exercise 4 - Turns in place (180°) first arrow. WheelSim VR Image courtesy of LIFEtool.

Coding: In Unity an invisible box is created on the first arrow(see figure 29) with an active trigger and the tag "Umdrehen2Einblenden". If this is passed, the second arrow is shown (see figure 30). Enclosed the code is shown:

```
Private void OnTriggerEnter(Collider other)
{
   var colliderTag = other.gameObject.tag;
   var drivingLog= GameStatics.Player.GetDrivingLog();

   switch (colliderTag)
   {
      case “Umdrehen2Einblenden”:
         GameStatics.Umdrehen_2.SetActive(true);
         break;
   }
```

Listing 3 Code to set arrow 2 active.

figure 30 Exercise 4 - Turns in place (180°) second arrow. WheelSim VR Image courtesy of LIFEtool.

4.3.5 Can avoid obstacles while moving

Verbal instruction: Drive in a slalom through the traffic cones. Start on the left-hand side. Avoid collisions with the traffic cones.

In the slalom exercise(see figure 31) the driver runs around the traffic cones and in the exercise passing through (see in figure 32) the driver must drive between the traffic cones.

figure 31 Exercise 5 - Can avoid obstacles while moving - Slalom. WheelSim VR Image courtesy of LIFEtool.

Verbal instruction: Pass the barrier on the left and drive straight between the 4 traffic cones.

figure 32 Exercise 5 - Can avoid obstacles while moving - passing through traffic cones. WheelSim VR Image courtesy of LIFEtool.

Coding: Enclosed is the code that the collisions with the traffic cones can be read out in the driving logs.

```
voidOnCollisionEnter (Collison collision)
{
   var collisonTag= collision.gameObjekt.tag;
   var drivingLog = Gamestatics.Player.GetDrivingLog();

   switch (collisionTag)
   {
      case"TrafficCone":
         drivingLog.GetLogData().KollisionenMitVerkehrshuetchen+=1;
         break;
   }
}
```

Listing 4 Code to read the collisions with the traffic cones in the driving logs

4.3.6 Getting onto and down a sidewalk and drive on the sidewalk

Verbal instruction: Drive up onto the sidewalk and drive straight ahead without leaving it on the right or left.

In figure 33 you can see the sidewalk on which the driver should drive onto and should not leave the sidewalk. If the driver leaves the sidewalk, it will be counted as a “Kollisionen mit dem Gehsteigrand”.

figure 33 Exercise 6 - Getting onto and down a sidewalk and drive on the sidewalk. WheelSim VR Image courtesy of LIFEtool.

Coding: In Unity, an invisible box is created to the left and right of the sidewalk with an active trigger and the tag "GehsteigRand". Enclosed the code for the output in the driving logs:

```
Private void OnTriggerEnter(Collider other)
{
   var colliderTag = other.gameObject.tag;
   var drivingLog= GameStatics.Player.GetDrivingLog();

   switch (colliderTag)
   {
      case "GehsteigRand":
         drivingLog.GetLogData().KollisionenMitGehsteigrand+=1;
         break;
   }
}
```

Listing 5 Code to read the collisions with the edge of the sidewalk in the driving logs.

4.3.6.1 Test course - Illinois Agility Test

The exact test procedure and the developed course based on the IAT is shown in chapter 4.1.3. During the test, the collisions with the wall and with the traffic cones are counted and are shown in the driving logs. A start and finish line are displayed so that the time can be measured accurately.

figure 34 Conceptual designed and developed test course -
based on the Illinois Agility Test. WheelSim VR Image courtesy of LIFEtool.

Coding: In Unity, an invisible box collider is created with an active trigger and the tag "StartlinieAusblenden" and in the middle of the run an invisible box collider is created with an active trigger and the tag "ZiellinieEinblenden". Enclosed the code is shown:

```
Private void OnTriggerEnter(Collider other)
{
   var colliderTag = other.gameObject.tag;
   var drivingLog= GameStatics.Player.GetDrivingLog();

   switch (colliderTag)
   {
      case "StartlinieAusblenden":
         GameStatics.Startlinie.SetActive(false);
         break;

      case "ZiellinieEinblenden":
         GameStatics.Ziellinie.SetActive(true);
         break;
   }
}
```

Listing 6 Code to hide the start line and to show the finish line.

The functional and technical requirements and the developed and integrated exercises in WheelSim VR are tested by test users in the evaluation.

5 Evaluation of a power wheelchair driving simulation in VR

To evaluate the developed exercises in the traffic-free area of a power wheelchair driving simulation in VR, a heuristic evaluation approach, pioneered by Nielsen and Molich [71] was chosen. A heuristic evaluation describes a review of a product by experts, typically usability experts or experts in the products domain. For this thesis, five user tests followed by semi-structured expert interviews and SUS (System Usability Scale) questionnaire were conducted. For the user-based testing a group of representative users must be selected [59, p. 260]. In this thesis five occupational therapists were selected for the user-based testing, as the usability test with people with disabilities who need a power wheelchair as a mobility aid was not possible due to Covid-19 in Austria (due to the fact that those belong to vulnerable groups). The data derived from the usability testing of the developed exercises in the traffic-free area, the SUS questionnaire and the interviews were analyzed. Extracted points and statements relevant to the functional requirements of the power wheelchair driving simulation in VR and the research questions of this thesis were gathered and used to evaluate the feasibility and usability of the prototype [72, pp. 61–64]. Insights into the specific setup of the evaluation is given in chapter 5.1. An evaluation of the testing results, the SUS score, and the expert interview results can be found in chapter 5.2 Evaluation results and in chapter 5.3 the findings are described.

5.1 Setup of the evaluation

Participants

Comparable to the semi-structured interviews to understand the training processes, tools, and techniques that are currently used in practice of wheelchair training in chapter 3.1 occupational therapists were selected for the usability testing. Experts have technical process orientated and interpretative knowledge on topics relevant to their specific professional activity. Which means that expert knowledge does not only consist of reproduceable and accessible knowledge, but also of practical knowledge acquired by the expert [59, p. 273]. To benefit from the practical knowledge of occupational therapist in instructing power wheelchair training, a panel of five occupational therapists who have at least two years of professional experience with clients using a wheelchair was chosen. Five test user were conducted, because according to Virzi five users will find approximately 80% of usability problems in an interface [73]. A detailed list of all participants, their work experience and their respective medical field can be seen in Table 9 Participants of the expert interview of the usability test.

Participant	Work experience as occupational therapist	Medical field
P1	14 years	neurology and geriatrics
P2	11 years	neurology and geriatrics
P3	8 years	neurology and geriatrics
P4	7 years	neurology
P5	10 years	neurology and geriatrics

Table 9 Participants of the expert interview of the usability test.

Design & Procedure

The evaluation tests were conducted individually and in compliance with the hygiene guidelines in face of the current Covid-19 situation, which is explained in Appendix C. Also, all participants signed a form of consent (see Appendix A). As an introduction into the topic the aim of the master thesis was explained, followed by an introduction regarding the principles of VR. Furthermore, an explanation of the driving simulator WheelSim VR was given. The testing was carried out according to the testing guideline, which can be found in Appendix D. After adjusting the VR headset (lens) and the fit of the VR headset and the explanation and practice of the joystick in the practice park the testing procedure started. The test user drove one round in the test course (based on the Illinois Agility Test) then two rounds in the developed obstacle course in the traffic-free area. And lastly, the test was finished by one round of the test course. During the runs on the test course, the parameters time and collisions were noted and compared in retrospect. By means of a semi-structured expert interview and SUS (System Usability Scale) questionnaire the complete test procedure was finalized.

The SUS questionnaire can be analysed with a standardized scale. This scale is described to be reliable and of low cost. It has been proven as a valuable evaluation tool that measures usability. The questionnaire as well as the assessment guidelines are freely available [74].The questionnaire consists of ten predefined questions about system usability. The answers of the SUS questionnaire are valued with a Likert Scale which means that the participants can disagree or agree to a statement on a five-point scale starting from “strongly disagree” to “strongly agree”. The SUS Score is composed of ten statements:

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

The SUS questionnaire is presented in the Appendix E. For the questioning of the power wheelchair driving simulation in VR, the statements got translated into German. The statements get scored on a five-point scale which evaluates the strength of agreement. The statements alternate between negative and positive statements which has to be considered in the evaluation[75]. The whole evaluation process is shown in figure 35.

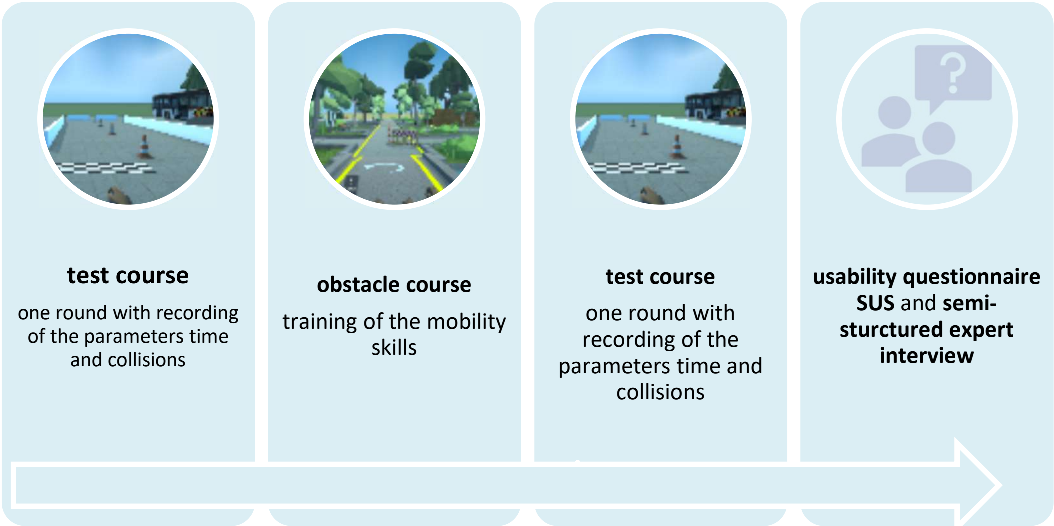

figure 35 Evaluation process.

Apparatus & Materials

For further analysis and to document the interviews, the interviews were audio recorded, and notes were taken by the interviewer. Supported by the interviewer´s notes, the transcripts were analysed for the evaluation. In the subsequent chapter the results are presented and discussed.

5.2 Evaluation results

This section deals with the upcoming results. The section is separated in three subitems – the testing results, the SUS score, and the expert interview results.

5.2.1 Testing

Every participant completed the two test runs and the obstacle course with semi-supervised verbal instructions. The parameters time and collisions were noted and in retrospect compared. As you can see in Table 10 all participants were able to complete the second run of the test course faster. The biggest difference between test course 1 and test course 2 was a time difference of 30 seconds by participant 1. Three seconds was the smallest difference by participant 3. It resulted in an average improvement of 17.2 seconds from test course 1 to 2.

	Time in seconds of the participants					
	P1	P2	P3	P4	P5	average
test course 1	129 sec	104 sec	92 sec	115 sec	118 sec	111.6 sec
test course 2	99 sec	93 sec	89 sec	95 sec	96 sec	94.4 sec
difference	30 sec	11 sec	3 sec	20 sec	22 sec	17.2 sec

Table 10 Time needed in seconds in test run 1 and test run 2.

Table 11 shows the number of collisions in the test course 1 and test course 2. It is like with the parameter time all participants reduced the number of collisions in the second test run. The lowest difference of number of collisions (participant 1) was one. The highest number of collisions (participant 3) was seven in the test course 1 and zero collisions in the test course 2. It resulted in an average reduction of 3.2 collisions in test course 2 in comparison to test course 1.

	Number of collisions of the participants					
	P1	P2	P3	P4	P5	average
test course 1	1	5	4	6	7	4.6
test course 2	0	2	1	4	0	1.4
difference	1	3	3	2	7	3.2

Table 11 Number of collisions in test run 1 and test run 2.

5.2.2 System Usability Scale

Every participant answered all ten questions of the questionnaire. Thus, every questionnaire can be used for the evaluation. The final system usability scores can reach from zero to one hundred. The higher the score the better is the usability of the tested system. To calculate the SUS score, first the scores from each item are summed up. Each item's score contribution will range from zero to four. For items one, three, five, seven ,and nine the score contribution is the scale position minus one. For items two, four, six, eight, and ten, the contribution is five minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SUS [74]. The outcome of the evaluation is illustrated in Table 12.

Participant	Question										SUS Score
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	
P1	4	4	4	4	4	4	3	4	4	3	**95.0**
P2	1	4	4	4	4	4	4	4	4	4	**92.5**
P3	3	4	3	2	4	4	3	3	2	4	**80.0**
P4	3	4	4	0	1	4	4	4	4	4	**80.0**
P5	4	4	4	4	4	4	4	4	4	4	**100.0**
							Total SUS score:				**89.5**

Table 12 Total SUS score

The power wheelchair driving simulation in VR reached an average SUS Score of 89.5. The total SUS score does not allow a statement to which extent the system is usable. It must be further defined by a rating scale. Preferred scales included: adjective rating, acceptability ranges, and school grading scales[75]. In figure 36 the different rating scales in relation to the SUS scores are illustrated. The adjective ratings scale was chosen for this thesis.

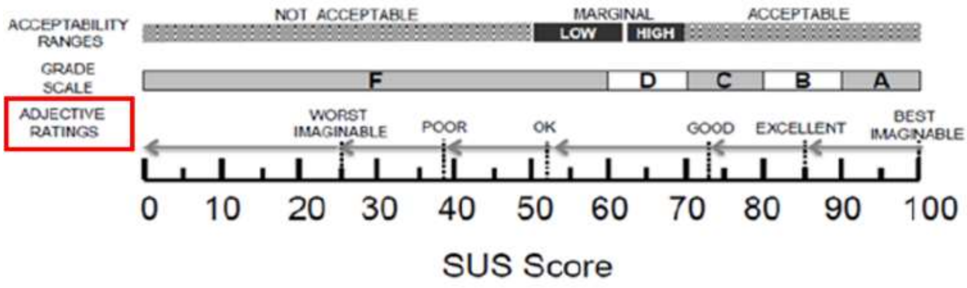

figure 36 Rating scales (acceptability ranges, grade scale, adjective ratings) in relation to the total SUS scores [74].

Table 12 demonstrates the outcome of all participants separately. The lowest rating was 80 the highest was 100. The lowest score (participant 3 and 4) is associated with a good usability (80). Participant 1 and 2 classified the application's usability as excellent (95 and 92.5). Participant 5 even rated the usability as best imaginable (100).

5.2.3 Expert interview

In order to gain further insights into usability, a semi-structured expert interview was conducted which can be seen in Appendix F. This was done after the testing and the SUS questionnaire. The first question was about what supported the test user in learning the basic mobility skills for driving a power wheelchair in the driving simulation in VR. All of them answered that the visual representation of the exercises (e.g., yellow street lines, barriers, etc.) and the obvious structure of the obstacle course was helpful. In addition, the acoustic stimuli were very useful in a collision, which was mentioned by all experts. Furthermore, P1 and P3 said that the range of different exercises to learn how to use the joystick (turning, ramp, keeping distances) was rich in variety. P1 said: "I liked that I was able to collide intentionally with an object to see how the wheelchair reacted and I felt very safe". P1 also noted that driving in VR felt very real what she enjoyed very much. P5 mentioned, that the supervised instruction of the exercises was very helpful. The second question dealt with what was obstructive for the test user in learning the basic mobility skills for driving a power wheelchair in the driving simulation in VR. Three of the five test user said that the motion sickness was very limiting for them. When asked what additional elements the power wheelchair driving simulation in VR should be integrated, the following responses were given: Two test users mentioned that the increased use of everyday objects should be included so that the training does not become too fictional. An important input, given by two of the five test users was an ascending level design would be motivating.

All test users agreed that the selected exercises were relevant, and they all were able to complete all exercises independently. Suggestions for improvement included, for example, that the exercise "turns in place (180°)" should not take place on the bridge, as it was very narrow there. Or the exercise "can avoid obstacles while moving" misses the relevance to everyday life, as there are rarely so many obstacles in a row on the ground along a path. It would be better to use objects such as dust bin or pedestrians. Another input was that the sidewalk is not immediately recognisable as a sidewalk because the slanted edge is missing. Furthermore, an integration of different widths, curves of the pavement and oncoming pedestrians would be exciting. As an additional exercise to learn basic mobility skills, the test users would offer reversing and hazard braking. All the test users had the impression that they were able to improve their driving performance with a power wheelchair with the exercises in the obstacle course. Especially the joystick control and the estimation of distances are supported. In addition, everyone felt very safe in power wheelchair driving simulation in VR.

When asked about the experience in the test course at the beginning and at the end of the testing, four test users believed that the test course had the right duration and route. P3 noted that the total time is very short and therefore not as meaningful as the obstacle course. The test was very motivating for the test users as they wanted to improve the result of the first run. The limiting factor in the test is that the motion sickness became very strong in three out of five users especially at the slalom. P5 said:" Arrows on the ground for routing would have been helpful in the testing course".

All the test users would use the power wheelchair driving simulation in VR in their work as occupational therapist for wheelchair training. P1 thinks, that the simulation offers a possibility to clarify if the wheelchair user can handle a power wheelchair. On the one hand as an investigation of motor skills, like the joystick can be controlled with the fingers and on the other hand of the cognitive abilities, like if the driver can learn from the mistakes and whether there is a learning outcome. Moreover, the power wheelchair simulation offers an additional training option for users at home. Suggested adaptations for the power wheelchair driving simulation in VR were that the joystick should be able to be fixed in different positions and additional exchangeable ergonomic grips would be useful. P2 said: *"It would also be useful if the different speeds could be set in a realistic way by the user".* Another input was that the total overview of collisions and time should be displayed automatically for the user *after* each run. P5 noted that motion sickness can be a limitation. As an alternative to VR the power wheelchair driving simulation could be shown on a big screen. When asked which people could benefit most from the power wheelchair simulation in VR four of the test users said that especially young wheelchair users will benefit from it. However, P1 thinks that older people who have no experience with a joystick can benefit from the power wheelchair driving simulation in VR. Another possibility is for wheelchair users for whom driving in the "real world" is still too dangerous. An additional comment from P1 was that the experience was very exciting, funny, and motivating. P1 said: "For me it felt very real, and I think there is also a transfer to everyday life. "

5.3 Evaluation of the findings

The following chapter describes the results of the thesis and summarizes the results of the subcategories usability testing, SUS, and expert interview. The test users reported that the obstacle course helped them to improve their driving performance, especially the joystick control and the estimation of distances. Thus, it can be said that specifically selected exercises improve driving performance. This subjective feeling can be confirmed with the measurable parameters time and collision in the test courses before and after the obstacle course. As you can see in figure 37 and figure 38 each of the test users were faster and had less collisions in the second run compared to the first run.

figure 37 Time needed for the test run 1 and 2 in comparison.

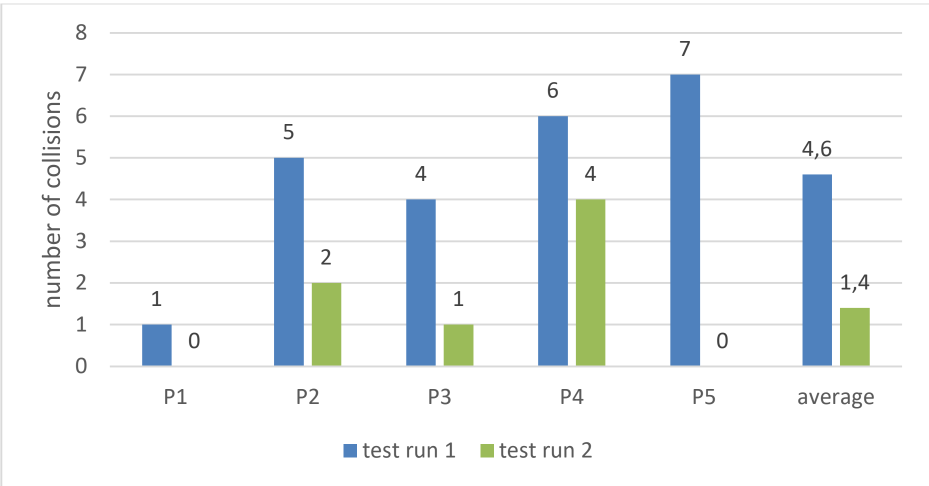

figure 38 Counted collisions in the test run 1 and 2 in comparison.

On closer inspection of the obstacle course, an improvement in the parameters at lap 1 to 2 was also observed. This indicates that repetitions also have an important role on the driving performance.

For usability of the power wheelchair driving simulation in VR, the questionnaire System Usability Scale (SUS) was completed by the test users. A SUS score from zero to fifty is not acceptable, a score from fifty to seventy is marginal. With a score from seventy or higher a system is acceptable [75]. The SUS score of the power wheelchair driving simulation in VR is 89.5 as you can see in figure 39. Also illustrated are the individual SUS scores of each participant. The highest SUS score is 100 and the lowest score is 80. By considering all SUS Score results in the power wheelchair driving simulation in VR, all scores are over 70 and that is why it can be described as an acceptable or excellent usability.

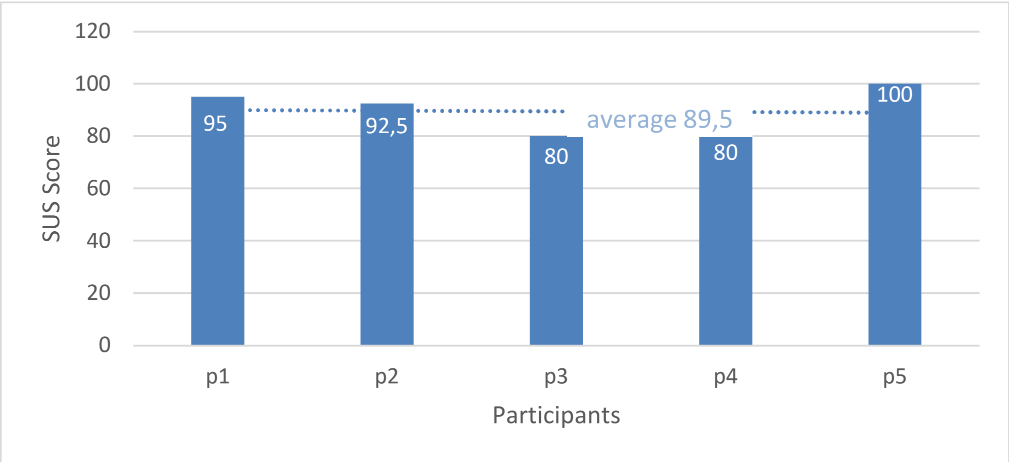

figure 39 SUS Score of the participants.

In the interview it became apparent, that the selected exercises for learning the basic mobility skills in the traffic-free area were relevant for the participants. The structure of the exercises was clearly defined for the test users and suitably presented by visual and acoustic representation. Besides, everyone felt very safe in power wheelchair driving simulation in VR. This proves that VR is a possibility for safe training and accidents in real life can be prevented in the firs learning phase. In addition, there are suggestions for improvement regarding increased relevance to everyday life and specific graphic presentation of the exercises. Also, an important finding was, that an ascending level design would be motivating and the exercises reversing, and hazard braking could be included.

For both, the test course and the obstacle course, the test users reported motion sickness. One test user therefore had to switch to the desktop version. All of the test users would use the power wheelchair driving simulation in VR in their work as occupational therapist for wheelchair training, especially for young wheelchair drivers but also for older people. The test users also mentioned adaptions in the hardware, like a fixed joystick with exchangeable ergonomic grips or that the simulation can be shown on a big screen, if the motion sickness is too strong. Furthermore, they would like to have a possibility to change the speed settings easily and an automatically overview of collisions and time for the user.

6 Discussion

The main goal of this thesis was to design and evaluate a power wheelchair driving simulation in VR. The first goal of this thesis was to give an overview of the state-of-the-art literature research regarding power wheelchair as a mobility aid, guidelines for learning to drive a power wheelchair and VR in training. Followed by the second objective the user-centered design requirement and user need evaluation and the development of a prototype. Lastly, the evaluation of the power wheelchair driving simulation VR with five test users was the final objective.

Considering that powered and manual mobility market globally is projected to grow exponentially due to aging baby boomers and increasing longevity [4] and that wheelchair manoeuvres have an important role in causing injuries of wheelchair users [5] it is important to provide adequate training for power wheelchair training. One possibility is the training environment VR. As VR is already used for learning car driving skills [51]. The VR driving simulator is used to teach driving a car in a safe environment using cognitive learning methods and gamification [52]. Given the need for cognitive learning methods and the gamification in wheelchair learning environments, VR was also seen as an appropriate concept for this thesis. However, the simulations are highly limited and are mainly used for research purposes at universities [55] [56] [57]. The wheelchair driving simulation in VR WheelSim VR was chosen for this work, because this is the only product that aims to be a training tool for wheelchair users at home or in the clinic. Another reason is that WheelSim VR was developed with the inclusion of people with mobility impairments and was developed of the Austrian company LIFEtool [8]. In this thesis WheelSim VR was further developed. A power wheelchair driving simulation offers flexibility for safely evaluating the individual’s driving and it makes it possible to measure numerous variables involved in the driving process [6] and this symbolizes a great promise.

Driving a power wheelchair is a complex activity and that is why the development of a power wheelchair driving simulation in VR is also complicated. In the literature 110 skills and abilities are mentioned which are needed to drive a power wheelchair [41]. In order to integrate the most important skills and abilities in the power wheelchair driving simulation in VR three evidence-based guidelines for learning to drive a power wheelchair were compared. The guidelines were Wheelchair Skills Program, Obstacle Course Assessment for Wheelchair User Performance and Power Mobility Community Driving Assessment [33] [34] [35]. After the literature review, the requirements and user needs were evaluated through a semi-structured interview with experts. The exercises from each guideline were compared and were rated by the experts in the semi-structured expert interviews. The data collected through the semi-structured expert interviews and the literature research allowed the specification of functional requirements and development of the prototype according to the user-centered design. Skills which were used in practice and were technically feasible, were filtered and implemented in the power wheelchair driving simulation in VR. The selected exercises in the traffic-free area were:

- Rolls forward short distance and stops
- Ascends and descends slight incline and stops two times
- Turns while moving forward
- Turns in place (180°)
- Can avoid obstacles while moving
- Getting onto and down a sidewalk and drive on the sidewalk

The exercises were set up in an obstacle course, because in the expert interviews the demand for a comparable obstacle course came up, where in the literature a constant obstacle course is also used in the Wheelchair Skills Program [39]. Furthermore, in the expert interview mentioned learning contents like specific training techniques and structure of the wheelchair training were analysed and implemented in the prototype. In the expert interviews it became also apparent that mainly the easy and medium basic mobility skills are trained in the real world. Therefore, the developed exercises in the traffic-free area also focuses on these basic mobility skills. In the interviews it came up that in practice no measurable parameters are collected for wheelchair training, but the need is there. With a simulation VR it is possible to measure numerous variables involved in the driving process [6] that is why the two parameters time and collision were collected in the test course of the prototype.

The assumption that a power wheelchair driving simulation in VR can improve the driving performance was confirmed by conducting the usability tests, the questionnaire SUS and semi-structured interviews. The test user drove one round in the test course (based on the Illinois Agility Test) then two rounds in the developed obstacle course in the traffic-free area. And lastly, the test was finished by one round of the test course and was compared retrospective with the test course at the beginning. Each of the participants demonstrated an improvement in driving performance in test run two compared to test run one. Furthermore, the following questionnaire SUS showed very good results. The SUS score of the power wheelchair driving simulation in VR is 89.5. The lowest rating of the SUS score was 80 and the highest was 100. Two participants valued the usability as good, two participants as excellent and one participant even rated the usability as best imaginable. Furthermore, all tasks were able to be executed successfully and the participants received and understood of the software rather well. They reported that they would use such an application in the future.

According to Carlosson et al. a proper training program will contribute to increased safety and mobility for power wheelchair drivers [5]. In the final semi-structured expert interviews, it was confirmed that the developed power wheelchair driving simulation in VR is a proper training program, because all participants reported that all of them felt very safe in the power wheelchair driving simulation in VR and the obstacle course helped them to improve their driving performance, especially the joystick control and the estimation of distances. Thus, it can be said that specifically selected exercises improve driving performance. This subjective feeling can be confirmed with the measurable parameters time and collision in the test courses before and after the obstacle course. Each of the test users were faster and had less collisions in the second run compared to the first run. Further findings are that the selected exercises for learning the basic mobility skills in the traffic-free area were relevant for the participants. The structure of the exercises was clearly defined for the test users and suitably presented by visual and acoustic representation. Besides, everyone felt very safe in power wheelchair driving simulation in VR. This shows that VR is a possibility for safe training and accidents in real life can be prevented in the first learning phase. The prototype has the potential to include two phases of motor learning. The motor learning exists of acquisition, retention, and transfer of skills [38, pp. 2–25]. The first two can be integrated like acquisition is the initial practice or performance of a new skill. This can be trained in the prototype. Additionally, retention is the ability to demonstrate attainment of the goal or improvement in some aspect, following a short or long-time delay in which the task is not practiced. This is achieved by training several times on different days. The third phase, transfer requires the performance of a task similar in movement yet different from the original task practiced in the acquisition phase. This means the transfer from driving in VR in the real world and that would require further research.

Limitations

Although literature describes that five subjects are sufficient for a usability test, the sample size is still very small [76]. In this thesis five occupational therapists were selected for the user-based testing, as the usability test with people with disabilities who need a power wheelchair as a mobility aid was not possible due to Covid-19 in Austria. Further tests with people with the need for a power wheelchair as mobility aid would help to improve the application and to continue development of new functionality. Another limitation is the very homogeneous sample. All participants are occupational therapists who work in the field of neurology and geriatrics. All of them work in an urban space and work in a rehabilitation centre. Further studies should be done with occupational therapist from further medical fields like from paediatrics or orthopaedics from the city.

Furthermore, the test course where the parameters time and number of collisions were collected is with an average duration of 74 seconds very short and therefore only of limited significance. Future studies should consider more precise parameters, such as acceleration, cruising radius and velocity could be integrated for a more precise analysis of the driving performance in the test course.

An additional limitation for the deployment of the power wheelchair driving simulation in VR is the user interface. A VR hardware and a joystick to control the application is needed. Controlling with the computer's arrow keys is not very close to reality because you cannot extend straight and steer to the right at the same time.

Finally, four of the five test users reported as well in test course and the obstacle course motion sickness. The test subjects were healthy people, so it is essential that further investigations are conducted on people with special needs.

7 Conclusion

The demographic change of the current society will increase the demand of powered wheelchair mobility. One of the challenges is to ensure that wheelchair users can adequately use the power wheelchair without causing accidents leading to injuries. One way to increase the adequate use of power wheelchairs is to use and develop technology-supported learning environments. More specifically, VR is one possibility. Therefore, VR and how it can be used for developing better power wheelchair driving skills is examined in more detail in this thesis. Studies indicate that like driving simulation with a car, a wheelchair driving simulation in VR will increase safety and mobility skills. To answer the research questions of this thesis, an existing WheelSim VR application of LIFEtool was ongoing technical developed and tested. The development was done based on a user-centered design approach, making use of a semi-structured expert interviews to set functional requirements and expert interviews after the usability tests to evaluate the developed prototype.

The main research question was, if exercise in a traffic-free area in a VR power wheelchair simulation can improve driving performance for a selected group of wheelchair trainers. To answer the question the findings of the usability test, SUS questionnaire and the semi-structured interview with five experts were used. Furthermore, in the testing, the quantitative measurements time and number of collisions were collected and evaluated. The findings suggest that the developed exercises in the traffic-free area improved the driving performance. Two aspects underline this finding. First of all, the test users reported a subjective improvement in driving performance. And secondly, the measurement of quantitative parameters also showed an improvement in driving performance. Furthermore, all users were able to complete all tasks on the testing guideline without any issues. Which indicates no major usability problems. In addition, the questionnaire SUS showed very good results. It can be said that specifically selected exercises improve driving performance. The structure of the exercises was clearly defined for the test users and suitably presented by visual and acoustic representation. Besides, everyone felt very safe in power wheelchair driving simulation in VR. Suggestions for improvement included the graphic representation of the exercise and the increased use of everyday objects instead of abstract objects, such as traffic cones.

The first sub question was about which exercises from manual and power wheelchair training can be found in literature and by expert interview with wheelchair trainers. The question was answered with literature and semi-structured expert interviews with three occupational therapists. The experts helped to understand how the power wheelchair training is set up in “real world” and which parameters the trainers observe. A total of six exercises which were used in practice and were technically feasible, filtered and implemented in the power wheelchair driving simulation in VR.

The second sub question was, on how wheelchair driving safety can be assessed, evaluated, and used in simulative VR power wheelchair training. To answer this research question, five experts tested the prototype based on literature and an individual semi-structured interviews were conducted. Based on the Illinois agility test, which is an existing and well-known test to evaluate the driving performance of wheelchair drivers, the qualitative parameters time and collisions were recorded in the test course before and after the obstacle course in the traffic-free area.

In this regard, this thesis points out very interesting points, such as the use of the power wheelchair driving simulation in VR on the one hand as additional home training for wheelchair users and on the other hand as an evaluation tool for wheelchair trainers or health insurances. In the future, a kind of certificate or “wheelchair driving license” could be developed to ensure that the wheelchair user can drive safely in everyday life and in road traffic. This could serve as a decision-making basis for health insurances if they will finance a wheelchair. In relation to this, it would still be necessary to survey if the training in VR has an impact on driving with the power wheelchair in the real world.

In this thesis, the first simple technical parameters of time and number of collisions were collected in the test course and in the obstacle course. The developed exercises in the traffic-free area are important for improving the driving performance, but unfortunately there is no automated interpretation yet. This means an ongoing technical development of the driving parameters for a precise driving analysis. For example, how far in front of the obstacle does the driver stop or what is the distance to the obstacle when passing. In addition, the proposed graphic improvements of the exercises and the adaptations of the hardware should be carried out. Furthermore, an ascending level design would be meaningful. As of now, VR is still limited through the phenomenon of motion sickness further research to reduce motion sickness is needed.

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Abbreviations

IAT	Illinois Agility Test
OCAWUP	Obstacle Course Assessment for Wheelchair User Performance
PCDA	Power Mobility Community Driving Assessment
PMD	Power mobility device
UCD	User-centered design
VR	Virtual Reality
WSP	Wheelchair skills program
WST	wheelchair skills test

Appendix

A Declaration of Consent

Gegenstand des Forschungsprojekts und Grundlage der Einwilligungserklärung

Forschungsprojekt: Design, Entwicklung und Usability-Testung einer Elektrorollstuhl Fahrsimulation in Virtual Reality.

Beschreibung des Forschungsprojekts: Die Masterarbeit befasst sich mit Design, Entwicklung und Usability-Testung einer Elektrorollstuhl Fahrsimulation in Virtual Reality. Der Fokus bei dem Interview liegt auf den Erfahrungen von Ergotherapeut*innen als Trainer*innen beim Rollstuhltraining mit dem Elektrorollstuhl für Patient*innen.

Ich bin daran interessiert, alle Trainingsprozesse, Werkzeuge und Techniken zu verstehen, die Sie derzeit in Ihrer Praxis verwenden.

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Kontaktdaten der verantwortlichen Person: E-Mail-Adresse: dh191824@fhstp.ac.at

Art der personenbezogenen Daten des Betroffenen (der interviewten Person) / besondere Kategorien personenbezogener Daten:

Persönliche Angaben, nämlich: Berufserfahrung in Dienstjahren, Fachbereich

Aufnahmen, nämlich insbesondere: Tonaufnahmen, Abschriften und Notizen

Einwilligungserklärung der betroffenen Person

Das Interview wird vom Autor aufgezeichnet und transkribiert. Alle Daten, die eine Identifizierung der interviewten Person ermöglichen würden, werden verändert oder aus dem Transkript entfernt (pseudonymisiert). Um dem Leser einen Kontext zu geben, werden in der Arbeit nur Teile des Interviews zitiert.

Die persönlichen Daten werden unabhängig von den Interviewdaten gespeichert und nach Abschluss der Arbeit gelöscht.

Die Teilnahme an den Interviews ist freiwillig. Sie können das Interview jederzeit abbrechen, Ihre Zustimmung zur Aufzeichnung und zur Abschrift des Interviews widerrufen, ohne dass Ihnen dadurch Nachteile entstehen.

Mit Ihrer Unterschrift erklären Sie sich mit der Teilnahme an dem Interview und mit der Verwendung der erhobenen Daten für eine Masterarbeit einverstanden. Alle Daten werden aufgezeichnet, gespeichert und verarbeitet. Die Daten werden nicht für andere oder kommerzielle Projekte verwendet.

____

Vor-, Nachname

____

Ort, Datum, Unterschrift

B Expert interview Guideline

Experten Interview

Die folgenden Fragen beziehen sich auf Ihre Erfahrungen als Trainer beim **Rollstuhltraining mit dem Elektrorollstuhl** für Patienten. Ich bin daran interessiert, alle Trainingsprozesse, Werkzeuge und Techniken zu verstehen, die Sie derzeit in Ihrer Praxis verwenden.

Demografische Fragen

Seit wann sind Sie Ergotherapeut*in?

Im welchen Fachbereich arbeiten Sie?

Rollstuhltraining mit Elektrorollstuhl

1. **Verwenden Sie evidenzbasierte Trainingsprogramme für Rollstuhlfahrer in Ihrer Arbeit?** *Evidenzbasierte Trainingsprogramme für Rollstuhlfahrer sind solche, die durch wissenschaftliche Forschungsergebnisse gestützt und in begutachteter Literatur dokumentiert sind.*

	Ja	Nein
Ich verwende evidenzbasierte Rollstuhl-Trainingsprogramme		

2. **Welche Lerninhalte beinhaltet ihr Rollstuhltraining typischerweise?**

	Immer	Manchmal	Selten	Nie
Bedienelemente des Elektrorollstuhls (z. B. Ein-/Ausschaltendes Rollstuhls, Kipp/Legefunktionen)				
Transfers zum und vom Rollstuhl				
Grundlegende Mobilitätsfähigkeiten (Manövrieren um Hindernisse, Kurven, Rampen, geradeaus fahren, stoppen)				
Fahrregeln (Position in Gängen, auf Gehsteigen)				
Geschwindigkeitskontrolle (z.B., Geschwindigkeitsauswahl)				
Einbindung des Elektrorollstuhls in die Aktivitäten des täglichen Lebens (ADL) und I-ADL´s (z. B. Körperpflege, Anziehen, Kochen, Putzen)				
Nutzung von Öffentliche Verkehrsmitteln				
Navigieren in der Umgebung (z. B., Routenplanung, Problemlösung)				
Notfallmaßnahmen (z. B. Anfordern von Hilfe)				
Verkehrsregeln, Verhalten im Straßenverkehr				
Anmerkungen:				

3. Bitter ordnen Sie die grundlegende Mobilitätsfähigkeit den Schweregrad der Übung zu. *Es wird davon ausgegangen das erste Mal einen Elektrorollstuhl zu bedienen.*

	Leicht	Mittel	Mäßig schwer	schwer	
Rollstuhl ein und ausschalten					
Geschwindigkeit verändern					
Vorwärts fahren und stoppen					
Rückwärts fahren und stoppen					
Am Platz drehen (180°)					
Spur verändern während des Vorwärtsfahrens (90°)					
Spur verändern während des Rückwärtsfahrens (90°)					
Seitlich stellen („parallel einparken“)					
Kann Hindernissen ausweichen					
Fährt eine leichte Steigung hinauf					
Fährt eine leichte Steigung hinunter					
Fährt leichte Steigung hinauf und bleibt stehen					
Fährt leichte Steigung hinunter und bleibt stehen					
Fährt auf einen niedrigen Gehsteig					
Fährt von niedrigem Gehsteig hinunter					
Kann auf Gehsteig geradeaus fahren					
Kann durch Türrahmen fahren					
Kann auf einem Teppich fahren					
Kann auf einem Schotterweg fahren					
Kann auf rutschiger Fahrbahn fahren					
Kann zwischen 2 Hindernissen einparken					
Kann auf der Straße fahren					
Kann durch Menschenmengen fahren					
Kann eine Kreuzung überqueren (mit Zebrastreifen)					
Kann Straße überqueren ohne Ampel					
Kann Straße überqueren mit Ampel					

4. **Welche der oben genannten grundlegenden Mobilitätsfähigkeiten verwenden Sie bei Ihren Rollstuhltrainings?** *Bitte setzen sie ein Kreuz in die letzte Spalte*

5. Bitte geben Sie an, welche Feedbacktechniken Sie als Trainer beim Rollstuhltraining für den Elektrorollstuhl anwenden.

	ja	nein
Verbale Hinweise		
Visuelle Hinweise		
Versuch und Irrtum		
Demonstration (mit dem Joystick des Patienten)		
Demonstration (mit einem zweiten Rollstuhl)		
Führen (Hand auf Hand)		
Spiele		
Hindernissparcour		
Gruppentraining		
Fahrsimulator oder Computerspiel		
Andere:		

6. Bitte beschreiben Sie den Aufbau, welchen Sie verwenden, um das sichere Fahren mit einem Elektrorollstuhl zu trainieren.

7. Wie vergleichen Sie die Fahrleistung bei aufeinanderfolgenden Rollstuhltrainings?

Vorgegebene Übungen	ja	nein
Beobachtung		
Befragungen		
Video		
Messbare Parameter		
Andere:		

8. Gibt es messbare Parameter an der Sie die Fahrleistung des Rollstuhlfahrers messen?

	ja	nein
Zeit		
Kollisionen		
Andere:		
Nein ich verwende keine messbaren Parameter		

9. Was würden Sie sich für das Rollstuhltraining wünschen? (Technologie, Zubehör,...)

10. Könnte eine Rollstuhlsimulation mittels Virtual Reality für Elektrorollstuhlfahrer eine sinnvolle Trainingsmethode sein?

11. Welche zusätzlichen Informationen über Ihre Erfahrungen bei dem Rollstuhltraining für Elektrorollstuhl würden helfen, die aktuelle Praxis in diesem Bereich zu verstehen?

C Rules of Conduct and Hygiene Measures

The generally valid hygiene measures and the Covid 19 prevention concept of St. Pölten University of Applied Sciences are followed, during the test.

The following special hygiene measures are followed for the test:

- Test users have a negative Covid test that is not older than 48 hours.
- Interviewer has a negative Covid test from the same day.
- The room is aired regularly (~ 5 minutes every 20 minutes).
- Test users are tested individually (no overlap with other test users).
- Test users wear FFP2 masks indoor.
- Performers of the test wear FFP2 masks indoor .
- The increased minimum distance of two metres must be maintained.
- VR headset and joystick are disinfected after each use (as well as chairs, pens, etc.).
- VR headset is put on by the test user himself.
- Testing takes place on a voluntary basis.
- Reference to COVID 19 risk is communicated in advance.

D Testing Guidelines for the Test Users

Liebe/r Testnutzer*in,

vielen Dank für die Teilnahme am Usability-Test der Übungen im verkehrsfreien Bereich einer Elektrorollstuhl-Fahrsimulation im Rahmen meiner Masterarbeit an der Fachhochschule St. Pölten. Die Übungen im verkehrsfreien Bereich sind in die verwendete Applikation WheelSimVR von LIFEtool integriert. Der Usability-Test untersucht, ob die entwickelten Übungen im verkehrsfreien Bereich einer Elektrorollstuhl-Fahrsimulation einen Einfluss auf die Fahrleistung beim Fahren eines Elektrorollstuhls haben. Im Anschluss an den Test werden der SUS (System Usability Scale) Fragebogen und ein halbstrukturiertes Interview durchgeführt, welche aufgezeichnet und transkribiert werden.

Die Teilnahme an diesem Test ist freiwillig, alle persönlichen Daten werden pseudonymisiert und der Test kann vom Teilnehmer jederzeit abgebrochen werden.

Anweisungen

Übungspark

Nach der Einstellung des VR-Headsets (Linse) und dem richtigen Sitz des VR-Headsets und der Erklärung des Joysticks, führen Sie bitte die folgenden Anweisungen aus:

a)Bitte fahren Sie an den Verkehrshüttchen auf der linken Seite entlang. Am letzten Kegel drehen Sie bitte um und fahren zurück in die Ausgangsposition.

b) Biegen Sie links ab und fahren Sie die Rampe bis zur ersten Kurve hoch. Wenden Sie dann erneut und kehren Sie in die Ausgangsposition zurück.

Test

Führen Sie eine Runde des eingangs erläuterten Illinois Agility Tests durch. Vermeiden Sie es, die Wände oder die Verkehrshüttchen zu berühren.

Hindernisparcour mit den Übungen im verkehrsfreien Raum

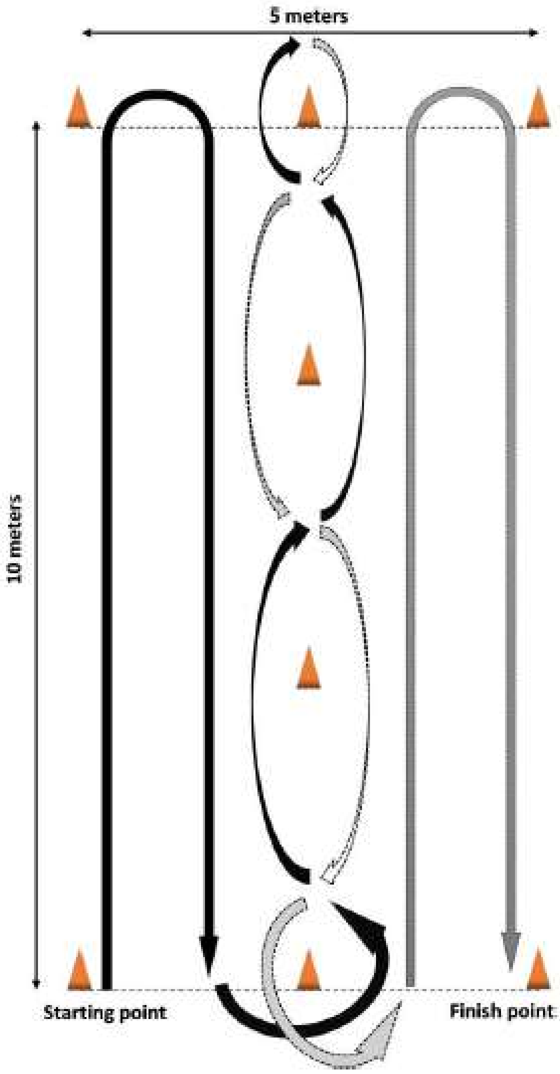
1. Fahren Sie gerade aus und bleiben Sie kurz vor dem Hindernis stehen.
    a. Schaffen Sie es wird das Hindernis verschwinden. Danach warten Sie bis das Hindernis verschwunden ist und fahren weiter.
    b. Sie sind mit dem Hindernis kollidiert. Fahren Sie ein Stück rückwärts und bleiben Sie vor dem Hindernis stehen, danach warten Sie bis das Hindernis verschwunden ist und fahren weiter

2. Fahre Sie die Rampe hinauf und stoppen Sie bei der 1. Linie. Fahren Sie danach weiter und stoppen Sie bei der 2. Linie. Fahren Sie danach wieder weiter.

3. Vor Ihnen am Boden erscheint ein Pfeil. Drehen Sie an dieser Stelle um 180° um und fahren Sie zum nächsten Pfeil, an dem Sie wieder umdrehen.
4. Fahren Sie in einen Slalom durch die Hüttchen. Beginnen Sie dabei links. Vermeiden Sie Kollisionen mit den Verkehrshüttchen
5. .Fahren Sie rechts an der Absperrung vorbei und zwischen den 4 Hüttchen gerade durch.
6. Fahren Sie auf den Gehsteig hinauf und fahren Sie gerade aus ohne ihn rechts oder links zu verlassen.

3.Test

Führen Sie eine Runde des zu Beginn erklärten Illinois Agility Test durch. Vermeide die Wände oder die Verkehrshüttchen zu berühren.



E System Usability Scale

Dies ist ein Standard-Fragebogen, der die allgemeine Benutzerfreundlichkeit eines Systems misst. Bitte wählen Sie die Antwort aus, die am besten ausdrückt, wie Sie die einzelnen Aussagen empfinden, nachdem Sie die Elektrorollstuhl-Fahrsimulation in VR heute benutzt haben [74].

Fragebogen zur System-Gebrauchstauglichkeit

1. Ich denke, dass ich das System gerne häufig benutzen würde.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

2. Ich fand das System unnötig komplex.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

3. Ich fand das System einfach zu benutzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

4. Ich glaube, ich würde die Hilfe einer technisch versierten Person benötigen, um das System benutzen zu können.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

5. Ich fand, die verschiedenen Funktionen in diesem System waren gut integriert.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

6. Ich denke, das System enthielt zu viele Inkonsistenzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

7. Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit diesem System sehr schnel lernen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

8. Ich fand das System sehr umständlich zu nutzen.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

9. Ich fühlte mich bei der Benutzung des Systems sehr sicher.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

10. Ich musste eine Menge lernen, bevor ich anfangen konnte das System zu verwenden.

Stimme überhaupt nicht zu 1	2	3	4	Stimme voll zu 5
○	○	○	○	○

F Expert interview Guideline- Evaluation

Liebe/r Testnutzer*in,

vielen Dank für die Teilnahme am Usability-Test der Übungen im verkehrsfreien Raum der Elektrorollstuhlsimulation in Virtual Reality als Teil meiner Masterarbeit an der Fachhochschule St. Pölten. Die Übungen im verkehrsfreien Raum sind in der WheelSimVR Applikation von LIFEtool integriert. Es wird in dem Usability Test untersucht, ob die entwickelten Übungen im verkehrsfreien Raum in der Elektrorollstuhlsimulation in VR einen Einfluss auf die Fahrleistung haben. Dabei werden Basis Mobilitätsfähigkeiten für das Fahren eines Elektrorollstuhls trainiert. Im Anschluss an den Test wird der SUS (System Usability Scale) Fragebogen und ein semi-strukturiertes Interview durchgeführt, welche aufgezeichnet und transkribiert werden.

Die Teilnahme an diesem Test ist freiwillig, alle persönlichen Daten werden pseudonymisiert und der Test kann vom Teilnehmer jederzeit abgebrochen werden.

Fragebogen Usability Testung

Wie lange sind Sie Ergotherapeut*in?

In welchem Fachbereich arbeiten Sie?

1. Welche Dinge hatte die Elektrorollstuhlsimulation integriert, die Ihnen das Erlernen der Basis Mobilitätsfähigkeiten für das Fahren eines Elektrorollstuhls erleichtert haben?

2. Was war für Sie hinderlich an Erlernen der Basis Mobilitätsfähigkeiten für das Fahren eines Elektrorollstuhls?

3. Welche Dinge könnte die Elektrorollstuhlsimulation zusätzlich integriert haben, um Ihnen das Erlernen der Basis Mobilitätsfähigkeiten für das Fahren eines Elektrorollstuhls zu erleichtern.

4. Wie bewerten Sie die ausgewählten Übungen des Parcours bzgl. Relevanz, Durchführbarkeit und Darstellung?

Übung	Relevanz	Durchführbarkeit	Darstellung
Vorwärts fahren und stoppen			
Rampe hoch und hinunterfahren inkl. Stops			
Drehen während der Vorwärtsbewegung (Kurve)			
Am Platz drehen (180°)			
Kann Hindernisse während des Fahrens ausweichen (Slalom + zwischen Hüttchen fahren)			
Auf Gehsteig hinauf und hinunter fahren			
Zusätzliche Anmerkung:			

5. Hat Ihnen eine spezielle Übung, um Basis Mobilitätsfähigkeiten zu erlernen gefehlt?

6. Haben Sie den Eindruck, dass sie mit den Übungen im Parkour die Fahrleistung mit einem Elektrorollstuhl verbessern konnten?

7. Bitte sagen Sie mir, wie sicher Sie sich beim Erlernen der Basis Mobilitätsfähigkeiten für das Fahren eines Elektrorollstuhls gefühlt haben.

8. Bitte erzählen Sie mir von Ihrer Erfahrung bei dem Test zu Beginn und am Ende?

9. Würden Sie die Elektrorollstuhlsimulation für ein Rollstuhltraining in ihrer Arbeit als Ergotherapeut*in verwenden?

10. Wie würden sie die Anwendung adaptieren, um sie in ihrer täglichen Arbeit integrieren zu können?

11. Welche Personen könnten am Meisten von der Elektrorollstuhlsimulation in VR profitieren?

12. Haben Sie weitere Kommentare oder Anmerkungen?