FEEDBACK ON GAZE BEHAVIOUR IN VIRTUAL REALITY BICYCLE TRAINING FOR CHILDREN WITH A DEVELOPMENTAL COORDINATION DISORDER

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Abstract

Roessingh Research & Development has developed a virtual reality bicycle training in order to train children with Developmental Coordination Disorder to participate in basic traffic situations in a therapy setting. The objective of this graduation project is to develop a system which allows the therapist using it to assess the gaze behaviour of children with Developmental Coordination Disorder.

By retrieving the gaze points computed by the combination of eye tracking in the Fove Virtual Reality headset, and the environment in Unity, a visualization of the child's gaze behaviour is made. This is done by placing five circles per second at the gaze points the patient displays. Three different therapist views were developed, of which the first person perspective and the top-down view can be seen during the simulation in Virtual Reality and the recap view can be seen after the simulation.

By using formative testing for several iterations of the feedback system, a final prototype was developed. This prototype was assessed by asking the participants to answer questions using the Likert scale. These questions were assumed to have a correct reliability, and to be normally distributed. This proves at a 5% significance that the feedback system increases the understanding of gaze behaviour of the therapists, that it shows a better visualization of the gaze behaviour, and that it makes the therapist think that their feedback is better implemented. However, it cannot be proven at a 5% significance level that the patient thinks he or she implemented and understood the feedback given, and that they thought the therapist understood their gaze behaviour better with the feedback system implemented.

It can thus be concluded that the therapists using the system have an improved understanding of the gaze behaviour, that the visualizations of the gaze behaviour are better, and that they think that the children implemented and understood their feedback better. Furthermore, it can also be concluded that the understanding of the therapists does not result in better feedback.

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1 | Introduction

This chapter will describe the problem this graduation project will target and its relevance. Also, the objectives and challenges will be discussed. Furthermore, the research questions will be formulated. Lastly, the rest of the report will be outlined.

1.1 Problem

Cycling is something normal to most Dutch people (Wendel-Vos et al., 2018). However this is not the case for children with Developmental Coördination Disorder (DCD). These children have subpar motor performance which may result in clumsiness and poor balance (Blank, Smits-Engelsman, Polatajko & Wilson, 2012). They participate in therapy and training in order to safely engage in traffic. Roessingh Research & Development (RRD) is currently developing a virtual reality bicycle training in which children with DCD are taught to participate in basic traffic situations. Two groups of students have worked on this project for their graduation project last year. They have accomplished a stable system in which children can bike through an environment with distractions, which can be seen in figures 1.1 and 1.2. However, there are some problems with the project. One of the problems is the amount of motion sickness in the developed virtual reality world. Another problem is that there is no implementation that allows the therapist to assess gaze behaviour and give feedback on it. Therefore the appropriate gaze behaviour is hard to enhance. This graduation project will thus focus on the *'development of a feedback system on gaze behaviour in children with DCD'*.

Figure 1.1: Environment in virtual reality, retrieved from Gagelas (2018)

Figure 1.2: The virtual reality bike, retrieved from Gagelas (2018)

In the current state of the project, a child with DCD can bike in the virtual reality environment and react to basic traffic situations. The therapist can see the same view on a separate screen, as the child sees though the virtual reality goggles. However, this does not determine where the child is looking at in that view, because a view only shows the general direction the child is looking toward. He or she could for example be either looking at a traffic sign or a tree in the same view. To assess where the child is actually looking at the therapist could for example ask the child were they are looking at or if they saw a certain sign. However, this is not desired and assessment of this gaze behaviour and visualization of this gaze behaviour should be part of the application. There is also no feedback system specifically tailored to virtual reality bicycle training and should thus be developed.

1.2 Objectives and Challenges

The feedback system on gaze behaviour should take multiple elements into account. Firstly, the system should be clear and usable for the therapist working with it. They should have input on what kind of visualizations are desired for the assessment of gaze behaviour. Secondly the system should take into account its target audience, which is children with DCD. The symptoms of the disorder should be taken into account and also often seen comorbidities. From these requirements a main objective can be drawn, namely: *Developing a system to assess gaze behaviour of children with DCD, when using the Virtual Reality Bike, in such a way that therapists could give feedback on and enhance the gaze behaviour of that child.*

The main challenge is having one system which satisfies all the therapists using it. Each therapist will likely have different requirements and desires for this system and combining this might be hard. Next to this, tailoring the system for children with DCD might prove difficult. Because the fact that the entire project is in the development stage, there will be no testing with these children.

1.3 Research questions

The objective and problem lead to the following research question:

> *How can a feedback system be developed for children with DCD on gaze behaviour using eyetracking, in such a way that it helps to enhance gaze behaviour in a VR bicycle training environment and visualizes this gaze behaviour for the child's therapist?*

In order to answer this research questions, there are also some sub questions. These are defined in order to help analyze and research different aspects related to the main question. The four sub-questions are stated below.

1. Which kind of visualizations are valuable for showing gaze behaviour in virtual reality to the therapists?
2. How can the symptoms of children with DCD be taken into account in such a way that the system is tailored to them?
3. What is an effective way to give feedback to children using the VR bicycle training in order to draw their attention to the correct objects in the virtual reality environment?
4. Which key features are used in assessing gaze behaviour through virtual reality?

1.4 Outline

For this paper the Creative Technology design process will be used. Firstly, in chapter 3 this process and the methods will be explained. Secondly the ideation will be discussed in chapter 4. This chapter will include the brainstorm, scenarios, requirements, and design. Furthermore, in the realization, chapter 6, the prototypes, tests, and design decisions throughout the project will be shown. Next, the in chapter 7 the project will be evaluated. In chapter 8, conclusions will be drawn from this and problems will be discussed. Lastly, there will be a chapter on future work to determine what should be the next steps in order to continue this research.

2 | Background

2.1 Developmental Coordination Disorder

This section will be divided in two parts. First the definition and symptoms of Developmental Coördination Disorder (from now on called DCD) will be discussed in order to find what needs to be taken into account when developing a feedback system on gaze behaviour. Secondly, there will be a focus on the co-occuring disorders contributing to often seen symptoms in children with DCD. The symptoms of these co-occuring disorders will be given.

2.1.1 Definition and symptoms

Throughout the years multiple names have been used to describe DCD. Some of the names being clumsy child syndrome, developmental dyspraxia, and sensory integrative sysfunction. (Carslaw, 2011). During *'The International Consensus Meeting on Children and Clumsiness'* in October 1994 a consensus was reached on the clarification and the official DSM-IV term, being *'Developmental Coordination Disorder'* (Dewey & Wilson, 2001) (Polatajko & Cantin, 2005) (Missiuna & Polatajko, 1995). (1995)). However, according to Sugden, Kirby and Dunford (2008) the term *'developmental dyspraxia'* is still used in clinical practise. Overall the most common name is *Developmental Coordination Disorder*, although *Developmental Dyspraxia* will still be accepted in clinical practise.

Developmental Coordination Disorder, also often shortened as DCD, can be diagnosed in young children and is an often seen disorder in primary schools. DCD is mostly diagnosed between the ages of 6 and 12. Symptoms may however be found earlier (Carslaw, 2011). Barnhart, Davenport, Epps and Nordquist (2003) concluded that DCD is a common found disability and is seen in 5% to 8% of all school-aged children. However it is stated by Wright and Sugden (as cited in Kirby and Sugden 2007) that this percentage lies slightly lower and is 4-5% in mainstream primary schools. It can be concluded that between 4 and 8% of school aged children are affected with DCD and that the disorder is often first diagnosed between the ages of 6 and 12.

Most of the symptoms and criteria of these children relate to their coordination and delayed development. Cermak and Larkin (2002) state that people with DCD have poor motor skills, which are not due to low intellect, primary sensory or motor neurological impairments. The *Diagnostic and Statistical Manual, Fourth Editions (DSM-IV)* (as cited in Polatajko and Cantin, 2005) is mostly in line with this definition, but defines it a bit different. Here it is defined as a motor skill disorder in which impairment in the development of motor coordination affects daily activities and/or academic achievement. Polatajko and Cantin (2005) note that the disorder can often be recognized by delayed development in walking, crawling and sitting, dropping objects, clumsiness, poor sport performance and poor handwriting. Carslaw (2011) has another list in order to show the activities children with DCD might find difficult, which include handwriting, planning and organizing, tying laces, doing up buttons, threading, applying tooth paste, brushing hair, using cutlery, balance, and sports. This list is also visualized in figure 2.1. She also points out that as adult the symptoms will still be present and can lead to problems such as unemployment. There is a lot of disagreement concerning the criteria involving the diagnose of DCD, although nearly all studies have a main criterion relating to poor motor functions, state Geuze, Jongmans, Schoemaker and Smits-Engelsman (2001). Often used diagnostic criteria exist out two inclusive and two exclusive criteria (Sugden et al., 2008), see table 2.1. To conclude, DCD affects basic motor function which makes every day tasks harder.

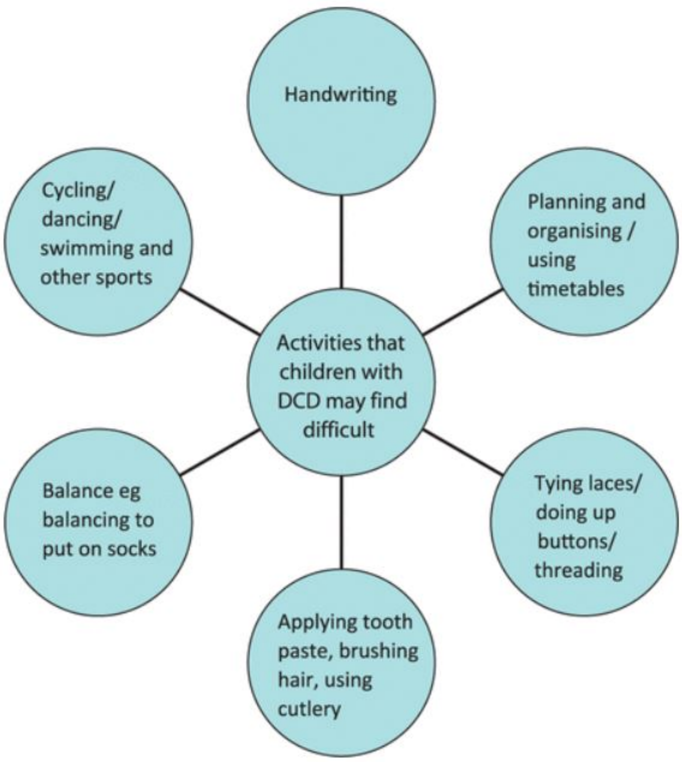


Figure 2.1: Activities that school aged children with DCD may find challenging (Carslaw, 2011)

A	Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones (e.g., walking, crawling, and sitting), dropping things, "clumsiness", poor performance in sports, or poor handwriting.
B	The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living.
C	The disturbance is not due to a general medical condition (e.g., cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet criteria for a Pervasive Developmental Disorder.
D	If Mental Retardation is present, the motor difficulties are in excess of those usually associated with it.

Table 2.1: Diagnostic criteria for DCD (Sugden, Kirby & Dunford, 2008)

2.1.2 Co-occuring disorders

Next to the above described symptoms, symptoms of other disorder may also be observed in these children. The reason for this is that DCD has a lot of co-occuring disorders. Visser (2003) states that the main co-occuring disorders are: Attention Deficit Hyperactivity Disorder (ADHD), Reading Disability (RD), Specific Language Impairment (SLI). Sugden et al. (2008) extends this list by also naming Autistic Spectrum Disorder (ASD) as a co-occurring disorder. Sugden et al. (2008) have also concluded that the co-occurance between ADHD and DCD is 60%, between SLI and DCD is 60% and between reading difficulties and DCD is 55%. To conclude, symptoms of ADHD, RD, SLI and ADS can be often be seen in children with DCD.

Attention Deficit Hyperactivity Disorder (from now on called ADHD) has two main symptoms. According to Barkley (1997) the first main symptom is inattention. Barkley (2014) lists the examples of inattention as: no/little attention to details, difficulties in sustaining attention when playing or doing tasks, absent, difficulties in organizing, often distracted and forgetful in daily activities. The children with DCD which are being treated with the VR bicycle training might thus be quickly distracted. Luckily the children are not expected to concentrate for a long extended period of time in the VR environment, because the simulation takes under fifteen minutes to complete. Barkley (1997) also state that the second main symptom is hyperactive-impulsive behaviour. Fidgeting, restlessness, completing sentences, difficulties awaiting turn, interrupting, excessive talking and inability to stay seated are examples of hyperactive-impulsive behaviour according to Barkley (2014). This behaviour could also affect the therapy sessions, when a child has the inability to stay seated on the bike, or is restless during the simulation. This could for example cause more active gaze behaviour than a neurotypical child would display. Next to this he also states that both inattention and hyperactive-impulsive behaviour should be directly affecting social and academic activities in order to be a symptom of ADHD. In short, inattention and hyperactive-impulsive behaviour are the main symptoms affecting children with ADHD and could influence this research in such a way that children display hyperactive gaze behaviour and will be quickly distracted.

There are three types of reading disabilities. These types are defined by Gough and Tunmer (1986). The same types are used by van Daal and van der Leij (1999). The first sort, dyslexia, is a neurological disability in which difficulties with word recognition and poor spelling and decoding abilities are seen, as stated by Lyon, Shaywitz and Shaywitz (2003). Wolff and Lundberg (2003) conclude however, that poor literacy skills are not the main problem. Dyslexia is more than just reading and spelling according to them. Grigorenko, Hoien and Lundberg (as cited in Wolff and Lundberg, 2003) state that dyslexia is a phonological weakness originating in different brain functions and genetic predisposition. The second sort, hyperlexia, is a developmental disorder often seen in children. According to Aram (1997), these children learn to decode text early but are impaired when it comes to comprehension of this text. This weaker comprehension and strong word recognition skill is also pointed out by van Daal and van der Leij (1999). The last sort, the garden-variety reading disability, includes non-specific poor readers (Share, 1996). Catts, Hogan and Fey (2003) add to this by also labeling the garden-variety as slow learners. Besides, they also state that children labeled as garden-variety poor readers, often perform poorly on IQ tests and are also often labeled as slow learners. Thus, the most common types are dyslexia, hyperlexia and the garden-variety poor readers.

A Specific Language Impairment (from now on called SLI) is an impairment focused on the development of language. Dorothy VM Bishop (1992) points out that SLI is an underdevelopment of normal language that is not due to other handicaps, hearing loss, emotional disorders or environmental deprivation. Dorothy V.M. Bishop (2006) and Joanisse and Seidenberg (1998) supports this definition and all state that these children often have troubles when learning to talk and have no other issues in development in other areas. Leonard (2014) concludes in his research that SLI can influence a child's academic, social, emotional, and economic future. Next to this, he also states that even though this impairment is not as widely known, it is at least as common as dyslexia and ADHD. To conclude, SLI is an often seen impairment and influences the development in speech without underdevelopment in other areas.

Autistic Spectrum Disorder has many variations and symptoms which often influence aggression and communication. Shattuck et al. (2007) list the variation of Autistic Spectrum Disorder (from now on called ASD) as Autistic Disorder, Asperger's Disorder and Pervasive Developmental Disorders-Not Otherwise Specified (PDD-NOS). Examples of often seen symptoms are: obsessions, aggression, tantrums, inappropriate or inadequate social skills, restrictions in family life, and ineffective communication as stated by Fong, Wilgosh, and Sobsey (as cited in Seltzer et al., 2003). Thus, Autistic Disorder, Asperger's Disorder and PDD-NOS are often seen variations of ASD and often revolve around lack in communication and social skills and aggression.

ADHD, reading disabilities, SLI, and ASD all will influence the design decisions which will be made. Firstly, the inattention and hyperactive-impulsive behaviour in children with ADHD should be taken into account. Tasks should not be long, and distractions should be limited. Secondly, the amount of text the children need to read needs to be minimal in order to counteract the poor word recognition and poor decoding abilities of dyslexia, the impairment of comprehension of text of hyperlexia, and the lower intellect of the garden-variety poor readers. Furthermore, the children with the co-occuring disorder SLI often have trouble with speech. The new feedback system should not require them to talk more. Otherwise it might limit them in the development the correct gaze behaviour due to their delayed development in speech. Lastly, the symptoms of ASD should not limit the therapy sessions for children with autism spectrum disorders. These children often have trouble communicating. The system should require little active input from the child. This way he/she can listen to the things the therapist says and communicate when he/she feels like it. Next to this, the system should not encourage the aggression and tantrums sometimes seen in children with ASD.

2.2 Eye tracking

Eye trackers can see where the user is looking. The early versions were developed for scientific exploration. The technology and data is used in multiple fields, such as ophthalmology, neurology, psychology and studies concerning oculomotor characteristics and abnormalities. More recent fields are marketing and advertising (Jacob & Karn, 2003).

2.2.1 Eye tracking Analysis

In order to analyze data retrieved from eye tracking with the least amount of information loss, visualization techniques can be used. Venugopal, Amudha and Jyotsna (2016) point out that eye tracking is hard to analyze. Often the data cannot be compressed without losing information. Because of this, visualization techniques are used. Blascheck et al. (2014), agrees with Venugopal et al. (2016) in that there are six key features of eye tracking data visualizations. Some of these visualizations are displayed in figure 2.2. The six features can be recognized as Fixation, Saccade, Smooth Pursuit, Scanpath, Stimulus and Area of Interest.

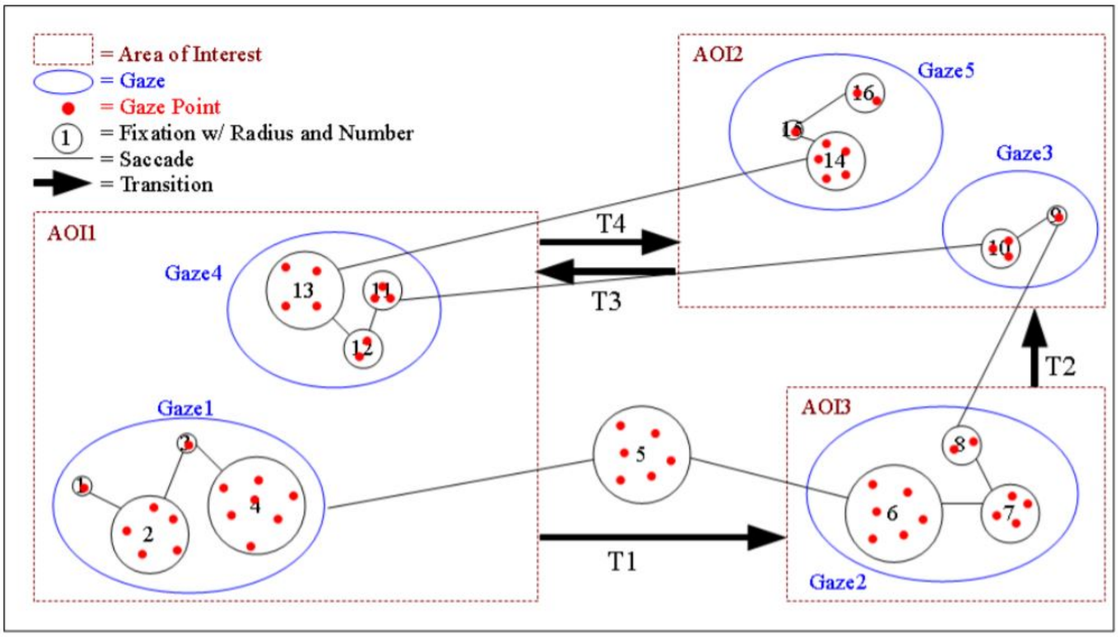


Figure 2.2: Overview of used terms in gaze behaviour seen with eye tracking (Blascheck et al., 2014 (p. 3))

A fixation is an occurrence when a person is looking at one spot for a longer time. According to Kasneci, Kasneci, Kübler and Rosenstiel (2015), this area in fixation where is focused upon is also called an area of interest. They also state that fixations often take 200 - 300ms and depend on the search task. The aggregation area is usually between 20 to 50 pixels. Often used metrics are the fixation count, fixation duration (measured in milliseconds), and the fixation position as stated by Blascheck et al. (2014). Thus a person is fixating when he/she is looking for a longer time at an area of interest, which is about 20 to 50 pixels.

Saccade is a fast movement of the eye. Blascheck et al. (2014) state that saccades are also known as rapid eye movements and are the fastest movements of the body. Kasneci et al. (2015) point out that the duration of a saccade is between 10ms and 100ms. Often seen metrics are the saccadic amplitude, saccadic duration and the saccadic velocity according to Blascheck et al. (2014). Thus a saccade is a rapid eye movement between 10ms and 100ms.

Smooth pursuits are conjugate eye movements which happen when following a moving target with the eye. Following the description to Kasneci et al. (2015) they cannot happen when there is no visually pursued target. They also point out that there can be multiple directions in one smooth pursuit. One often seen measure contributing smooth pursuit is the smooth pursuit direction, as described by Venugopal et al. (2016).

A scanpath is a combination of fixations and saccades. Blascheck et al. (2014) comments that this combination shows the search behaviour of a person. The direction in a scanpath can change multiple times in one scanpath, as mentioned by Venugopal et al. (2016). Blascheck et al. (2014) add to this by discussing the fact that the ideal scanpath would have less changes in direction and would be as straight as possible. Often used metrics are the general direction according to Venugopal et al. (2016). Blascheck et al. (2014) also labels the convex hull, scanpath length, and scanpath duration as often used metrics. To conclude, a combination of fixations and saccades, also known as scanpath, show the search behaviour of people and would ideally be as straight as possible.

A stimulus is visual content which can be presented in 2D, as well as 3D and can be passive (objects which are not moving) or dynamic (moving objects). There is usually a difference between active and passive content according to Blascheck et al. (2014). Active content is influenced by the actions of the viewer and can thus also be seen as a dynamic stimulus. Passive content, on the other hand, is watched by viewers, but not interacted with. In this scenario the stimulus can be either dynamic or static.

An area of interest is an often used term when measuring gaze behaviour. Blascheck et al. (2014), as well as Venugopal et al. (2016) state that an area of interest (AOI) is a region interesting for research. These AOIs can be predefined in research or found through research (Blascheck et al., 2014). An AOI can also be an object of interest (OOI)(Blascheck et al., 2014). Defining an AOI can help to analyse dwells, transitions and AOI hits according to Venugopal et al. (2016). Blascheck et al. (2014) points out that often used metrics are the dwell time and AOI hit. Thus, in research a AOI can be predefined or found through research.

2.2.2 Visualization of Gaze Behaviour for Eye Tracking

There are multiple ways to visualize gaze behaviour in order to asses it. Blascheck et al. (2014) makes use of three categories of visualization, which are statistical graphics, point-based visualization techniques, and AOI-based visualization techniques. Stellmach, Nacke and Dachselt (2010b) focus on gaze visualization techniques for three-dimensional environments. In their article they name the following visualization techniques: three-dimensional scan paths, models of interest timeline, and three-dimensional attentional maps. Stellmach, Nacke and Dachselt (2010a) also wrote an article in which they point out three categories of attentional maps, which consist of projected, object-based, and surface-based. For the analysis of gaze visualization the three categories of Blascheck et al. (2014) will be used. Firstly, according to Blascheck et al. (2014) line charts, bar charts, scatter plots, box plots, and star plots are often used statistical graphics in eye tracking visualization. They do however point out that these visualizations are not specifically made for visualizing gaze behaviour. Secondly, point-based visualization techniques are defined by Blascheck et al. (2014) as visualizations which make use of spatial and temporal data. Some of the visualizations they list are timeline visualizations, attention maps scanpath visualizations and space-time cubes. Kurzhals et al. (2016) only name attention maps and gaze plots as the most used point-based visualization techniques for visualizing eye tracking data. Lastly, AOI-based visualization techniques focus on regions or objects which are of interest to the user, according to Blascheck et al. (2014). The sorts of AOI-based visualization they list are timeline AOI visualization and relational AOI visualization. Kurzhals et al. (2016) only name scarf plots as common visualization techniques. Although each researcher has defined categories of visualization differently, it can be concluded that statistical graphics, point-based visualization techniques, and AOI-based visualization are some categories which are well described in existing research.

2.3 Gaze behaviour in traffic

Currently research which assesses children in realistic traffic situations is lacking and differences between simulated and non-simulated tests are often seen. Downing (as cited in Zeedyk, Wallace and Spry, 2002) has for instance tested with a non-simulated environment, in which children had to search for their toy across the street. Some other research projects have included simulated environments, such as pretend roads (Lee et al., 1984 Young and Lee, 1987), kerbside judgements (Demetre et al., 1993) and traffic gardens (Sandels, 1975) (all cited in Zeedyk et al., 2002). Zeedyk et al. (2002) observes that both these simulated and non-simulated environments encourage children to demonstrate better behaviour than they would with normal circumstances. They also note that there is a superior technique, which is videotaping children's actions inconspicuously. This technique, however, is often incomplete. The studies of Dicks, Button, and Davids (2010), Dicks et al. (2010), Foulsham et al. (2011) (all cited in Zeuwts et al., 2016) for example show that inconsistencies between artificial and real-life situations do exist. However, Zeuwts et al. (2016) argue that all these inconsistencies could be due to other factors. Although the authors show that lab experiments regarding gaze behaviour might give insight to gaze behaviour in real life, they also note some differences between the gaze behaviour in a real-life and lab environment. For instance, people fixated more on the road when cycling in real life instead of the focus of expansion in a lab environment. Overall, all these papers do agree that valuable information can be gotten from staged environments, however there still are major differences between simulated and non-simulated tests.

Regardless of all the differences between non-simulated and simulated tests, children often perform very poorly when faced with basic traffic situations. Zeedyk et al. (2002) observed during their research that only 18% of neurotypical children between 5 and 6 would ask their parents for assistance when crossing the road and thus recognizing that they were faced with a traffic situation. They also observed that children crossing on their own did so poorly: about 40% did not look at moving cars, 60% did not stop before crossing the road, and 75% ran or skipped when crossing the road. The researchers noted that the children had a restricted gaze pattern in which looking for dangers was limited to one observation. Kitanzawa and Fujiquama (as cited in Biassoni, Bina, Confalonieri and Ciceri, 2018) have used eye tracking in order to analyze exploration of the road by pedestrians. Although this research is not focused on children, it still shows the general gaze behaviour of people. In this research, they found that pedestrians focus on ground surfaces more often than they fixate on potentially dangerous obstacles. They also state that pedestrians focus on static obstacles more often than approaching ones.

Biassoni et al. (2018) also lists some other causes of why children can less safely engage in traffic than adults. Firstly, she states that children often have a different point of view than adults, because of the simple fact that they are smaller. Secondly, children have problems localizing sounds, confuse right and left sides, are not able to understand the cause-effect relationship, and are not able to process much at the same time as noted by Sandels (as cited in Biassoni et al., 2018). Furthermore, small children (preschoolers) often have trouble seeing the details and shapes of objects. Children also capture the most visible stimulus which they can see. In short, children perform very poorly in traffic situations with some of the reasons being a restricted gaze pattern, focusing on the ground or the most visible stimulus, their point of view, underdeveloped senses, and inability to understand cause-effect relationship.

2.4 Applications and Techniques

In this section commercial applications and techniques will be discussed. To give a clear overview, this work has been divided into two categories. Firstly eye tracking technologies and softwares will be discussed. Lastly, related project will be described.

2.4.1 Eye tracking hardware and software

There are a multitude of eye tracking technologies and some will be discussed in this section. However this might not be the complete list of existing eye tracking technologies.

Tobii eyetracking

This eye tracking technology can be used in virtual reality as well as laptop, and automotive. Tobii claims to have three key innovations, which are: the fact that the optics are unaffected by ambient light, that users can move around and look different, and their applications offer intuitive user experiences and insights. For visualization of where a gamer in virtual reality is looking at they advise SteelSeries Engine. There is also a new VR goggle which is the VIVE Pro Eye with Tobii Eye Tracking. This is made in cooperation with HTC and will have integrated eye tracking. (Tobii, n.d.)[1] Some of the available technologies are TX300, X2-30/X2-60, X60/X120, T60/T120 and X1 (Eyetracking, n.d.).

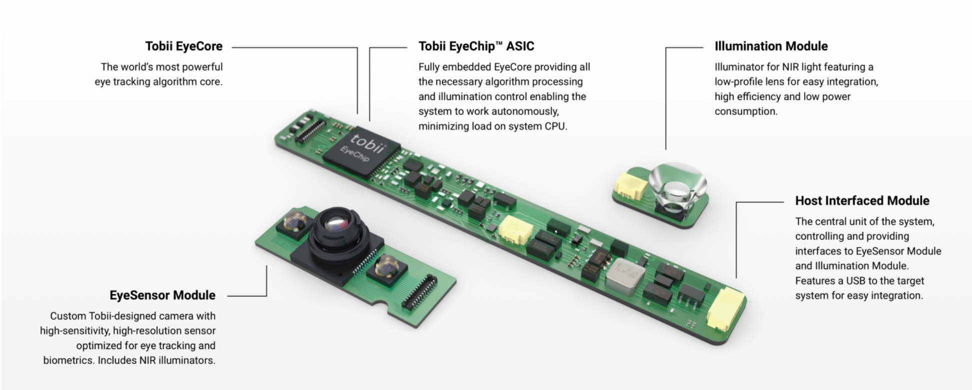


Figure 2.3: The IS5, 7th generation eye tracker from Tobii, retrieved from (Tobii, n.d.)

[1]https://www.tobii.com, last accessed 14 April 2019

Fove

The Fove is a virtual reality goggle with build-in eye tracking targeted at developers, creators and researchers. They state to have 25 million monthly users and that currently they are an often seen object in Korean and Japanese internet cafes. They are developing SteamVR and OSVR drivers. (Fove, n.d.) [2] In the virtual reality environment example Fove provides on their website, the eyes are visualized by two different colored dots.

Figure 2.4: The Fove virtual reality goggle with eye tracking build in, retrieved from (Fove, n.d.)

The Eyegaze Edge

The Eyegaze Edge by LC Technologies is a tablet with a camera which reacts to the user's gaze. This device gives the user access to language and communication for children and adults, environmental access, computer control, and the ability to connect and communicate with the world around them using just their eye movements. Users of the system include people with ALS, Cerebral Palsy, Multiple Sclerosis, Rett Syndrome, Muscular Dystrophy, SMA, Werdnig-Hoffman, brain injuries, strokes, and spinal cord injuries. Through a quick calibration, the one eye needed in order to track movements, can be calibrated. Furthermore, therapist and family members can change settings in order to make the Eyegaze more adapted to the user. The actions which can be done with the Eyegaze include surfing the internet, playing games, accessing social media, online shopping, digital book reading, music and videos, sending and receiving emails, syncing with an android phone in order to send texts and receive phone calls. Lastly the device can also be connected to any PC in order to act as a mouse or keyboard.(EyeGaze, n.d.) [3]

[2] https://www.getfove.com, last accessed 14 April 2019
[3] https://eyegaze.com, last accessed 14 April 2019

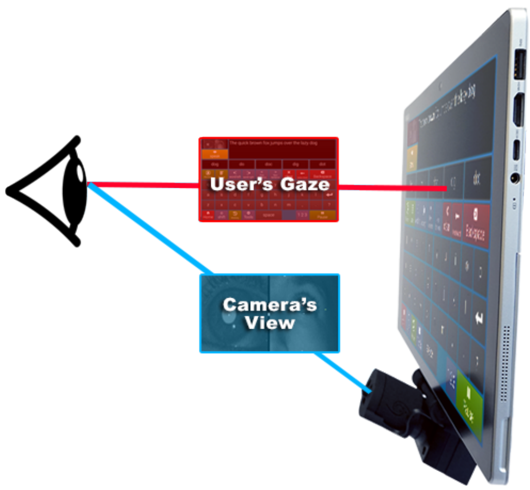


Figure 2.5: The EyeGaze Edge, retrieved from (EyeGaze, n.d.)

Mirametrix

Merametix is a platform which can track a user's eyes, gaze, face, fatigue and emotions. This platform can run on Windows, Linux and Android and works through AI without any special hardware. Some use cases they mention are measuring gaze on PC, and detecting fatigue in a vehicle. (Mirametrix, n.d.) [4]

FaceLAB 5

FaceLAB 5 is an eye tracking system from Seeing Machines. After a (1-9) point calibration, the user can generate data on eye movement, head position and rotation, eyelid aperture, and pupil size. FaceLAB 5 is marketed as a device which can be used in research. They also offer purpose-built hardware platforms for undertaking experiments in vehicle or aerospace environments, for example. FaceLAB 5 also offers analysing of data, which can be done visually and statistically. Some visualizations and analysis, which can be retrieved are heat-maps, bee swarm analysis and advanced eye-gaze analytics. (ekstemmakina, n.d.) [5]

Figure 2.6: FaceLAB 5 eye tracking system by Seeing Machines, retrieved from (ekstemmakina, n.d.)

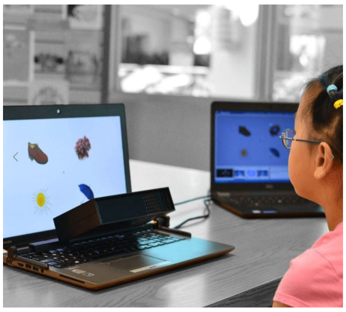
[4]http://www.mirametrix.com, last accessed 14 April 2019

[5]http://www.ekstremmakina.com/EKSTREM/product/facelab/index.html, last accessed 14 April 2019

SR Research EyeLink

According to SR Research, the EyeLink eye tracker is a standard for academic research and is used in thousands of labs for multiple scenarios. They offer a multitude of items. Firstly, they offer the EyeLink 1000 Plus, which can be in a head supported and head free-to-move mode. Besides the precision and accuracy they promise, they also state that it can be used for infants through elderly users and non-human species. Secondly, the EyeLink Portable Duo is a more compact eye tracker which measures gaze location and pupil size. This system is promised to have mobility, flexibility, superior data quality, ease of use, and compatibility. Lastly, the EyeLink II has the fastest data rate and highest resolution of any eye tracker which is head mounted according to SR Research. The system is promised to for example have 0.5 degrees average accuracy, 0.01 degrees resolution, and access to data with a 3.0 msec delay. All these technologies are integrated with SR Reseach Experiment Builder, Data Viewer, and third-party software and tools such as E-Prime, Presentation, MATLAB, and Psychtoolbox. SR Research Experiment Builder is a tool in which experiments can be created. There are existing templates which for example measure change blindness, smooth pursuit, pro-saccade task, and Stroop task. EyeLink Data Viewer is a program for viewing, filtering, and processing data of gaze behaviour. Some of the visualizations are static and dynamic interest areas, and heatmaps. The program can also output dependent measures like Dwell Time and Saccade Onset. (Research, n.d.) [6]

(a) EyeLink 1000 Plus



(b) EyeLink Portable Duo

(c) EyeLink II

Figure 2.7: The three technologies of SR Research (Research, n.d.)

[6] https://www.sr-research.com, last accessed 15 April 2019

2.4.2 Related projects

There are a lot of related projects for the virtual reality bicycle training. Many projects such as, VirZOOM, CycleVR (Puzey, n.d.) [7], The NordicTrack VR (Bible, 2019) [8] bike, and Zwift(Zwift, n.d.) [9] are using virtual reality bikes for exercising. Because of the similarity between these projects, only VirZOOM will be discussed. Next to this a few papers will be discussed where related projects are researched.

VirZoom

VirZOOM is a virtual reality environment which can get linked to a bike. The goal of VirZOOM is to keep users engaged and entertained in order to stimulate them to exercise. They also offer the ability to set up VR competitions and have a diverse set of games which can be played. (Fitness, n.d.) [10] Some of the environments they offer are scenic rides, explore the world, workout trainer, oval race, le tour, thunder bowl, jailbreak, lotus pond, gate race, and river run. VirZOOM claims to have achieved a better average of exercising per day and higher duration of the workout. (VirZoom, n.d.-b) [11] Some customers experience motion sickness, however they state that the motion sickness is less than with other VR games and sometimes even non existent. A lot of people are happy with the VirZOOM and on Amazon, it has received an average of 4.1 stars. There are, however, some people who find it hard to connect, did not read the description well enough and found the seat uncomfortable. (VirZoom, n.d.-a) [12]

Figure 2.8: Virzoom bike, retrieved from (VirZoom, n.d.-a)

There are some similarities between the virtual reality bicycle training and the VirZOOM. They both use virtual reality and involve bikes. However, there are some

[7] http://www.cyclevr.com, last accessed 17 April 2019
[8] https://gearjunkie.com/nordictrack-vr-virtual-reality-bike-htc-vive-focus, last accessed 17 April 2019
[9] https://zwift.com, last accessed 17 April 2019
[10] https://lifefitness.com/virzoom, last accessed 17 April 2019
[11] https://www.virzoom.com/, last accessed 17 April 2019
[12] https://www.amazon.com/VirZOOM-Virtual-Reality-Exercise-playstation-4/dp/B01HL84HN4/Ama, last accessed 17 April 2019

differences. The virtual reality bicycle training should in the end make use of eye tracking which the VirZOOM does not. Next to this the VirZOOM has little motion sickness, while that is a problem with the bicycle training.

PaperDude: A Virtual Reality Cycling Exergame

PaperDude has developed a VR cycling game to have more immersion and less motion sickness. Through the perspective of a first person avatar, the user can deliver papers in a suburban neighbourhood. Mokka et al (as cited in Bolton, Lambert, Lirette and Unsworth, 2014) have concluded that using a bicycle as input leads to a better sense of immersion when it comes to virtual reality. They made a system with a Wahoo Kickr Power Trainer, Trek FX 7.2 bicycle, Unity, a iOS app, and Kinect camera. (Bolton et al., 2014)

Figure 2.9: PaperDude setup, retrieved from (Bolton, Lambert, Lirette & Unsworth, 2014)

This project has many similarities to the virtual reality bicycle training and brings new insights to techniques which can be used by the bicycle training. However, these new techniques, such as the use of Kinect in order to reduce motion sickness, are not the focus of this graduation project.

The FIVIS project

The FIVIS project is a bicycle training system which can generate any desired traffic situation. For this project, a bike, physical sensors (e.g. acceleration, steering angle, declination), motion platform, and projection screens are used. The motion platform recreates things like bumps in the road. They do quickly mention that the immersive experience can lead to dizziness. (Schulzyk, Hartmann, Bongartz, Bildhauer & Herpers, 2009) Although they only state this once in a quite positive way, this might be motion sickness, however, and is thus not beneficial to the system.

Figure 2.10: FIVIS setup, retrieved from (Schulzyk, Hartmann, Bongartz, Bildhauer & Herpers, 2009)

The motion platform, using the screens instead of virtual reality, and not having eye tracking are some of the differences between FIVIS and the virtual reality bicycle training. Although the fact that some of the aspects like the motion platform and the usage of the screens could be beneficial towards reducing motion sickness if used the correct way, this will not be implemented for this graduation project.

Using an Eye-Tracker to Assess the Effectiveness of a Three-Dimensional Riding Simulator in Increasing Hazard Perception

This research wants to target the amount of cycling accidents involving young people which are not good in identifying risks. They found that four training sessions with their device could decrease the time needed to detect new hazards. They use a Tobii eyetracker, TFT 17" monitor, and Honda Riding Trainer for this developed training. By having participants completing four different routes, the participants would encounter hazards. They tested with the dependent variables of latency of the fist fixation and the number of crashes following. (Alberti, Gamberini, Spagnolli, Varotto & Semenzato, 2012)

Figure 2.11: The experiment setup, retrieved from (Alberti, Gamberini, Spagnolli, Varotto & Semenzato, 2012)

There are some differences between this project and the virtual reality bicycle training. The main difference is the goal. This research is done with neurotypical people, while the bicycle training targets children with DCD. However there are quite some similarities. Both projects for instance focus on the improvement of gaze behaviour in traffic. Some valuable information can be gotten from this research for this graduation project. For instance the dependent variables that could be tested on whether or not this is an effective way to measure the gaze behaviour of children with DCD.

3 | Methods and Techniques

3.1 Research Method

For this graduation project the design process for Creative Technology by Mader and Eggink (2014) will be used. This process can be seen in figure 3.1.

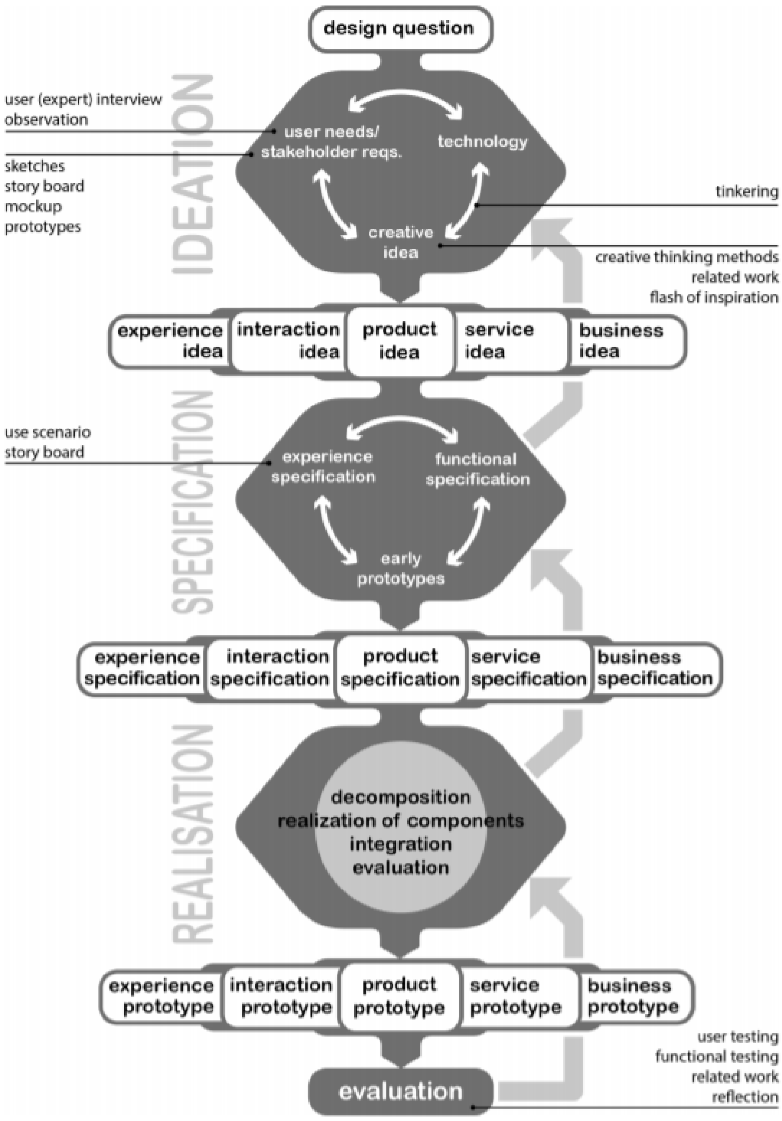


Figure 3.1: Creative Techonlogy design process, retrieved from (Mader & Eggink, 2014)

3.1.1 Ideation

In the ideation phase information will be gotten from experts, existing projects, and the stakeholders. With this information multiple solutions to the research questions will be formulated. With the use of sketches, mock-ups, and prototypes these ideas will be shown to the client and feedback will be gotten. This feedback can then be implemented and multiple iterations of design ideas will lead to a finalized idea.

3.1.2 Specification

In the specification phase requirements will be formulated. These requirements will be sorted on priority through the MoSCoW method, which is used by Miranda (2011). In order to achieve these requirements a People, Activities, Context, and Technologies analysis (PACT-analysis) and stakeholder analysis will be executed.

3.1.3 Realisation

Based on the product specification, the final product will be realized. By fist decomposing the product in multiple aspects, these aspects can be realised, the aspects can be tested on their own, and potential problems can be fixed. After the development of all these aspects they can all be integrated into one project and it can be tested. After the testing the feedback will be implemented and several iterations will give one final product prototype. Each time a prototype has been developed, it will be evaluated and, if needed, changes will be specified. So it is also possible to go back to the specification in order to then adapt and make a new prototype in the realisation.

3.1.4 Evaluation

The evaluation will focus on the requirements and realisation of them and the user testing will be discussed. Furthermore a conclusion will be drawn and a discussion will find place.

4 | Ideation

This graduation project focuses on two practical aspects. Firstly, the gaze behaviour needs to be visualized in such a way that therapists can easily get valuable information from them in order to enhance the gaze behaviour of the children they are treating. Secondly, possible ways to affect gaze behaviour of children need to be found in order to train them correct gaze behaviour.

4.1 Concept to draw attention from the child

There are multiple ways to draw attention from a child in any sort of environment. Each of these ways can be divided into the five traditional senses, which are sight, hearing, taste, smell and touch. In order to see which ways of drawing attention would work in the VR bicycle environment, the mindmap in figure 4.1 was made.

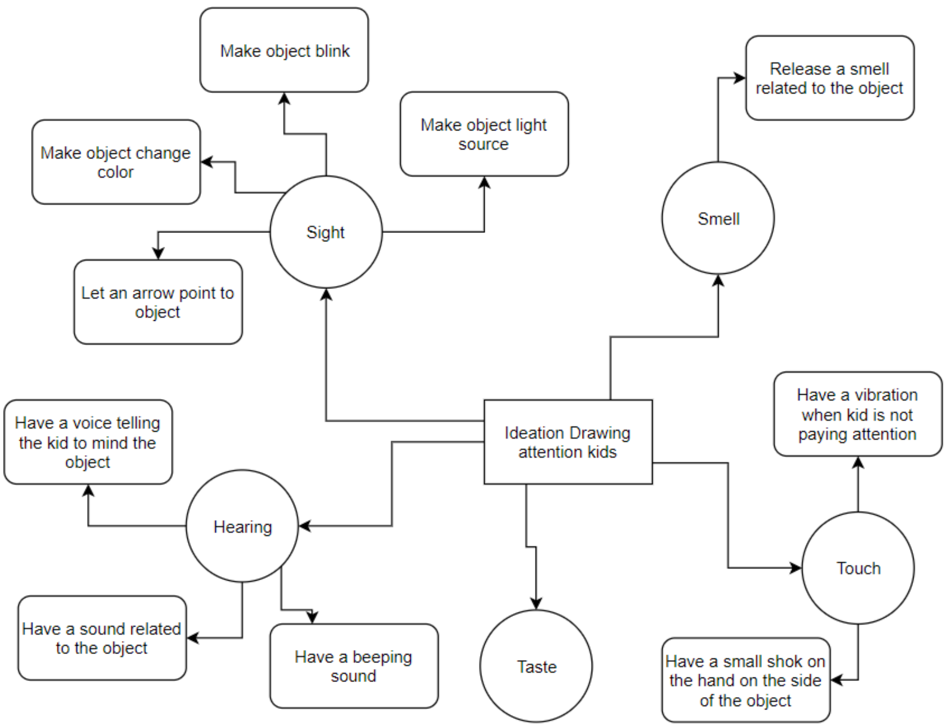


Figure 4.1: Mindmap for drawing attention from children in a VR bicycle environment

The ways to draw attention mentioned in figure 4.1 are not all optimal to use in a VR bicycling environment. For example, taste, touch and smell add another element which could distract the children with DCD, as well as the children with ADHD and ASS, but it is also not the thing which needs training when participating in traffic. It is thus important to focus on the senses sight and hearing. Furthermore, in the current version of the environment there are already sounds implemented for all kinds of aspects including the dangers on the road. This, however, has not been sufficient to draw the attention of the children to these dangers and is not a sufficient way to draw attention. Also a beeping sound when a child is not minding the obstacles on the road is not specific and might pull focus from the children. Finally making the object which needs to be addressed a light source could work but is almost the same as an object blinking and the changing of color.

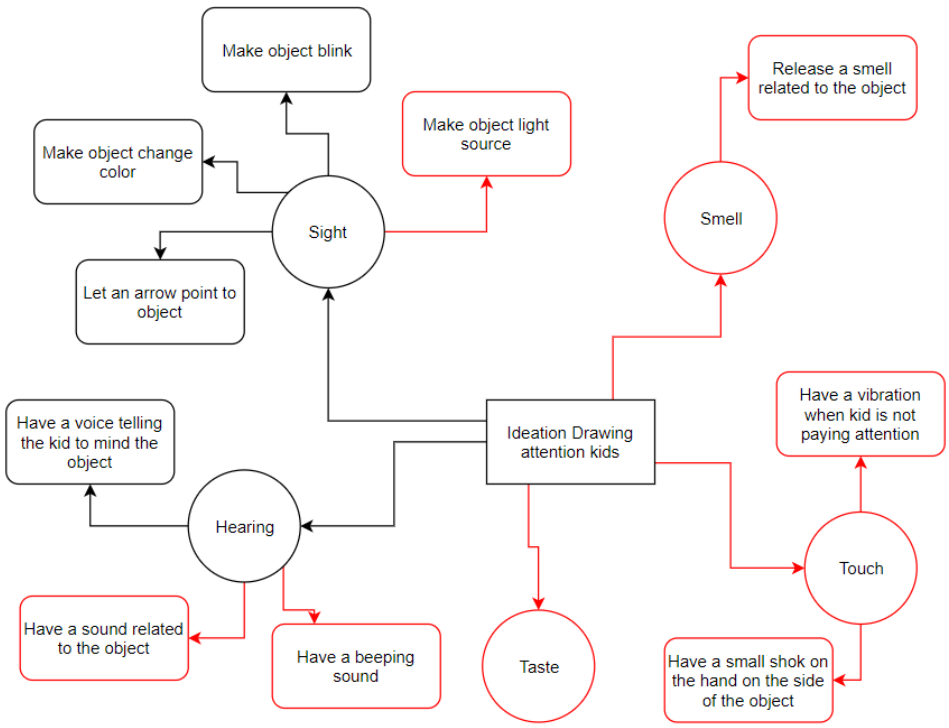


Figure 4.2: Mindmap for selected ideas with the purpose of drawing attention from children in a VR bicyle environment

When all these ways are crossed off, only four ways to draw attention remain. These ways can be seen in figure 4.2. In order to figure out which way is superior, a test will be executed. Firstly, in a small experiment the best visual way to draw attention will be determined. Secondly, the visual way to draw attention and the option to vocally coach the children will be given to therapists who will be working with this system. Their decision together with research on teaching children to participate safely in traffic will finalise which way to draw attention will be used.

4.1.1 Experiment drawing attention with sight

For this experiment three ways to draw attention had to be tested, which are a blinking object, an object changing color, and an arrow pointing towards an object. An additional way tested was a blinking arrow. For this experiment there was a sample group of n=8. Participants were shown the scene in figure 4.3 through the

Fove VR goggles. In the experiment they were asked to focus on the pink ellipse in the middle until one of the blue spheres would draw their attention. If this was the case they could look in that direction until they were instructed to once again focus on the pink sphere. This process happened multiple times in order to let every participant see every effect. The effects shown to the participants were randomized in order to counteract learning effect and preference for the last effect showed. Also the participant's gaze could be drawn by two objects instead of one in order to counteract that the participant knows exactly what to expect. Both those two objects look exactly the same to make the results of the experiment as reliable as possible.

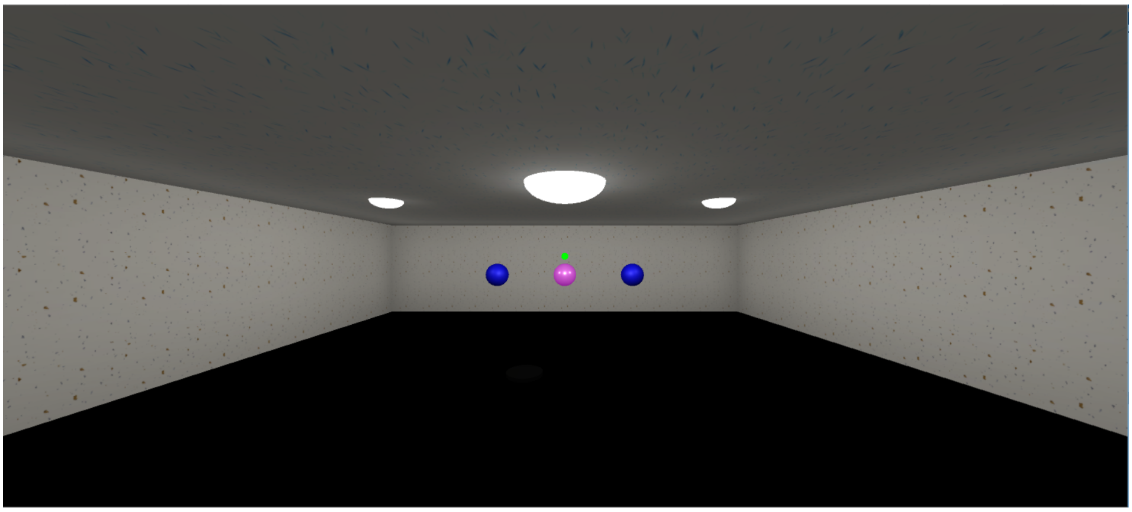


Figure 4.3: Scene in unity to find best way to visually draw attention

After the experiment participants were asked to answer a few questions to determine the best effect and possible enhancements to these effects. In the questionnaire participants were asked to score the attention drawn and the clarity of the effect on a scale from one to 5. The mean can be seen in table 4.1. The participants were also asked to suggest some enhancements for these effect in order to make them better if they are to be used in future research. This can be seen in table 4.2. Lastly the participants were asked to select the effect that drew their attention the most. This is visualized in figure 4.4.

Effect	Question	Mean
Color changing	Attention drawn	3.8
	Clarity effect	4.6
Blinking	Attention drawn	3.9
	Clarity effect	4.4
Arrow	Attention drawn	4.5
	Clarity effect	4.9
Blinking Arrow	Attention drawn	4.5
	Clarity effect	4.5

Table 4.1: Results questions clarity and attention drawn per effect

Effect	Feedback
Color changing	Bigger contrast, hard for some people to see (e.g. color blind)
Blinking	Combine it with color changing, increase time between blinks
Arrow	Change of color, different placement, a second arrow
Blinking Arrow	Give the ball a different color, blinking was not really drawing attention

Table 4.2: Feedback and possible enhancement per effect

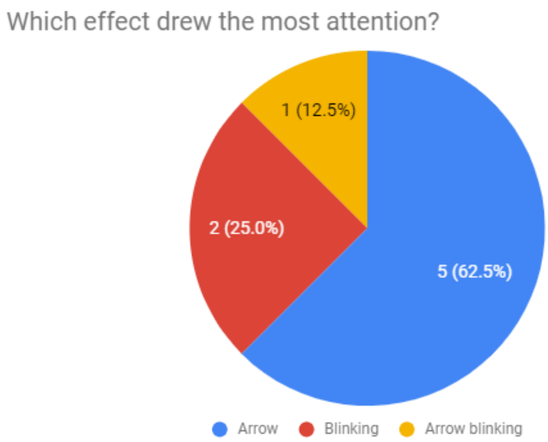


Figure 4.4: The best effect according to the opinions of the participants

As can be seen from table 4.1, the arrow and blinking arrow scored the highest when it came to the attention drawn to them. The arrow also scored the highest when it came to clarity. In addition the arrow was found the effect which drew the most attention, which can be seen in figure 4.4. This shows that overall the arrow is the best visual effect to use in order to draw attention.

4.1.2 Input therapist

The options which were being tested were shown to the therapists involved in this project. Also the results off the test were shared with them. When giving the option to either use the visual effects tested or coaching the children themselves using their voice, they preferred to coach the children themselves. The reason given for this, is that the children are not taught correct gaze behaviour when using the visual effects. Coaching can be easier adapted for each child and they would still like to stay in control of the therapy session.

4.1.3 Conclusion

As can be seen in chapter 4.1.1, the arrow is the best way to draw attention when it comes to a visual effect. However, vocally coaching the children is chosen over the visual effect. The reason for this is that correct gaze behaviour can be taught in this way, and that feedback can be adapted for each child specifically.

4.2 Concept to give feedback to the therapists

In order to give the therapist feedback on the gaze behaviour of the children they are treating, several mock-ups have been made. These mock-ups should show the frequency a child is looking at something. Below four different mock-ups are shown. The mock-ups are based upon a small brainstorm session with one other person.

Figure 4.5: Feedback for the therapist using grey scale

Firstly the gaze behaviour can be visualized by coloring all object in a grey scale. The darker an object is, the more it is gazed towards. This visualization can be seen in figure 4.5.

Figure 4.6: Feedback for the therapist using intensity and bubbles

Secondly, by using circles, gaze behaviour can be visualized. A few times a second these circles can be placed at the location the child is looking at. By making these circles semi-transparent, there will be a different in intensity which shows the most looked at objects. This is visualized as seen in figure 4.6 and is similar to a heat-map.

Figure 4.7: Feedback for the therapist using a circle for each eye

Lastly, by using two circles the two eyes can be visualized. In this way the therapist could see where the patient is looking at. This is already a function implemented in the Unity plugin from Fove. However, the circles displayed should be a bit bigger in order make them easier to see in a big environment and to counteract some of the margin of error.

These three visualizations were shown to the therapists which will be treating the children with DCD in the VR bicycle environment. They expressed a strong preference towards the second option, the heat-map. The therapists are the primary users of the software which will be developed through this graduation project, thus the heat-map should be implemented.

4.3 Final product idea

For the final product a VR environment needs to be developed. This environment should be easy to use and it should be clear to see the gaze behaviour of the children being treated. In order to visualize this gaze behaviour for the therapists a heat-map will be built. From the four options for drawing the attention of the child, the option of vocally coaching the children was chosen and thus the system will allow for the therapist to coach the children in order to safely participate in traffic.

5 | Specification

In order to specify the requirements and the tools to build the project, some other steps need to happen. Firstly, there will be a stakeholder analysis in order to understand which requirements should be set. Next to that a People, Activities, Context, and Technologies analysis (PACT-analysis) will take place. In this analysis the people, activities, context and technologies will be discussed in order to get a better understanding of the project. Finally the requirements for this project will be set. These requirements will be prioritized with the MoSCoW method.

5.1 Stakeholder analysis

In this stakeholder analysis multiple steps will be taken. First the stakeholder will be identified. These stakeholders will then be prioritized and their interest and impact will be determined. Lastly, the key stakeholders and their interests will be discussed.

5.1.1 Identifying Stakeholders

For this project there are multiple stakeholders. These stakeholders are affected by the project, have influence on the project or are interested in its success. The stakeholders are the therapists, the children with DCD, team members working on this project (currently working on different aspects of the project, like the motion sickness), parents of the children, the public, Roessingh, TwinSence (who have an advisory role in this project), and University of Twente. In section 5.1.2 the stakeholder will be analyzed.

5.1.2 Prioritizing Stakeholders

In order to know which stakeholders have more influence and which stakeholders should be prioritized when formulating the project requirements, a stakeholder interest and impact table has been made. In the stakeholder interest and impact table seen in table 5.1, the stakeholders can be seen. Also their interests, estimated project impact and estimated priority are shown here.

The stakeholders can be classified according to their power on the project. Each stakeholder can be classified as keep satisfied, manage closely, monitor (minimum effort) or keep informed. This can be done in an Power/Interest Grid, which can be seen in figure 5.1.

Stakeholder	Interests	Estimated Project Impact	Estimated Priority
Therapist	Has to work with the system	High	1
Children with DCD	The feedback given on gaze behaviour is on their gaze behaviour. However they do not have to work with the system directly, because there is no focus anymore on drawing their attention to certain objects.	Low	6
Team members working on the project	Want to develop the project further and are interested in its success	Medium	4
Parents of the children	They want their kids to be able to safely bike through he streets, however they do not directly interact with the system.	Low	7
The public	There will be a reduced chance of traffic accidents if these children can safely participate in traffic	Low	8
Roessingh	They are the client for this assignment and they want to achieve a funding to be able to further research and finish this project.	High	2
TwinSence	Advisor and helping to develop the project	Medium	3
University of Twente	They are supervising some students who work on the project for their thesis	Medium	5

Table 5.1: Stakeholder interest and impact table, adapted from (Smith, 2000)

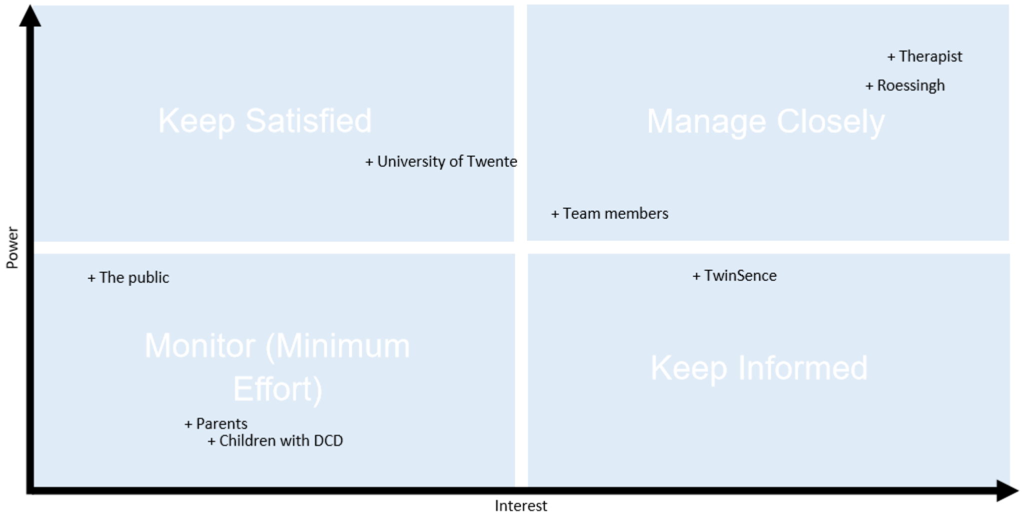


Figure 5.1: Power/Interest grid for the stakeholders, adapted from (Thompson, n.d.)

5.1.3 Understanding Key Stakeholders

Prioritising of stakeholders shows that there are two stakeholders with a high interest. These are the therapists and the client from Roessingh. In order to understand what these key stakeholders want in this project, multiple items like motivations and their opinions will be discussed for these stakeholders.

Financial/emotional interest

The therapists have no financial interest in this project. They get paid through Roessingh and their job is not to maximise profit. They do have emotional interest in this project however. They want to treat their patients to the best of their ability. By being able to understand how the children with DCD are looking in the VR environment, the therapist can more easily provide feedback for the children. This can lead to a faster integration of the child in traffic.

Roessingh is financially and emotionally interested. They are in the process of asking for funding for the VR bicycle project. Having a working prototype of the gaze feedback could help them achieve this goal. When they do receive this funding, they could make the VR bicycle environment more extensive and add more levels. Roessingh is also emotionally involved. They want to give the best care to the children with DCD, just like the therapists.

Motivation

The therapists are motivated to help the children with DCD. This motivation is what formulated their need for such an implementation.

Roessingh, however, is motivated to make the product complete and prove its worth in the treatment of children with DCD. In order to do so flaws have to be solved. The problem that therapists cannot see the gaze behaviour of the children, is thus another motivation for them.

Other influences

The therapists and Roessingh are also influenced by the children they are treating and their parents. If there is information from the children or parents that the system is not working correctly or is not functional, then this will surely influence their opinion on the system developed here.

Also the other people working on the project could influence their opinion. The other people working on this project are currently working on other aspects. However, if they find something flawed or inaccurate they could easily influence this project. Roessingh and the therapist are also their key stakeholders.

5.2 PACT analysis

By having a PACT analysis, more specific requirements can be determined. In the PACT analysis the items people, activities, context, and technologies will be discussed.

5.2.1 PACT analysis

By using a PACT analysis, a better specification of the project can be given. Also some key points for evaluation can be gotten from this analysis.

People

The people this system is targeting are the therapists. These people are all adults with experience in giving therapy to children with DCD. All these therapists give their therapy in Dutch, as the children they are treating are often Dutch. Their affection with technology can be diverse however, so the application should not be too technical in order to stimulate easy usage. If there are any features which are harder to understand, an instruction manual should be given. There are no special needs like blindness or wheel chair users which the system should take into account. Color blindness will not be taken into account for now, because the system will only be used at first with a small amount of users. The users of the system are just the therapists and this group can thus be called homogeneous. The users of the system can be called committed users as they would have to work with it regularly and there has to be no motivation in the system for the users to return. Also will the therapists be frequent users, because they would need to use the therapy with multiple children.

Activities

The goal of this system is to provide the information needed for the therapist in order to improve the gaze behaviour of the children under treatment. In order to do so there are several tasks the therapist needs to perform in order to retrieve this information from the feedback system. The therapist should be able to turn on the visualization, understand the visualization and turn this understanding into feedback for the child being treated. The therapist should be able to perform these tasks regularly and the tasks should thus be easy to do. However, the tasks are on one hand well defined and on the other hand vague. The well defined tasks are things like turning the visualization on. Tasks which are less defined are how exactly to give feedback to the child. This is their interpretation of the visualization and multiple therapists will most likely give different feedback to the child. The activities are individual and multi-tasking is asked from the therapist. The system would need to give errors in order to let the therapist know when something is wrong. This can be done in Unity. These errors should be looked at by the therapists.

Context

The physical environment is a room at Roessingh Research and Development where the therapy takes place. This room has a door, so the noise around the therapist and child can be limited. There are some things which could distract a child, especially with DCD, ADHD, or ASS. The system is mostly used during daytime, when therapy sessions are planned.

Technologies

For the input of the system, a person should wear the glasses and look around them in a VR environment. For this, the Fove is used. It has eyetracking and can track each individual eye. By getting a direction and combining it with the objects in VR, gaze points can be seen. Next to this the therapist should input certain data to determine the difficulty of the environment. The system then outputs the screen of the VR, the screen for the therapist, and sound. There is communication between people, as well as between devices. The therapist and the patient should communicate in order to enhance the gaze behaviour of the patient. The VR goggles and the computer, as well as the screens communicate together. The system can be run without any network and is a real-time system.

5.3 Requirements

ID	1
Requirement:	The gaze feedback system must make use of the already existing virtual reality bicycle training developed by Roessingh Research & Development.
Source:	Graduation Project Assignment
Rationale:	The new addition to the system should contribute to a better understanding of gaze behaviour which is shown in the already existing virtual reality bicycle training environment.
Priority:	Must

ID	2
Requirement:	The system must allow for the vocal coaching of the children by the therapists.
Source:	Therapist input
Rationale:	They are mentioned when shown the results of the test in chapter 4.1.1
Priority:	Must

ID	3
Requirement:	The system should visualise the gaze behaviour by placing multiple circles a second on gaze points.
Source:	Therapist input
Rationale:	In the ideation some possibilities for visualizations were shown to the therapist. They showed their preference for this option.
Priority:	Must

ID	4
Requirement:	It must be clear from the visualizations where a child is looking.
Source:	PACT analysis
Rationale:	The therapist can only give feedback on gaze behaviour when it is known where the child is looking toward.
Priority:	Must

ID	5
Requirement:	A simulation with the feedback system should not have harder tasks or tasks that take longer than without the feedback system for the children in the simulation.
Source:	Background research
Rationale:	Children with ADHD experience inattention and have a small attention span
Priority:	Should

ID	6
Requirement:	The gaze feedback system should have multiple views in order to properly assess the gaze behaviour of the children with DCD.
Source:	Own Requirement
Rationale:	Because of the fact that the environment is in 3D and the therapist uses a 2D screen, depth and height could be better estimated if an environment can be seen from multiple angles.
Priority:	Should

ID	7
Requirement:	The system should be in Dutch.
Source:	PACT analysis
Rationale:	The system will be used by Dutch therapists and Dutch children.
Priority:	Should

ID	8
Requirement:	There should be a instruction manual with the necessary information included.
Source:	PACT analysis
Rationale:	Some steps which are more difficult to do, should be explained to the therapists in order to make it easier for them to use.
Priority:	Should

ID	9
Requirement:	There must not be any additional distractions caused by the feedback system for the children.
Source:	Background research
Rationale:	Children with ADHD experience a lot of hyperactive-impulsive behaviour. Because of this they are easily distracted.
Priority:	Won't

ID	10
Requirement:	There must not be a large amount of reading involved.
Source:	Background research
Rationale:	Children with a reading disability have difficulties with reading or comprehension of text.
Priority:	Won't

ID	11
Requirement:	The system should in no way stimulate aggression and tantrums from the participating children.
Source:	Background research
Rationale:	Children with ASD often have tantrums and show aggression. This should not be stimulated or triggered.
Priority:	Won't

6 | Realization

The realization consists of two parts. After finalizing the first prototype, testing with students will be done in order to improve this prototype. This formative experiment has as goal to find mistakes and get feedback. The client will also give formative feedback on the system. Secondly, the final prototype is tested in order to determine its value to the therapist who will eventually use it. In this test students and regular adults will be playing out a therapy session. From this test statistical results will be gotten.

6.1 First prototype

In this part the first prototype will be discussed. This prototype is tested with five participants. This stage is mainly meant to find mistakes and points of improvement. In between each interview with a participant the prototype is adapted in order to work in an iterative way to retrieve the best end result. Some smaller problems will be adapted after the testing stage.

6.1.1 Design prototype

The prototype was made in the Unity environment created by bachelor students who graduated on this assignment last year. In this environment a countryside can be seen. This is level 1 in the game and is thus still quite simple. There is only one kind of obstacle the child needs to stop for and be careful of, and that are ducks. These ducks cross the street multiple time in one game. Each time there is a traffic sign which warns the child for the crossing ducks. The environment can be seen in figure 6.1.

As can be seen in the specification, the goal is to show a heat-map by using the Fove eye tracking VR goggle in order to visualise gaze behaviour. By using the gaze direction and collision boxes, invisible boxes around objects to see if something hits it, the program could see approximately where the user was looking. However, knowing exactly where the user was looking was a challenge. The environment previously made was not made with the intention of using eye tracking in it. There were a lot of collision boxes throughout the environment which were simply meant for the user to stay on the road. Next to that there were some items, which had larger collision boxes than necessary, which resulted in the fact that the eye tracking thought that there was an object at places there was none. There were also some objects without any collision boxes. If an user was to look at one of those objects, the environment would not register it. So the first step in this process was to change the collision boxes in the environment in such a way that the eye gaze collision was possible. These gaze points can be seen in figure 6.2. The pink dot shows the left eye and the blue point the right eye.

Figure 6.1: Environment made by previous graduates

Figure 6.2: Gaze points determined by collision boxes and gaze direction

When the eye tracking was working a code was written in order to place some circles at the gaze point throughout the virtual reality scene. This was first done for a top down view, which can be seen in figure 6.4. However, as a therapist you would not be able to estimate the height of the circles drawn, so the decision was made to add a first-person perspective, which can be seen in figure 6.3.

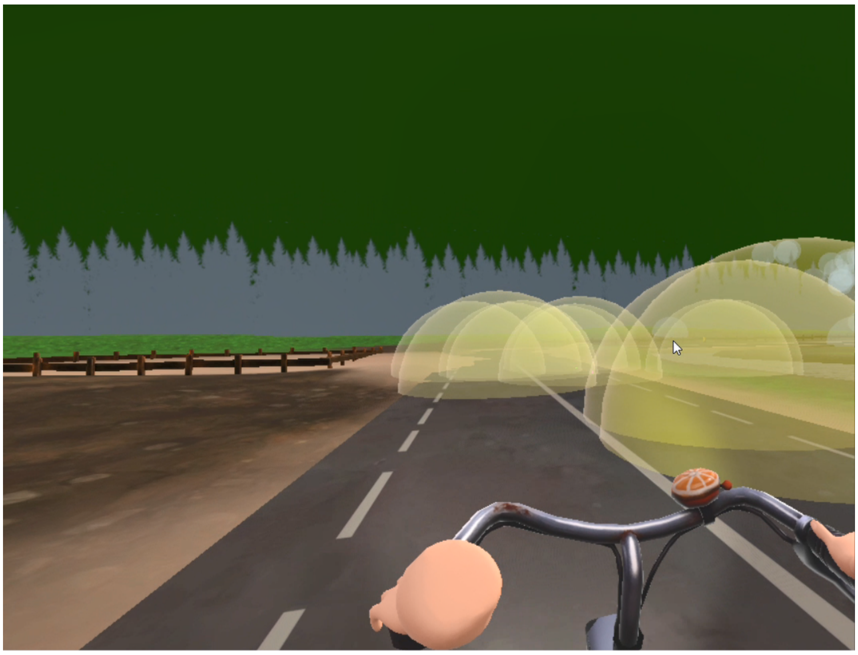


Figure 6.3: first-person perspective with too big ellipses

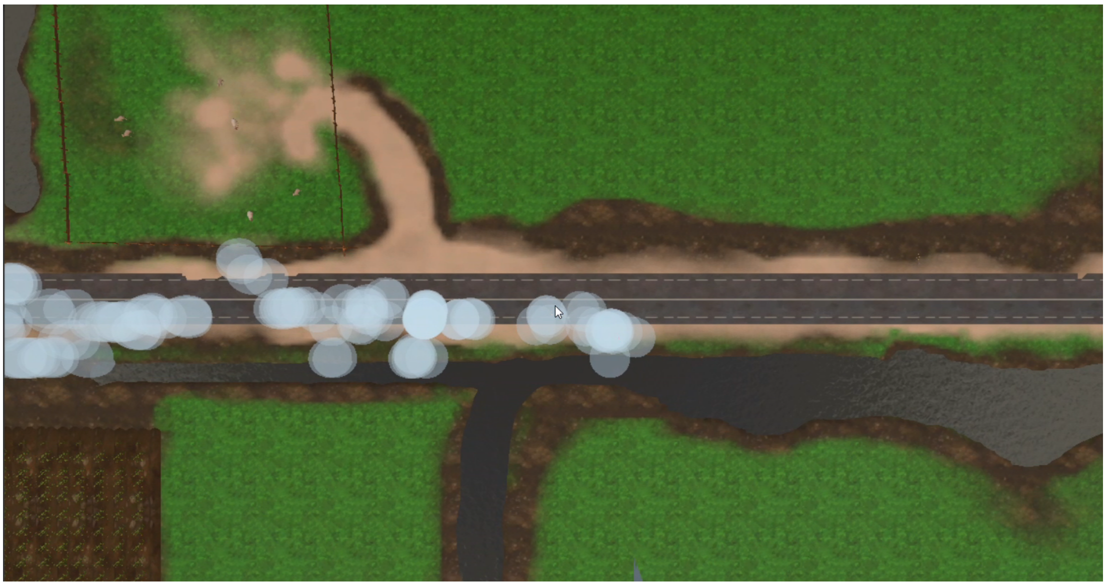


Figure 6.4: Top down perspective with too big ellipses

By increasing the amount of circles placed per second and decreasing the size of them, a better visualisation was made. The final visualisations can be seen in figure 6.5 and figure 6.6. The therapist can press ’H’ on the keyboard for the heat map top-down view and ’P’ for the first-person perspective. These keys can however be easily adapted in such a way that other keys can be used for this purpose.

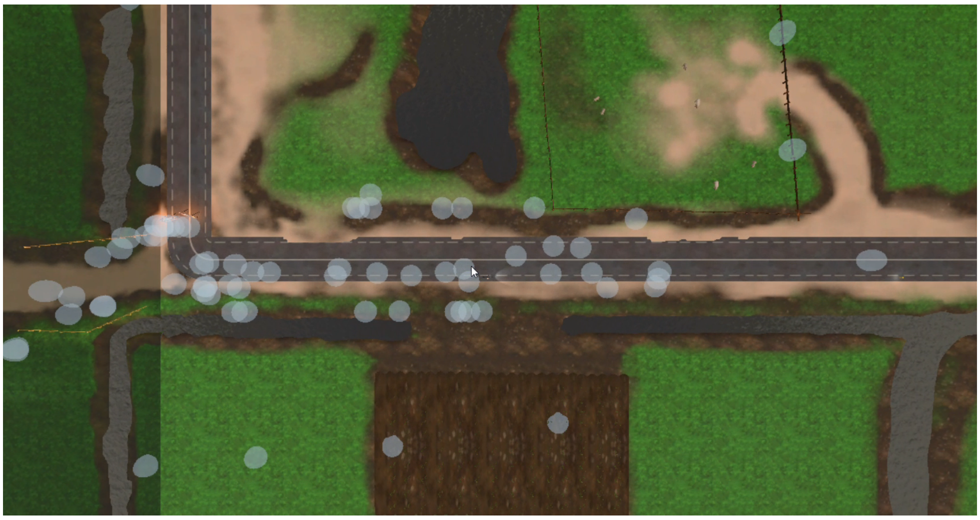


Figure 6.5: Final first prototype on the top down view

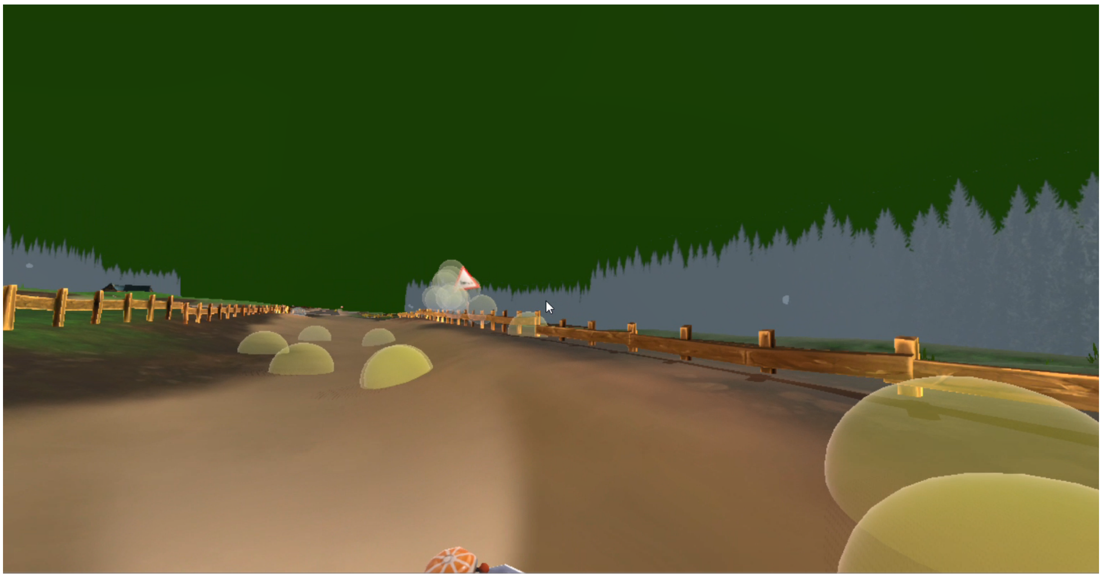


Figure 6.6: Final first prototype on the first-person perspective

Also, a feature has been added in which the simulation will create a new .txt file and save the gaze points of the simulation. The file name will include the date and time on which the simulation was started, which can be seen in figure 6.7. Also, the data is saved in a simple format which could be used for future research, which can be seen in figure 6.8. This feature will not be shown to the participants during the testing phase, because this feature is not part of the objective of this graduation project, but has only been developed for future research.

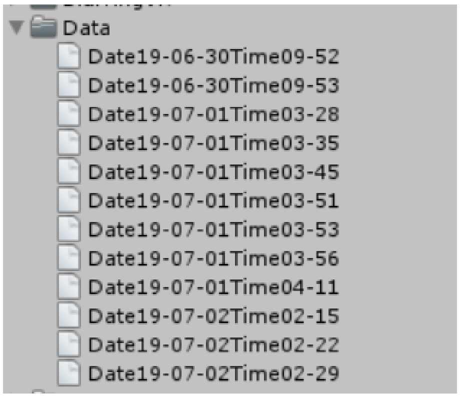


Figure 6.7: Files created to save the gaze data

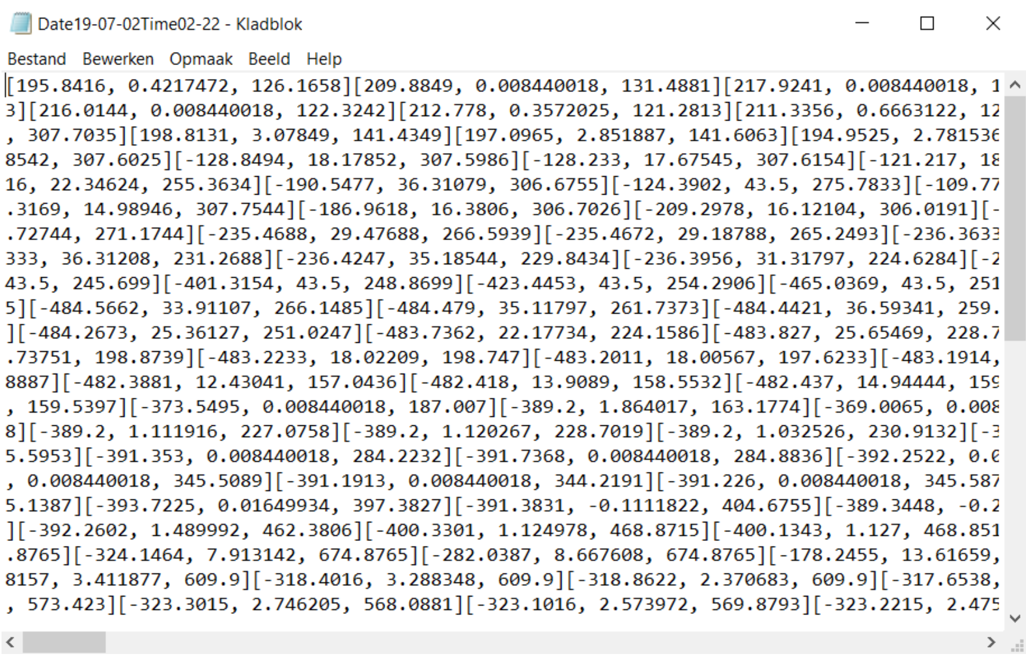


Figure 6.8: The saved gaze points

6.1.2 Goals and aims

Goal

The goal of testing this prototype is to find any flaws, mistakes or missed features. By having multiple scenarios, which all show a different gaze behaviour, the interpretation of the visualisations of the therapist can be tested. This interpretation can be compared with its intended interpretation to see whether or not the visualisations show the information correctly. Next to this a user can give feedback on the visualisation itself.

Aim of Evaluation

By seeking mismatches between the visualisation's intended interpretation and the actual interpretation, the causes for this can be analysed and translated into new changes to make the feedback system for the therapists clearer. Also by having the participants comment on the visualisation itself and on what information they based their interpretation on, design flaws can be seen. The goal of this evaluation is to retrieve these feedback points, flaws, and missed features and to decide which should be implemented in the next iteration.

6.1.3 Limitations

There are some expectations regarding the outcome of this experiment. There is still a small technical issue with some colliders, which are used in order to detect when the ducks should start walking. The Fove eye tracking works through translating a certain direction and a collision with such a collider into a gaze point. So when a user is biking through the environment some gaze points are not correct. This should be adapted in a second iteration and some participants in this study might find this flaw.

Next to this, the visualisations are currently only shown during the simulation and a recap view is not included. The client of this graduation project has already given feedback that a visualisation after the VR simulation would be desired. This way the therapists would be able to discuss the gaze behaviour with the children they are treating and use this as a reference to improve the gaze behaviour of these children.

Furthermore, on the top down view the bike is to small to properly be seen. This might confuse some of the participants and get some attention from them.

6.1.4 Setup

For this experiment there are three scenarios of the therapist's feedback system. Each scenario shows a different gaze behaviour and all these scenarios consist of two different videos. One video shows a first-person perspective and the other a top down view of the bike and its environment. Both videos show the yellow ellipses discussed in section 6.1.1, which show multiple gaze points per second. A participant can switch between these two videos any time he/she desires and as often as desired. This will be done by playing these two videos simultaneously and letting the user switch with ALT+TAB in such a way that one of the videos is always seen on full screen.

Scenario 1 shows a gaze behaviour in which a user is distracted by his/her environment and is thus not minding the road. This gaze behaviour is meant to simulate a distracted child which is often seen in children with DCD. Scenario 2 shows a user which is mostly looking down at a short distance in front of him/her. This user is not minding any important details like traffic signs and the crossing ducks. This simulation is meant to simulate a child which is not comfortable enough biking, which motivates him/her to mostly just stare at a few meters in front of his/her bike. Scenario 3 shows a user which is showing a scanpath to look for dangers. Some objects, which deserve the attention of the user, become an area of interest. Even though this scenario targets the desired gaze behaviour, the gaze behaviour still has some flaws due to the fact that a perfect gaze behaviour is hard to simulate when working with human users.

For this experiment only one participant at the time is tested. Each participant will be asked to playact as if he/she is a therapist. The goal for this participant

Participant	first scenario	second scenario	third scenario
1	1	2	3
2	1	3	2
3	2	3	1
4	2	1	3
5	3	1	2

Table 6.1: Order of scenarios per participant

is to give feedback to a child in the VR environment regarding its gaze behaviour. This experiment will be within subjects which means that each participant will see each scenario. This way, less participants are needed and participant variables are reduced. However, one of the cons for this is the fact that there might be a learning effect or fatigue effect. This will be partially counterbalanced by changing the order in which the participants will see the scenarios. This order of scenarios can be seen in table 6.1. In total five participants will be asked to provide feedback on the system.

Before the experiment begins the participant will receive an information sheet and a consent form, which needs to be signed. Next the participants will receive an explanation in order to inform the participant of what is asked of him/her. This explanation includes a description of what kind of gaze behaviour should be stimulated, what the setup of the experiment is and what is expected of him/her. The participant should try to stimulate the usage of a scanpath and well defined area of interests on important objects without staring at them. Foremost they should stimulate safe gaze behaviour in traffic. This explanation is followed by turning on the videos and letting the participant watch them and having the participant giving feedback on the gaze behaviour. Afterward they will receive some questions in order to understand how they interpreted the visualisations and what could have caused any misinterpretations. This cycle will then be repeated twice with two more scenarios. To end the process the participant will be asked some general questions related to all of the scenarios. All the questions asked in the experiment will be semi-structured which means that the open questions will serve as a begin point for getting as much formative information as possible. For this experiment it is important to receive as much information from the participant as possible in order to understand what should change for the next iteration of the project, thus a structured interview would be less valuable than a semi-structured one. Throughout the experiment a laptop will be placed in front the participant in such a way that the participant has easy access to the keys needed to switch the videos and has a clear view of the visualisations.

The questions consist of a part asked after each scenario and a part asked at the end of the experiment. All these questions are the basis for a semi-structured interview, thus are not binding. All these questions can be seen in Appendix A.

6.1.5 Recruitment and selection of participants

For this test no real therapists will be used. They are often quite busy and feedback on general visualisations can also be given by other people. Some students with experience in visualisation and/or Unity will be asked to participate. These participants have experience in what is possible with Unity and/or visualisations and how to best design such systems in such a way that it is clear to users how to use or how to interpret the information retrieved from it.

6.1.6 Methods

Type of experiment

This experiment will be a within subjects experiment and will be formative. Which means that there will be a focus on getting input and the product can be tweaked in between subjects. By having a semi-structured interview and an observation problems should arise.

Variables

In this experiment there are some independent variables, which are experience with Unity, experience with VR, experience with visualisations, and intellect. The subjects will be pre-screened in order to select participants who have experience with Unity, VR or making visualisations. Some extraneous variables are for example the environment, the mood of the participant, and the researcher. By ensuring that the conditions are the same for all participants, the extraneous variables are minimized. The dependent variables in his experiment are interpretation and opinion. These will be measured by post-interviews and observations when the participant is providing feedback.

6.1.7 Outcome analysis

The outcome analysis will consist of three parts. Firstly, the questions given in the semi-structured interview will be discussed. Each question will be shown and the answers of the users will be summarized. For clarity the participants will be called P1, P2, P3, P4, and P5 and the scenarios will be called S1, S2, and S3. Secondly, the problems formulated by the participants will be noted down and the severity and whether or not it has to be fixed in the next iteration will be decided. Lastly, misinterpretations during the observation and interviews will be discussed and their possible reasons will be analysed.

6.1.8 Results

Interview questions

Each participant had to answer the questions which can be seen in section 6.1.4. The questions were answered by all five participants (P1, P2, P3, P4, and P5) and their answers are summarized below.

Scenario 1
Where was the focus of the user during the simulation? How could you see that?
All participants found that the focus of the patient was on the road just a short distance away. He did not/almost never look to the sides. P1, P3, P4, and P5

mention that they could see this because of the circles, which are placed only on the road. P3 specifies this by saying that the circles did not approach any important objects, and P2 notices that the traffic signs and ducks received no attention from the patient. P1, however, mentions that there is fixation on the road in front of the patient and no fixation to the sides.

What objects were interesting for the user? How could you see that? P1, as well as P3, P4, and P5 mention that only the road received attention from the patient. This could be seen from the transparency and stacking of circles according to P1. P2, however, found that the patient is mainly looking at the road, but also a single time at the ducks and at the coins along the way.

What advice would you give the user during a therapy session? On what information would you base that advice? Every participant would tell the patient to look around them and not to focus on the road in front of them. According to P1, this is mostly based on the fixation which is at a point close to the cyclist. P2 adds to this that the traffic signs should receive more attention from the patient.

How would you describe the gaze behaviour of the user? P1 mentions that sometimes a scanning movement can be seen, however this is often quite fast and not often enough. Fixations do happen a couple of times directly in front of the patient. All the participants agree that only the point right in front of the cyclist is noticed. They all have different terms to describe this gaze behaviour, such as: not interested, not enough confidence to look around him, static, not paying attention, staring towards the ground right in front of him, just looking at one point, unfocused, and that the patient is in his own little world.

Would you describe the gaze behaviour as correct? No participant would describe this gaze behaviour as correct. P2 adds to this that the patient would not know if traffic approached him from either the right or left, because the cyclist just notices nothing at all.

Which things were unclear or incorrect in the visualisation of the gaze behaviour? According to P1, the visualisations were very dynamic and a tracker detecting outliers would be useful. Also some more interface elements could help. There is still a small mistake in the placing of the circles at two points during the simulation and P2 and P5 noticed this. P2 also noticed that new circles were sometimes hard to see and that there were already some circles in the environment before the video started. P4 suggests that maybe a timer would be useful. The placed circle would then disappear after a certain time.

Scenario 2

Where was the focus of the user during the simulation? How could you see that? All the participants agree that the patient was not minding the road. Things mentioned by the participants where the cyclist would focus on were: the scenery, a fence, the sky, and houses. This was seen by P1, P4, and P5 through the first-person perspective in which the camera would turn if the patient would turn his head. P3, P4, and P5 noticed that the circles would be placed far away from the cyclist.

What objects were interesting for the user? How could you see that? Things mentioned here by the participants were: the fences, houses, landscape, everything far away, sheep, trees, the fields, road block. P3 also mentioned that the traffic signs were ignored. This could again be seen by participants by the circles drawn in the environment.

What advice would you give the user during a therapy session? On what information would you base that advice? All participants would recommend the patient to look at the road. P1 also mentioned that it is good to look around, however the main attention of the patient should be focused on the road. P5, would base his advice on the fact that it is hard to know for the patient where he is going if he does not mind the road.

How would you describe the gaze behaviour of the user? Words and phrases used by the patients to describe the gaze behaviour shown are: chaotic, distracted, not a lot of fixation, looking everywhere but the road, exploring in a dangerous way, unfocused, capricious, every object in the distance was interesting, absent, dreamy, random, and not paying attention.

Would you describe the gaze behaviour as correct? None of the participants would find this gaze behaviour correct. P1 even mentioned that this patient really needs help.

Which things were unclear or incorrect in the visualisation of the gaze behaviour? P2 and P4 again mentioned the problem with circles spawning incorrectly which was also mentioned in S1. P1 and P5 both find that some of the circles placed far away are not really that visible. P1 finds this medium troublesome. P5 says it might be an idea to show an indication in the top down view when a circle is placed out of the view of the camera, because P5 thinks that zooming out with the top down camera would be troublesome, for things would be seen less clearly. P3 mentioned that he was still getting used to the visualisations, for him this was his first scenario. However, if he would see such a video again it would go better and the top down view was insightful according to him. He could clearly see where the patient had looked.

Scenario 3

Where was the focus of the user during the simulation? How could you see that? P1, P3, and P4 mention that the focus was on things like traffic signs and ducks. P1 however does not perceive this as positive, as he thinks that these objects only deserve a small amount of attention. He mentions that traffic signs for example are visual clues and the patient should have only looked at this object for a short time. The ducks should have just been avoided and not paid attention to that much. However, P3 and P4 find this gaze behaviour really positive and perceive the items such as ducks and traffic signs as important to look at. P3 even goes as far as describing the gaze behaviour of the patient as exemplary. P2 sees that the patient is often looking to the sides, not enough to the front and sometimes gazes at things which are not important, however he does mention that the patient did look at the important items next to the road. P5 agrees with P4 when it comes to the none important directions the patient is looking toward. He also mentioned that the ducks were seen but the side streets were ignored. He sees this because of the circles which are focus points and the amount of focus points show the longitude of the focus according to him.

What objects were interesting for the user? How could you see that? All participants mention that the patient focused on the traffic signs and only P2 does not mention the ducks. P1, P2, and P5 also mention fences or road blocks as an object of interest. P1 saw this because of the stacking of the circles. P5 however, does mention that the patient was looking at random parts of the road and that he often looked at a short distance from the bike. P3 does not agree with this and states that the user would look at an object if it was different than expected.

What advice would you give the user during a therapy session? On what information would you base that advice? P1 will recommend that the patient should mostly mind the road. Traffic signs are made to retrieve information fast and should thus not get too much attention. Also the cyclist should look back first to see if there is nobody behind him before breaking to look at ducks. He calls this breaking reckless. P2 would instruct the patient to look in front of him instead of to the side if the patient knows that there can be nothing there. The patient was looking to the sides at 90 degrees and this should be 45 degrees in order to mind the road better according to him. P3 however finds the gaze behaviour really good and would say that the therapy was successful. One small note was that sometimes the cyclist could look a bit more forward. P4 also has no big advices and thinks the gaze behaviour is good, but does mention that the cyclist could have looked back when breaking for the ducks. P5 would recommend the cyclist to think about where he wants to go and to keep that in mind.

How would you describe the gaze behaviour of the user? P3 and P4 would describe the gaze behaviour as good and exemplary. P1 en P5 however do not agree at all. P1 mentioned that the gaze behaviour was reckless, too much fixated, and focused on things in close proximity. P5 found that the patient was impatient and had a short attention span. P2 is found this gaze behaviour better than his first scenario, which is S1. He does think it is safe, but this can also be achieved with less effort.

Would you describe the gaze behaviour as correct? At this scenario the opinions are divided. P1 and P5 do not think that this is the desired gaze behaviour. P2, P3, and P4 do think that this gaze behaviour is correct. P2 however does mention that there is room for improvement and that it is a close pass.

Which things were unclear or incorrect in the visualisation of the gaze behaviour? P4 mentioned the wrongly spawned circles again which is also described at S1 and S2. P3 and P5 thought that the visualisations were very clear. P3 forgot the existence of the top down view because he was very satisfied with the first-person perspective view. P1 mentioned that you could always see where the circles were placed. He also interpreted that the cyclist was moving slower in this scenario and that helped him with seeing the gaze behaviour better; note that the bike moved at the same speed in every scenario. P4 mentioned that the depth between some gaze points is big and wonders whether or not these are the real gaze points. After explanation by the researcher how the gaze points are calculated he is satisfied with that answer.

There were also some questions at the end of the simulation, which are as follows:

Which gaze behaviour did you perceive as the best? Why? Every participant experienced S3 as the best scenario except for P1. P2 calls S2 the average of too focused on the road and looking around to much. Both P3 and P4 mention that S3 is the best because the patient looked around his environment well. P5 mentions that this gaze behaviour is the best because the patient is focused at the road, however some side streets are missed. P1 is the only participant who finds S1 the best. His reasoning is that in S2 the patient would look at any thing surrounding him and that in S1 the cyclist did not notice ducks, so he was not distracted by them like in S3.

Which gaze behaviour did you perceive as the worst? Why? All the participants agree that S2 showed the worst gaze behaviour. P3 was doubtful whether to choose S1 or S2, but finally thought S2 would be more dangerous, because the patient was not minding the road at all. This was the same reasoning as P2, P4, and P5. P1 also found that in S3 the patient would at least mind the road and he did not see this happen in S2.

Did you get valuable information from both of the visualisations? Which information could you get from each of them? P1 mentioned that he liked the first-person perspective the best. The reason for this is that the orientation is better. However, if the circles are farther away from the bike, they are harder to see. In this case the top view will provide more information for him. So he concludes that both visualisations have valuable information in them. P2 agrees that the first-person perspective is more useful. He liked that he could look from the patients' perspective and see the same view as them. P3 also finds the first-person perspective more intuitive. However, he does mention that he could imagine finding the top view quite powerful if he gets used to it. He thinks that the top view requires a higher learning curve. P4 clearly found the first-person perspective a lot more valuable. P5 thinks that they are both valuable, however he found the top down easier to begin with and the first-person perspective easier to use when the patient was looking further into the distance.

Should one of the visualisations be deleted? Only P4 estimates that the top down view would not be missed. P1 strongly thinks that the first-person perspective should stay but thinks that the top view can add more clarity when necessary. P2 finds that they both have value in different ways. Top down is useful to look at after the VR simulation and the first-person perspective is useful to look what is happening real time. P3 agrees that they both have their specific use cases. Top down is calmer to look at and the first-person perspective might tire a therapist when he needs to look at it often. P5 thinks that both visualisations should stay.

Should there be another visualisation? If so, what kind of visualisation? P1 does not have any other kinds of visualisation he desires. P2 would like a faster visualisation after the simulation has ended in which some important statistical things can be seen. He would like some number to show how many ducks the patient has noticed for example. P3 found that the visualisations gave a good information on where a patient was looking, however he could not see in the top down view how high a patient was looking. P4 would like a heat map when the simulation has ended on where the focus was during the simulation. This could then be taken into next sessions to see improvement. P5 would like to see a circle around important obstacles in order to read the top down view better. And also suggests that a view looking forward from the bike's perspective might be useful if the patient is tilting his head often. However, he does wonder if it is really necessary, for a therapist might know exactly what is coming if he had given the therapy often. Generally P5 found the visualisations clear.

Problems and improvements

In the interview participants had the chance to give feedback on the visualisations after each scenario. At the end of the interview the participants were asked again but could also suggest improvements. All these problems and improvements have been noted down. For each of these points a severity has been determined. This severity is based on whether or not other participants had problems with it, if it was a system mistake or a user error, and if it is solvable. This will also determine if a solution for the problem or the improvement will be implemented. The problems and improvements suggested, the severity, whether it will be implemented, and the reasoning behind this decision can be seen in table 6.2.

As can be seen from this table, there are five problems/ improvements which will be taken into account in the next prototype. First are some circles which are misplaced in the VR environment. The reason for this is a detection built in the environment to know when the ducks can start walking. This will be solved in another way in order to solve this problems. The second point is that there are sometimes already circles in the environment. This will be solved by starting the eye tracking only when the therapist has pressed the start button. The third suggestion which will be implemented is some statistical information at the end of the simulation. There will be a similar view to the top-down view when the simulation has ended in order to analyse the gaze behaviour together with the patient and to use it in order to document progress. The last implementation is making the important objects more visible. This will be done with circles just like suggested in the interview. They will be made red in order to show the therapists that this is a object that deserved attention.

Problem/improvement	Severity	Will be changed	Argumentation
Tracker detecting outliers	3	False	It is a good idea, however more research needs to be done for this and it might be better to implement this in the future.
Collision boxes where they do not belong	10	True	The eye tracking should work correctly, however these collision boxes are preventing that so it does need to be solved.
New circles are sometimes hard to see	4	False	Other users did not experience this problem.
There were already some circles in the environment before the video started	9	True	This could confuse people and make the scene more chaotic because more gaze circles would exist.
Timer to let circles disappear	3	False	This was not perceived this way by other users. This might make interpreting the gaze behaviour harder because not the full picture can be seen.
Some circles placed farther away from the patient are hard to see/ indication in top down view when a circle is placed out of reach of the camera	5	False	This is something which might be tackled in a late stadium of the project. A bigger screen for visualising for the therapist might help as well.
Statistical information after simulation	8	True	Some information can not be seen well in a short time. Some statistical information would help the user to better assess the gaze behaviour of the patient.
Can not see in the top down view how high a person is looking	2	False	This can easily be seen by switching to the other view.
Top-down view when the simulation has ended	7	True	This was also requested by the client and is very useful to help and see progress.
Circles around important objects to make them clearer	8	True	From the top view a lot of items like traffic signs are often overlooked. By indicating them with a colored circle the therapist can clearly see a danger zone.
View forward to see path in front of bike	1	False	The view in front of the bike can be seen in the top down.

Table 6.2: Problems and possible improvements with their severity and whether or not it will be implemented in the next iteration

Misinterpretations and misconceptions

Next to the feedback given, there are also some misinterpretations and misconceptions from participants. Firstly, in the interview some misinterpretations and misconceptions came forward. Secondly, when observing the participants when giving feedback to the 'patient' some misinterpretations and misconceptions were seen. In this section those misinterpretations will be discussed and possible causes for them will be determined.

Scenario 1 was not supposed to show correct gaze behaviour. Every participant saw that the patient was mainly looking at the ground and every participant would recommend looking around more in the environment. However, P1 does receive this scenario as the best of all three of them. But it was not supposed to be.

Scenario 2 was supposed to imitate a really exited child which found the VR environment really interesting and who is distracted quite fast. With this scenario every participant agreed that the focus of the patient was everywhere and that he was not minding the road. Every participant would also recommend the cyclist to look at the road. Also the terms with which they described the gaze behaviour shown was in line with the intended effect.

Scenario 3 was supposed to show a normal gaze behaviour on a bike. However, this was not always interpreted that way. P1 for instance finds it bad that the patient is looking at the ducks and at the traffic signs for a longer time, for he sees these objects as a distraction. However, these objects were meant as obstacles. P1 also points out that the cyclist should have looked behind him when breaking. P2 also observes that the patient is often looking to the sides and is not looking enough in front of him. This is also not something meant to be seen in this scenario. P4 states that that the patient is sometimes looking in random directions and that some side streets were ignored. Also these two things were not meant to come across to the participants.

When observing the participants giving feedback on the 'patient', some more misconceptions came forward. P1 for example states at one time during the observation of scenario 3: "The patient is looking at a traffic sign, so I can now clearly see what causes the distraction." and another time: "Traffic signs are distracting him. I would say, do not focus on traffic signs as much.". This traffic sign is meant to be seen and is supposed to receive attention from the patient. P2 also comments on scenario 3 during the observations that the patient is looking a lot of times to the side and that means that he is not looking in front of him. In scenario 3 P5 states that the patient is not looking at the crossroad while looking at the top down view. However from the first-person perspective it can bee seen that the crossroad is not visible yet. He also describes the gaze behaviour as random during the observation.

All the above mentioned misconceptions and misinterpretations are visualised in table 6.3. Some of them are not misconceptions or misinterpretations, but mistakes made while filming the videos. Misinterpretation 2 for example is a correct observation. During the filming the cyclist did not look back, while it would be safe to do so. Also misinterpretation 3 is a mistake made when recording the scenario. During the recording the cyclist did look to the sides quite often and the interpretation of this being incorrect is a valid one. The last misinterpretation which can be considered a mistake is the fact that the patient

ID	Misinterpretation/misconception
1	P1 thinks it is negative that the patient is looking at the ducks and traffic signs for a extended period of time in S3 and sees these items as distractions
2	P1 states that the cyclist should have looked behind him when breaking in S3
3	P2 observes that the patient is often looking to the sides in S3 and should look forward more
4	P4 and P5 state that the patient is looking in random directions at certain times in S3
5	P4 states that the patient sometimes ignores side roads
6	P5 states that the patient is not looking at the crossroad in S3 while the crossroad is not visible yet for the cyclist

Table 6.3: Misinterpretations and misconceptions found

sometimes ignores the side roads. This is true and is thus a good observation and not a misconception.

Misinterpretation 1 however is a real misinterpretation. The ducks and traffic signs should be an area of interest and should not be considered distractions. It is true that there should be no long fixation on those objects. Possible causes could be a misinterpretation of the desired gaze behaviour or not understanding that the ducks are supposed to be obstacles.

At item 4 this random gaze behaviour should have been perceived as a scanpath, however this did not happen with these two participants. Two other participants did find this gaze behaviour a good one. Possible reasons for this misinterpretation is that they do not have enough experience with these visualisations, do not know what a scanpath entails, or that the visualisation was a bit exaggerated and this conveyed the wrong message.

In item 6 P5 uses the top down view to judge that the patient is not looking at the crossroad. However, once looking at the first-person perspective it can be seen that this crossroad is not visible enough for the cyclist yet. The other four participants mostly used the first-person perspective in order to judge these kinds of things and they did not notice anything alike. So this misconception might be due to the main usage of the top down view.

Misinterpretation 1, 4 and 6 are again visualised in order to show the possible reasons and the solution to the misinterpretation in table 6.4.

6.1.9 Client feedback

There was a meeting with the client, Monique Tabak, from Roessingh Research & Development and the supervisor in which some feedback was given. This was a meeting just before the testing of the first prototype. There was a miscommunication for example, an assumption was made that the visualisations wanted were real-time visualisations, however the client mainly envisioned a total overview of the scene after the simulation. This need for a top down overview also arose from the observations and interviews of the participants during the

ID	Possible causes	Solution
1	Misinterpretation of the desired gaze behaviour. / Not understanding that the ducks are obstacles.	In the future explaining more clearly to the users of the system what desired gaze behaviour is and what the goal is of the level of the simulation
4	Not having enough experience with the system. / Do not know what a scanpath entails. / The visualisation was exaggerated.	Making sure the videos are better the next time and explaining better what the desired gaze behaviour is and what it entails.
6	The usage of the top down view as main camera.	Explaining to the therapist that the perception of distance can differ between both cameras and that it is best to switch between them and also use the first-person perspective in order to clearly see what the patient sees.

Table 6.4: Solutions to the misinterpretations

experiment. There was positive feedback on the two real-time views during the experiment from prototype one and only one participant found that one of the two views should be deleted. It is thus useful to keep these views in order to also be able to give real-time feedback.

The client would also love to see more clearly divergent gaze behaviour which is linked to the papers found in chapter 2. In order to do so the suggestion was made to have a table with divergent gaze behaviour and the visualisations for this. This table is made and can be seen in table 6.5.

Furthermore it was advised to also do one or two rounds of testing with the therapists for the final prototype as long as this is possible.

Divergent gaze behaviour	Source	Measure gaze behaviour	visualisation
Looking for dangers is often limited to one observation due to restricted gaze patterns.	Zeedyk, Wallace and Spry (2002)	The amount of observations.	In the final prototype this could be visualised by having a counter for the more important obstacles which show the amount of observations of that object.
Staring at the most visible stimulus	Biassoni, Bina, Confalonieri and Ciceri (2018)	Seconds of staring at the object and amount of times stared	The most visible stimulus is hard to visualise, because this might be different for each child. In order to make this clear to the therapist however, staring in general can be targeted. When a child stares at an object, a counter will go up.
Children often look at a close range while adults often spend more time looking farther away.	Tapiro, Meir, Parmet and Oron-Gilad (2014)	Distance	This is done by showing the therapist the real time visualisations. The therapists can interpret the correct gaze behaviour from these.
Children have a different point of view.	Sandels (as cited in Biassoni, Bina, Confalonieri and Ciceri, 2018)	Height	This cause of divergent gaze behaviour is hard to tackle. However, the bike in the environment is bigger than that of a child and this should help in the beginning in order to teach the correct gaze behaviour to the child.
Children confuse left and right sides.	Sandels (as cited in Biassoni, Bina, Confalonieri and Ciceri, 2018)	Direction	This should be taught by the therapist to the child. A visualisation would most likely be less effective.
Children do not understand the cause-effect relationship.	Sandels (as cited in Biassoni, Bina, Confalonieri and Ciceri, 2018)	Understanding	This is also something which should be vocally coached to the child. Even though it does not understand the relationship, by vocal coaching the child might learn what is expected and the understanding might come when he gets older.
Are not able to process much information at the same time.	Sandels (as cited in Biassoni, Bina, Confalonieri and Ciceri, 2018)	Amount of information	The therapist should vocally coach the child which information is not important in order to limit the amount of information which needs to be processed.

Table 6.5: Divergent gaze behaviour and solutions

6.2 Final prototype

In this part the final prototype will be discussed. First the changes made for this prototype will be shown. Then the prototype will be tested again. This time it is tested with eleven groups of two participants, who are all students or regualar adults. The groups will act out a therapy session in order to then answer questions. This will result in a statistical analysis.

6.2.1 Changes made

There will be five changes made, which are: changing some misplaced circles, having some circles at the start, adding some statistical information, having a semi-transparent heat map when the simulation has ended, and adding circles for important objects.

Misplaced circles

There were some misplaced circles placed in the scene, which affected the gaze behaviour visualisations while they should not do so. They were necessary in order to determine when the ducks should start walking, so they could not be deleted. These collision boxes were labeled with 'Ignore Raycast' and with this the problem was solved.

Circles before start

There were circles in the environment before the therapist pressed the button 'Let player start'. This was a mistake made in the code. This is now adapted. The gaze circles will only start appearing once the button 'Let player start' has been pressed.

Statistical information

At the request of the client and the participants during the test of the first prototype, some statistical information has been added. This can be seen in the top down view during the simulation and the recap screen at the end. The information which can be seen is the amount of objects seen per category, the amount of seconds the patient has stared throughout the simulation, and the amount of seconds looked at the objects from the different categories, with the categories being: ducks, traffic signs, and roadblocks. An example on how this is visualised is seen in figure 6.9.

Figure 6.9: Statistical information shown in the top down view during the simulation

Heat map when simulation ended

When the simulation is done, the therapist can press Tab in order to go to the recap screen. In the recap screen a top down view can be seen. In this view there are predetermined camera positions and switching between them is possible with the arrow keys. In this view the entire route can be seen and everywhere the patient has looked. The view can be seen in figure 6.10.

Figure 6.10: Recap screen with visualisations and statistical information

Circles for important objects

There was a need for circles indicating important obstacles. These are implemented by placing red circles in the environment around traffic signs, ducks and road blocks. It can only be seen from the therapist views. The circles can be seen in figure 6.11.

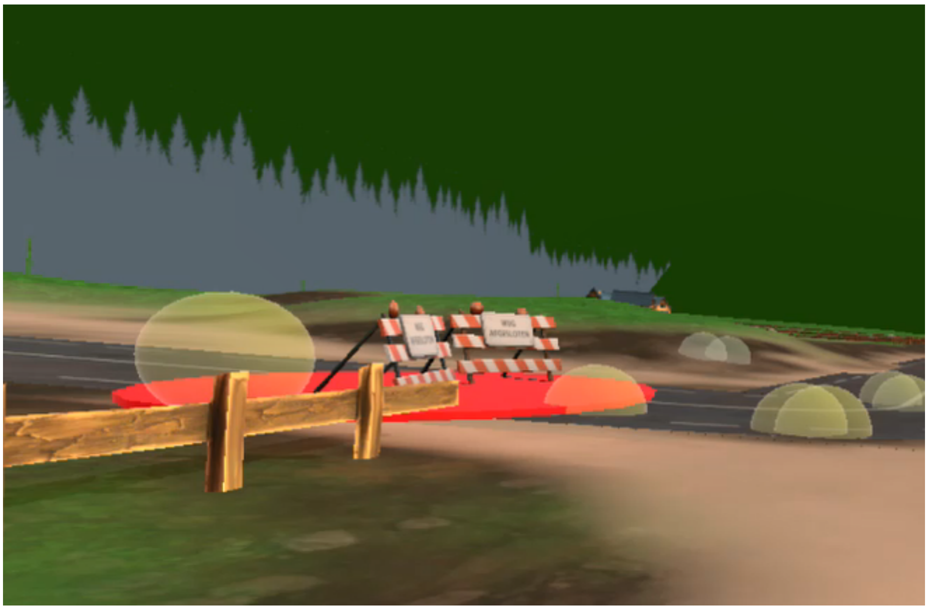


Figure 6.11: Red circle around important obstacles seen from the first-person perspective

6.2.2 Goals and aims

Goal

The goal of this experiment is to test if the system can help with providing the tools necessary to give better feedback on the gaze behaviour of patients. This has two parts to the experiment. Firstly the therapist should be able to use the visualisations correctly. Secondly the advice given to the patient should be correct.

Aims of evaluation

By not only measuring if the therapist's experience of giving feedback is better, but also if this feedback is received better and is applied by the patient while using the system, an indication could be given on whether or not the feedback system could enhance the gaze behaviour of the patients.

6.2.3 Expectations

The keys used to control the switching between visualisations might be difficult to remember at first. This could result in the system not being as effective as it would be once used multiple times.

The testing will happen with students playing the patient. This is. however, not the intended target and these people are older, know how to bike and the gaze behaviour which belongs to biking and their gaze behaviour will thus be harder to analyse for the therapists.

6.2.4 Setup

For this experiment there are two conditions. Firstly, there is the condition with the old system in which there will be no feedback system shown. Secondly there is the condition where the current prototype is shown. The participants will participate in the experiment with groups of two. One will play the therapist and one will play the patient. The experiment will be within subjects, because each participant will receive each scenario. The scenario they will receive first will be randomized.

The patient will have to wear the VR goggles and steer the virtual bike with the arrows on a keyboard in front of them. They will be asked to bike normally and imitate a child's gaze behaviour. For this they will get a clear protocol on what this entails in order to standardize the gaze behaviour the patient is showing. If they receive any feedback from the therapist they can implement this. After each scenario they will get a list of questions on a Google form to determine if the feedback provided by the therapist was valuable.

The therapist will have a laptop in front of him/her and an overview of all the keys, which can be used and their functions. Before each scenario they will get an explanation on what can be seen in the visualisations and how they can be used. During the experiment they will be recorded while giving feedback on the gaze behaviour of the cyclist. After each scenario they will be asked to answer a few questions. These questions will be asked through a Google form in order to determine if the information provided by the visualisations is helpful to give more insightful feedback.

The questions which will be asked can be seen in appendix B and C. Most questions are statements in which the participant can score the statement from 1 up to 5. Some questions are open in order to give the participants a chance to share information which they have not been asked for throughout the rest of the questionnaire. This information can then be taken into the discussion or future research.

6.2.5 Recruitment and selection of participants

The participants will be students at the University of Twente or normal adults. For this experiment there will be no pre-screening and everybody is welcome to participate. The participants from the last experiment are, however, not allowed to play the therapist, because they have experienced this role before and have experience with the visualisations. There are eleven groups of two people who will be participating in this experiment.

6.2.6 Methods

Type of experiment

This experiment will be a within-subjects experiment and will be a comparative experiment. In this experiment there will thus be no control group and all the conditions will stay the same except for the condition which determines if the simulation is with or without the developed feedback system. The result can then be concluded from the dependent variables and the difference between them.

Variables

The independent variables in this experiment are: experience with Unity, experience with VR, experience with data visualisations, intellect, and biking experience. Some extraneous variables are for example the environment, the mood of the participant, and the researcher. By ensuring that the conditions are the same for all participants, the extraneous variables are minimized. The dependent variables will be the interpretation and opinion. These variables will be measured through post-interviews and observations.

6.2.7 Outcome analysis

For each of the statements which can be assessed on a scale from one up to five, a mean will be calculated for each category. However, this will only be done if Cronbach's Alpha shows a correct reliability. Also a statistical test will be performed. The statements of both scenarios and their scores will be compared. Also the opinion of the therapist and the patient will be compared. Finally the open questions will be discussed and some recommendations might be done for future research.

6.2.8 Results

Statistical Results

Eleven groups of two participants were tested. These teams executed the tasks stated in 6.2.4. The therapists were asked to answer multiple choice questions on the Likert scale regarding the interpretation of the gaze behaviour, the visualisation of the gaze behaviour and if the child understood and implemented the correct gaze behavior. These categories will be named understanding, visualisation, and child implementation respectively. Also the patients were asked to answer some questions regarding if they understood/implemented the feedback given and if the therapist understood their gaze behaviour correctly. Respectively, these categories were named implementation, and understanding therapist.

In order to know if the questions used to answer these principles are reliable, the internal consistency is estimated using the Cronbach's Alpha (Stephanie, 2014). The Cronbach's Alpha in relation to the internal consistency is shown in table 6.6. All the values for the Cronbach alpha should be more than 0.7 in order to assume a correct reliability.

Cronbach's Alpha	Internal consistency
$\alpha \geq 0.9$	Excellent
$0.9 > \alpha \geq 0.8$	Good
$0.8 > \alpha \geq 0.7$	Acceptable
$0.7 > \alpha \geq 0.6$	Questionable
$0.6 > \alpha \geq 0.5$	Poor
$0.5 > \alpha$	Unacceptable

Table 6.6: Cronbach's Alpha in relation to the internal consistency, adapted from Stephanie (2014).

The calculated values can be seen in table 6.7. This is done by using an online calculator (Wessa, 2017) and taking the Cronbach Alpha of all the questions in one category. This results in one Cronbach's Alpha indicating an acceptable internal consistency, two indicating a good internal consistency, and two indicating an excellent internal consistency. The requirement of needing at least a score of 0.7 or higher for each category is met and thus reliability will be assumed.

Category of question	Cronbach's Alpha
Therapists: Understanding	0.8186
Therapists: visualisation	0.8542
Therapists: Child implementation	0.7734
Patient: Implementation	0.9135
Patient: Understanding therapist	0.9113

Table 6.7: Cronbach's Alphas for each category of questions.

The next step is to test if the assumption of a normal distribution can be made. The Shapiro-Wilk Test will be used for this purpose. The hypotheses used are:

H_0 : *The sample belongs to a normal distribution*

H_1 : *The sample does not belong to a normal distribution*

The Shapiro Wilk value is calculated in order to find whether or not the normal distribution has to be rejected. These values can be seen in table 6.8 (Dittami, 2009). With $\alpha = 0.05$ and $n = 11$ a threshold of $W_\alpha = 0.850$ is used. This means that if $W < W_\alpha$ the H_0 should be rejected. None of the W-values are lower that this threshold, which means that H_0 cannot be rejected. Thus normality will be assumed.

Category of question	Condition	W
Therapists: Understanding	1	0.947
Therapists: Understanding	2	0.921
Therapists: visualisation	1	0.902
Therapists: visualisation	2	0.961
Therapists: Child implementation	1	0.864
Therapists: Child implementation	2	0.904
Patient: Implementation	1	0.852
Patient: Implementation	2	0.928
Patient: Understanding therapist	1	0.951
Patient: Understanding therapist	2	0.933

Table 6.8: W for each category of question and each condition. Calculated with Dittami (2009)

Because of the fact that the assumption of a normal distribution has been made, and that independence between test conditions can be assumed due to counterbalancing, a paired sample T-test will be used to estimate if the findings hold statistical significance. Another assumption which can be made is that the mean of condition 2 will be higher than the mean of condition 1. The main reason for this is that the feedback system in condition 2 is supposed to improve the understanding and visualisation of gaze behaviour. Because of this, an upper-tailed alternative hypotheses can be chosen. This gives the following hypotheses:

$$H_0 : \mu = 0$$
$$H_1 : \mu > 0$$

For each category of questions the t value has been calculated, as well as the p value. This can be seen in table 6.9.

Category of question	t	p (Upper-tailed)
Therapists: Understanding	3.22	0.0046
Therapists: visualisation	2.04	0.0002
Therapists: Child implementation	2.2925	0.0224
Patient: Implementation	0.563	0.2930
Patient: Understanding therapist	0.788	0.2245

Table 6.9: t and p values calculated for each category of questions

For each category the H_0 will be rejected if $p < 0.05$ for $\alpha = 0.05$. This means that the H_0 is rejected for the following categories: Therapist: Understanding, Therapist: visualisation, Therapist: Child implementation, because 0.0046, 0.0002, and 0.0224 respectively lie in the rejection zone. At a 5% significance level it is proven that the feedback system improved the three categories of visualisation, understanding, and child implementation for the therapists. The H_0 can not be rejected for the categories: Patient: Implementation, and Patient:

Understanding therapist. Their respective p-values of 0.2930, and 0.2245, do not lie in the rejection zone and thus the influence of the feedback system did not differ significantly, at a 5% level of significance.

6.2.9 Given feedback

Next to the multiple choice questions on the Likert scale, the participants have given some extra feedback points. These feedback points can be seen in table 6.10. In this table it can be seen that there are still a lot of possible things to implement. This will be discussed further at future work in chapter 10.

Therapist/ Patient	Feedback
Therapist	Looking at the sky is not visible in top down view.
Therapist	Cannot see if a child looks at an object far in advance.
Therapist	Red surfaces were very helpful
Therapist	Final overview refreshed the memory and made explanations more concrete with visual support.
Therapist	The first-person mode was best, other modes were good but not as effective.
Therapist	Only a general direction could be seen.
Therapist	An option to give visual feedback to patient would be useful.
Therapist	Scale that points out outliers.
Therapist	Controls on the screen which are used by participant.
Therapist	Sound when gaze diverts from the road.
Therapist	Graphical view of the statistical results.
Therapist	See the order in which the dots appear.
Therapist	See user view at all times.
Therapist	Different keys.
Therapist	Replay function.
Patient	Other traffic and different distractions at the same time.
Patient	Vertical gaze was not always interpreted correctly.
Patient	Feedback came later and was less direct in simulation 2.
Patient	The therapist did not take into account the turns, so the feedback was of because off this.
Patient	Something which guides the eyes back to the road to show the correct gaze behaviour.
Patient	Steering the bike with the controls was hard.

Table 6.10: Feedback and possible implementations given by the participants.

7 | Evaluation

In this chapter there will be an evaluation of this graduation project. First some feedback and evaluation points are given by the therapists for whom this system has been designed. Following, the requirements formulated in chapter 5.3 will be discussed.

7.1 Therapist feedback

In a session with the therapists their opinion, and also their feedback was asked. Firstly, in the future it would be valuable for them if there would be a quicker overview to see if the gaze behaviour is adequate. Currently it is still hard for them to see what the desired gaze behaviour is and the system could show in the future what gaze behaviour is desired when the adequate gaze behaviour is not displayed. Also a score would give them an easy indication on the gaze behaviour of the children. However, they do mention that they desire this in a future prototype, but did not expect if from this graduation project yet, due to the lack of research done in correct gaze behaviour. They thought that the statistical information shown on the recap and top-down view were a step in the right direction. Next to this, they mention that the top-down is a quicker way to interpret gaze behaviour and to make this more clear they would like to have additional colors instead of using just the opacity of the circles in order to visualize areas of interest. The therapists found the saved gaze data interesting and that it might be useful for research. Furthermore, they mentioned that some therapists found the first person perspective a bit confusing, even though another therapist did like it. They got the feeling that the gaze circles distracted them from the environment and only pulled their attention to the gaze behaviour which made it hard to focus on other elements. Also, they question if the recap view will be discussed with the children, due to the fact that the interpretation is reasonably abstract and might be hard for children to understand.

7.2 Requirements evaluation

In order to know if the system adheres to the requirements formulated in chapter 5.3, these should be evaluated. In table 7.1 the requirements and their implementation are shown. As can be seen most requirements are implemented, however just some of them are not. The reasons for this are also shown in the table.

ID	Requirement	Priority	Implementation
1	The gaze feedback system must make use of the already existing virtual reality bicycle training developed by Roessingh Research & Development.	Must	Implemented, Every aspect is kept, only for testing with the Fove the VR bike has been left out.
2	The system must allow for the vocal coaching of the children by the therapists.	Must	Implemented, the system does allow for vocally coaching the children, this is also done in the experiments in the realization phase.
3	The system should visualise the gaze behaviour by placing multiple circles a second on gaze points.	Must	Implemented, there are five gaze points placed in one second throughout the environment.
4	It must be clear from the visualizations where a child is looking.	Must	Implemented, in the first prototype, it was tested if participants understood the gaze behaviour and they often saw correctly where the child was looking.
5	A simulation with the feedback system should not have harder tasks or tasks that take longer than without the feedback system for the children in the simulation.	Should	Implemented, there are no extra tasks for the children. Only things are added on the therapist side of the system.
6	The gaze feedback system should have multiple views in order to properly assess the gaze behaviour of the children with DCD.	Should	Implemented, the top-down, first person perspective and the recap view were made.
7	The system should be in Dutch.	Should	Not implemented, almost everything is in Dutch, however the statistical information on the top-down and the recap screen has been added in English but could easily be translated to Dutch.
8	There should be a instruction manual with the necessary information included.	Should	Not implemented, due to time restraints.
9	There must not be any additional distractions caused by the feedback system for the children.	Won't	Requirement met, only things are added at the therapist side, and thus are not visible for the children.
10	There must not be a large amount of reading involved.	Won't	+, nothing has been added on the children side, so they do not need to read any information.
11	The system should in no way stimulate aggression and tantrums from the participating children.	Won't	+, Nothing has been added to the children side of the system, thus there will be the same amount of risks in getting a tantrum.

Table 7.1: Evaluation of requirements

8 | Conclusion

The goal of this graduation project was to answer the main research question, which is "How can a feedback system be developed for children with DCD on gaze behaviour using eyetracking, in such a way that it helps to enhance gaze behaviour in a VR bicycle training environment and visualizes this gaze behaviour for the child's therapist." In order to do so, four sub-questions were formulated; " Which kind of visualizations are valuable for showing gaze behaviour in virtual reality to the therapists?", "How can the symptoms of children with DCD be taken into account in such a way that the system is tailored to them?", "What is an effective way to give feedback to children using the VR bicycle training in order to draw their attention to the correct objects in the virtual reality environment?", and "Which key features are used in assessing gaze behaviour through virtual reality?".

First of all in chapter 2 multiple ways to visualize gaze behaviour were found. Three main categories are statistical graphics, point-based visualization techniques, and AOI-based visualization techniques. These were used in order to visualize the gaze behaviour for the therapist of a child with DCD.

Secondly, these children with DCD have a lack in motor skills which influences their everyday tasks. Next to this they can also have co-occurring disorders like: Attention Deficit Hyperactivity, Reading Disability, Specific Language Impairment, and/or Autistic Spectrum Disorder. These could all lead to a variety of symptoms like inattention, hyperactive-impulsive behaviour, poor spelling, poor decoding abilities, difficulties with word recognition, underdeveloped speech, aggression, and communication. These symptoms were all taken into account when making the requirements for the gaze feedback system.

Also which way to effectively draw attention from children in a VR bicycle training environment has been researched. In chapter 4.1 a mind map has been made in order to ideate some ideas. The visual ideas were tested, which showed that having an arrow pointing towards the most important aspect in a VR environment was the best way from the chosen visual effects. The therapists preferred to vocally coach the children in order to tailor the feedback to each child specifically.

Finally the key features of assessing gaze behaviour have been found, which are fixation, saccade, smooth pursuit, scanpath, stimulus, and area of interest. These were used in order to define to participants which kind of gaze behaviour was preferred in the test at prototype one and the final prototype, which is a scanpath without long fixations.

After answering all these questions, this was combined in one final prototype, which answers the main question in which a feedback system for children with DCD was asked. What can be seen from the statistical results calculated in chapter 6.2.8, is that the designed system does increase the therapists' understanding of the gaze behaviour shown, they also think that the gaze behaviour is visualized better, and they find that the children implement the feedback given on their gaze behaviour better. It can thus be argued that part of the main research question has been answered in which the gaze behaviour should be visualized for the therapists. However, it can be argued that that there is not enough proof to say that the system did not enhance the gaze behaviour of the children. This could be due to the fact that the patient did not feel that therapists understood their gaze behaviour correctly and that they did not always understand and implement the feedback given to them.

9 | Discussion

First of all, the participants playing patients in the experiment at the final prototype, did not find the feedback of the therapists better with the feedback system. Also they did not notice a significant difference in the understanding of their gaze behaviour by the therapist. One of the reasons for this could be that some participants playing the therapist did not feel comfortable in that role. This is also indicated by participants themselves. Also the system might require a learning curve and the therapists had to get used to the system, which limited them in the amount of feedback they could provide. To know if the feedback on gaze behaviour does improve for certain, real therapists and real children should be used in another experiment.

Also the therapist mentioned in a feedback session that the feedback system might require their attention for too long. Usually the child with DCD should be watched during a simulation, in order to make sure he/she does not for example break the VR goggle or bike. The system should thus show the feedback on gaze behaviour more clearly, in such a way that it can be seen much faster. However in order to do so, the correct gaze behaviour of children should be known. This is still a subject which is often being researched and especially with the addition of having a virtual environment it is not clear yet what this correct gaze behaviour specificly includes. It could be interesting, however, to look at the research of Alberti et al. (2012), where they use the first fixation and the number of crashes in their research to assess the effectiveness of a three-dimensional riding simulator. Such an experiment might give some extra insight on how the gaze behaviour in the virtual reality bicycle training should be assesssed.

Another interesting thing is that different people find other views more intuitive. In the experiment of the first prototype, one participant stated that the top-down view seemed to have more of a learning curve than the first person perspective. However, another participant thought that the first person perspective had a bigger learning curve. This shows that both views can interpreted and experienced differently by other people. A difference could also be seen in the feedback session with the therapists in the evaluation. Some therapists indicated that they found the first person perspective a bit confusing, while another therapist liked this view. This again shows that the opinion of the visualizations could depend on the personal preference of participants or therapists.

Every test during this graduation project is executed with students or adults. There is a big difference with testing with adults and children when it comes to gaze behaviour and according to the therapists there is also a big difference between neurotypical children and children with DCD. Because of this, some of the results gotten from this test might divert from if the test were to be done with the target group. Unfortunately, testing with this group was not possible due to ethical reasons, which will be explained below. The therapist suggested in the evaluation feedback session that it would be good to test with neurotypical children what desired gaze behaviour is, in order to then determine what divergent gaze behaviour is.

Finally, the small amount of research done on children wearing VR goggles is a bit concerning. There are three main reasons why wearing VR goggles are discouraged for children, which are: in a VR goggle there can be small parts which might be eaten, children have little spacial awareness which might lead to accidents, and the eyeball distance of children is different than that of adults. This could cause symptoms like eyestrain, headache, migraines, discomfort, disorientation, nausea, motion sickness, and dizziness (Micic, 2017). Even VR goggles from some of the major brands warn for children not to wear their goggles. Children under the age of 13 should for example not wear the Oculus Rift, according to Oculus (Oculus, n.d.). HTC states that their goggle is not designed for children and that the goggles should be kept out of reach (VIVE, n.d.). Also motion sickness might be a problem and could cause disorientation, vertigo, drowsiness, pallor, sweating, vomiting, etc (Ku, 2018). HTC also recommends a break of 10 to 15 minutes every 30 minutes in a simulation. This is to keep the spacial awareness, to stay oriented, and decrease the chance of seizures. This could be an ethical concern for using the VR bicycle training. However, a child will only have approximately three sessions with the virtual reality bicycle training and will then move on to other aspects of their therapy. Also the sessions only take half an hour, which includes the welcoming and saying goodbye to the child. The child will never be in the virtual reality environment longer than the maximal recommended uninterrupted time and will only enter the simulation approximately three times. It can be argued that the risks of VR are not big due to this, and that the benefit of having this therapy beats the risks.

10 | Future Work

There are multiple ideas suggested throughout the study which require more research in order to estimate their added value for this project. In table 6.2 some of these ideas came forward. Firstly a tracker detecting outliers was suggested. This could be implemented during a next prototype. There does need to be some research on how to implement this tracker correctly and how to visualize this. Secondly the fact that new circles are not distinguished from the others should be looked at. This could for example be solved by giving the last several circles a different color or to make the new circle blink. Also a timer was suggested to let some older circles disappear. This could be implemented, however it should be researched if the disappearing of circles has any added value and contributes to a better understanding of the gaze behaviour shown. Next, there is also the point targeted at the farther away circles in the top down view. In this view some circles are places out of the scope of the camera. This could be solved by having an arrow point towards the direction the circle is placed for a few seconds after it has been placed. Also a zoom in and zoom out could be useful in this case. Furthermore, a participant stated that it could not be seen from the top down view how high a patient was looking. This could be solved by letting the therapist switch between the top down view and the firs person perspective more. Finally it was suggested to have a small view forward in every perspective in order to know what is in front of the bike at any time. However, it was also mentioned that the therapists might know what is coming very well if they have executed the simulation often and this might not be necessary.

Also from the final user testing some more suggestions came forward. One problem which, could be solved is that it cannot be seen if a child looks at an object far ahead. An implementation of another visualization can be added in order to visualize this. In order to know which visualization to pick, this first should be researched. Another interesting addition would be graphical views of the statistical results. This way the gaze behaviour can be read more easily. Also the order in which the dots appear can be shown. The visualization for this should be researched. Lastly a replay function was suggested. It should be researched if there is a need for this function with the therapists.

In order to add the feedback system developed in this graduation project to the already existing VR bicycle, another VR goggle should be bought and implemented. The Fove does not have any controllers and is at times lacking in precisely displaying gaze behaviour. The VR bike works with controllers and is thus not compatible with the Fove. In order to merge the two projects, both projects should implement the usage of a HTC VIVE with Tobii eyetracking.

Finally, tests should be done in order to determine normal gaze behaviour with normal children. This way the therapists can know what divergent gaze behaviour is and this behaviour could then be recognized with the feedback system. If this is done, a score could be calculated which shows the amount of correct gaze behaviour. This is a thing which the therapists would desire to have in the future.

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A | Questions semi-structured interview prototype 1

Questions for after each scenario are as follows:
Where was the focus of the user during the simulation? How could you see that?

What objects were interesting for the user? How could you see that?

What advice would you give the user during a therapy session? On what information would you base that advice?

How would you describe the gaze behaviour of the user?

Would you describe the gaze behaviour as correct?

Which things were unclear or incorrect in the visualization of the gaze behaviour?

The following questions where asked once the experiment had ended:
Which gaze behaviour did you perceive as the best? Why?

Which gaze behaviour did you perceive as the worst? Why?

Did you get valuable information from both of the visualizations?

Which information could you get from each of them?

Should one of the visualizations be deleted?

Should there be another visualization? If so, what kind of visualization?

B | Questions therapist final prototype

Demographics
Have you ever worked with Unity before? Multiple choice; yes or no.

Do you have any experience in making data visualizations? Multiple choice; yes or no.

Do you have any experience with Virtual Reality? Multiple choice; yes or no.

After both scenarios the following questions were asked:
The view for the therapist was easy to interpret. Likert scale from strongly disagree to strongly agree.

I found it easy to give feedback on the gaze behaviour based on this simulation. Likert scale from strongly disagree to strongly agree.

I felt like the patient implemented my feedback correctly. Likert scale from strongly disagree to strongly agree.

I had all the information necessary to give correct feedback on the gaze behaviour. Likert scale from strongly disagree to strongly agree.

I feel like the other therapists would form the same advices based on these visualisations. Likert scale from strongly disagree to strongly agree.

It was clear what the visualisations were visualising. Likert scale from strongly disagree to strongly agree.

I immediately knew how to interpret the visualisations. Likert scale from strongly disagree to strongly agree.

I would feel comfortable using this system regularly in order to give feedback to the patients. Likert scale from strongly disagree to strongly agree.

I think that working with this system takes practice. Likert scale from strongly disagree to strongly agree.

These things were unclear in the therapist view. Open question.

This could still be implemented. Open question.

Other comments. Open question.

C | Questions patient final prototype

Demographics
Have you ever worked with Unity before? Multiple choice; yes or no.

Do you have any experience in making data visualizations? Multiple choice; yes or no.

Do you have any experience with Virtual Reality? Multiple choice; yes or no.

After both scenarios the following questions were asked:
I think that the therapist understood me. Likert scale from strongly disagree to strongly agree.

I think that the therapist interpreted my gaze behaviour correctly. Likert scale from strongly disagree to strongly agree.

The therapists gave directions which were not in line with my gaze behaviour. Likert scale from strongly disagree to strongly agree.

I adapted my gaze behaviour when the therapist asked me to do so. Likert scale from strongly disagree to strongly agree.

I think that I could better my gaze behaviour with the therapist coaching me in this way if I was a child with DCD. Likert scale from strongly disagree to strongly agree.

I think that my gaze behaviour would be analysed in the same manner with other therapists. Likert scale from strongly disagree to strongly agree.

These things were unclear. Open question.

This could still be implemented. Open question.

Other comments. Open question.