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TO TEACH SOCIAL AND DAILY LIVING SKILLS TO CHILDREN AND
ADOLESCENTS DIAGNOSED WITH AUTISM SPECTRUM DISORDER

BY
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DENMARK

PhD Dissertation

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To my mother, Elli
for all her sacrifices

برای مادرم ، الهه
به خاطر همه فداکاری هایش

Author CV

Ali Adjorlu received his BSc and MSc in 2011 and 2013 in Medialogy at Aalborg University Copenhagen. Subsequently, he spent approximately one year in the industry, working as a developer. In 2015, he returned to Aalborg University in Copenhagen to work as a research assistant. In 2017, he was appointed as a Ph.D. stipend at the Department of Architecture, Design, and Media Technology. Additionally, During the Ph.D. project, he has been teaching the course Interaction Design and supervising semester projects on the Medialogy bachelor and master program while being affiliated with the Multisensory Experience Lab.

Abstract

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by impairments in social and daily living skills of individuals diagnosed with it. Consequently, upon adulthood, individuals diagnosed with ASD often rely on support from their parents or social services. Virtual environments have shown potentials in helping children and adolescents diagnosed with ASD in obtaining social and daily living skills. However, few studies have investigated how the new wave of 6 degrees of freedom (6DoF) Virtual Reality (VR) hardware can help this target group in obtaining the required skills for independent adulthood.

In this thesis, I set out to explore how teachers and psychologists can use the new wave of consumer VR technologies as a tool to help children and adolescents diagnosed with ASD.

The emergence of affordable and high fidelity virtual reality hardware and software enables the opportunity to place the users diagnosed with ASD inside relevant, interactive virtual environments within which they can receive appropriate treatment for their social and daily living skills deficits. In addition to allowing the training to take place in virtual environments resembling the real-world environments within which the desired skills are to be performed by users diagnosed with ASD, VR hardware supporting 6DoF also allows the interactions in these environments to be similar to interactions required in the real-world environment of the desired skills.

In close cooperation with teachers and psychologists working with children and adolescents diagnosed with ASD, several VR interventions are designed, developed, evaluated, and presented in this thesis.

These interventions address several social and daily living skills required for independent adulthood, such as shopping, safe street crossing, money management, turn-taking, sharing, disruptive classroom behavior, and social anxiety.

In some of the VR interventions presented in this thesis, the teachers are passive observers, while some of the VR interventions allow the teachers to control the VR intervention during training using the keyboard or mouse. Finally, some of the interventions allow the teachers and psychologists to be present in the virtual environment with the child or adolescent via HMD and VR input devices controlling a virtual avatar as well as the training session.

The design processes and evaluation results of these interventions are described in the papers presented in the second part of this thesis. Due to the low sample size, none of the studies described in this thesis can conclusively claim that VR is more efficient than the traditional methods to teach social and daily living skills to children and adolescents diagnosed with ASD. However, the studies do illustrate the potentials of VR and propose a variety of methods to allow the teachers and psychologists to use VR to address the social and daily living skill deficits of children and adolescents diagnosed with ASD.

Resumé

Autisme Spektrum Forstyrrelse (ASF) er en udviklingsforstyrrelse karakteriseret ved afvigelser i sociale evner og hverdagsfærdigheder. Personer diagnostiseret med ASF er ofte afhængige af støtte fra forældre eller sociale ydelser, selv i voksenlivet.

Virtuelle miljøer har vist potentiale til at hjælpe børn og unge med ASF til at udvikle en række sociale evner og hverdagsfærdigheder. Kun få studier har imidlertid undersøgt, hvordan den nye generation af virtual reality (VR) hardware, som registrerer bevægelse i alle retninger, kan hjælpe førnævntemålgruppe med at udvikle de basale færdigheder, der kræves for at kunne leve et selvstændigt voksenliv.

I denne ph.d.-afhandling undersøger jeg, hvordan lærere og psykologer kan anvende den nye generation af VR-udstyr som et værktøj til at hjælpe børn og unge med ASF med at udvikle de færdigheder, der er nødvendige for at leve et selvstændigt voksenliv.

Det nye VR-udstyr, som både er billigere og af bedre kvalitet, gør det muligt at placere brugeren diagnostiseret med AFS i relevante, interaktive virtuelle miljøer, hvori de kan modtage passende behandling for deres manglende sociale evner og hverdagsfærdigheder.

Udover at træningen finder sted i virtuelle miljøer, som visuelt minder om den virkelige verden, som de ønskede færdigheder skal anvendes i, muliggør det nye VR-udstyr også, at interaktionerne i disse miljøer ligner interaktionen i den virkelige verden.

Gennem et tæt samarbejde med lærere og psykologer, som til daglig arbejder med børn og unge diagnostiseret med ASF, har jeg i løbet af dette ph.d.-projekt designet, udviklet og evalueret en række forskellige VR-applikationer. Disse VR-applikationer retter sig mod en række sociale situationer og hverdagsituationer som fx at handle ind, krydse en vej, betale med kontanter, vente på ens tur, dele legetøj, undgå forstyrrende klasseværelsesopførsel og hjælpe dem med deres sociale angst.

I nogle af disse VR-applikationer er læreren en passiv iagttager, hvorimod han eller hun i andre applikationer kan styre VR-oplevelsen ved at bruge tastatur og mus. Endelig præsenterer jeg nogle VR-applikationer, som giver læreren eller psykologen mulighed for at være til stede i det virtuelle miljø sammen med barnet eller den unge ved at bruge VR-briller og -kontroller, mens han eller hun styrer en virtuel avatar.

Designprocesserne og resultaterne af evalueringen af VR-applikationerne er beskrevet i artiklerne i anden del af denne ph.d.-afhandling. På grund af de lave antal deltagere kan ingen af de studier, der er præsenteret i denne afhandling, endegyldigt konkludere, at VR er mere effektiv til at træne sociale evner og hverdagsfærdigheder end traditionelle metoder. Studierne viser imidlertid et potentiale i VR og anviser en række metoder, som gør det muligt for lærere og psykologer at anvende VR til at adressere udfordringerne med manglende sociale evner og hverdagsfærdigheder hos børn og unge med ASF.

Preface

Thesis Roadmap

This thesis consists of two main sections: first, an introduction followed by a collection of papers.

The introduction opens with my motivation for working on this topic, followed by a brief introduction to Autism Spectrum Disorder (ASD) and the challenges relevant to this project faced by individuals diagnosed with ASD. I will then attempt to describe traditional methods to teach social and daily living skills to children and adolescents diagnosed with ASD to get inspirations for how VR can be used for the same purpose. The second chapter of the introduction focuses on virtual reality, providing a brief introduction to how it has been used to help individuals with different disabilities. Additionally, a literature review of studies using VR to help children and adolescents diagnosed with ASD is presented in this chapter. Based on the description of ASD and studies on VR, the chapter is concluded with a set of advantages and potential drawbacks of using VR to teach social and daily living skills to children and adolescents diagnosed with ASD. The next chapter presents three research questions followed by a chapter providing a summary of the thirteen papers presented in the second part of this dissertation.

Acknowledgments

First and foremost, I wish to express my substantial gratitude towards my supervisor Stefania Serafin who has been my mentor, guide, role model, and primary source of support during this project. Not only did she provide the opportunity that made this Ph.D. possible, but she also allowed me to pursue a topic of research that I was passionate about. Whenever I approach Stefania with questions about research, life as a Ph.D. student, or any other topic, she has been quick to reply, accessible, always in high spirit, and always willing to help. Her support has made the past three years much more enjoyable for me than I could have imagined. I also wish to thank the teachers Thor Jønnson, Bo Jacobsen, Claes Kiilsgaard, Tina Johansen, Tina Christensen, Majken Jacobsen, Lone Jørring, Rune Hviid and, Anita Drejser Høgh for their invaluable input on the design and their contribution in help evaluating the VR interventions described in this thesis. I also wish to thank Sune Buch-Sloth and Rødovre Municipality for creating the opportunity for the collaboration between the teachers from the schools STUEN Rødovre, Valhøj Skolen and Skovmoseskolen and me. My appreciation also goes to the psychologists Søren Benedikt Pedersen, Jens Henrik Thomsen, Lærke Juel, and Sara Arvig for their valuable input on the design and evaluations of some of the interventions described in this thesis.

Additionally, I wish to thank the co-authors of the presented papers Emil Rosenlund Høgh, Luca Mangano, Aishah Hussain, Camilla Mødekjær, Nicoline Austad, Nathaly Barriga, Lars, and Nicklas Andersen, Vito Gentile, Davide Rocchesso and Salvatore Sorce. Also, I wish to thank Anna Kristine Schwartzbachs for sharing her experiences on working with children diagnosed with autism spectrum disorder, and I also want to thank Susanne Wendt, Clara Smedegaard and the children from the Danish National Children Choir for giving us their valuable time and allowing us to do 360 video recordings of their choir sessions.

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Ali Adjorlu
Copenhagen, January 31, 2020

Thesis Details

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The main body of this thesis consist of the following papers:

[A] A. Adjorlu, " Virtual Reality Therapy", *Springer International Publishing AG*, 2018.

[B] A. Adjorlu, S. Serafin, " Virtual Reality (VR) for Children Diagnosed With Autism Spectrum Disorder (ASD): Interventions to Train Social and Everyday Living Skills", *IGI Virtual and Augmented Reality in Mental Health Treatment*, 2018.

[C] A. Adjorlu, S. Serafin, "Teachers' Views on how to use Virtual Reality to Instruct Children and Adolescents Diagnosed with Autism Spectrum Disorder", *IEEE Conference on Virtual Reality and 3D User Interfaces*, 2019

[D] V. Gentile, A. Adjorlu, S. Serafin, D. Rocchesso, S. Sorce, " Touch or touchless?: evaluating usability of interactive displays for persons with autistic spectrum disorders", *Proceedings of the 8th ACM International Symposium on Pervasive Displays* , 2019

[E] A. Adjorlu, E. Rosenlund Høeg, L. Mangano, S. Serafin , " Daily Living Skills Training in Virtual Reality to Help Children with Autism Spectrum Disorder in a Real Shopping Scenario", *IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct)*, 2017

[F] A. Adjorlu, S. Serafin , "Head-Mounted Display-Based Virtual Reality as a Tool to Teach Money Skills to Adolescents Diagnosed with Autism Spectrum Disorder", *3th EAI International Conference on Design, Learning & Innovation*, 2018

[G] A. Adjorlu,"Social Virtual Reality as a Tool to Teach Money Skills to Children andAdolescents Diagnosed with Autism Spectrum Disorder", *Submittet to IEEE Conference on Virtual Reality and 3D User Interfaces*, 2020

[H] A. Adjorlu, S. Serafin, " Co-Designing a Head-Mounted Display Based Virtual Reality Game to Teach Street-Crossing Skills to Children Diagnosed with Autism Spectrum Disorder", *8th EAI International Conference: ArtsIT, Interactivity & Game Creation*, 2019

[I] A. Adjorlu, A. Hussain, C. Mødekjær, N. W. Austad , " Head-Mounted Display-Based Virtual Reality Social Story as a Tool to Teach Social Skills to Children Diagnosed with Autism Spectrum Disorder", *IEEE VR Third Workshop on K-12+ Embodied Learning through Virtual & Augmented Reality (KELVAR)*, 2018

[J] A. Adjorlu, N. B. B. Barriga, S. Serafin, "Virtual Reality Music Intervention to Reduce Social Anxiety in Adolescents Diagnosed with Autism Spectrum Disorder", *Proceedings of the 16th Sound & Music Computing Conference*, 2019

[K] S. Serafin, A. Adjorlu, L. Andersen, N. Andersen ," Singing in Virtual Reality with the DanishNational children's choir", *14th International Symposium on Computer Music Multidisciplinary Research (CMMR)* , 2019

[L] A. Adjorlu, S. Serafin, L. Andersen, "Singing in Virtual Reality. A tool for Psychologists to Perform Exposure Therapy on Children with Social Anxiety", *Submitted to ACM Conference on Human Factors in Computing Systems* , 2020

[M] A. Adjorlu, S. Serafin, " Head-Mounted Display-Based Virtual Reality a sa Tool to Reduce Disruptive Behavior in a Student Diagnosed with Autism Spectrum Disorder", *4th EAI International Conference on Design, Learning & Innovation*, 2019

In addition to the main papers, the following publications have been made during this PhD.

[1] S. Serafin, A. Adjorlu, N. Nilsson, Lui Thomsen and R. Nordahl, "Considerations on the use of virtual and augmented reality technologies in music education", *2017 IEEE Virtual Reality Workshop on K-12 Embodied Learning through Virtual & Augmented Reality (KELVAR)*, 2017

[2] R. Nordahl, N. Nilsson, A Adjorlu, E. Magalhaes, S. Willemsen, N. Andersson, J. Wang, and S. Serafin, "12 Hours in Virtual Reality: Two Cases of Long-Term Exposure to Consumer-Grade Virtual Reality", *IEEE VR Workshop on Immersive Sickness Prevention*, 2019

[3] K. Konovalovs, J, Zovnercuka, A. Adjorlu and D. Overholt, "A Wearable Foot-mounted / Instrument-mounted Effect Controller: Design and Evaluation", *BegivenhedNew Interfaces for Musical Expression (NIME)*, 2017

This Ph.D. thesis has been submitted for assessment in partial fulfillment of the Ph.D. degree. The Ph.D. thesis is based on the published or submited scientific papers listed above. Parts of the papers are used directly or indirectly in the extended summary of the Ph.D. thesis. As part of the assessment, co-author statements have been made available to the assessment committee and are also available at the Faculty.

Contents

Part I

Introduction

Background

> *"I'd attended school in the real world up until the sixth grade. It hadn't been a very pleasant experience. I was painfully shy, awkward kid, with low self-esteem and almost no social skills. Online, I didn't have a problem talking to people or making friends. But in the real world, interacting with other people - especially kids my own age - made me a nervous wreck."* [40]

From the safety of his hideout, Wader Watt, the protagonist of Ernest Cline's novel "Ready Player One," attends school in a virtual world called "The Oasis." In the real world, he feels insecure due to his physical appearance and is often ridiculed and abused by the other students. When he logs in to the virtual world, he is confident, has friends, and is socially active. His avatar in the Oasis is leaner and taller than himself and does not have teenage acne-like in the real world, allowing him to focus more on his studies than on his physical appearance and social acceptance. In Ernest Cline's virtual universe, even the teachers prefer teaching in the Oasis compared to its real-world counterpart since the virtual classroom software mutes any disruptive student behavior, allowing the teachers to focus on their teaching instead of being babysitters. Additionally, lectures could take place in relevant, interactive virtual environments such as historic locations in the history lectures or a trip to a virtual version of Musée du Louvre during art lessons.

Ernest Cline started working on this vision of a virtual world back in 2001, long before the release of affordable and mainstream virtual reality (VR) head-mounted displays (HMDs) [67].

In 1968, a time where consumer displays only had the capability to plot dots or draw simple lines, Ivan Sutherland proposed the Ultimate Display, describing it as *"With appropriate programming, such a display could literally be the Wonderland into which Alice walked"* [161]. Today, due to the availability of affordable and high-fidelity HMDs, and intuitive software designed to create virtual environments, chunks of Ernest Cline's and Ivan Sutherland's visions can become a reality [67]. Due to these developments, the public can have access to interactive virtual environments designed to teach, rehabilitate, or help specific target groups with specific needs. Pioneering researchers have already laid the foundations for these types of applications back in the early 90s, where HMDs were costly, had low resolution, slow framerate, and limited field of view [135, 134]. Already back in the early to mid-90s and despite the technical limitations of VR hardware of the time, researchers managed to show the potentials of virtual environments to help individuals with specific phobias such as acrophobia [120]. Unfortunately, these applications did not reach the mainstream audience in the 90s due to the technical immaturity and the high price of VR equipment [67]. Today, it is not the technology but our imagination that sets the limits for how VR can be used to help individuals with different needs.

As a child growing up in Iran, I loved to play football on the streets of Teheran. Unfortunately, due to a medical condition during my childhood, I would break my bones more frequently than children without that condition. This did not keep me from participating in physical activities with other children, but as a consequence, I was often wearing large plasters due to some broken bone in my body. One day when visiting some family in Teheran, I got to see a video game console for the first time in my life: the Atari 2600 on which we played the game, Pong. Since that day, I've been dreaming about computer simulations with which I could perform "dangerous" activities such as playing football or skateboarding without risking the traumatizing experience of breaking my bones. That day kickstarted my pursuit of interactive digital technologies that lead me to get a Master's degree in Medialogy from Aalborg University in Copenhagen. Finally, my primary motivation for this dissertation comes from my current voluntary work at the Danish Youth Red Cross, where I often interact with lonely young individuals diagnosed with Autism Spectrum Disorder (ASD). Talking to these individuals and hearing about their social and daily challenges inspired me to delve deeper into the topic, investigating whether my background as a Medialogist can help them learn the necessary skills required for them to have a better life.

1 Autism Spectrum Disorder

In 1943, Leo Kanner published a paper describing eleven children all below age eleven who lacked social skills, attend to objects more frequently than to people, and who reacted negatively towards unexpected changes in their environment [80]. Kanner, an Austrian-American Psychiatric working at the John Hopkins University School of Medicin in Baltimore, USA, coined the term "Infantile Autism" to describe his newfound psychiatric condition [26]. Kanner chose to name this condition autism, which origins from the Greek word Autos meaning self [131] since all 11 of the children depicted in his paper seemed happiest in isolation with themselves. Case 1, named Donald T. described in Kanner's article, is today known as the first person to ever be diagnosed with Autism. He is described as being happiest when left alone, never noticed when his mother or father entered the room, and in general, avoided interacting with others. When the parents brought him to a playground with a slide that was being used by other children, Donald would not get close to the slide. When the parents picked him up and placed him on the slide, Donald seemed terrified, screaming, and tried to get away from it as fast as he could. However, the next morning, when there were no other children around, he walked out to the slide, climbed the slide, and slid down. That became a daily habit for him, but only in the morning when there were no other children at the playground. At the age of seven, daily living activities such as eating, washing, and dressing were still only done with his mother's insistence and assistance. Donald ignored verbal instructions from his parents, showing difficulties in imagining and making sense of what they were trying to teach him. Despite him not giving any attention to other people, he did enjoy visual media such as watching movies and looking at old issues of Time magazine. Kanner goes on to describe similar traits in the other ten cases he describes in his paper: lack of social skills and interests and a general lack of imagination, as well as repetitive behavior. Kanner's article from 1943 goes on to make medical history, placing him as the one who discovered this new condition. However, in 1938, five years before the publication of Kanner's paper, a pediatrician named Hans Asperger was lecturing about a group of children he discovered in his clinic in Vienna, Austria, that shared the same personality traits as the children described in Kanner's paper [152]. Asperger used the term "autistic psychopaths" to describe this target group in his lecture. Kanner starts his 1943 article with: *"Since 1938, there have come to our attention a number of children whose condition differs so markedly and uniquely from anything reported so far, that each case merits - and, I hope, will eventually receive - a detailed consideration of its fascinating peculiarities".* [80]. The year 1938 was the same year as to when Asperger started lecturing about "autistic psychopaths."

Before the time of the internet, it might be possible that Kanner did not know about Asperger's work being conducted on a different continent under Nazi-occupied Austria. However, the journalist Silberman discovered that the chief diagnostician in Asperger's clinic in 1938 moved to Maryland to work under Leo Kanner at the John Hopkins University later the same year [152]. In 1944 Asperger published a paper in German describing the group of children similar to those described in Kanner's article [84]. However, Asperger's paper went almost unnoticed, while Kanner's paper is highly cited. Kanner went on to ignore Asperger's work for most of his career despite him speaking German. Consequently, the English speaking research community did not pay much attention to Asperger's work until the psychiatrist Lorna

Wing published an in English article in 1981, describing Asperger's findings [177]. In her paper, Wing classifies children described by Asperger as "autistic psychopathy" to lack social interaction, communication, and imagination skills, which is similar to Kanner's findings. She is the first to coin the term "Asperger's syndrome" instead of "autistic psychopathy." She argues that the word "psychopathy" is often related to sociopathic behavior, which could lead to misunderstandings. Wing goes on to describe findings based on her own and other researchers' observations on individuals that shared the characteristics described by Asperger. She describes the school experience of these individuals to include merciless bullying resulting in becoming anxious and show school refusal behavior. Upon adulthood, she reports a high unemployment rate while some did have jobs doing repetitive, structural tasks and seem to enjoy it. Wing states that depression and suicidal thoughts are also frequently observed upon adulthood while finding appropriate living accommodation is also described as an issue, where individuals often live with their parents are hostels wit caretakers upon adulthood. Therefore, Wing argues that education is essential to develop the required skills that can increase the individuals' chance for a happy and independent adulthood. Depending on the capabilities of each individual that can be described by the symptoms related to autistic traits, the educational goals can vary from teaching necessary daily skills to academic skills, according to Wing. She goes on to argue that it is vital that parents and teachers understand these individuals' difficulties in following verbal instructions, which can be abstract for them and hard to imagine. Therefore, instructions communicated via visual elements such as images can be more efficient with this target group.

Today, the terms "autistic psychopathy," Kanner's "Infantile Autism" and Wing's "Aspergers Syndrome" have all been replaced by one umbrella term introduced in the fifth edition of the "Diagnostic and Statistical Manual of Mental Disorders" (DSM-5) called Autism Spectrum Disorder (ASD) [5]. To summarize the pioneering publications on children sharing the traits that describe Autism, several primary deficits emerge [80, 177]. Lack of social, communication, and daily living skills, repetitive behavior, as well as reduced imagination capabilities. The DSM-5 describes ASD as a spectrum due to the variety of these deficits in each individual diagnosed with ASD. Recent studies confirm these characteristics described by the likes of Asperger, Kanner, and Wing.

1.1 Social and Communication Skills

Morrison et al. conducted a study in 2017, comparing social skills between adults diagnosed with Autism Spectrum Disorder (ASD), schizophrenia (SCZ), and typically developing (TD) children in a set of real-world social interactions scenarios [112]. The participants completed a three-minute role-playing session from the Social Skills Performance Assessment (SSPA) [166], within which they were to greet a new neighbor acted out by one of the experimenters. The sessions were recorded and coded for scores to asses their ability to meeting somebody for the first time. Results indicated a significantly worse social skills performance by individuals diagnosed with ASD and SCZ compared to the TD group. Additionally, individuals diagnosed with ASD asked fewer questions during the conversation than the SCZ group, while they illustrated more repetitive physical movements. The SCZ group's social skills were significantly related to each individual's IQ, with those with higher IQ being more socially engaged in the conversation. However, the ASD group's social interaction was unrelated to each individuals' IQ score. Other similar studies have illustrated the reduced social and communicative skills of individuals diagnosed with ASD [71, 147, 102].

Eye contact is one of the essential ways of social interaction, with the eyes delivering a variety of social cues. Studies show that TD adults and even infants shift their attention reflexively towards others' gaze to establish eye contact [148, 54]. However, studies show that individuals diagnosed with ASD often attempt to avoid eye contact, reducing the quality of their social interactions [149, 76, 103].

Theory of Mind (ToM) or Mind Blindness is a theory developed in the 80s and 90s describing the social and communicational difficulties in individuals diagnosed with ASD [12]. The theory developed by Simon Baron-Cohen proposes through a variety of studies that children diagnosed with ASD have a reduced ToM, which in its essence describes one's ability to put oneself into someone else's shoes [10, 13]. Typically developed individuals are capable of making sense of others' behavior (f.x., Why is he looking down, why is he scratching his head). Additionally, TD individuals are capable of understanding others' mental states (f.x., He is sad, or he is going to ask me a question in a bit). Due to a reduced ToM in children diagnosed with ASD, others' behavior is more confusing, unpredictable, and at times frightening. Baron-Cohen et al. conducted a study investigating whether children with ASD are capable of understanding that others can have different beliefs about a particular situation than themselves [13]. In this study, children with ASD were presented with two dolls by the experimenter. One of the dolls was called Sally and the other one Anne. Sally had a small basket in front of her while Anne had a small box in front of her. The experimenter showed a small marble to the participant and then placed the marble in Sally's basket. Then the experimenter removed Sally from the scene without her basket. This was followed by the experimenter taking the marble from Sally's basket and placing it in Anne's box. Sally then re-entered the scene. Now the child was asked the central question of the study: *"Where will Sally look for her marble?".* If the child points at the basket, which was the location of the marble before Sally left the scene, then she passes the test. If she points at the actual position of the marble in Anne's box, then she fails the test since she did not consider the doll's beliefs. The results are only valid if two control questions are answered correctly: *"Where is the marble really?"* and *"Where was the marble in the beginning?"* Baron-Cohen et al. conducted this study on three groups of children: One group diagnosed with ASD, one group with Down's Syndrome, and a group of TD children. The results showed that 85% of the TD children and 86% of children with Down's syndrome answer correctly to the central question of the experiment. However, only 20% of children diagnosed with ASD answered correctly to the same question, showing that they have difficulties understanding that others can have different beliefs about certain situations than themselves. Consequently, children with ASD can have problems understanding that some people might not say what they mean while they often assume that everyone is telling the truth [9, 11]. Additionally, children with ASD have more difficulties understanding what might hurt others' feelings compare to TD children [14]. This reduced understanding and confusion about others' feelings might be one of the factors for the high level of social anxiety observed in children [21, 89, 106] and adults with ASD [157].

1.2 Daily Living Skills

Independent adulthood requires daily living skills (DLS) such as shopping skills, money management, cleaning, cooking, and transportation. Unfortunately, independent adulthood is not common among individuals diagnosed with ASD. Farley et al. conducted a study investigating the adult outcome of 41 individuals diagnosed with ASD [53]. All of the participants had an IQ of 70 or above and an average age of 32.5 (SD = 5.7, range = 22.3-46.4). Via interviews and surveys, Farley et al. gathered data about participants' overall functioning and independent living. The results show that twenty-three of the participants (56%) lived with their parents, while only five (12%) lived independently in their own homes. The rest of the participants had different levels of support from social agencies or parents either at special homes, hostels or with their parents. Additionally, only eleven (27%) of the participants were employed full-time. The rest of the participants had either part-time or volunteering jobs or were unemployed. Daily living skills of the participants were measured using the Vineland Adaptive Behavior Scales-Survey (VABS) [118]. Based on their results, Farely et al. conclude that DLS measurements in their study were the variable that most closely correlated with their participants' independent adulthood outcome, pinpointing the importance of interventions to teach DLS to this target group. Another study conducted by Esbersen et al. compared the adult outcome of 70 adults diagnosed with ASD with 70 adults diagnosed with Down's Syndrome [52]. Esbensen et al. conclude that adults with ASD are more residentially dependent on help from parents or social agencies, had more limited functional and DLS abilities and had more unmet service needs compared to the group diagnosed with Down's Syndrome. Another study conducted by Szatmari et al. investigated the development trajectories of DLS in children and adolescents diagnosed with high functioning ASD [163]. Their results showed that the path of development of DLS decreases over time, pinpointing the importance of interventions to teach DLS during early adolescence to this target group. A total of thirteen ASD stakeholders, including four parents, three service providers, five researchers, and one individual diagnosed with ASD, were asked about significant challenges during the transition towards adulthood for individuals diagnosed with ASD [87]. During these interviews, twelve of the participants pinpointed the importance of interventions to teach DLS and self-advocacy skills as early as possible to this specific target group. Participants also stated that since individuals diagnosed with ASD have a wide range of skills and capabilities, researchers, designers, and developers should create specialized interventions for each individual diagnosed with ASD instead of treating them as a homogenous group.

1.3 Traditional Methods to Teach Social and Daily Living Skills to Individuals with Autism Spectrum Disorder

To be able to investigate how VR can be used to teach social and everyday living skills to children and adolescents diagnosed with ASD, it is essential first to gain an understanding of what traditional interventions have proven to be effective. Since the publication of Kanner's paper in 1943, researchers have tried to help individuals diagnosed with ASD. A meta-analysis by Wang & Spillance provides an overview of evidence-based interventions developed to teach social skills to children diagnosed with ASD. A total of thirty-six studies meet the criteria of Wang & Spillane [173]. Out of these thirty-six studies, four main categories of interventions types emerged: Social stories, Peer Mediated Training, Video Modeling, and Cognitive Behavioral Therapy. Another review article by Bennett & Dukes found fourteen peer-reviews studies on interventions designed to teach DLS to children and adolescents diagnosed with ASD [22]. The primary strategy emerging from the review was the Applied Behavior Analysis (ABA) method [6], which is described as a method that applies Skinner's behaviorism to improve human behavior.

Social Stories

Social stories is a type of intervention developed by Gray & Garand in 1993, designed to teach children diagnosed with ASD about how to behave in different social situations [62]. Social stories are short stories constructed using simple text and supported by visuals such as images or drawings, often taking the shape of a comicstrip. Social stories must be individualized with a social situation, writing, and illustrations that are easy for the specific child with ASD to relate to and understand. A social story must include four basic sentences: descriptive, directive, perspective, and affirmative. The descriptive sentence should describe where the situation is taking place, what is taking place, and why. The directive sentence should describe what the appropriate behavior is and what is expected of the child diagnosed with ASD in the specific situation described in the social story. Perspective sentences should explain what others within that particular situation are thinking or feeling. Finally, the affirmative sentences are conclusive sentences used to make sure that the child understands and is capable of remembering the story. One of the main benefits of social stories, according to its author Carol Gray is its ability to address difficulties associated with the reduced ToM in children diagnosed with ASD: understanding others' feelings and intentions [62]. Additionally, individuals diagnosed with ASD prefer to focus on details, which often can be irrelevant, resulting in having a hard time understanding the general context of a situation [65]. Social stories focus on the relevant information by including sentences and illustrations that emphasize the essential details. Finally, individuals diagnosed with ASD prefer visual instructions, which is one of the main components of social stories [129, 100]. Despite these advantages, research on the effectiveness of social stories has been described to lack certain methodological values such as lack of control group, lack of investigation on whether the training can be transferred to other contexts, and whether the training is maintained over time [145, 4, 141].

Peer Mediated Therapy

Peer-mediated training refers to a method where TD peers (e.g., school students) are trained to teach social, functional, or academic skills to their classmates diagnosed with ASD [33]. The peer can operate within different contexts, such as a playground, classroom, or school cafeteria, teaching the child with ASD appropriate behavior in these contexts. The peer can model, explain, and reinforce appropriate behavior for the child diagnosed with ASD. This enables the child with ASD, who prefers visually communicated instructions [129, 100] to visually see both the context and the appropriate behavior of the peer. Additionally, this method enables the repetition of the desired skill, which can help with generalization and transfer of the skills from one context to the other [32, 159]. However, training a child to teach his peers diagnosed with ASD can be a demanding task. Additionally, the instructions and guidance provided by the peer might not be on the same level as a professional therapist or teacher. Finally, a peer focusing on teaching his school-mate diagnosed with ASD about social, functional, and academic skills might miss out on his own social and educational goals in the school.

Video Modelling

Video modeling refers to an intervention in which the child with ASD sees a video of a peer, adult, or the diagnosed individual self-performing the desired skill in its appropriate context [72]. The children diagnosed with ASD are then asked to imitate the desired behavior they have seen in the video. In the review article on interventions designed to teach social skills to children diagnosed with ASD, Wang & Spillance state that video modeling is the most effective intervention compared to social stories, peer-mediated training, and cognitive behavioral therapy [173]. Several studies concluded that video-modeling is an effective method due to visual instructions followed by the child imitating the desired skill [7, 23, 115, 132]. In contrast, several studies have shown that children diagnosed with ASD have a reduced ability to imitate other people, which has been used as one of the primary explanations for the diminished social and communicational skills [176, 154, 140]. The child diagnosed with ASD might be conscious about the fact that the person seen on the video is not real, and he, therefore, is capable of focusing more on imitating the desired skill. Kanner describes in his original paper that some of his eleven cases attended more to images of people compared to actual people, which can be an advantage for the video-modeling intervention [80].

Cognitive Behavioral Training

Cognitive Behavioral Therapy (CBT) is a form of talk therapy where a therapist, teachers, or sometimes parents talk to the child to spot negative thoughts about specific situations [44]. The CBT method seeks to modify these thoughts so that the child can become capable of coping with that particular situation in the future. Studies on CBT for children and adolescents diagnosed with ASD have focused on anxiety issues [170], disruptive behavior [156, 153], and some negative core symptoms of ASD, such as lack of social skills [175]. As an example, with children suffering from anxiety, CBT aims at identifying the negative, often irrational thought that triggers the fear and then removing them by introducing the child with new rational thinking about the fear-inducing situation [153]. Additionally, some studies have investigated the effectiveness of CBT to help the reduced ToM often observed in children with ASD by introducing them to ideas such as trying to understand others' goals, feelings, and emotions [156]. CBT usually occurs in two to three sessions per week for several months.

Applied Behavior Analysis

Wolf et al. describe ABA as: *"The process of systematically applying interventions based upon the principles of learning theory to improve socially significant behaviors to a meaningful degree, and to demonstrate that the interventions employed are re-*

sponsible for the improvement in behavior" [8]. ABA is an umbrella term for methods that use principles of learning and motivation, such as reinforcements, extinction, and stimulus control, to teach a variety of skills to children diagnosed with ASD. The main element of all ABA is that all behaviors can be strengthened or weakened via positive or negative consequences [105]. A systematic positive consequence to a specific behavior increases the likelihood of the future occurrence of that behavior, while negative consequences decrease that likelihood. A positive consequence or removal of a negative consequence after a specific behavior is referred to as reinforcement while removing the positive consequence of a behavior is called extinction. B. F. Skinner coined the term orphan conditioning, which refers to human actions being dependent on the consequences of these actions [60]. To illustrate this, he created the orphan conditioning chamber, also known as the Skinner Box. The chamber allowed the experimenter to repeatedly reinforce an animal to alter its behavior without having to handle the animal repeatedly physically. Albert "Skip" Rizzo argues that VR can be described as an "Ultimate Skinner Box," allowing researchers to place their clients inside virtual environments within which desired behaviors can be reinforced [135]. In the next section, VR technologies and their potentials to help children and adolescents diagnosed with ASD will be discussed.

2 Virtual Reality

The cognitive revolution occurred approximately 70,000 to 30,000 years ago, allowing us, the Homo Sapiens, to communicate using language in a way never seen before [66]. According to the historian Yuval Noah Harari, since the cognitive revolution and the development of language, we humans have been living in two realities: the physical reality and the imagined reality [66]. Ever since the development of language, we have been the only species capable of telling each other stories about fictional events that never occurred, objects that never existed, and people, creatures, and animals that never lived in the physical world. This desire to tell and be told fictional stories has been a desire of humans ever since, and we keep striving for more immersive imaginative experiences while we also look for more efficient methods to deliver these experiences. Approximately 17,000 years ago, our ancestors discovered a new way to provide fictional stories: by painting on the walls of caves such as the caves of Lascaux in southwestern France, on which the ancient drawing is still intact today [97]. Approximately 5,000 years ago, with the invention of cuneiform writing, the ancient Sumerians in Mesopotamia introduced another method to tell stories to other homo sapiens [85]. It is due to these old scripts, some fictional, some actual events from the physical world that we today are capable of imagining the lives of ancient Babylonians, Persians, and Greeks. Since then, inventions such as the camera and the moving pictures have allowed us to immerse people into imaginative fictional worlds using displays. Ivan Sutherland is widely known to have designed the first head-mounted display (HMD) with which one could experience computer-generated content back in 1968 [162]. It was called the sword of Damocles due to its heavyweight, and it allowed its users to experience a low-fidelity wireframe virtual environment. Words such as heavyweight, low-fidelity, and expensive can describe the series of head-mounted displays released in the 80s, 90s, and the beginning of the 2000s resulting in what is called the nuclear winter of VR [137]. On August 1st, 2012, a Kickstarter project was launched by Oculus, promising a 300 dollars VR HMD with a weight of around 0.22 kilograms, 6-degrees of freedom (6DoF), and 110 degrees diagonal field of view [67]. 6DoF refers to the ability to track the users' head movement and hand movement on six different axes: forward/backward, up/down, left/right directions, as well as yaw, roll, and pitch rotations [17]. This Kickstarter project started the development of a new wave of high fidelity and affordable VR equipment. Today, immersive, interactive virtual environments are accessible to a large chunk of the population. By substituting sensory information from the real world with digitally generated ones, it is possible to place people inside relevant virtual environments designed to help with a variety of mental disorders. In 2013, 70 psychotherapy experts answered a survey, stating their predictions on the future of interventions for psychotherapy [116]. VR was ranked 4th among the top 45 predicted interventions for psychotherapy to be the most common in 2023. As Albert "Skip" Rizzo mentioned in his Keynote speech at the IEEE VR 2018 conference title, "Is clinical VR ready for its prime time?", VR applications will become a vital tool in the toolbox of psychologists researchers and practitioners in the future [135].

2.1 Clinicial Virtual Reality

One of the first known studies to use HMD-based VR to help an individual with a mental disability was a study conducted by North & North in 1994 to help a patient suffering from aerophobia, the fear of flying [117]. A 32-year-old woman with aerophobia experienced eight sessions of an HMD-based flying simulator for 30 minutes at a time. A real-world post-experience evaluation in a real helicopter showed that the intervention helped to reduce her fear of flying. Since then, a large number of studies have investigated the effectiveness of VR to help treat or assess individuals suffering from a variety of mental disabilities such as eating disorders [64], substance-use disorders [70], and post-traumatic stress disorder (PTSD) [138]. A VR exposure therapy application was developed at the University of Southern California's Institute for Creative Technologies (ICT) to help Iraq war veterans suffering from PTSD. The war veteran suffering from PTSD is placed inside a virtual environment resembling a city in Iraq with old buildings, desolate streets, mosques, shops, moving vehicles, and pedestrians [138]. The therapist can control the experience using a control panel, changing the location of the veteran, and control the general narrative of the experience using a mouse. This allows the therapist to provide the veteran with multisensory stimuli that are relevant to that specific veteran's needs. In a study conducted on patients suffering from anorexia and bulimia showed that virtual food is more effective than photographs of food in triggering the negative psychological responses in patients suffering from eating disorders [70]. Virtual environments have also been used by researchers to perform cue-exposure therapy (CET) for patients suffering from substance-use disorders. CET is a method in which an individual addicted to a specific substance such as cigarettes is exposed to stimuli that usually triggers cravings without the presence of that specific substance [70]. VR applications placing the users inside virtual environments such as bars have been proven to be an effective method to perform CET on individuals suffering from substance-use disorders [70].

Strickland et al. conducted one of the first known studies on how VR can be used to help children diagnosed with ASD [160]. In this pioneering study, an HMD-based VR intervention is presented, designed to teach traffic safety skills to two children diagnosed with ASD. One of the main aims of the study was to investigate whether the participants can accept wearing the VR HMDs and whether they are capable of navigating and interacting within a virtual environment. To prepare the children for the evaluation, mothers of the participants had them try a variety of different helmets a week before the VR experience. On the first attempt, both children had no problems wearing the HMD while they both immersed themselves in the virtual environment. They were both capable of following the cars in the virtual scene and identifying and saying out loud the color of each vehicle. Mainly due to technical limitations, the study was not capable of implementing a VR solution capable of teaching safe street crossing to the participants. However, an important step was taken by the authors to explore whether children diagnosed with ASD are capable of accepting and interacting with HMD-based VR applications. Since then, a variety of studies have investigated the effectiveness of VR to help children diagnosed with ASD.

In the following section, we will look into how VR has been used to help children and adolescents diagnosed with ASD.

2.2 Virtual Reality for Children and Adolecents Diagnoesd with Autism Spectrum Disorder

The purpose of this thesis is to investigate how VR can be used to teach social and DLS to children and adolescents diagnosed with ASD. Therefore, a literature review was conducted to find studies on VR and autism spaning on a timeline from Strickland et al. pioneering work conducted in 1996 [160] to January 2017, which is when this Ph.D. project started. A total of 60 studies on VR and ASD were discovered and are listed in Table 1. Out of these 60 studies, only 5 used an HMD to mediate their virtual intervention [160, 74, 18, 35, 126]. A total of 25 of these publications use the term virtual reality in either their title or abstract, with the majority of them referring to VR as interventions that mediate virtual environments on a desktop computer. This poses the question: what is VR? The term virtual reality was the first coined by Jaron Lanier, the chief executive officer of Virtual Programming Languages (VBL) in the late 80s [101]. The company founded by Lanier, VBL, developed products such as the DataGlove for manipulating digital objects, the EyePhone, an HMD to explore virtual environments, and the DataSuit, a full-body outfit for the tracking of body movement in the virtual space [48]. All of these devices were designed by VBL to mediate immersive virtual environments that could be experienced while wearing an HMD. In a recent book published by Lanier "Dawn of the New Everything: Encounters with Reality and Virtual Reality," [94] he provides 52 definitions of virtual reality with one of them being: *"An ever growing set of gadgets that work together and match up with human sensory or motor organs. Goggles, gloves, floors that scroll, so you can feel like you're walking far in the virtual world even though you remain in the same* *physical spot; the list will never end".* This describes a version of virtual reality that immerses one into a virtual world by using technology to substitute sensory inputs from the real world with digitally generated sensory information. Lanier believed that VR can provide *"training simulators for anything, not just flight"* and that it can be the *"instrumentation to make your world change into a place where it is easier to learn".* These are relevant properties of interventions to teach social and daily living skills to children and adolescents diagnosed with ASD. Many of the advantages of VR as a clinical tool can benefit from immersive HMD-based VR. Despite these advantages, only five studies were found that looked into the potentials of HMD-based VR to help children and adolescents diagnosed with ASD.

Traditional Display Based Interventions

In this section, the term traditional display covers interventions that use desktop monitors, TVs, projectors, and touchscreens. Thirty-five of the studies in table 1 mediated their intervention on a traditional desktop screen. Five studies used small touchscreens, while four studies used projectors or large screens to mediate their virtual interventions for children and adolescents diagnosed with ASD. A total of nine studies use Cave Automated Virtual Environments (CAVE), which are room-scale environments with projectors projecting the virtual information on three to six walls of the room. Teaching or assessing social skills were the most common goal of the studies that did not apply HMDs to communicate their virtual environments to the children and adolescents diagnosed with ASD. Didehbani et al. [50] used SecondLife played on a computer screen to teach specific social skills to children and adolescents diagnosed with ASD. The participants played through a set of social scenarios such as consoling a friend who has just lost his dog, dealing with bullies, or meeting strangers. Two therapists logged into the same virtual environment and controlled the avatars that the child or adolescent diagnosed with ASD interacted with. They could communicate with each other using a microphone while controlling their avatars using the keyboard, mouse, or a joystick. After completing ten one-hour sessions across five weeks, improvements were measured in the participants' emotion recognition, social attention, and social execution skills.

Driving and traffic safety skills were the most frequent daily living skills teaching goals of the traditional screen-based studies found. Josman et al. [77] conducted a study investigating the effects of learning traffic safety skills in a virtual environment. Six children diagnosed with ASD were included in the experimental group, while six TD children of the same age and gender were included in the control group. The intervention was run on a desktop computer and included two virtual crossroads: one with a pedestrian island in the middle and one with a traffic light. The participants' tasks were to decide when it is safe to cross the street. The participants could use three keys on the keyboard to interact with the system: one button for looking left, one button for looking right, and one button for crossing the street. A varying number of virtual cars would appear from the left or right of the user at different speeds. The number of virtual vehicles and their speed would increase after the users completed each level. If the user managed to cross the street safely, the next level would be initiated. If the user got hit by a virtual vehicle, a breaking sound would play accompanied by an accident sign on the screen. The user would then have to repeat that level. Before trying the virtual street crossing intervention, the participants' street-crossing skills were measured using the "pedestrian safety scale" (PSS) on a real street. The real street environment was a safe environment designed for training street crossing skills. The participants then tried the virtual street-crossing application for eight sessions once to twice a week in their school. Each session lasted from 10 to 30 minutes. One of the participants with ASD never understood how to use the application while the remaining five figured out how to use the buttons to cross the street after the second session. All of the TD children in the control group managed to figure out how to use the application on the first attempt. Additionally, all six children in the control group managed to finish all nine levels of the intervention upon their first attempt. Children in the experiment group only managed to get into level four during their first three sessions. After the 8th session, all of the members of the experiment group managed to finish all of the levels. However, there was a significant difference between the children diagnosed with ASD and the TD children in figuring out how to use the application and finishing the levels. After the virtual street-crossing training, the participants' skills were again measured on the real-life street using the PSS. Three out of the six participants in the experiment group had improved their real-life street crossing skills.

Head-mounted Display Based Interventions

Including the work of Strickland et al., only five studies used an HMD in their VR interventions for children or adolescents diagnosed with ASD. Jarrold et al. [74] used an HMD-based virtual classroom environment to assess the social attention of 37 children diagnosed with ASD compared to 52 children with a similar IQ but without ASD. The children experienced a virtual classroom environment using an eMagin z800 3DVisor HMD with a resolution of 600x800 pixels and a field of view of 40 degrees and 3DoF. For comparison, the HTC Vive HMD, released in 2016 (three years after the study conducted by Jarrold et al.), has a resolution of 2160 x 1200 pixels, a field of view of 120 degrees and offers 6DoF. Despite the limited technical capabilities of the z800 3DVisor HMD compared to today's standards, it was sufficient to provide an ecologically valid virtual environment to evaluate social attention in the participants. Via the 3DVisor HMD, the participants experienced a virtual classroom with nine virtual avatars sitting in front of them. They were then asked by the experimenter to answer a set of questions while paying attention to the virtual avatars. The results indicate that children diagnosed with ASD looked less at the avatars in the scene compared to TD children with a similar IQ.

Another study conducted by Beach & Wendt [18] investigated whether an HMD-based VR intervention can be used to teach social interaction skills to children diagnosed with ASD. Two boys aged 8 and 15 attending a camp for children with reduced social skills participated in this study. Six social scenarios in the virtual environment were designed using Second Life released by Linden Research Inc. In 2014, a VR plugin was developed by Linden Research group, allowing Second Life users to experience the virtual worlds of Second Life using the Oculus Rift SDK1 while being able to move their avatar around using the keyboard and mouse on the desktop computer. The 15-year-old male was introduced to a VR scenario where he had to have a conversation with an aggressive senior student. The second scenario placed him in a virtual library where he was supposed to study with a small group of avatars, who acted as if they were annoyed about something and, finally, a third scenario within which he experienced virtual bullies. The 8-year-old male also experienced three social situations in the virtual environment. In the first scenario, he was asked by the experiment moderator to walk up to a virtual avatar in a virtual park and ask for directions. In the second scenario, he had to apply to a job in a virtual hospital. In the third scenario, he had to ask a virtual librarian for help finding a book in a virtual library. These scenarios were designed by the camp leader to match each of the participant's social skills deficits. The camp leader, camp teachers, and researcher were controlling other virtual avatars in the scene using the keyboard and mouse on separate computers. The participants were observed while interacting with the virtual environment and were interviewed by the researchers afterwards. It is not mentioned in the paper how many times and for how long the participants experienced the VR social skills training interventions. During the interviews, both participants stated that they felt that they were actually in the virtual environment. They both enjoyed the ability to freely explore the virtual environment while being able to look around via their head movement. The 8-year old participant even walked up to the roof of the hospital and jumped down, which he described as the most memorable part of his experience. After the VR intervention, the participants tried similar social scenarios in real life at the social skills training camp they were attending. According to the camp leader, both participants were more confident when interacting with others in the real world after training with VR. The participants also stated that they felt less stressed and nervous when interacting with others in real-life. However, it is not clear if these social skills developments emerged from the VR intervention or from attending the camp design to teach social skills to children.

Cheng et al. conducted another study in 2015 [35], investigating the effectiveness of HMD-based VR to teach social skills to children diagnosed with ASD. Three children diagnosed with ASD participated in this study, starting with a baseline session to measure their social skills followed by the VR intervention and a social skills maintenance measurement 20 days after the VR sessions. The baseline and the maintenance measurements were conducted by asking the participants a set of 12 questions from a set of social event cards, which consisted of 12 events that could occur in the classroom or school environment of the participants. For the training intervention, the authors developed two VR scenarios. One where the participants could get on a bus and one where they could navigate from the street into a virtual classroom. The participants moved in the scene via a joystick while they experienced the virtual world wearing an I-glasses i3 TV HMD. A total of 24 questions were designed and asked during the baseline, VR intervention, and maintenance evaluation of the study. These were questions such as *"Would you like to pick a seat on the bus?"* and *"Can I talk loudly on the bus?"* during the virtual bus scenario and *"Can I hide my classmate's pen from him"* in the classroom scenario. The participants could press buttons 'x' for "no" and 'o' for "yes" on the keyboard to answer these questions while wearing the HMD. Each participant received a total of six VR training sessions once a week for six weeks. The results showed improvement to these questions in all three participants during the VR and maintenance sessions compared to the baseline session. As an example, during the baseline sessions, one of the participants was very quiet and ignored the questions asked. During the maintenance sessions, however, he was very talkative and was elaborating on his answers with more details.

Expect for the pioneering study conducted by Strickland et al.,[160] all of the studies that use HMD-based VR did so to teach or assess the social skills of children and adolescents diagnosed with ASD. Additionally, the study conducted by Strickland et al. was the only study with 6DoF VR within which the participants could physically walk around in the virtual environment instead of having to use a joystick or keyboard like the other three studies. As Jaron Lanier states, VR can, by using a variety of gadgets, enable the opportunity to walk and move in the virtual environment as if one is walking the real world. Designing interventions for children and adolescents diagnosed with ASD using 6DoF VR equipment enables the opportunity to create virtual training simulations that require the same interactions for performing the training as it is required in the real-life where the trained skills are to be performed. An intervention designed to teach traffic safety to a child diagnosed with ASD can potentially benefit from immersing the child in a virtual street environment using an HMD. An HMD-based VR traffic safety training intervention can require actual head movement to see if any cars are approaching and leg movement to cross the street. Physical movement in a virtual training intervention that is similar to the activities required in the real world enables procedural training in relevant virtual environments. Despite these advantages, there is a limited number of studies in the timespan from the pioneering study by Strickland et al. pioneering study up until January 2017 that investigates how HMD-based 6DoF VR can help children and adolescents diagnosed with ASD. Therefore, one of the main objectives of this thesis will be to design, develop, and perform explorative studies on 6DoF HMD-based VR solutions to train social and daily living skills.

Table 1: Overview of studies on VR for children or adolescents diagnoesd with Autism Spectrum Disorder

Author(s)	Instrument	Goal
Strickland et al. (1996) [160]	HMD & 3D mouse	Traffic Saftey
Hirose et al. (1997) [69]	Projector & Joystick & Wand	Virtual Sandbox therapy
Leonard et al. (2002) [96]	Screen & Joystick & Mouse	Social Skills
Rutten et al. (2003) [142]	Screen & Joystick & Mouse	Social Skills
Parsons et al. (2004) [125]	Screen & Joystick & Mouse	Social Skills
Moore et al. (2005) [111]	Screen & Mouse	Social Skills
Parés et al. (2005) [122]	Multisensory Room	Creative expression
Parsons et al. (2006) [124]	Screen & Joystick & Mouse	Social Skills
Jung et al. (2006) [78]	CAVE	Sensory integration therapy
Mitchell et al. (2007) [110]	Screen & Joystick & Mouse	Social Skills
Self et al. (2007) [146]	Screen & Mouse & ScentPlate	Fire Saftey
Herrera et al. (2008) [68]	Touchscreen	Imagination skills
Josman et al. (2008) [77]	Screen & Keyboard	Trafic Saftey
Cheng et al. (2010) [34]	Screen & Mouse	Social Skills
Milne et al. (2010) [108]	Screen & Mouse & Keyboard	Social Skills
Sheppard et al. (2010) [151]	Screen & Button	Driving hazard perception
Wallace et al. (2010) [171]	Cave	Social presence in VR
Abirached et al. (2011) [1]	Screen & Mouse & Keyboard	Social Skills
Alcorn et al. (2011) [3]	Touchscreen	Social Skills
Rajendran et al. (2011) [130]	Screen & Mouse & Keyboard	Assesing multitasking skills
Weiss et al. (2011) [174]	Touchscreen	Social Skills
Greffou et al. (2012) [63]	CAVE	Assesing Postural Hypo-Reactivity
Millen et al. (2012) [107]	Screen & Mouse & Keyboard	Creative expression
Lahiri et al. (2012) [91]	Screen & Mouse	Social Skills
Bartoli et al. (2013) [15]	Screen & Kineckt	Assesing attention skills
Bekele et al. (2013) [20]	Screen & Eyetracking	Assesing expression detection
Cai et al. (2013) [30]	CAVE	Social and finemotor skills
Classen et al. (2013) [39]	Screen & Steering wheel	Assesing driving skills
Finkelstein et al. (2013) [56]	CAVE	Exsercise
Jarrold et al. (2013) [74]	HMD	Assesing social awareness
Kandalaft et al. (2013) [79]	Screen & Mouse & Keyboard	Social Skills
Ke & Im (2013) [81]	Screen & Mouse & Keyboard	Social Skills
Reimer et al. (2013) [133]	Projector	Asessing Driving Skills
Wang & Reid (2013) [172]	Screen & Mouse	Contexual Processing Skills
Bartoli et al. (2014) [16]	Screen & Kineckt	Coordination & Attention Skills
Beach & Wendt (2014) [18]	HMD	Social Skills
Bernardini et al. (2014) [25]	Touchscreen	Social Skills
Christinaki et al. (2014) [37]	Screen & Kineckt	Social Skills
Garzotto et al. (2014) [59]	Screen & Kineckt	Social Skills
Maskey et al. (2014) [104]	CAVE	Variety of phobias
Smith et al. (2014) [155]	Screen & Mouse & Keyboard	Job Interview
Stichter et al. (2014) [158]	Screen & Mouse & Keyboard	Social Skills
Wade et al. (2014) [168]	Screen & Steering wheel	Assesing Driving Skills
Cheng et al. (2015) [35]	HMD & joystick	Social Skills
Kuriakose & Lahiri (2015) [88]	Screen & Mouse & Keyboard	Social Skills
Lahiri et al. (2015) [92]	Screen	Social Skills
Parsons (2015) [123]	Screen & Mouse	Social Skills & Collaboration
Saiano et al. (2015) [143]	2x2m display & Kineckt	Traffic Saftey
Tzanavari et al. (2015) [164]	CAVE	Traffic Saftey
Wade et al. (2015) [167]	Screen & Steering wheel	Driving Skills
Xu et al. (2015) [178]	Screen & Kineckt	Self-care & Mobility & Social Skills
Bekele et al. (2016) [19]	Screen & Mouse & Keyboard	Socail Skills
Cox et al. (2016) [42]	210° screen & Steering wheel	Assesing Driving Skills
Didehbani et al. (2016) [50]	Screen & Mouse & Keyboardd	Social Skills
H. H. S. Ip et al. (2016) [73]	CAVE	Social Skills
Lorenzo et al. (2016) [99]	CAVE	Social Skills
Parsons & Carlew et al. (2016) [126]	HMD & Display	Assessing cognitive & motor skills
Wade et al. (2016) [169]	Screen & Steering wheel	Driving Skills
Zhang et al. (2016) [180]	Smartphone	Collaboration Skills
Zhao et al. (2016) [181]	Screen & Leap Motion	Social Skills

2.3 Advantages of Virtual Reality for Children and Adolescents Diagnosed with Autism Spectrum Disorder

The main advantage of the studies described in the previous section is the ability to have the user practice social and daily living skills in virtual environments that are similar to their real-life counterparts. Josman et al. [77] let their participants practice safe street crossing skills on a virtual street while Didehbani et al. [50] enable practicing how to socialize in a virtual school environment or a park. Interactions within these virtual environments can also be similar to their real-life counterparts due to the development of 6DoF VR equipment. As an example, these types of equipment will allow practicing street crossing skills by moving the head to look for cars and walk across the street by actually walking. Based on the studies described in the previous section, the characteristics of individuals diagnosed with ASD described in 1, as well as design considerations for virtual environments described in several publications [139, 28], the following section will propose a set of advantages of HMD-based VR for children and adolescents diagnosed with ASD.

Ecological Validity

The main advantage of these VR applications to help individuals diagnosed with a variety of mental disorders, is the interventions' ability to deliver ecologically relevant stimuli to the users. The ecological validity of an intervention refers to the degree of similarity between the intervention and its real-life counterpart [139, 127]. A virtual bar is an ecologically valid environment to perform CET to an alcoholic compared to a therapist's office in a CBT session [70]. Similarly, virtual food experienced wearing an HMD is perceived more real by users compared to photographs of food [70], while a virtual city designed to look similar to cities experienced by war veterans in Iraq is effective in treating PTSD [138]. Comparibly, virtual environments can be designed to teach social and daily living skills to children and adolescents diagnosed with ASD in virtual classrooms, streets, restaurants, supermarkets, and public transportation. These virtual environments have the potential to activate some of the same emotions, anxieties, and behavior children and adolescents with mental disabilities experience in the real-life. As an example, a study conducted in 2009 showed that children with ADHD, as they would in a real-world classroom, were more affected by distraction in a virtual classroom compared to TD children [2]. Despite the low-quality graphics and fidelity of VR interventions developed in the early to mid-90s, they were still useful in helping individuals suffering from a variety of mental disabilities such as aerophobia [117].

This indicates that photo-realistic, high polygon graphics might not be necessary for achieving the required ecological validity for effective VR treatment interventions. According to Bouchard & Rizzo, as long as the critical elements of the VR environment include the essence of their real-life counterpart and require the same interaction to navigate, the ecological validity will be sufficient for effective interventions [27]. Therefore, I believe that in order to create ecologically valid VR interventions, it is essential to implement interactions in the virtual environments that are similar to the interactions required in the real-world version of that specific environment.

Procedural Skills Training

Procedural skills refer to knowledge applied in doing tasks such as riding a bike or crossing streets, which require learning a sequence of actions in the three-dimensional space to perform [47]. In order to gain procedural skills, one must understand the basic sequences and steps required to accomplish a task as well as their relationships. Mastering these tasks often require repetitive performance of the procedures required for these tasks. One of the earliest examples of an intervention designed to help to achieve procedural skills is the flight simulator called the Link Trainer, developed by Ed Link in 1929 [75]. Back in 1920, Ed Link purchased an expensive flight lesson but was disappointed when the flight instructor did not let him touch any of the controls during the lesson, not allowing him to achieve his learning by doing. This episode inspired Link to create the Link Trainer, which is known as the first flight simulator. It allowed its users to sit in a cockpit that moved in 3D space based on the interaction of the user with the simulation's flight control [75]. This prepared the pilots for controlling a real plane in the same way as VR can by allowing the performance of procedural tasks in VR, prepare children and adolescents diagnosed with ASD to perform those tasks in real-life. Mastering daily living skills such as shopping, cooking, or cleaning requires the development of an understanding of the primary sequence of actions and their interrelationships in order to achieve one's goals. This type of information is usually stored in our long term memory via repetition and retrieved when needed, often unconsciously [128].

Reflections on the feedback received after performing specific procedures can result in experiential learning [55]. Instead of learning how to cross the street safely, procedural training on a virtual street can result in experiential learning emerging from the users' reflections upon the outcome of their actions on the virtual street. Burke et al. evaluated the ability of a screen-based Virtual Interactive Training Agent (ViTA) to support experiential learning through job-interview role-play sessions [29]. The results showed improvement in the participants' skills in answering behavioral, social, and situational questions during a job interview.

The development of VR HMDs that support 6DoF and intuitive input devices such as the Oculus touch controllers or the HTC Vive wands enables creating applications within which procedural skills can be rehearsed, repeated, and stored in the long term memory. This ability to move the body naturally is what distinguishes VR from keyboard and mouse interventions, allowing for the leverage of embodied cognition. A simplified definition of embodied cognition refers to the idea that our mind is influenced by our organs and muscles, which, with their movements and activities, can help us learn skills. In a study conducted by Calvo-Merino et al., [31] two groups of dancers, each specialized in one specific style, watched recorded videos of the two different dance styles. At the same time, their brain activities were being scanned via an fMRI by the researchers. The results show that the mirror system of their brains became much more activated when they saw a video of their specific dance style, which they had physically repeated thousands of times. Physical processes required for daily living skills such as crossing the street or shopping can be repeated again and again in a virtual reality environment.

A study conducted by Grantcharov et al. showed the effectiveness of VR to teach procedural skills to medical students [61]. In this study, a group of medical students trained a procedural operation in VR. This was followed by them operating in real-life, and their performance was compared to a control group that did not receive VR training. The results indicate that the surgeon trainees, who had received VR training, made fewer mistakes, were faster, and showed more effectiveness compare to those who did not receive VR training.

Motivation

According to Anders Ericson, a psychologist specialized in human performance, anyone who is good at anything today was once bad at it [51]. The key to getting good at anything according to Ericson is the repetition of purposeful practice with specific goals, immediate feedback, no distraction, and frequent discomforts. However, such practice and repetition of practice requires motivation. VR has the potential to increase users' motivations for performing repetitive practice. Virtual environments have been used to help increase post-stroke patients' motivation to perform repetitive physical rehabilitation activities [49, 93, 98]. These studies often immerse users in gamified virtual environments. Gamification elements such as leaderboards, points, and badges in therapeutical or cognitive training interventions have the potential to increase users' motivation [57]. Interventions created for rehearsal and learning of social or daily living skills can incorporate game inspired challenges that match the users' skills, thereby keeping the users motivated by keeping them in what Csikszentmihályi called the "flow channel" [43]. In addition to stroke patients, gamification elements have proven to motivate the elderly to perform cognitive training exercises [86], interventions to help patients with eating disorders [64], and VR therapy for individuals suffering from obsessive-compulsive disorder [90].

In a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis by Rizzo & Kim on the properties of VR as a tool for rehabilitation and therapy, gamification to promote motivation was placed as one of the opportunities of VR [139].

Newbut et al. found out that children and adolescents diagnosed with ASD generally accept VR HMDs and are willing to complete tasks within virtual environments while wearing HMDs [113]. A study conducted by Mineo et al. compared the engagement of children diagnosed with ASD in four types of different screen-based media: an animated video, a video of themselves engaged with activity both on a traditional screen and a 360-degree first-person video views using an HMD [109]. The results indicate that the children were more engaged in the video experience via an HMD when compared to the control conditions. Engagement in learning intervention is one of the most important predictors for successful learning in children and adolescents diagnosed with ASD [83]. Studies have shown that 3D animations and sound effects in multimedia interventions have shown to increase the motivation of individuals diagnosed with ASD [95, 36]. However, it is important to present the users with ASD with few animations, and sound feedback at a time, due to their decreased ability to process sensory information [5]. Finally, providing real-time positive feedback right after the correct performance of the desired behavior have shown to increase the motivation of individuals diagnosed with ASD when using multimedia applications [95, 45]. Positive, rewarding feedback that includes colors and movement has shown to motivate individuals diagnosed with ASD [165, 58].

Individualized Treatment

From tall virtual buildings to treat people with acrophobia [41] to virtual bars to help individuals suffering from a substance-use disorder [70], VR can be used to create interventions based on each individual's specific needs. This is especially relevant for children and adolescents with ASD since they can have a variety of different social and daily living skills deficits, each requiring individualized treatment. By involving stakeholders such as teachers or parents in the design process, interventions can be more effective to help the specific needs of the individuals diagnosed with ASD as they can have a wide variety of different needs [82, 144]. Additionally, individualized treatment in VR can be delivered to the user by the therapist systematically based on the user's skills, deficits, and requirements. The task complexity should be provided based on each individual's skills, and gradually increase based on their performance. An intervention to teach a child with ASD how to socially interact with others on a school playground can be initiated on a virtual school playground with only one virtual kid on it and with very few sensory distractions. As the child progresses, and when the therapist feels the child is ready, more virtual avatars and sensory distractions can be placed in the scene. Additionally, the users can receive real-time feedback from either the system or professionals running the VR treatment sessions. Feedback can be delivered in the form of positive and negative reinforcements to promote the desired learning, making VR the ultimate Skinner box as described by Rizzo [135]. This feedback can be communicated to the user either by the system or the therapist via the user's visual, audio, or haptic sensory input channels. Visual, audio haptic stimuli can also provide necessary cues for the user to achieve the required tasks based on each user's specific skills and capabilities.

Remote Treatment

Affordable VR and high-speed Internet connections enable the opportunity to perform the required VR treatment activities at home and without the physical presence of a professional. This is especially relevant for individuals diagnosed with ASD who often feel uncomfortable in unfamiliar surroundings, such as a therapist's office or a new school. The therapist can even log in to the same virtual environment as the person receiving the treatment in order to provide relevant feedback and cues. In a study conducted by Didehbani et al., the clinicians, logged in to the same virtual environment as the adolescents diagnosed with ASD while controlling the avatar of other children in the virtual environment to teach appropriate social skills [50]. The VR systems could also provide data about the users performance to the professionals remotely, without them having to be present. A low level of maintenance requirements is needed for the users or the users parents to be able to run the application properly from home without the presence of professionals. However, remote VR interventions without the presence of professionals might introduce some risks due to the lack of guidelines and assistance provided by the professional [136]. Therefore, remote VR interventions during this Ph.D. study will mainly be multiplayer experiences where the professional can log in to the same virtual environment as the child or adolescent simultaneously.

Safe and Less Time-Consuming Treatment

Performing exposure therapy by placing the user, for example, on top of a tall building in a virtual environment, is safer than doing in-vivo exposure using a real-world tall building. Teaching a child diagnosed with ASD how to cross a street on a real street with real cars is more dangerous than teaching him how to cross a street in a virtual cross-section while wearing an HMD. Additionally, especially for children and adolescents diagnosed with ASD, there is the social safety of being isolated from other people, from whom, due to ASD, they often feel uncomfortable around. This enables them to focus on their training or treatment instead of having to focus on not being negatively judged by or trying to understand the social expressions of their teachers, therapists, or classmates in real-life. Additionally, VR can help save time and resources compared to some real-life treatments such as in-vivo exposure therapy. Bringing a client who has aerophobia on a plane or a client who has acrophobia to a tall building to perform in-vivo exposure therapy can require a substantial amount of time and resources.

Potential Drawbacks of Virtual Reality

During this Ph.D., the purpose of designing VR intervention to help children and adolescents diagnosed with ASD will not be to replace therapists, teachers, and other professionals already working with this target group. Instead, the purpose of these interventions should be to create tools in the toolbox of professionals working with this target group so that they can more efficiently help the children and adolescents diagnosed with ASD. It is essential for the researchers, designers, and developers who create VR interventions for individuals with ASD to involve professionals experienced in working with these specific target groups in the design process. These professionals are familiar with the skills and limitations of children and adolescents diagnosed with ASD. All of the VR interventions to be designed, developed, and evaluated during this Ph.D. will involve teachers in the design process, with them making sure that the interventions follow the ethical guidelines of their school and current teaching methods. Additionally, due to ethical issues, assessment of VR interventions to help children diagnosed with ASD will be performed either directly by teachers, therapists, or other professionals who work with these children daily or at least with them being present during the evaluation. These professionals will be the best to judge who among their students are capable of participating and benefiting from VR interventions, while they will know their limits, and are able to introduce, guide, and assist the children during their VR experiences.

Additionally, having professionals present during the children's interaction with VR interventions helps to know whether the children are comfortable using the HMD or whether the intervention should stop due to factors such as cybersickness. Cybersickness is not going to be thoroughly discussed or evaluated in this thesis. Cybersickness refers to a sensation similar to motion sickness that occurs when exposed to virtual environments [46]. The symptoms of cybersickness include vertigo, nausea, disorientation, eye strain, and in extreme cases vomiting [46]. One of the reasons cybersickness occurs due to incongruency between sensory information received by our bodies and the information delivered by the VR system. This is similar to motion sickness that occurs due to conflicts between sensory input received by the visual, auditory, and vestibular modalities. It is, therefore, essential to develop VR interventions that deliver sensory information based on the users' physical movement. Conflicts between the users' sensory modalities during VR experiences can also result in negative aftereffects such as disturbed locomotion, drowsiness, and fatigue [136]. Adverse aftereffects can take place if the users have to readapt to the sensorimotor requirements of the real world after trying a VR application with different sensorimotor requirements than the real world. The risk of addiction to the VR simulations is another potential consequence that can occur as an adverse aftereffect of VR interventions [136]. Children and adolescents diagnosed with ASD who have difficulties interacting with real people in unpredictable real-world contexts might find virtual agents and environments so appealing that they would prefer to stay in VR rather than returning to reality. Parents and professionals have expressed their fears of children and adolescents diagnosed with ASD's withdrawal from society due to technology [121, 24]. Safety is one of the advantages of VR, but it can also be one of the disadvantages if the users perceive a false sensation of safety. The consequences of getting hit by a car in a VR traffic safety training intervention is less catastrophic than getting hit by a vehicle in the real world. This can put the users at risk if they do not develop an understanding of the difference between the consequences in the real world and the virtual world. Therefore, the users of VR interventions should be made aware of the consequences of actions in the real world by the designers and mediators of VR interventions. In general, more research is required to investigate the adverse physiological and psychological consequences of prolonged usage of VR interventions, especially on children diagnosed with ASD. Therefore, interventions designed during this thesis will require a maximum of 10 to 15 minutes of interaction and will only be conducted under the supervision of professionals who work with children and adolescents diagnosed with ASD.

Research Question

When starting this Ph.D., very few studies had investigated how HMD-based VR can be used to help children and adolescents diagnosed with ASD. With the development of affordable high fidelity HMDs and VR equipment on the market, it is now relevant to investigate how these technologies can help this specific target group. But which deficits of ASD can mostly benefit from HMD-based VR interventions? When looking into ASD, two main categories of deficiencies emerged: lack of social skills and lack of daily living skills 1. In order to design interventions for these deficits, we need to understand more specifically which social and daily living skills can benefit the most from VR training. Therefore, stakeholders such as teachers, therapists, and psychologists working with children and adolescents diagnosed with ASD daily will be involved in setting requirements and specific needs that can be helped via HMD-based VR solutions. Based on the above, the following research question is proposed:

Q1: *Which social and daily living skills are most suited to be trained via HMD-based VR interventions?*

When looking into the advantages of VR to help individuals with mental disorders, ecological validity stands out as one of the main perks of the technology (see Section 2.3). Ecological validity refers to the similarity between the training intervention with its real-life counterpart. Additionally, due to 6DoF HMDs, and controllers, VR enables procedural training. 6DoF HMDs and VR controllers allow us to create VR training simulations where both the virtual environments and the interactions within these virtual environments are similar to their real-world counterparts. During this Ph.D. thesis, it will be investigated how 6DoF VR equipment can help teach social and daily living skills to children and adolescents diagnosed with ASD. These will be designed in close cooperation with stakeholders such as teachers who work with ASD every day. This leads to the next research question of this thesis:

Q2: *How can 6DoF HMD-based VR be used to teach social and daily living skills to children diagnosed with ASD?*

Children and adolescents diagnosed with ASD have a hard time interacting with other people, thus making it more troublesome for teaching interventions that require direct interaction with people. Virtual environments can offer training interventions within which the child or adolescent can focus on the training instead of trying to understand and analyze the verbal and gestural social cues send by their real-life teacher. Additionally, if needed, virtual agents can be placed in the virtual environment to enhance the experience. However, this poses the question: what should the role of teachers, therapists, and psychologists be when using VR to help children and adolescents diagnosed with ASD. These professionals are one of the major stakeholders of VR training interventions. They will be involved not only in the design process but also in the evaluation of the interventions to be created during this Ph.D. They are going to be the main mediators of VR interventions, but what exactly should their role be during these interventions? Therefore one of the main research questions of this thesis will be:

Q3: *What should the role of teachers, therapists, and psychologists be when using VR to teach social and daily living skills to children and adolescents diagnosed with ASD?*

Summary of Included Papers

The main contribution of this Ph.D. thesis consists of the thirteen publications presented in part two. The main goal of these publications was to answer one, two, or all three of the research questions described in the previous section. This chapter provides a summary of the motivation, methods, and findings of each publication. The goal of paper A was to get a helicopter view on studies within VR for therapy in general. Writing paper B provided valuable knowledge on the potentials of VR for children and adolescents diagnosed with ASD. Paper C describes a focus group interview with four teachers working with children and adolescents diagnosed with ASD. The purpose of the focus group was to map out how they see the potentials of VR for their students. Paper D describes a study on adolescents diagnosed with ASD, investigating the usability and user experience of mid-air interactions, which is one of the primary interaction schemes of 6DoF VR. Papers E, F, G, and H describe interventions developed during the Ph.D. to teach daily living skills to children or adolescents diagnosed with ASD. Paper, I, J, K, L, and M describe interventions developed during the Ph.D. to help children or adolescents diagnosed with ASD with their social skills deficits.

Paper A: Virtual Reality Therapy

The primary motivation of the first publication was to find a definition for VR therapy and gain a better understanding of its history. Additionally, the peper attempts to look at different areas within which researchers have applied VR for therapeutical purposes to help inspire the creation of 6DoF VR for children and adolescents diagnosed with ASD. While writing the paper, I learned that HMD-based VR had been applied since the early 90s by researchers to help a variety of different mental and physical disabilities. In addition to studies looking into how VR can be used to help children and adolescents diagnosed with ASD, researchers have also looked at VR anxiety, post-stroke patients, psychosis, and eating disabilities, among many other mental disabilities. One main advantage reoccured in using VR for these different mental and physical disabilities: the opportunity to place the user inside safe, controllable, and often interactive virtual environments tailored to treat the specific ailment. Most of the studies on VR for therapeutical purposes illustrate the potentials of the technology. However, the majority of the studies do not live up to the expectations of standard clinical research due to perhaps the novelty of the technology or the restrictive access to individuals with specific mental or physical disorders for conducting significant studies. This paper was published in Springer Encyclopedia of Computer Graphics and Games 2018.

Paper B: Virtual Reality (VR) for Children Diagnosed With Autism Spectrum Disorder (ASD): Interventions to Train Social and Everyday Living Skills

The motivation for this publication was to gain a better understanding of the difficulties faced by individuals diagnosed with ASD and the interventions designed to help to reduce these difficulties. Social challenges, bullying, and school refusal behavior during childhood and dependence on parents or social agencies upon adulthood are some of the main challenges faced by people diagnosed with ASD discussed in this chapter. Additionally, four main categories of interventions emerged when writing this chapter: social stories, video modeling, peer-mediated training, and cognitive-behavioral therapy. The chapter then looks into how VR has been used to help children and adolescents diagnosed with ASD following a list of advantages of VR based interventions. These advantages include the ability to create ecologically valid training simulations, increased motivation towards training, ability to develop individualized training simulations, ability to deliver training with difficulties based on the users' skills, safe training environment, and the ability to train outside of school and clinics. Additionally, the chapter discusses the possibilities to use VR to replicate conventional methods such as social stories, peer-mediated interventions, and video modeling. Immersive social stories can be created in the form of an HMD-based VR application where the child diagnosed with ASD will be inside the story instead of seeing the story via visual drawings on paper. Virtual peers inside relevant virtual environments can perform Peer-mediated training interventions inside a virtual environment. The peer avatars can even be controlled by a teacher or professional, removing the difficulties training a typically developed child to help a peer diagnosed with ASD. Finally, Immersive HMD-based VR can be used to similar to traditional video modeling, show 360 videos of appropriate behavior to children and adolescents diagnosed with ASD. Similar to the previous publication, this publication concludes that there is a lack of studies that, via clinically valid evaluations, prove the effectiveness of VR interventions for children and adolescents diagnosed with ASD compared to the traditional methods. This paper was published in the IGI global Virtual and Augmented

Reality in Mental Health Treatment 2018.

Paper C: Teachers' Views on how to use Virtual Reality to Instruct Children and Adolescents Diagnosed with Autism Spectrum Disorder

One of the main research questions of this Ph.D. project is *Which social and daily living skills are most suited to be trained via HMD-based VR interventions?* This paper is an attempt to present this question to teachers working with children and adolescents diagnosed with ASD. Three teachers from three different schools participated in a workshop session. Two of the teachers came from schools for children with special needs while one of the teachers was from a school for adolescents with mental disabilities. An Oculus rift HMD and a capable laptop were brought to the workshop session to familiarize the teachers with VR. After trying a variety of VR applications, the teachers discussed how they could use the technology in their daily work with children and adolescents diagnosed with ASD. Three categories of skills suitable for being taught using VR interventions emerged from the discussion, as seen in table 2.

Table 2: Potential skills to teach children and adolescents diagnosed with ASD using HMD-based VR

Daily Living Skills	Social Skills	Academic Skills
Traffic Saftey	School Refusal	Remote classroom
Shopping	Social Anxiety	Sexual Education
Public Transportation	Facial expressions	Geometry
Money Managment	Gestural Expressions	Time and the Clock
Laundry	Turn taking	Converting units

The main opportunity offered by VR, according to the teachers, was the ability to place their students inside relevant environments within which they can practice a variety of different skills. A virtual shop can be developed to practice shopping skills, virtual playgrounds to practice turn-taking or a virtual classroom to receive lectures from home. The information provided throughout this workshop will inspire the interventions to be designed, developed, and evaluated throughout this Ph.D. thesis. The teachers and other professionals will keep being the main contributor to the design of these VR interventions. This paper was presented at the 2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR).

Paper D: Touch or touchless?: evaluating the usability of interactive displays for persons with autistic spectrum disorders

One of the main research questions of this Ph.D. project is to investigate how 6DoF VR can be used to teach social and daily living skills to children and adolescents diagnosed with ASD. One of the main advantages of 6DoF VR is that it allows its users to move on six different axes physically: X, Y, Z, pitch, roll, yaw. This enables mid-air interaction using the VR controllers for actions such as grabbing objects in the virtual world. In this paper, a study is presented evaluating the usability and user experience of mid-air interaction compare to a more traditional touchscreen interaction for adolescents diagnosed with ASD.

Two similar interfaces are designed, each allowing the user to navigate through and pick a musical instrument from a set of musical instruments. Each interface includes five intractable areas: three musical interfaces and two arrows on each side of the screen. The three musical instruments can be selected by the user to listen to the sounds of the specific musical instrument. The arrows allow the user to navigate through the set of musical instruments. The main difference between the two interfaces is the input method: one version allows the user to interact with the application via traditional touchscreen interaction, and the second version allows the user to interact via mid-air gestures tracked by a Microsoft Kinect sensor (see figure 1).

Fig. 1: Layouts of the touch (left) and touchless (right) UIs

The two versions of the application were evaluated in a school for adolescents with mental disabilities. Eight participants diagnosed with ASD tried both versions of the application in a within-subject setup. There were two days between each evaluation session to reduce the carry-over effect. The participants' interaction consisted of two sessions: training and the main stage. A teacher was present during the evaluation sessions. During the training session, the participants were asked to interact with the system without any instruction. If the participants were unable to understand how to interact with the interface, a researcher would provide instruction from a list of premade instructions every 30 seconds. After the training sessions, the participants were asked to perform a set of tasks, such as selecting the instrument in the middle or selecting the right arrow twice. During the participants' interaction with the interfaces, observation data such as time required to complete the training stage and tasks, as well as the number of tasks completed, were collected. After the participants' interaction with the system, a simplified version of the System Usability Scale (SUS) was used to evaluate the usability and user experience of the application. The results indicate that the users' were more effective using the traditional touchscreen interface, while the mid-air interaction was more enjoyable to use in this explorative study. I won the best presentation award for presenting this paper at the Ninth ACM International Symposium on Pervasive Displays 2019 in Palermo.

Paper E: Daily Living Skills Training in Virtual Reality to Help Children with Autism Spectrum Disorder in a Real Shopping Scenario

This paper presents a study investigating the effectiveness of an HMD-based VR application designed to teach shopping skills to children diagnosed with ASD. According to the teachers participating in the workshop described in paper C, shopping skills have the potentials to be trained in a virtual environment while being one of the essential daily living skills for independent adulthood. The study toke place at a school in Rødvre municipality for children with special needs. Using Autodesk Maya and Unity 3D, a virtual supermarket was designed and developed to run on the HTC Vive VR equipment. The virtual supermarket was designed to look similar to a real supermarket familiar to the participants to increase the ecological validity of the training intervention.

Additionally, the items on the shelves of the virtual supermarket looked similar to items found in real danish supermarkets. The users can navigate around in the supermarket either by walking within the Vive lighthouse tracking area or via VR teleportation. On the one hand, the user carried a Vive controller, which could be used to pick up items from the shelves of the virtual supermarket and to see a virtual shopping list. On the other hand, the users carried a real-shopping basket with a VIVE tracker sensor attached to it.

While wearing the HMD, the user could see a virtual shopping basket, which could be moved around by moving around the real-life shopping basket (See figure 2).

The users' main task was to navigate around the virtual supermarket,

Fig. 2: Virtual shopping list and basket and the Danish supermarket items

locate items on their virtual shopping list, pick up the items, and place them inside their virtual shopping basket. The procedure of finding the right item, picking it up and putting it in the shopping basket in the VR intervention is very similar to its real-world counterpart.

Nine children diagnosed with ASD aged 9 to 15 participated in the study, starting with a baseline and finishing with a post-treatment assessment, both taking place in a real-supermarket. In between the evaluations in the real supermarket, four out of the nine participants received seven VR supermarket training sessions mediated by one of their teachers. In general, the results indicate some potentials of the VR intervention to improve the real-life shopping skills of the children diagnosed with ASD discussed in the paper. However, the small sample size prevents making any definitive assumptions about the effectiveness of the intervention. This paper was published and presented at the 2017 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct).

Paper F: Head-Mounted Display-Based Virtual Reality as a Tool to Teach Money Skills to Adolescents Diagnosed with Autism Spectrum Disorder

This paper describes an HMD-based VR application designed to teach money skills to adolescents diagnosed with ASD. The previous study described in paper E did not include purchasing training. According to the teachers, money handling is one of the deficits of adolescents diagnosed with ASD. Four teachers working at a school for adolescents diagnosed with mental disabilities participated in the design of the intervention through design workshops. The teachers stated that money and purchasing skills training is one of the daily living skills often trained at the school. Training would consist of role-playing sessions. The teacher would play the role of a salesman selling pictures of everyday items such as milk and butter cut out from supermarket newspaper. The students were then asked for a specific price that they could pay using play money from the board game Monopoly. The teachers mentioned a lack of motivation and engagement and easy distraction as one of the primary downsides of this role-playing method. Additionally, the teachers stated that skills learned using monopoly money is not easily transferable to real danish bills and coins. The teachers were then introduced to HMD-based VR and, together with the authors of the paper, designed a gamified VR money skills training intervention within which their students could practice purchasing virtual supermarket items using virtual Danish coins and bills. While wearing the Oculus Rift HMD, the users were placed in front of a virtual salesman. A variety of supermarket items appeared on the table in front of the virtual salesman, followed by a verbal request for the amount to be paid for that specific item. The amount to be paid would also appear on a virtual cash register machine in front of the virtual salesman. A variety of Danish coins and bills were placed on a virtual table next to the student. He could walk up to that table, grab the desired coins or bills using the Oculus touch controllers, and put them on the table in front of the virtual salesman. The interaction for grabbing money and placing it in front of a salesman in the virtual environment was done via physical mid-air interactions while holding touch controllers, very similar to the actions required for the same purpose in the real world. If the right amount of money was placed in front of the virtual salesman by the student, the virtual salesman would say out loud, *"Thank you,"* followed by a dance animation randomly picked from a variety of five different dance animations to reward the students' current answer (see figure 3).

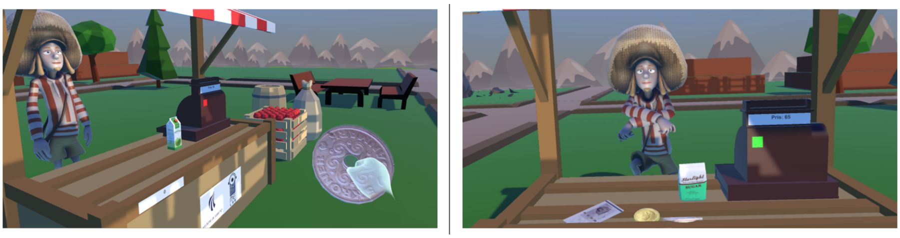

Fig. 3: The bazaar stand and its salesman. Each time the correct amount of money was placed on the bazaar stand, the 3D model would start dancing one out of the five animated dance moves.

If the student failed to provide the correct answer, a variety of verbal instructions would play, telling the user precisely what coins and bills to place

Table 3: Overview of studies on VR for children or adolescents diagnoesd with Autism Spectrum Disorder

Participant	before	After
Student A	19	30
Student B	9	30
Student C	3	8
Student D	0	2
Student E	0	0

on the table. Additionally, after being introduced to the possibilities of VR, the teachers request designing two additional levels to be played before the mini-game with the virtual salesman. According to the teachers, some of their students with ASD had a hard time understanding the concept that some coins and bills have a different value than others. Therefore, the teachers proposed a level in which the students could grab a virtual coin or a bill and then practice placing them on a small table with a matching picture of the grabbed coin or bill. Once the student completed this level, the next level would then require similar actions from the students, but this time the virtual coins and bills had to be placed on virtual tables with matching numbers indicating the value of the currency. Five adolescents diagnosed with ASD and picked by the teachers due to their difficulties with money participated in the evaluation of the VR intervention. Pre- and post-treatment measurement of the participants' money skills was performed, inspired by a study conducted by Cihak & Grimm using real money [38]. The pre- and post-treatment measurements were performed by asking the students to use real danish money to pay for a total of 30 price tags while counting the number of correct answers. The students went through five sessions of VR training, each lasting from 10 to 15 minutes within two weeks. Following the VR training sessions, the participants' real-world money skills were re-evaluated. The results can be seen in table 3. The results illustrate some improvements in the participants' money skills. However, observations during the interaction with the VR intervention showed that the verbal guidance provided by the application was not sufficient to help the students in placing the right amount in front of the virtual salesman. Perhaps, if a teacher could control the virtual salesman in realtime, he could provide the necessary and needed feedback to each student to help increase their learning outcome. Additionally, some of the students found the application boring after several sessions due to its repetitiveness. If the teacher could be more in control of the application, he could make sure to provide the teachers with relevant and fresh tasks that could help increase the students' motivation for training with the application.

This paper was published and presented at the EAI International Conference, Design Learning, and Innovation (DLI 2018).

Paper G: Social Virtual Reality as a Tool to Teach Money Skills to Children and Adolescents Diagnosed with Autism Spectrum Disorder

In paper F, a study was presented evaluating the effectiveness of VR to teach money skills to adolescents diagnosed with ASD. One of the main limitations of that application was the limited feedback and instructions provided to the user. The 3D avatar provided the user with several pre-programmed verbal instructions, activated if the user struggled to answer the right questions. The second iteration of the application presented in this paper attempts to meet those limitations by allowing a teacher to control the VR intervention. This paper is also an attempt to answer the research question on what the teachers' role could be when using VR to teach daily living skills to students diagnosed with ASD. More specifically, the teacher can log into the same virtual environment as the student while controlling a 3D avatar of a cashier in a virtual supermarket. Both users can see each others' avatars and communicate with each other via voice chat using their microphones (VoIP). More than one student can log in to the virtual environment allowing the teacher to work with more than one student at a time. Finally, the teacher can log in to the virtual environment from the school while the students can log in and receive relevant daily living skills training in the virtual supermarket from the safety of their home while still being under the teacher's supervision. In the virtual environment, the teacher can scan items via the scanner in his cashier machine with the total price of the scanned items appearing on a screen in front of the customer avatar controlled by the student (see figure 4). The student controls a wallet with one of their VR hand controllers and, via mid-air interaction, grab virtual coins and bills to pay for the products using the VR hand controller in their other hand. Understanding the different values of the different coins and bills was one of the major challenges of the children diagnosed with ASD in the previous study. In this second iteration, the students can show their wallet to the teacher, who can then explain the values of different coins.

Future iterations of the application can incorporate elements from paper D (the virtual supermarket) to include the whole process of a shopping scenario: picking up items from the shopping list, walking to the cashier, placing the items on the cashier table, conversing with the salesman avatar and paying for the items. Additionally, the application allows multiple users to log in to the virtual supermarket using VR HMDs to create a more realistic scenario of a crowded supermarket where the users can also experience standing in line waiting for their turn. The application was presented to a teacher work-

Fig. 4: Point of View of the customer. To wallet of the buyer can be seen on the left. The wallet is attached to the buyers hand. He can grab different coins and bills using the other hand. The screen in front of the buyer shows the total amount that needs to be paid as well as the name of each scanned item.

ing at a school for adolescents diagnosed with ASD and who had experience teaching money skills to his students. The teacher stated that this would allow him to teach money skills as he does in the classroom (using monopoly money and cut out pictures of daily product) but instead in a virtual supermarket environment, using virtual representations of real danish money and products. He proposed that the system should also allow the students to become the cashier and the teacher a customer to rehearse more advanced money and math skills. Additionally, he mentioned that he would also allow his students to be both the cashier and costumers in the virtual supermarket, allowing him to take care of his other daily tasks in the school while the students were busy learning in VR. Finally, the teacher asked for future iterations of the application to allow him to control the level of ambient sounds in the virtual supermarket, which he describes as one of the challenges for his students diagnosed with ASD to cope with. This paper has been submitted to the 2020 IEEE Conference on Virtual Reality and 3D User Interfaces.

Paper H: Co-Designing a Head-Mounted Display Based Virtual Reality Game to Teach Street-Crossing Skills to Children Diagnosed with Autism Spectrum Disorder

Safe mobility in the community is one of the most important daily living skills for achieving independent adulthood. Children diagnosed with ASD have difficulties processing sensory information, which can result in inattentiveness and street crossing accidents. Additionally, learning disabilities are common among children with ASD, making it difficult for them to learn safe street-crossing skills [119]. Teaching street crossing skills in its natural setting on a real street has proven to be an effective method to help typically developed children learn the required skills [179]. However, according to teachers working at a school for children diagnosed with mental disabilities in Copenhagen, it is a resource-demanding and cumbersome task to bring children with mental disabilities to real street settings to teach them appropriate street crossing skills. Therefore, in this paper, an HMD-based VR street crossing training interventions is presented, designed in cooperation with four teachers working at a school for children with mental disabilities. Two of these teachers had specific experience teaching traffic safety skills to children diagnosed with ASD and were familiar with the requirements of the danish council for traffic safety. The teachers were presented with HMD-based VR by trying a variety of applications on an HTC Vive VR set. They were told about the possibilities for creating an interactive street setting that can react to users' body movements. During the discussion after the teachers' were presented to VR and the opportunities it offered, they proposed a set of requirements for a VR traffic safety application:

- Cartoonish virtual environment to increase users motivation to participate
- Inspired by the video modeling method, the first level of the application should allow the user to see someone else perform safe street crossing.
- The application should require the user to cross a virtual street while following a set of safety instructions.
- After a successful street crossing by the user, the application should present another more challenging level.

Several street-crossing levels were designed together with the teachers before being implemented as a VR application. Following that, a colorful virtual street with buildings and sidewalks was implemented to run on an HTC Vive VR set. In the first level, the user would spawn on the sidewalk in front of a 3D avatar of a child. The 3D avatar will start introducing himself by saying: *"Hello. My name is Niels. When I am to cross the street, I will always* *start by finding the nearest crosswalk and walk to it"*. Following the audio, the 3D avatar would walk up on the sidewalk to the crosswalk. He will then say: *"Once I am by the crosswalk, I will always look to left, right a couple of times to make sure no cars are coming. If there are no cars or all the cars or standing still, then I will cross the street"*. While this audio is playing, the 3D avatar will look to his left and right several times (see figure 5). Following that, the 3D avatar will cross the street. Once he reaches the other side of the street, the 3D avatar will do a celebratory dance. Then the scene goes dark and restarts.

Fig. 5: The 3D avatar of the instructor showing the user how to look to both sides before passing the street.

An audio instructor would then say out loud: *"Now it is your turn to cross the street. First, finde the nearest crosswalk and walk ti it"*. A visual cue will illustrate to the user where the crosswalk is. The user can then use his feet to walk up to that crosswalk while wearing the HMD. This application requires ample physical space for the user to walk around while wearing the HMD. Once the user reaches the crosswalk, the audio instructor would say: *"Good job. Now you must first look to your left to see if any cars are approaching."* The application is programmed to detect whether the user is looking to his left down the road. Additionally, a large moving 3D arrow will appear in the air in front of the user to visualize what left is. Once the user has done that, the system will, in a similar way, ask the user to look to his right and then tell him that now you can cross the street since there are no cars. Once he crosses the street, a clapping sound will play, and the next level starts with the user placed back on the sidewalk. This level will be similar to the previous level expect for it will include moving cars. Once the user safely completes this level, the next level will start with moving cars and crosswalk pedestrian lights and appropriate audio and visual guides. In each level, if the user crosses the street before following all of the instructions, an audio clip will play: *"That was too early, you will have to try again,"* and the level will restart. The main difference between the 6DoF HMD-based VR intervention developed during this thesis and the intervention proposed by Josman et al. [77] is the ability for procedural training introduced in this paper.

Before testing the VR intervention on children diagnosed with ASD, we will have to wait for approval from the Danish Council for Traffic Saftey. Until that time, the application will be further developed in close cooperation with teachers working with this target group. One of the essential focus areas of future iterations of the intervention will be to avoid giving the users a false sense of safety to cross a street. In its current form, the intervention will turn to black and restart if the user passes the street without having followed all of the necessary traffic safety rules. Additionally, future iterations will include more levels with increased sensory information to prepare the users for the unpredictable scenarios on a real-street. Once ready, the application's usability, user experience, and its ability to allow the users to transfer the knowledge gained in the simulation to the real world will be evaluated on children or adolescents diagnosed with ASD. This paper has been published and presented at the 8th EAI International Conference: ArtsIT, Interactivity & Game Creation 2019.

Paper I: Head-Mounted Display-Based Virtual Reality Social Story as a Tool to Teach Social Skills to Children Diagnosed with Autism Spectrum Disorder

Inspired by the social story method, this paper presents an HMD-based VR intervention designed to teach social skills to children diagnosed with ASD. Three teachers working with children diagnosed with ASD daily and familiar with the social story method were involved in the design of the VR application. The teachers mentioned that one of the major social skills challenges of their students was sharing, negotiation, turn-taking, and conflict resolution. The teachers' main complaint about traditional social stories was that their students often had a hard time understanding the feelings and mental states of the characters described in the social stories. Based on the input from the teachers, a VR intervention was developed by the authors to be used to teach about sharing and turn-taking to children diagnosed with ASD. The children experienced the characters of the application from a first-person perspective to help them better understand the feelings and mental states of the characters involved. A virtual classroom was designed to look similar to the real-life classroom of the students participating in the study. A 3D teacher avatar was created and placed in the virtual classroom. Similar to the traditional social stories method, the teacher would be the moderator of the VR social skills training intervention. Via a microphone, the teacher can talk to the children during the VR social skills training sessions. The children will hear the teacher's voice as if it is coming from the 3D teacher avatar. Additionally, the teacher can via the keyboard control the events taking place in the virtual social story. Before starting the intervention, the teacher can choose between three different social scenarios via a GUI using their mouse. All three scenarios include the user (the child diagnosed with ASD), the teacher, and a 3D avatar taking the role of a third child in the scene. The social scenarios were as follows:

- The user sees the 3D avatar of a child playing a game on a computer. The teacher tells the user to grab the computer. The child can walk up to the virtual avatar and using a Vive controller, grab the computer, which is in front of the 3D avatar. This will initiate an animation and audio sequence of the 3D child avatar, looking sad and complaining that he was not finished playing on the computer. The teacher can then press the P button on his keyboard to force the user to focus on the teacher avatar. He can then talk to the child about the social scenario and why it is not right to take someone's computer or toy without asking for permission first.

- In the second scenario, the user is instructed by the teacher to ask the 3D avatar playing with the computer about whether it is okay if he borrows the laptop. Once the user verbally asks the 3D avatar to borrow the computer, the teacher can press either the J or the N button to activate two different actions from the 3D avatar of the child. The J button initiates a sequence in which the avatar will give the computer to the user (see figure 6). The N button will activate another sequence where the avatar will tell the user to wait until he is finished playing on the computer. The teacher can then talk to the child about the social scenario.

- In the third scenario, the child will start the scene by playing a simple mini-game on the virtual computer (see figure 6). The teacher can at anytime activate a sequence in which a 3D avatar of a child will take the computer away from the user without asking for permission. The teacher can then talk to the child about turn-taking and sharing.

The teachers performed VR social story sessions using the developed application on five students diagnosed with ASD. The teachers reported that the students were capable of putting themselves in the shoe of the character in the virtual social story, being able to understand his mental state better than they would if they used a traditional social story. Additionally, the teachers stated that having the teacher avatar in the scene and the capability to communicate with the child throughout the VR session increased the

Fig. 6: On the left: the students view while playing the game himself. On the right: the virtual student accepting to share the computer with the real student.

effectiveness of the social skills training session. However, further work is needed to improve the usability and user experience for the teachers so they can more effectively interact with the child in the VR environment during the VR training session. This paper was published and presented at the 2018 IEEE Workshop on K-12 Embodied Learning through Virtual & Augmented Reality.

Paper J: Virtual Reality Music Intervention to Reduce Social Anxiety in Adolescents Diagnosed with Autism Spectrum Disorder

Social anxiety can have a negative consequence on the lives of individuals diagnosed with ASD due to increased isolation from interaction with peers, lack of friendship, romantic relationships, and school refusal behavior. Exposure therapy is one of the most common non-pharmaceutical methods to help individuals suffering from anxiety. In this paper, a VR exposure therapy application is proposed by the authors to help children diagnosed with ASD in coping with their social anxieties. A teacher working at a school for adolescents with mental disabilities picked four of his students diagnosed with ASD and who have shown signs of social anxiety to participate in the study. According to the teacher, these four students would often avoid school singing sessions. Therefore, a VR application was developed within which the users could sing in front of a reactive virtual audience in a virtual concert hall. To gradually increase the tension, the user would start in an empty concert hall.

An audio-announcer would than announced in Danish: *"Hello. You are in the concert hall. Are you ready to make some noise? If you are ready, say come in out* *loud. Once you say come in, the audience will enter the concert hall".* The application was programmed to recognize the verbal phrase *"come in,"* which will activate the virtual audience who will then enter the concert hall through a door, find a chair, and sit down. Once they were all seated, the audio-announcer would say: *"The audience is now seated and ready to start. Once you are ready, say start so we can begin the show".* The system was also programmed to recognize the phrase *"start,"* which resulted in a song chosen by each participant to start playing with its lyrics appearing behind the virtual audience. A total of eight virtual audience animations were created, including a variety of facial expressions and body movements. These animations changed based on the amplitude of the users singing. If the user did not sing, the virtual audience would look down or put their hand under their chin while looking sad (see figure 7). If they started singing, the virtual audience would smile. Singing with higher amplitude would trigger a variety of clapping, standing up and clapping as well as some dancing. The goal

Fig. 7: The virtual audience reacting to the performance. Each member of the audience switched between eight different animations depending on the users' singing amplitude. The lyrics appeared on a screen behind the virtual audience.

of the study was to measure the participants' willingness to sing in front of a virtual audience. A simplified version of the Immersive Tendency Questionnaire (ITQ) and the Witmer Singer presence questionnaire was used to investigate whether the participants were immersed in the VR environment. Simplified versions of these two questionnaires were used since the teacher believed that the students diagnosed with ASD would have a hard time understanding the sentences in the original and more extended versions of these questionnaires. A smiley Likert scale replaced the traditional Likert scale to make it easier for the participants to answer the surveys. The willingness of the participants to sing in the virtual environment, as well as their level of immersion and anxiety during the VR sessions, can provide some information about the potentials of VR to be used as an exposure therapy tool to help adolescents diagnosed with ASD. Finally, the participants were asked if they felt any anxiety during the VR singing session.

The results show that all four participants agreed to try to sing in front of a virtual audience. Three of the participants sang with confidence in front of the virtual audience while one of the participants could not pronounce the verbal lyrics, therefore only made some homing sounds. Despite the attempt to simplify the questionnaires, one out of the four participants was not capable of understanding and answering them. The remaining three answered relatively high on both immersion and presence questionnaire. Additionally, all three participants stated that they felt minimal to no anxiety when singing in front of the virtual audience. The teacher stated that he was surprised that they would sing in VR since they always refused to sing in front of other people in real life. The teachers argued that the reason his students did not feel any anxiety during the VR singing session might be due to them not feeling that they were being observed or judged by any real people. Despite being reactive to the users singing amplitude, the 3D virtual audience designed for this intervention did not look or moved like a real person. Placing the user in a virtual environment within which they would be asked to sing in front of real people recorder with 360 camera might feel more realistic and anxiety-inducing for this target group. Additionally, placing a real person together with the child in the virtual environment might induce some of the same anxiety as having to sing in front of others in real life. This paper was published and presented at the 16th Sound and music computing conference.

Paper K: Singing in Virtual Reality with the Danish National children's choir

Paper J presented an HMD-based VR intervention designed to perform exposure therapy on adolescents suffering from social anxiety in addition to being diagnosed with ASD. The users were asked to sing in front of a reactive virtual audience. Four children tried the application, and all four seemed immersed and ended up singing in front of the virtual audience despite their teachers stating that they would always avoid situations where they had to sing in front of people in real life.

One reason for that could be that the users sang in front of 3D virtual avatars that did not look very realistic. Therefore, in this paper, a VR exposure therapy application for social anxiety is described, within which the users can sing together with the danish national children choir. More specifically, the authors got the chance to do 360 recordings of the Danish National Children Choir singing sessions in one of their studios. A total of 25 children from the choir were recorded performing warm-up sessions as well as two different singing sessions. In each singing session, the children lined up in two rows in front of the choir conductor. Each singing session was recorded with three different camera placement. One where the camera was placed on the back row behind most of the students (see figure 8). One where the camera was placed on the front row, and finally one where the camera is placed next to the choir conductor facing all of the other children.

Fig. 8: A screenshot from the captured footage during the performance of one song, with the camera placed on the second row.

The purpose of these different camera placements was to change the amount of social anxiety when using the VR application. Additionally, four virtual relaxation rooms were created, which the child can enter if he gets overwhelmed by the virtual singing experience. These relaxation rooms consisted of a beach, a forest, an empty room, and a furnished room.

Two psychologists and two interns, all working at a clinic for children with anxiety disorders, tried the VR exposure therapy application and participated in a join discussion afterward. During the discussions, one of the psychologists underlined that children suffering from anxiety each require their specific plan that may differ from other children suffering from anxiety. He mentioned that it is the job of the psychologist to improvise during exposure therapy sessions, and therefore, full control of the VR application is critical. The psychologist requested full control in the form of the ability to effortlessly pause, play, rewind, and forward the 360 videos depending on the child's reaction. He also requested the ability to talk to the child while immersed in the VR environment about the child's emotions during the exposure therapy sessions. This he mentioned could be done by giving both the psychologist and the child the ability to point at different areas in the scene and talk about them. This paper was published and presented at the 14th International Symposium on Computer Music Multidisciplinary Research (CMMR 2019).

Paper L: Singing in Virtual Reality. A tool for Psychologists to Perform Exposure Therapy on Children with Social Anxiety

Based on the finding of paper K, this paper presents a new iteration of the VR singing intervention for social anxiety. This iteration was designed to provide the psychologist with full control of the VR exposure therapy session. Similar to paper K, the user can experience singing with the danish national children choir while wearing an HMD. However, in this iteration, two different interfaces are developed to provide the psychologist with full control of the users' experience during the VR singing exposure therapy. One of the interfaces is a classical GUI on a desktop computer that the psychologist can switch between the 360 videos experienced by the users, as well as pause, play, rewind, fast forward these 360 videos.

In the second interface, the psychologist is immersed in the same virtual environment as the child while wearing an HMD and holding VR input devices connected to a second computer. In the virtual environment, the psychologist and the child each control a 3D avatar while they can see each others' avatars and communicate via voice chat. While wearing the HMD, the psychologist can move a 3D UI via his left hand with the required buttons to change the virtual scenes, pause, play, rewind, and fast forward the 360 video experience by both the child and the psychologist. The psychologist can press the buttons on the 3D UI using his right-hand VR controller (see figure 9). Finally, the 3D UI also includes a button that allows the psychologist avatar to become invisible if the psychologist wants the child to experience the 360 singing session on his own.

This iteration of the VR intervention was evaluated by two psychologists and two student workers, working at a clinic for children with anxiety disorders in Copenhagen. Two computers with two sets of Oculus Rift VR were brought to their clinic to evaluate the VR intervention. Each participant tried both interfaces via one of the two computers. At the same time, one of the authors of the paper logged into the same virtual environment on a different computer, playing the role of a child. After five minutes of interaction, the participants are given several tasks by the evaluator to evaluate the usability and user experience of the system. These tasks included changing the 360 videos, fast forward, pause, unpause, and make the psychologist avatar invisible and visible again. Once the psychologists completed the tasks, they were asked a set of questions from a revised version of Jakob Nielsen's heuristics about the system visibility, status, user control, and freedom as well as error prevention, flexibility, and efficiency of the system [114]. The same procedure was repeated for both interfaces. The results of the heuristic evaluation

Fig. 9: The 3D avatar which is controlled via the Oculus HMD and touch controllers or the keyboard and mouse.

indicate that both interfaces provided the psychologist with control of the exposure therapy session. However, some of them had some usability issues with the fast forwards and rewind buttons on the 3D UI, and they experienced accidental buttons presses. Finally, when asked about the control of their clients' experience when using the VR application, the participants mentioned that wearing an HMD can limit access to the clients' facial expressions and physical body movement. This can reduce their ability to analyze how the child is feeling during the exposure therapy session. In regards to the desktop version of the GUI, no usability issues were reported by the participants. However, it was mentioned that it was not easy to explore the scene using the mouse and keyboard. Following the heuristic questions, all participants and the authors had a joint discussion about the two versions of the VR intervention.

During the joint discussion, the most dominant topic about the 3D UI version of the intervention was the connection and equality it potentially can create between the child and the psychologist. According to psychologists, this equality can likely generate more trust between the two, making it easier to work with the child's anxiety. Additionally, the psychologist mentioned that being immersed in the virtual reality environment with the child and experience the same environment makes it easier for him to put himself in the child's shoes and have empathy for the child. Sometimes, the clients do not know the source of their anxiety. Therefore, it was mentioned that experiencing anxiety-inducing situations together with the child can make it easier for the psychologist to work together with the child towards understanding what creates the anxieties.

The most negative discussed topic on the 3D UI version of the intervention was the inability to see the child's facial expressions during the exposure therapy intervention due to the psychologist wearing an HMD. This can remove some of the psychologists' ability to analyze the emotional state of the child. On the contrary, it was easier for the psychologist to see the child's physical appearance when using the traditional GUI on the desktop. In regards to usability, all participants felt that it was easier for them to use the conventional GUI compare to the 3D UI. However, they mentioned that it was not as easy for them to navigate the scene as it was when wearing an HMD and that their connection with the child was not as good since the child now felt more alone in the virtual environment. This paper is submitted to the ACM CHI Conference on Human Factors in Computing Systems 2020.

Paper M: Head-Mounted Display-Based Virtual Reality as a Tool to Reduce Disruptive Behavior in a Student Diagnosed with Autism Spectrum Disorder

Disruptive behavior such as aggression towards classmates, throwing objects, or shouting can have a negative consequence on the teachers' ability to disseminate knowledge during a lecture as well as the students' motivation to learn. A nine-year-old student diagnosed with ASD and attending a school for children with mental disabilities in Copenhagen was reported by the teachers to perform disruptive behavior in the classroom daily. He would be verbally abusive, hit other students, and sometimes the teacher as well as throwing objects towards others in the school. The only action that would calm him down would be if the teachers brought him out of the classroom and waited with him outside for a while until he calms down. However, this would result in the teacher having to leave the class, leaving the rest of the students alone. Due to his ASD, they attempted to give him one to one lectures to see if his disruptive behavior was due to the other students present in the classroom. Unfortunately, his disruptive behavior continued even when receiving lectures one to one from a teacher. The disruptive behavior was often triggered if there were some tasks that he was not able to solve, resulting in him getting frustrated and performing disruptive behavior. In paper G, the adolescents diagnosed with ASD did not have any social anxiety when having to sing in a virtual environment compared despite them avoiding singing in the real-world. Therefore, we tried to investigate whether VR can provide a safe environment for the child to receive lectures while reducing his disruptive behavior, which is often taking place in real life. The teachers' requirements for a virtual environment to teach academic lectures to the student was:

- The teacher and the student should be able to be in the same virtual environment at the same time.
- The virtual environment should include an interactive screen to be used as a blackboard.
- Both the student and the teacher should be able to manipulate the objects on the interactive screen in the virtual environment

The application BigScreen VR was chosen for this study since it lives up to all the teachers' requirements. BigScreen VR is a consumer application that enables multiple users to log in to the same virtual environment within which they can watch movies, play games, or browse the internet on an interactive virtual display. Each user controls a virtual avatar using an HMD and its hand controllers while being able to see the avatars of other users logged into the same virtual environment (see figure 10). With a virtual keyboard and a virtual pointing device, the users can navigate their computer desktop while logged into the virtual environment. The ability to navigate the desktop of a computer while logged into the virtual environment enables the teacher to use the digital tools they use in real-life such as skoletube[1] and bookcreator[2]. Skoletube and Bookcreator are digital teaching material production and distribution platforms used by elementary schools in Denmark. Bigscreen VR allowed the student and the teacher to log into the same virtual environment and work on the same presentations and assignments together. The student logged in to the VR environment using an HTC Vive HMD from one room without the presence of the teacher while the teacher logged into the same virtual environment from a different room. The participant received lectures by the teacher while both logged into the Bigscreen VR three times a week for two months. The teacher used the interactive screen in the virtual environment to give math and danish lectures to the student with two twenty minutes sessions with a short break in between.

At no time during the VR lectures did the student showed any disruptive behaviors such as aggression or abusive language. He was calm, listen to the teacher, solved tasks, and asked appropriate questions when in doubt. However, unfortunately, his disruptive behavior remained the same when he returned to the real classroom environment. One of the main differences between the real-class room and the virtual environment is their presence of other "real" people. The teacher's avatar was a cartoonish, low fidelity 3D model, not resembling a realistic person and unable to show any facial

[1]https://www.skoletube.dk/
[2]https://bookcreator.com/

Fig. 10: The participant logged in to the virtual environment in one room while the teacher is logged into the virtual environment from another room (buttom right). Screenshot from the teachers view (top right).

expressions, giving the child fewer social cues analyze, which is one of the primary deficits of individuals diagnosed with ASD. Another difference between the virtual environment and the real classroom is the frequency of unpredictable events taking place. In the real classroom, the student is presented with a lot of unpredictable sensory information, while the sensory information in a virtual environment is predictable and controllable. Finally, this study showed potentials for allowing the teacher or a professional to provide the appropriate treatment while present in the same virtual environment as the child diagnosed with ASD. This paper was published and presented at the 4th EAI International Conference on Design, Learning & Innovation 2019.

Conclusions and Future Work

The goal of this thesis was to explore how HMD-based VR can be used to teach social and daily living skills to children and adolescents diagnosed with ASD. I choose social and daily living skills due to these being essential skills required for independent adulthood. By looking into traditional methods to teach these skills to this target group, I learned that they often rely on the visualization of the desired behavior rather than verbal instructions. Methods such as video modeling and social stories show either still or moving pictures of the desired behavior to the child. Another method, such as peer-mediated training relies on a typically developed peer to teach the child with ASD the appropriate behavior while being physically present in a relevant context to the specific social skill to be taught, such as the playground. I believe that virtual reality can merge these traditional methods. Virtual reality enables placing the user inside relevant virtual environments within which they can see, perform, and get feedback on the desired social or daily living skills. In the second part of this Ph.D., I present several papers describing virtual environments designed for children and adolescents diagnosed with ASD to see, perform, and get feedback on appropriate social and daily living skills. However, it is essential to point out that none of the studies described in this Ph.D. have the required standards to conclude that the VR interventions designed during this project are superior to the traditional methods. The main goal of this project was to explore the possibilities of HMD-based VR by designing, developing, and evaluating applications in close collaboration with teachers and other professionals working with this target group. Although some of the studies presented in this thesis attempt to evaluate the learning outcome of the proposed VR interventions, none of them can conclude that the skills are transferrable to real life and whether they can be maintained by the users over a more extended period after the VR interaction. Such evaluations would require more resources and participants that have been available in the scope of this project.

The main focus of this project was to explore which social and daily living skills can potentially be trained via HMD-based VR by children and adolescents diagnosed with ASD, how these should be designed and what the roles of the moderators of such interventions should be. In the following sections, I'll go through each of the research questions presented in section 2.3 and discuss how the publications presented in part 2 addressed each of them.

Q1: Which social and daily living skills are most suited to be trained via HMD-based VR interventions?

Teachers working with this specific target group and experienced in teaching them social and daily living skills are the most qualified to answer the first research question of this project. Therefore, in paper C, three teachers were asked to discuss how they believed VR could potentially benefit their work with children and adolescents diagnosed with ASD. Three main categories of skills to train in VR emerged from this discussion described in the paper: Daily living skills and social skills, which are the main goals of this Ph.D. project, as well as academic skills, a topic that I did not directly investigate. It can be argued that paper M dealt with academic skills by allowing the teacher to teach a student diagnosed with ASD in a virtual environment. The student who performed disruptive behavior in the real classroom stayed calm and received math and language lectures in VR. In general, the remote classroom was one of the main topics under the academic skills requested by the teachers in paper C. In addition to potentially help to reduce disruptive behaviors, a virtual classroom where the child and the teacher can log into from different locations can also help another major challenge observed in children and adolescents diagnosed with ASD: school refusal behavior. Remote classrooms can allow students diagnosed with ASD who illustrate school refusal behavior to receive academic lectures from the safety of their homes. Under the academic skills, the teachers also mentioned geometry, time/clock, unit conversion, and sexual education. Future studies should, therefore, further investigate how VR can be used to teach these topics to children and adolescents diagnosed with ASD. It can be argued that understanding time, converting unit, or sexual education are also daily living skills necessary for independent adulthood, and therefore could have been included in the scope of this Ph.D. project. As an example, the teachers stated that understanding the time of day, week, or months can be hard to understand for some of their students. Therefore, they suggested creating a virtual environment where the student could visually experience the difference between nine o'clock in the morning and nine o'clock in the evening or the difference between winter and summer. During this project, the focus was mainly on social and daily living skills. Papers E, F, and G focused on shopping and money skills, while paper H focused on street crossing skills. Shopping is an essential skill to master if one is to live independently and without help from parents or social agencies. Additionally, a variety of different skills are required in order to perform a complete shopping trip. Creating a list of items to be purchased, navigating around in a supermarket to localize the needed items, standing in line, and finally paying for the purchased items using either cash or a credit card. The supermarket might even be a crowded environment that can be hard to navigate in for an individual diagnosed with ASD. In paper G, a supermarket prototype is presented where multiple users can log in to the same virtual environment. This application has the potential to allow training in a virtual supermarket where the user will have to navigate and locate the desired items while being exposed to a gradually more and more crowded virtual supermarket, which might potentially prepare the user for a real-life supermarket experience.

Fig. 11: Screen shot of the public transportation 360 video training intervention

Under the topic of daily living skills, the teachers also requested public transportation and laundry training. In regards to public transportation, the teacher from a school for children with mental disabilities in Rødovre municipality introduced me to the case of a student who refused to take the bus home. Every day he would wait for more than an hour after the school day was over for his father to come and pick him up with a car while most of the other students would take the bus home. He would also always stay away from the school on days where they were going for a school trip using a bus. Together with the teacher and with permission from the student's parents, we designed a VR experience where the student could be exposed to the whole trip from his school to his house using public transportation. Using a 360 camera, in early 2017, we filmed the walk from the school to the bus stop (figure 11), filmed the process of purchasing a ticket, sitting on the bus, getting off at the station close to his house and then walking to his home. However, due to lack of image stabilization of the 360 camera and its low number of frames per second, experiencing the walk from the school to the bus station and the walk from the bus station to his home became a very cyber sickness-inducing experience. Therefore, the child did not tried that experience and no paper was published on this application.

In regards to social skills, papers J, K, and L proposed VR interventions to help children or adolescents diagnosed with ASD with their social skills deficits by relying on one of the most applied usages of VR: exposure therapy. Paper I proposes a social skills training application in the form of an interactive virtual classroom within which the children can practice sharing and turn-taking. In general, any social or daily living skill can be trained in VR, if the learning can take place in a virtual environment similar to its real-life counterpart and require the same interactions as its real-life counterpart. This lead to the secondary research question of this Ph.D. project.

Q2: How can 6DoF HMD-based VR be used to teach social and daily living skills to children diagnosed with ASD?

In the VR intervention presented in paper E, the users could walk around in a virtual supermarket that looked similar to a real danish supermarket. On the one hand, they hold a real shopping basket while, on the other hand, they hold a VR controller. The users could locate grocery items on their virtual shopping list, take them from the shelves and place them in their virtual shopping basket by doing the same physical movements required to perform the same action in the real world. In paper F and G, VR interventions are presented that allowed the users to grab money from a virtual wallet and place them in front of a virtual salesman by performing almost the same physical movements required to pay a real-world salesperson. The similarities between actions performed in the traffic safety application presented in paper H and the sharing and turn-taking social skill training presented in the paper I also required the same physical movements as required when crossing a real street or grabbing a real computer. This, I believe, is the main power of HMD-based VR with 6DoF: the ability to create VR training interventions that look similar and require the same physical movements as the real-world in which the desired skills are to be performed by the user. As an example, VR public transportation intervention designed using a 360 camera (see figure 11) was a 3DoF experience that, similar to video modeling method, would only allow its user to passively experience how to use public transportation from the first-person view. By implementing a 6DoF HMD-based VR version of a public transportation application, the user can try navigating from his school to the bus station, practice buying a ticket, finding a sit in the bus, and get off the bus on the appropriate station. Photogrammetry can be used to create an interactive virtual scene by photographing the environment from the school to the bus stop station and that stitch those images together [150].

While wearing an HMD supporting 6DoF VR, the user can then navigate through a virtual environment that resembles the real path from his school to the desired bus stops and take a bus that looks similar to real danish buses. Additionally, paper L explored the possibility of using 6-DoF VR to enable a psychologist to use a 3D UI to control what a child with anxiety is experiencing while being immersed in the VR environment wearing an HMD himself. In general, 6DoF interaction while immersed in 360 videos provides the opportunity to interact with 3D objects while experiencing a 2D 360 video. In another unpublished intervention developed during this Ph.D., 360 degrees recording of a concert for children were used to perform exposure therapy on children diagnosed with ASD and social anxiety. This intervention merged 6DoF interaction inside a 360-degree video experience by allowing the users to grab and play with several virtual music instruments, as seen in figure 12 using 6DoF VR controllers while experiencing a 360-degree video.

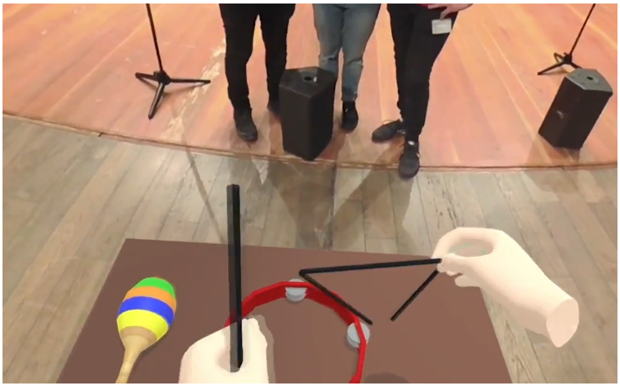

Fig. 12: Screen shot of thee exposure therapy intervention. The user can interact with 3D musical instruments while experiencing the 360 video of the concert

In general, 6DoF HMD-based VR enables placing the user inside relevant, interactive virtual environments within which the desired skills can be reheard by performing similar physical movements as required in real life. This enables creating virtual playgrounds where the user can practice walking up to a virtual peer and ask if he wants to participate in a play session or virtual laundry machine where the user can practice sorting his clothing in different colors before washing them. As another example, teachers from a school working with adolescents diagnosed with ASD in Copenhagen asked if a virtual kitchen could be developed to teach their students how to clean up the school kitchen after lunch by placing the glass, cops, and plates in their appropriate space. This resulted in another 6 DoF VR intervention developed during this Ph.D.: a virtual kitchen where the user can grab plates, glass, bowls, and cutlery and place them in their appropriate virtual cabinets, shelves, or drawers (see figure 13).

Fig. 13: Screen shot of the virtual kitchen. The user can grab all of the items and is asked to place them in their appropiate location

In the first level, pictures and names will appear next to the shelves, drawers, and cabinets, indicating whether the cops, plates, or cutlery should be placed in them. As the user advances in the application, the number of guides will reduce. This application will be evaluated in the future to see if it can help teach adolescents diagnosed with ASD how to keep a tidy kitchen, another essential daily living skill. Future studies will also attempt to investigate whether 6DoF HMD-based VR is more efficient than screen-based or 3DoF HMD-based VR training interventions to teach social and daily living skills to children and adolescents diagnosed with ASD.

Q3: What should the role of teachers, therapists, and psychologists be when using VR to teach social and daily living skills to children and adolescents diagnosed with ASD?

All of the interventions designed within the scope of this Ph.D. project are to be mediated by the teachers or other professionals working with children or adolescents diagnosed with ASD. This poses the question: what should their role be during VR training sessions? During the money training application presented in paper F or the traffic safety training described in paper H, the teacher was not directly involved in the VR intervention - the system provided most of the feedback to the user during training. In the sharing and turn-taking intervention described in paper I, the teacher can control the events by using keyboard buttons while being able to communicate with the child using a microphone. Similarly, in the exposure therapy VR intervention described in the papers J and K, the psychologist or the teacher were not directly in control of what the child can experience. In all these papers, the teachers and the psychologists requested more direct control of what the child or adolescent was experiencing during VR training intervention. Therefore, attempts were made to provide the mediators of the VR training with more control of the VR training interventions during the training sessions. Papers L, G and M were the main attempts in this Ph.D. to provide the teachers and psychologists with full control of the users VR experience. In paper L, a virtual supermarket is presented that allows multiple users to log into the same virtual environment while wearing an HMD, each controlling a virtual avatar. This enables the teacher to bring the shopping skill training lectures into a virtual supermarket instead of the classroom, within which he can freely instruct and guide his students on how to do daily shopping. Paper M provided the teacher with the opportunity to teach math and danish to a student inside a virtual living room within which the student who usually performed disruptive behavior stayed calm and concentrated during the lectures. The teacher had full control of what the child was experiencing by controlling a big screen in the virtual living room, while he could communicate with the child using a microphone, and, while they both controlled a VR avatar using HMDs and VR controllers. Paper L proposed a VR 360 video exposure therapy intervention within which both the child and the psychologist can log in to the same virtual environment while controlling 3D avatars using HMDs and VR controllers. While being logged into VR, the psychologist can control what 360 videos are being played while he is also capable of pausing, fast-forwarding, rewinding the 360 videos using a control panel presented to him via a 3D UI. Additionally, the psychologist can communicate with the child using a microphone. The 3D UI interface was compared to a 2D UI presented to the psychologists, which they could use via traditional mouse and keyboard interaction. The results indicated that the 2D UI used via traditional GUI interface was easier to use for the psychologist, especially since they are already used to work with this kind of interface. Therefore, further work is required to increase the usability of the 3D UI to be used while immersed in a VR environment. It can be argued that further exposure to 3D UI interfaces controlled using VR controllers can additionally increase the psychologists' ability to use such interfaces. In general, the psychologists agreed that being present in the same virtual environment as the child, experiencing what he is experiencing, and communicating with him on the same level can increase the outcome of the exposure therapy sessions. Therefore, in my future VR interventions designed for children and adolescents diagnosed with ASD, I will focus on allowing the teacher or the psychologist to be present in the same virtual environment as their students while wearing an HMD. One of the applications developed during this Ph.D., but not yet published, allows the students and the teacher to log into a virtual classroom that resembles the real-world classroom of those students in Rødovre municipality (see figure 14).

The school, after which the virtual classroom is designed, is a school for adolescents with mental disabilities. According to the teachers at the school,

Fig. 14: Screenshot of the virtual classroom. It is design to look similar to the users real world classroom. Multiple users can login to the same virtual environment

some new students are afraid to join a new school environment. The purpose of this application is to remotely introduce them to the school environment, where they can meet the teachers and current students whom each are logged into the VR environment using HMDs and VR controllers. Additionally, the intervention is designed to allow the students to practice social skills by playing games such as tick tack toe, draw on a virtual whiteboard together, or watch youtube clips on the virtual TV screen. All these are activities that are also available in the real-world classroom at the school. In this intervention, the teacher can be the main moderator, introducing new students to the classroom and their future classmates, or teaching how to participate in play activities. In the future, similar to the intervention presented in the paper M, the teacher can teach academic lectures such as math or danish to the students using the virtual screen.

The development and availability of affordable 6DoF VR HMD equipment enable a future where Ernest Cline vision of school can become a reality:

> *"In art class, we toured the Louvre while all of our avatars wore silly berets. In my astronomy class, we visited each of Jupiter's moons. We stood on the volcanic surface of Io while our teacher explained how the moon has originally formed. As our teacher spoke to us, Jupiter loomed behind her, filling half the sky. It's Great Red Spot, turning slowly just over her left shoulder."* [40]

Children and adolescents diagnosed with ASD can visit a virtual version of a high-school they are to attend together with a parent while receiving an introduction from a teacher. In such an intervention, all of the participants can experience the virtual school via HMDs and VR controllers. Virtual shopping can be rehearsed in real supermarkets, preparing them for the real-life supermarket, while using public transportation can be rehearsed together with parents and teachers in a virtual version of the real world. However, I do not believe that VR can replace lectures, instructions, and social interaction with peers in the real world. Real human contact should be maintained and practiced in the real world, with VR being used as a tool by teachers and other professionals to prepare children and adolescents diagnosed with ASD for their real-world encounters. We believe that there are many more opportunities for using HMD-based VR to help children and adolescents diagnosed with ASD than described in this thesis. Future innovations within VR hardware and software enables the development of VR interventions that will enable teachers, psychologist, and therapists to be present in relevant virtual environments together with children and adolescents diagnosed with ASD, helping them to learn new skills or cope with their anxieties.

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SUMMARY

Autisme Spektrum Forstyrrelse (ASF) er en udviklingsforstyrrelse karakteriseret ved afvigelser i sociale evner og hverdagsfærdigheder. Personer diagnosticeret med ASF er ofte afhængige af støtte fra forældre eller sociale ydelser, selv i voksenlivet. Virtuelle miljøer har vist potentiale til at hjælpe børn og unge med ASF til at udvikle en række sociale evner og hverdagsfærdigheder. Kun få studier har imidlertid undersøgt, hvordan den nye generation af virtual reality (VR) hardware, som registrerer bevægelse i alle retninger, kan hjælpe førnævntemålgruppe med at udvikle de basale færdigheder, der kræves for at kunne leve et selvstændigt voksenliv.

I denne Ph.d.-afhandling undersøger jeg, hvordan lærere og psykologer kan anvende den nye generation af VR-udstyr som et værktøj til at hjælpe børn og unge med ASF med at udvikle de færdigheder, der er nødvendige for at leve et selvstændigt voksenliv.

Gennem et tæt samarbejde med lærere og psykologer, som til daglig arbejder med børn og unge diagnosticeret med ASF, har jeg i løbet af dette Ph.d.-projekt designet, udviklet og evalueret en række forskellige VR-applikationer.

Disse VR-applikationer retter sig mod en række sociale situationer og hverdagsituationer som fx at handle ind, krydse en vej, betale med kontanter, vente på ens tur, dele legetøj, undgå forstyrrende klasseværelsesopførsel og hjælpe dem med deres sociale angst.

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