Emergent Behaviour of Therapists in Virtual Reality Rehabilitation for Acquired Brain Injury

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Abstract

This study investigates how therapists are able to adopt a virtual reality toolset for rehabilitation of patients with acquired brain injury. By conducting a case study where the therapists and their interactions with the system as well as with the patients are in focus. Video recordings, participant observers and field notes were the main sources for data used in an interaction analysis. Results reveal emergent behaviour and resourcefulness by the therapists in utilizing the virtual tools in combination with their conventional approaches to rehabilitation.

Keywords:

Acquired Brain Injury, Virtual Reality, Emergent Behaviour

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Introduction

The use of virtual reality (VR) for rehabilitation of various disabilities was deemed viable as early as in the mid 90’s (Kuhlen & Dohle, 1995), and in recent years it has been applied and researched extensively with promising results. Using VR in rehabilitation of upper limb mobility as well as cognitive functions seems especially useful (Pietrzak, Pullman, & McGuire, 2014), and combining traditional methods with VR might be more effective than either method by itself (Laver et al., 2017). Studies on VR in rehabilitation tend to focus on how a given VR system compares with traditional methods in relation to the improvements of the user’s condition. This often leaves out the role of the therapist who should be the expert when it comes to facilitating rehabilitation sessions, be it traditional methods, VR methods or a combination of both.

In the past two semester projects, the authors of this thesis have worked with VR for people with disabilities. The earliest study (Diaconu et al., 2019) investigated what aspects to consider when designing VR experiences for disabled people, while in the most recent study (Arnoldson, Vreme, & Sæderup, 2019) the focus was on how to make a flexible system that can be used by people with various degrees of disabilities caused by ABI. Subsequently, this semester project report is a follow-up study to the previous work done by the group. The methods used herein (case study, interaction analysis) are the same as in previous works by the authors.

The aim of this thesis is to explore how therapists at Lunden, a rehabilitation center located in Varde, Denmark, interact with a VR system designed to give the facilitator control over the virtual environment (VE) and the virtual artifacts within it, during a rehabilitation session. The design is based on how the therapists at Lunden use their resourcefulness when performing traditional therapy and is meant as an addition to the tools they already use rather than a replacement. Furthermore, a flexible system is needed as the patients at Lunden have individual needs depending on the nature and severity of their condition. The system should let the therapists use their general expertise, as well as their experience with the individual patients, to fine-tune the system and use it in combination with the existing tools and methods they have.

To better frame this study, the following research questions were formulated:

1. What tools and methods do therapists utilise in rehabilitation exercises with patients?
2. Which aspect of rehabilitation could be enhanced by VR?
3. Which aspect of rehabilitation should not be substituted by VR?
4. What can a computerized VR system offer to rehabilitation that traditional methods can not?
5. How does the conventional approach of therapists transfer to a virtual reality toolset.

The subsequent sections of this thesis are as follows. The second section goes through the theoretical background and related work of ABI rehabilitation and VR in healthcare. The third section gives an overview of the methods used in this thesis. In the fourth section the design and implementation is covered. The results are presented in the fifth section followed by a discussion in the sixth section. The last section is the conclusion.

Theoretical Background and Related Works

Literature Review

This section offers a brief introduction to acquired brain injury (ABI), ABI rehabilitation, the use of virtual reality (VR) in healthcare, and specifically the use of VR for ABI rehabilitation. The section begins by defining various terms used in this paper, such as VR and ABI. Afterwards, beginning from the work of Vreme (2019), the section continues with a view on the topic of VR in ABI rehabilitation from a selection of research from the past decade, covering non-conventional means of motor rehabilitation for patients with ABI. For the purposes of this paper, ‘conventional’ is used to refer to any means of therapy not making use of virtual environments of any kind.

VR definition

Henderson, Korner-Bitensky, and Levin (2007) conduct a review on the effectiveness of VR for motor upper limb rehabilitations of stroke patients. At the time of the review, the relevant research was more limited than today, and the review concludes that the existing evidence was promising enough to advocate for further trials on the matter. However, it is their definition for virtual environments that will be used in this paper. Henderson et al. (2007) classify VR applications either as fully immersive, or as non-immersive. The former category includes head-mounted displays (HMDs), large screen projections and other systems in which the environment is projected on a concave surface. The latter category includes any other application displayed on a computer screen. In a similar fashion to Saposnik and Levin (2011), this semester project report will use the aforementioned definition as distinguishing between VR applications based on the degree to which they isolate the user from the physical environment. Consequently, this report will refer to both immersive and non-immersive VR applications as ‘VR’, unless otherwise specified.

Acquired brain injury

ABI definitions

ABI is one of the most common causes of disability in adults, with ischaemic stroke (IS) and TBI being the most common forms of ABI (Feigin, Barker-Collo, Krishnamurthi, Theadom, & Starkey, 2010; World Health Organization, 2006). The World Health Organization (WHO) defines stroke as the “rapid onset of [...] cerebral deficit, lasting more than 24 hours [...], with no apparent cause other than a vascular one” (World Health Organization, 2006, p. 151). The WHO definition for TBI is that of injury to the brain caused by an external mechanical force (World Health Organization, 2006). This definition for TBI is also independently formulated later by Menon, Schwab, Wright, and Maas (2010).

The WHO places stroke as the third most common cause of death in industrialized countries, after heart disease and cancer and the second most common cause of mortality world-wide (World Health Organization, 2006, pp. 151, 156). Over a third of stroke survivors have severe disability, and psychosocial disabilities are more common than physical ones (pp. 156-157). IS is the most common form of stroke in developed countries (p. 151) and is “caused by the interruption of the blood supply to a localized area of the brain” (p. 157) resulting in the disruption of the metabolic processes in the affected area.

According to the WHO (World Health Organization, 2006), TBI is “the leading cause of death and disability in children and young adults” (p. 164). Even after mild TBI, disability is a problem, and after moderate or severe TBI disability may take different forms including disturbed mental and motor function (p. 165). Moderate disability is more common than severe after TBI, however the severe disability commonly includes a combination of physical and mental impairments (p. 167).

ABI rehabilitation

In terms of rehabilitation, the authors follow the definition given by Wade & Jong (2000). Notably, rehabilitation services contain a multidisciplinary unit of people, are reiterative, focused on assessment and intervention, and aim to “maximise the participation of the patient in his or her social setting” while minimising “the pain and distress experienced by the patient” (p. 1386). Additionally, a similar definition for stroke is posed by the WHO, the goal of stroke rehabilitation being to restore the patients to their initial mental, physical and social abilities, and typically requiring a multidisciplinary approach (World Health Organization, 2006, p. 159).

Turner-Stokes, Pick, Nair, Disler, and Wade (2015) offer an insight into the multidisciplinary aspect of ABI rehabilitation services, by conducting a review on the topic, regarding ABI in adults of working age. The reviewers note that the rehabilitation goals of non-retired adults differ from those of older populations, as they must cope with the effects of disability for most of their life. As such, any opportunity they may have to recover independence is worthwhile. The conclusions of the review indicate that multidisciplinary rehabilitation services conducted by experts do improve the effects after ABI and that faster and improved recovery is possible if these services are offered at higher intensity. Furthermore, cases of moderate to severe ABI benefit more from early intervention, and more from group rehabilitation with peers in the same situation than from individual intervention. Additionally, according to the review, “brain injury rehabilitation services are increasingly defined by the needs of patients, rather than by underlying pathology” (p. 3). These needs arise from a broad set of deficits: “various combinations of physical, communicative, cognitive, behavioural, psychosocial and environmental problems” (p.3), which according to the review require rehabilitation to be approached from an array of physical, social and personal contexts.

VR in healthcare

This section introduces the potential of VR in improving healthcare by adding to and replacing parts of medical practice (Wiederhold & Riva, 2019), distraction from pain during surgery (Mosso Vázquez et al., 2019), alternative to surgery (Li et al., 2018), assessment of trait paranoia (Riches et al., 2018), supplementing cognitive therapy (Ferrer-Garcia et al., 2019), treatment of clinical syndromes (Hacmun, Regev, & Salomon, 2018) and art therapy (Hacmun et al., 2018).

Hacmun et al. (2018) explore the possibilities of VR for art therapy and provide some directions for implementation. As a creative medium, VR is also unrestricted enough to be tailored to individual needs, and the interaction of the use with a therapist that mediates the experience “is effective in raising psychological well-being and treatment of clinical syndromes” (p. 4). Hacmun et al. (2018) describe the virtual environment as having support for full body movement range, a separate perspective for observers, and with new developments, support for shared creation possibilities. The virtual materials used are mostly visual, but they are much more flexible, allowing for undo/redo operations, saving the progress of word, and painting in three dimensions. Furthermore, VR possess characteristics such as animation/changes over time, unrealistic/fantastic colors and an infinite canvas size (Hacmun et al., 2018). According to them, the potentials for VR art therapy reside in several points. The first, that of presence and immersivity, allows for the alteration of the self through sensorimotor engagement that leads to a heightened perception of artistic creation. Secondly, VR allows for the manipulation of subjective viewpoint, allowing a therapist to observe through a third person perspective or even the first person perspective of the user.

Lastly, the combination of an embodied sensory experience with unrealistic elements in a space between reality and fantasy facilitates art therapy through enhancing its efficacy (Hacmun et al., 2018).

VR has great potential in improving healthcare using immersive technology, by helping medical practice and even replacing medical procedure (Wiederhold & Riva, 2019). A virtual environment has been successfully used to alleviate pain by providing distraction during minor surgery (Mosso Vázquez et al., 2019). In another case, VR exercises for improving eye posture offered a non-invasive alternative to strabismus surgery (Li et al., 2018). VR has also been used for the assessment of paranoid ideation in social situations (Riches et al., 2018) and as cue exposure therapy to reduce food craving as a supplement to cognitive behavioral treatment for eating disorders (Ferrer-Garcia et al., 2019).

Related Works

Current State of the Field

This section presents recent developments in VR ABI motor rehabilitation. According to these developments, within ABI therapy, VR is used commonly in post-stroke and post-TBI therapy, for both motor and cognitive rehabilitation. In motor rehabilitation, VR technology is commonly used for upper limb, balance and gait rehabilitation. Furthermore, the lowered cost and accessibility of VR systems add to the potential of VR rehabilitation (Aida, Chau, & Dunn, 2018; Corbetta, Imeri, & Gatti, 2015; Pietrzak et al., 2014). The existing body of work presented below indicates that replacing traditional rehabilitation methods with VR based ones, or adding VR to traditional methods has been reported to improve the rehabilitation results in patients with ABI (Aida et al., 2018; Corbetta et al., 2015; de Rooij, van de Port, & Meijer, 2016; Laver et al., 2017; Pietrzak et al., 2014; Viñas-Diz & Sobrido-Prieto, 2016).

Even just with VR based rehabilitation, improvements in before/after comparisons have been reported (de Rooij et al., 2016; Pietrzak et al., 2014).

In a review of 11 studies on immersive virtual reality rehabilitation for patients with traumatic brain injury, Aida et al. (2018) conclude that TBI therapy was improved by the use of immersive VR. The review indicates that immersive VR within the context of TBI rehabilitation is mostly used for gait and cognitive deficits. Additionally, TBI rehabilitation has the potential of becoming more engaging because of the increased availability of immersive VR, but the currently available studies are limited, which leaves a degree of uncertainty regarding the utility of immersive VR in the field. Notably, the review exclusively selects studies that use immersive VR in their approach. According to the reviewers, many studies label any computer-generated environment as VR, and by the definition used in this paper it is understood that Aida et al. use ‘VR’ to mean ‘immersive VR’. In terms of side effects, the usage of VR was reported to be well tolerated, but it did include motion sickness, discomfort, fatigue and frustration, which draws focus on users with a precedent of motion sickness (Aida et al., 2018).

Corbetta et al. (2015) review 15 studies, with the objective of examining the effects that VR rehabilitation have on gait, mobility and balance rehabilitation for patients that have suffered a stroke, in contrast to the conventional rehabilitation methods. The studies indicated that the improvements in VR based rehabilitation are significant over traditional practices, and that adding VR rehabilitation elements to traditional rehabilitation also has a positive, albeit less significant effect. In that regard, the reviewers add that although the improvements seen on the results of rehabilitation are relatively small, so is the cost of introducing VR based elements to existing practices, even more so at larger scales for multiple patients.

de Rooij et al. (2016) compare the effect of gait and balance training in VR on stroke patients with that of traditional therapy. They conduct a review covering 21 studies, including some of the same studies as Corbetta et al. (2015) and corroborate their findings. The selected studies indicate that when compared to conventional rehabilitation methods, therapy of stroke victims had significantly improved outcomes when done using VR. The review authors recommend additional investigation and longer follow-up stages.

Viñas-Diz & Sobrido-Prieto (2016) also review 25 studies covering the use of VR for therapeutic purposes. Again, there is a slight overlap with the pool of studies covered by Corbetta et al. (2015) and de Rooij et al. (2016), but the perspective is different. Viñas-Diz & Sobrido-Prieto (2016) attempt to identify the VR systems that are most used in stroke rehabilitation, as well as pinpoint the commonly addressed motor symptoms. The reviewers conclude that gait, balance, upper limb, and lower limb activity are significantly improved by employing VR based systems. Furthermore, they indicate that stroke is the neurological condition most often treated with VR. It is noteworthy that the reviewers highlight the distinction between immersive and non-immersive VR systems, as per the definition used in this paper. Among the systems mentioned in the review are the commercially available Nintendo-Wii (non-immersive) and PlayStation EyeMotion (immersive). The reviewers recommend further research to reach more conclusive results, specifically on the long term effects of VR rehabilitation and the optimum intensity and pace of treatment. Nonetheless, the review concludes that there is clear experimental evidence supporting the positive effects of VR on upper limb motor recovery in patients that suffered a stroke.

A different perspective on the topic is brought by Laver et al. (2017), who conduct a review on 72 studies on VR based rehabilitation for stroke patients. The review is conducted from the perspective of comparing the effectiveness of VR rehabilitation and video gaming methods with that of traditional means, and with a combination of both. The review primarily targets upper limb function, but secondary conclusions are also drawn on adverse effects, gait and balance. According to the reviewers, stroke patients did not show significant improvement in upper limb function when undergoing VR based rehabilitation, compared to the traditional methods. However, the effects were significantly more positive when the two approaches to rehabilitation were combined. Additionally, gait and balance VR rehabilitation effects were not statistically different from traditional method effects, and adverse effects were reported to be sparse and mild.

Pietrzak et al. (2014) cover 18 studies in their review on various methods available for VR rehabilitation for patients with ABI. The reviewers note that VR based systems offered positive results in before/after studies, but no significant difference in when compared to conventional methods. In this case, VR systems ranged from commercially available platforms to large, custom installations. The immersion, cost, and availability of these systems varied. Regarding motor rehabilitation, the results indicated improvements in the areas of balance and upper extremity functions. Overall, the review indicates that VR is particularly well suited toward rehabilitation of upper limb mobility and cognitive function. Furthermore, the prevailing attitude of the patients towards the technology is positive, and there is potential in the lower cost and accessibility of VR systems.

Commercial VR Hardware in Rehabilitation

The use of commercial gaming systems in rehabilitation often employs the Nintendo Wii and its balance board. Some studies label this as VR in the ‘non-immersive VR’ sense of the definition, as stated above in section VR Definition. However, these studies are similar in both scope and subject to this semester project, apart from the obvious difference in implementation (immersive vs. non-immersive VR). Therefore, the following studies are examples of the feasibility of commercial gaming systems as tools to enhance motor rehabilitation practices. They all share several traits, including flexibility, accessibility, and data logging.

Anderson, Anett, and Bischof (2010) develop a system called Virtual Wiihab that uses Wii remotes (Wiimotes) and the Wii balance board (WBB) in conjunction with a Windows PC for rehabilitation. The Wii is a commercial product, and as such it has some problems within rehabilitation, including lack of customization and quantitative measurements. Virtual Wiihab records performance during use, allows for customization and provides additional external motivating elements. The system can be used at the hospital by a patient with a therapist, or at home, by a patient monitored by a therapist online. The system offers customization options that allow the therapist to alter the movement speed of objects, the placement, size and amount of goals, as well as the amount and frequency of feedback stimuli. In this way, the therapist may adjust the requirements as the patient advanced through the rehabilitation process. There are several data logging methods in Virtual Wiihab. The system records button presses, acceleration of the Wiimotes and the shifting weight on the Wii balance board, among other data. Furthermore, the time each patient spends on tasks, time between interactions and the duration of each action (e.g. button press) is logged. Lastly, the final score and number of performed actions is saved. Virtual Wiihab offers several types of feedback cues for the user: on-screen visuals, audio and haptic rumble in the Wiimotes. The therapist can specify the type, duration and intensity of these feedback cues. The system allows for patient-therapist or patient-patient interaction to complete the tasks. According to Anderson et al. (2010), this is done to improve patient motivation and conformity. The four activities that patients can complete are designed to improve trunk control, balance and lower limb stability. The activities take the form of mini-games. A snowball fight which can be player versus another player or versus the PC requires the players to throw snowballs using the Wiimote and dodge on the WBB. Another game has the user complete a navigation task using the WBB, by leaning to control a mouse in search of cheese, either by themselves or along another player. The third activity requires the player to stand still on the WBB in order to avoid attention from sharks, while using the Wiimote to throw spears at fish. Lastly, the balance board is in a game where a UFO is controlled by shifting the player's weight.

Gil-Gómez, Lloréns, Alcañiz, and Colomer (2011) also use a WBB in their system Easy Balance Virtual Rehabilitation (eBaViR), developed for balance rehabilitation for patients with ABI. eBaViR uses custom software to achieve balance rehabilitation exercises, motivate the patients, and record their evolution. The system calibrates to the centre of weight of the patient, who can play three games that mask balance exercises where the input methods are the patient's weight transferences in sitting and standing position. The system is adaptive, by adjusting the maximum range of movement to comply with the disability of the user. Furthermore, a therapist can configure the difficulty by adjusting the speed of the exercises and number of goals on screen. eBaViR records the score and time of each exercise, as well as the maximum movement of the patient. According to their evaluation, the WBB-based system indicated significant improvement in static balance of patients compared to traditional therapy. Furthermore, they report significant improvement in dynamic balance over time, but not significantly better than the traditional therapy group. The results bolster the use of such systems for virtual rehabilitation.

Cuthbert et al. (2014) study the feasibility of commercially available VR gaming products in balance rehabilitation. Again, the Nintendo Wii is labeled using the loose definition of VR. In a randomized controlled trial, the study has patients perform rehabilitation exercises for balance training using conventional methods and by playing commercially available Wii games. This is the notable aspect of the study, where no custom software or hardware is used for the rehabilitation exercises. All the games used in the VR rehabilitation group are commercially available and use the same Wii Fit balance board as the previously mentioned studies. Although the VR training group did not have significantly increased results from the traditional therapy group, both of the groups indicates improved static and dynamic balance scores. The study suggests that there is a correlation between the WBB game scores and the standardized assessments. The study supports commercially available semi-immersive VR hardware and software as having potential in the treatment of TBI victims in need of balance training.

Holmes, Charles, Morrow, McClean, and McDonough (2016) combine several commercially available devices to form a VR rehabilitation system called the Target Acquiring Exercise (TAGER). TAGER is designed to augment physiotherapy with engaging exercises tailored to the user. The system makes use of a Microsoft Kinect and a Leap Motion controller to track input from the upper body and arms, a Myo armband for data logging and an Oculus Rift DK1 HMD for viewing. The reliability and robustness of the system is investigated, as well as the acceptability of the HMD. In this initial exploratory study, Holmes et al. task healthy participants to go through a trial of pointing at virtual objects in 3D space. Several levels of the trials contain different object attributes such as size and position, as well as multimodal cues from the HMD and Myo armband. The tasks were perceived to be easier with the HMD on, and the Leap Motion controller was found enjoyable. The main result was that object acquisition was improved with visual cues. The study attempts to linearly model movement time against index of difficulty for reaching tasks in 3D. While successful for most cases, they conclude that the data variance was high and a non-linear model should be used instead to better fit all users.

Previous Work

The authors of this report have previously work in the field of VR systems for people with disabilities. They have published an article based on their 8th semester project (Diaconu et al., 2019), as well as written a second study on the topic as their project report for the 9th semester (Arnoldson, Vreme, & Sæderup, 2019). As this paper is a direct continuation of the two previous semester projects, the respective papers will be summarized in the following section.

Multisensory Virtual Environment

In Diaconu et al. (2019) the authors designed a multi-sensory virtual environment (MSVE) based on the sensing room concept. The participants were all residents of a facility for the developmentally disabled and some had physical disabilities as well. Data gathering was done in the form of a case study that focused on how the participants interacted with the MSVE and and how the therapists/pedagogs facilitated the experience. A set of preliminary guidelines for designing facilitated VR experiences aimed at people with disabilities were established. The guidelines are based on observations from several sessions with the participants and the pedagogs/therapists.

- "The facilitator should be both familiar with the individual user, and well-versed in the full extent of the possibilities the system offers. This would ensure the best mediated Experience.
- Extra attention is necessary in making the controls as simple and intuitive as possible to ensure that the controls are understandable, usable, and memorable for the user regardless of their developmental level.

- The system must be reliable and flexible in order to rapidly adapt during use to the wide range of needs created by the larger context. Disruptions should not require a session to stop or restart." (Diaconu et al., 2019, p. 11)

9th Semester

The most recent work preceding this thesis is the 9th semester project by Arnoldson et al. (2019). The project included a total of five visits to a rehabilitation center where one point of interest was to find out, to what extent a consumer available out-of-the-box VR system could be used by people with ABI. A case study design was used in order to cover all factors, with multiple data gathering methods including video recordings, observations, participant observations and general feedback from the therapists. The system was designed as a toolbox for the facilitator to use for whatever exercise might be suitable and relevant for the specific user.

The facilitator had several options to change the controls and environment so that the experience could be customized to address the current user's unique condition. For example, there was a table that could be adjusted in height, and the way that buttons on the controller worked could be changed by the facilitator. With at least one therapist as a facilitator during the sessions, the participants interacted with different kinds of virtual objects and with different types of controls. The therapists were free to come up with tasks for the users as the session went along and to customize the experience. Based on an interaction analysis of the video recordings and the rest of the data, a tentative model with three categories of requirements for the users was created (fig.1).

	Requirement categories		
User	Dexterity	Mobility	Playstyle
W	Low	High	Sandbox
Gi	High	High	Social/Guided
B	High	High	Social/Guided
Ge	High*	Low	Social/Guided
St	High	High	Goal-oriented
F	High*	High	Sandbox
K	Low	Low	Social/Guided
Si	Low	High	Sandbox
M	High	High	Goal-oriented
R	High*	Low	Goal-oriented
T	High*	High	Social/Guided

Figure 1. Three categories of requirements from (Arnoldson et al., 2019).

Dexterity refers to how well the user was able to grab and use their hand/hands. Mobility describes the users range of motion in the upper body including the head. The playstyles describe the way the user prefered to interact with the VE and the facilitator. For example, sandbox is when the user wanted to play freely with minimum interaction with the facilitator. Goal-oriented is for the users who wanted a goal to achieve in the VE and did not necessarily see the point of using the system without one. Social/guided is for the users who liked to play with the facilitator and to perform task set for them during the session.

Based on the model appropriate solutions for each dexterity, mobility and playstyle were implemented to fit the different users. As an example, users with low mobility could interact with a mini model of larger objects that were visible some distance from them. This allowed for the user to utilize their limited movement to move the small objects, that then caused relatively large movements in the bigger models. Another example was the toggle grab for users with low dexterity where they could grab objects by pressing a button on the controller once and drop the object by pressing again, instead of having to hold down the button in order for the object to stay in their hand. This was useful if the user lacked the finger strength to hold down a button for longer periods of time.

Overall the project shed some light on what can be done in terms of software to make an out-of-the-box VR system useful for people with various limitations, and how the facilitator can play a role by guiding the users in performing activities that might be useful in improving their condition.

Expanding on Previous Work

This research group's previous work, detailed above, resulted in a preliminary model for categorizing members of the target group based on their requirements (Arnoldson et al., 2019). Apart from mobility and dexterity (low or high), the model established three different types of playstyles based on a user's goal when interacting with the VR system: sandbox, social/guided, and goal-oriented. Sandbox players want to be told what to do next (either by the game or by the therapist) and wish to have as much freedom as possible; Social/guided players seek interaction with, and guidance from, the facilitator or therapist; and goal-oriented players require a set of objectives to aim for, and some form of reward when completing these goals (Arnoldson et al., 2019).

The above three playstyles can be compared to the four archetypes (Explorer, Achiever, Socializer, Killer) presented by Bartle (1996), despite the difference in both scope and genre of the respective games. Where Bartle analysed early multiplayer video games (called MUDs, multi-user dungeons), this research group's VR system offers something closer to a single-player experience with cooperative elements. The overlap between the above described playstyles and Bartle's taxonomy is as follows:

- Sandbox players correspond to explorers (as defined by Bartle, 1996): both wish to have the freedom of setting their own goals, and both garner satisfaction from uncovering new ways of interacting with the world. For this project's VR system in particular, this player type is the one most likely to experiment with the multitude of toys available - and to break them by pushing the boundary of what was intended.

- The social/guided playstyle matches Bartle's socializer type, motivated by social interaction with other players. Within the context of this project's system, socialising occurs almost exclusively with the assisting therapist leading the session. Users matching this playstyle care less about what they do, and more about doing it together with someone.
- The goal-oriented playstyle corresponds to the achievers (Bartle, 1996): They seek goals within the existing framework of the game, and consistent rewards for achieving these objectives. This can range from a scoreboard keeping track of high scores, to diegetic rewards in the form of level progression or new items inside the game. In this project's VR system, goals are dictated by the respective therapy exercise being addressed, while rewards are mainly visual in nature.
- Killers, the fourth archetype coined by Bartle, has no counterpart in this playstyle model because of its inherent nature. Killers relish in direct competition to other players, often to the extent of eliminating them (albeit temporarily) from the game - hence the name of the archetype. The cooperative nature of this project's system prohibits direct competition, as does the lack of other end users with whom to compete in the first place.

While the archetypes proposed by Bartle (1996) have stood the test of time - including a later revision in 2006 which adds a third dimension to the taxonomy - there are those who argue against the merits of such a classification. Yee (2006) conducted a survey as part of his study in which over 3000 MMO online game players were questioned. The results of this study show, amongst others, that the explorer archetype as defined by Bartle is a misclassification stemming from a lack of empiric data. Yee (2006) groups motivating factors into three categories: achievement, social, and immersion. This matches Bartle's earlier work to a certain degree, with two of the categories being the same as his archetypes, and the third (immersion) containing the elements of exploration. Of particular relevance for this research project are four of the ten motivation factors proposed by Yee (2006), namely advancement, teamwork, discovery, and escapism.

Methods

Stakeholder

Lunden

Lunden is a living and rehabilitation center located in Varde, Denmark. Their mission is to provide specialized rehabilitation for patients suffering from ABI. Intensive therapy and training, both individual cognitive and physical training, but also involvement in ordinary everyday activities, is part of everyday life for a patient at Lunden. Lunden has a staff of around 120 people; Among them are social and healthcare assistants, physiotherapists, occupational therapists (OT), nurses and support staff.

Three therapists (one physiotherapist and two occupational therapist) working mainly with rehabilitation of patients at Lunden participated in the collaboration. One of the occupational therapists has been the main contact on the external collaboration. The collaboration happened on multiple levels and consisted of several methods that will be fleshed out in this section. From sessions of gathering requirements with the therapists alone to participation in testing the system on patients with ABI.

Case Study

The method used to structure this semester project's data gathering and analysis efforts was that of an explanatory case study, as defined by Hancock and Algozzine (2006). This type of case study aims to establish a causality - to determine which factors affect a certain outcome. In the case of this semester project, the aim was to determine how the VR system affects the practice of therapists (doing ABI rehabilitation), and vice versa. While case study is a method, it is used as a framework by which a research project is structured, making use of multiple other data collection and data analysis methods along the way (Hancock & Algozzine, 2006; Yin, 2014). In this paper, they are: participant observers, questionnaires, field notes, documents/archival research, video and audio recordings; as well as interaction analysis for dealing with the video footage collected. As a final classification, this semester project fits under the umbrella of a single case with embedded units (as defined by Baxter, 2008), whereby the subunits are how each patient receives their unique version of therapy.

A case study approach was chosen in lieu of other methods due to the complex nature of the subject being researched, which is a primary argument for using this method (Baxter, 2008; Hancock & Algozzine, 2006; Yin, 2014). When the context (be it social, geographical, temporal, etc.) cannot be divorced from the phenomenon being studied, quantitative methods are ill suited due to their reliance on controlled setups and minimal variables, where a case study is not (Hancock & Algozzine, 2006; Yin, 2014). On the contrary, a case study treats all such internal and external factors as a core part of the research. For this semester project, the context of Lunden cannot be ignored when conducting the study: Both the therapists and the patients are strongly dependant on the location of, the social environment at, and their history with Lunden as an institution.

Furthermore, the way in which rehabilitation therapy sessions occur are inherently unique to Lunden (as would be the case with any other similar rehabilitation center), thus warranting the use of a case study approach.

Interaction Analysis

This semester project uses a method known as interaction analysis (IA) to break down the events captured on video during the testing sessions at Varde Lunde. This approach has been used before by members of the research group, most notably in the 9th semester (Arnoldson et al., 2019), but also in other semester projects. Jordan & Henderson (1995) define interaction analysis as a method for analysing video footage and audio recordings, originally used in the field of ethnography, but later adapted to many other disciplines due to its flexibility. The main distinction of IA when compared to other analysis methods is the focus on the social setting where interactions occur - be they between people or between a person and a media technological artefact. The driving idea behind the concept of of IA is that more information can be garnered from the way people interact with objects and with each other, in a specific context, than from what they say or think in isolation (Jordan & Henderson, 1995).

Video recordings are the primary source of data for IA due to being repeatedly reviewable to check for inconsistencies and to ensure the conclusions drawn accurately reflect events (Jordan & Henderson, 1995). When compared to on-site observations and written notes, another advantage of video footage is an objective, unbiased recollection of events which can be analysed by any number of people at a later date. Nevertheless, IA does make use of other data collection methods such as field notes, observers (passive and participant), interviews, questionnaires, and other ethnographic practices (Jordan & Henderson, 1995). These are used to supplement the primary data source with context by relaying events that occur before or after video recordings, or that take place outside the field of view of the camera(s). Additionally, other relevant aspects such as smell cannot be captured on video, so they must be recorded in another way.

Due in part to its firm origin in ethnography, IA works best when paired with participant observers (Jordan & Henderson, 1995). This type of observation complements IA well because of its inherent aim to get close to the target group in a social context and learn by participating in their regular activities. Furthermore, IA is best done by researchers who have first-hand knowledge of the social setting and the participants due to their role as participant observers in the field (Jordan & Henderson, 1995). All this makes IA the prefered choice for this semester project: the four members of the group acted as participant observers in Varde for the duration of the project, they have in-depth knowledge of the location, the social context, and are familiar with the participants (both therapists and patients).

The exact process in which IA was conducted will now be detailed. First, the video recordings were content logged by two group members who participated in the field tests at Varde Lunden. This was done to have a reference of the timeline of events, and to be able to quickly refer back to certain video sections during the later stages of analysis and discussion. Additionally, content logs helped with the language barrier (between Danish and English). The content logs can be found in the Appendix. Afterwards, at a later date, each of the four group members went through the videos individually (to avoid bias), focusing their analysis on these key aspects: Interactions of therapists with the system (positive and negative); Novel/emergent interactions between therapists and the system; and interactions between therapists and end users. Finally, the four researchers came together and discussed their individual findings, looking for patterns and resolving any points of contention. This resulted in a series of common themes, which are presented in detail in section Results.

Note for transparency: for the same reasons detailed above, this entire methodological approach (of a case study followed by interaction analysis) was used in the 9th semester as well, in a similar manner (Arnoldson et al., 2019).

Chronology

The project group went to Lunden four times throughout the semester. The first visit was on April 24th 2019, where all four project group members participated. The visit was a meeting with the rehabilitation section leader, Margrethe Madsen Als, where it was agreed upon that the focus should be on the therapists and giving them the tools for VR rehabilitation. That tied in with what the project group found on their last visit to Lunden in January 2019 as part of the 9th semester project. Margrethe presented this project at a staff meeting. Furthermore, contact was established with the main OT. E-mails were exchanged and subsequently a phone conversation took place, where the goals and timeline were finalized.

The second visit to Lunden was on May 9th 2019, where all four project members, the main OT, and a physiotherapist participated. The purpose of the meeting was to gather requirements for development of the implementation, get feedback on the first prototypes that already was implemented, and get insights into conventional approaches in ABI rehabilitation. Several traditional rehabilitation methods, exercises and tests were presented to the project group, and discussed how to transfer to VR. The project group then presented a handful of prototype interactions that were developed for the system and let the therapists experience them. The results of this exchange can be found in Results.

The third visit happened on May 15th 2019, where three group members were present, together with two OT’s. This time, six patients with ABI tried out the VR system. The implementation covered two interactions, the wall and flex exercises (see Wall exercise system). Data gathering methods used included: Video recordings, participant observations and field notes. The longest test session was 16 minutes and the shortest was 5 minutes.

Fourth time, was on May 22nd 2019. This time five participants with ABI, where two of them were new participants, tested the current implementation. The same two therapists were facilitating the experience as last time. The implementation was an enhanced version of the wall exercise, that was more adjustable for the therapist (see Neglect Exercise). The test session length ranged from 13 minutes to half an hour. Data gathering methods again included: Video recordings, participant observations and field notes.

Design & Implementation

Introduction

This section presents the implementation of the VR tools and environments developed for this semester project. The hardware supporting the implementation is as follows: the HTC Vive virtual reality headset, Lighthouse house tracking system, Vive Wand controllers and two Vive trackers (“VIVE Virtual Reality System,” n.d.); a high-end desktop computer running an Intel Core i7-6700K processor running at 4 GHz, 32GB of RAM, Nvidia GeForce RTX 2080 graphics card, high speed solid state drive; two desktop monitors running at 1920x1080 pixels resolution. The VR capability of the software is ensured by SteamvR, the virtual reality platform developed by Valve Software (“SteamVR,” n.d.). The software development was done using the Unity3D game engine (“Unity,” n.d.) and the SteamVR plugin from the Unity Asset Store (“SteamVR Plugin - Asset Store,” n.d.). The section is separated into three parts based on which party was most served by the work: the HMD user (meaning the patient - Features Available to HMD User), the stakeholder (meaning the therapist, also referred to as the tablet user - Tools Available to Stakeholders), or the authors (Features of Development Process).

Features Available to HMD User

This section describes the full collection of features that the system can offer a user wearing the HMD. At the time of writing, these features are not collected into a single executable build that contains all of them at once, nor is this necessarily desirable. Typically, custom selections of these features were created for specific sessions with the users and stakeholders at Varde Lunden.This has an additional benefit because VR system performance is heavily impacted by the number of interactable objects and effects present in a scene; Thus, having only the relevant elements present reduces computational stress and ensures a smooth experience for the HMD user. However, all features are designed and implemented to function simultaneously, so in theory such an unified executable could be created quickly and easily.

Interactables

The term ‘interactable’ (used as a noun) can be considered a synonym of ‘toy’ or ‘tool’ in this context, and generally means an artefact in the VR scene that supports one main interaction. When these interactables are pre-arranged in the play area, they may form a system resembling a sandbox, or even a game with goals, depending on the arrangement. This section will refer to the standalone features that each interactable has, and present possible uses in conjunction with other parts of the system. These possible uses are merely examples of intended combinations; specific exercises or games are described separately, and behaviours that emerged from the play sessions with the stakeholders are not covered by this section.

Throwable cubes

One of the simplest interactables available in the system is the ‘throwable cube’. This type of cube has been present throughout the work done by this group in the 8th and 9th semesters. The standard variant can be picked up, held, thrown and stacked. Once the user approaches a cube with the Vive Wand, the cube highlights, indicating that it is interactable. All interactions are accomplished with the Vive controller, most often with the trigger button. Such cubes are literal building blocks, but also figurative building blocks in some of the other, more complex interactables present in the system. One variant of the cube is springy, bouncing much more when it collides with another surface, such as when it is dropped. These ‘bouncy cubes’ offer a more visually engaging feedback than their standard counterparts, as they ricochet around the scene once thrown at a target. A third variant of the cube ignores the simulated laws of gravity within the scene, thus floating away after being thrown or receiving an impulse, unaffected by air friction or gravitational forces. This ‘floaty’ cube encourages emergent gameplay behaviours because it requires a different aiming/throwing strategy when flung at a target, as it lack a trajectory arc. Furthermore, these cubes are much easier to lose, as they can easily float out of reach if left unattended. Each of the three variants of the cube is color coded: the standard cubes are white, the bouncy ones are red, and the floating ones are blue (Fig. 2).

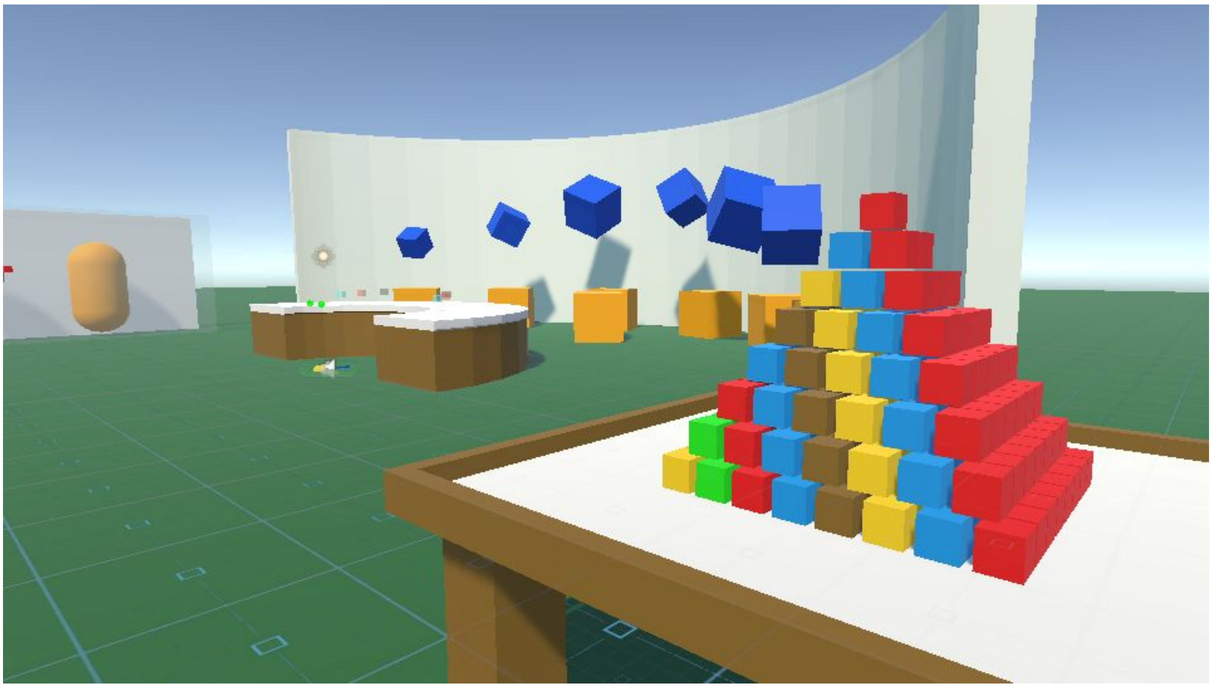

Figure 2. Throwable cubes.

Cube dispensers

This interactable was rebuilt in a very similar fashion to the existing one in previous work (Arnoldson et al., 2019). The cube dispenser is a semi-transparent cube that is fixed into space and cannot be picked up, pushed or otherwise moved. The dispenser only supports one use: once interacted with by moving the Vive Wand into its volume, the dispenser highlights. If the trigger on the Vive Wand is pressed, a throwable cube is spawned into the attachment point of the Vive Wand. As such, dispensers work as an infinite source of throwable cubes. Instead of using pre-arranged cubes in the world, the user can use this interactable to create new ones. The dispenser also comes in three color coded variants, appropriate for the three types of throwable cubes. Users can dispense standard, bouncy and floaty cubes. The use of dispensers is similar to that from the 9th semester; typically, dispensers are placed next to or above a surfaces where cubes can be stacked, or ahead of an area containing targets for the cubes to be thrown at (Fig. 3).

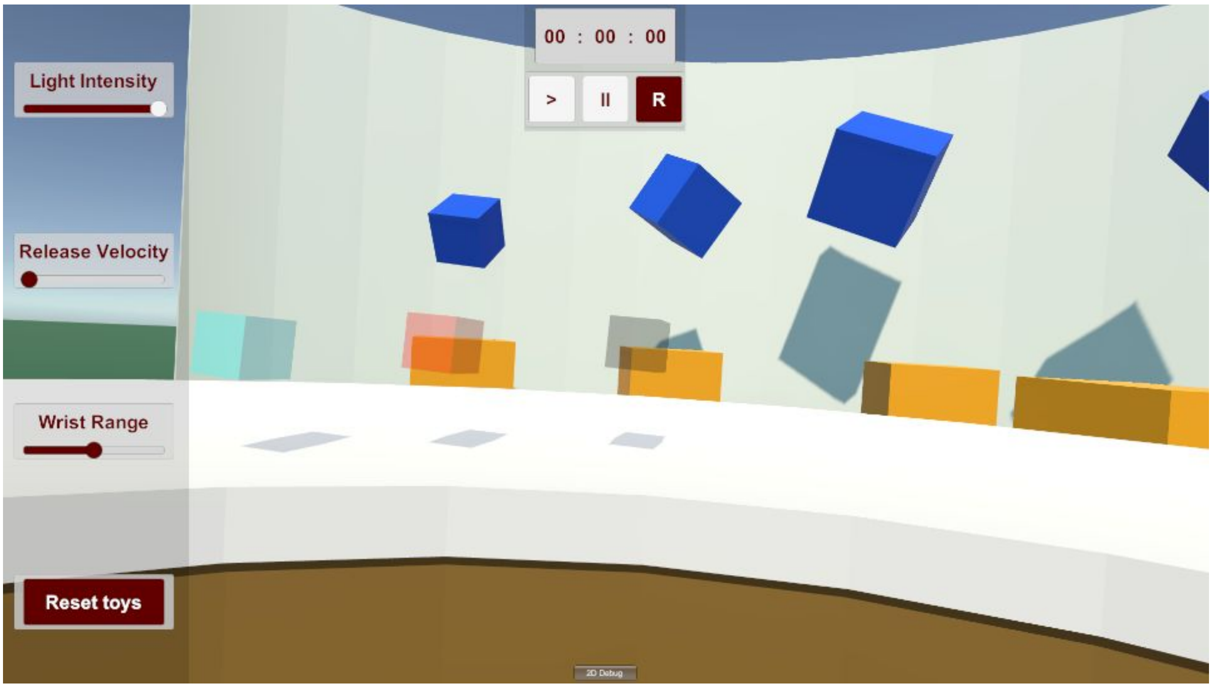

Figure 3. Cube dispensers (center left). Breakable cubes (center background).

Breakable cubes

The idea with these cubes is to keep the simple and familiar interactable object that was present in the previous work (Arnoldson et al., 2019), but with an extra “hidden” feature. The user is presented with one or more large cubes that can be cut or smashed into smaller cubes. The cubes can be set to break at a certain collision force that will split it into four smaller cubes. The smaller cubes can all be broken into four more cubes and so on, until the cubes break into a predetermined minimum size, wherafter they will disappear. A so called “apart force” can be set to make the four smaller cubes fly apart with some or no velocity. This invites the user to find different ways of using the cubes, such as breaking them carefully to get more cubes for stacking, or to throw into other cubes, causing a chain reaction. The cube works in a recursive way where each break will destroy the bigger cube and instantiate four of the same cube prefab, matching the destroyed cube’s position and velocity. Because of this there is a limit to how small the minimum size can be, as a chain reaction instantiating too many cubes can quickly become so computationally heavy, that the frame rate will drop significantly or cause the computer to crash. For this reason, the parameters of the cubes (such as minimum size and apart force) are reserved for the developers to adjust, as someone unfamiliar with the limits of Unity and the computer could cause unwanted scenarios for the user.

One variant of the breakable cube is the zero gravity variant. This version of the cube is blue, and does not respect the laws of gravity. Similarly to the floating throwable cube, this cube continues its movement along its trajectory indefinitely, unless stopped by another body. In the case of the breakable cube, the lack of gravity combines with the recursive breaking algorithm to create a chain reaction effect that litters the surrounding space with floating cubes of different sizes once the main cube has been broken. The breakable cubes are typically placed as targets for throwable cubes, either on the ground or floating in mid-air. The smaller pieces that arise can themselves be used either as new targets or throwable projectiles (Fig. 3).

Orbiter

The orbiter is another interactable present since the 8th semester project, and has not changed noticeably since. It still consists of a set of small, luminescent spheres, combine with a set of larger, colored spheres. All these spheres are invisibly tied with springs to a point in space that acts as a pseudo-center of gravity. In consequences, once disturbed from their still position, these spheres start orbiting around that point, seeking to return to their resting position, hence the naming of ‘orbiter’. A typical interaction with the orbiter consists of picking up the spheres and disturbing their patterns. Another interaction can achieve the same result, but with using another tool, such as a stick or a sword, to hit the spheres (Fig. 4).

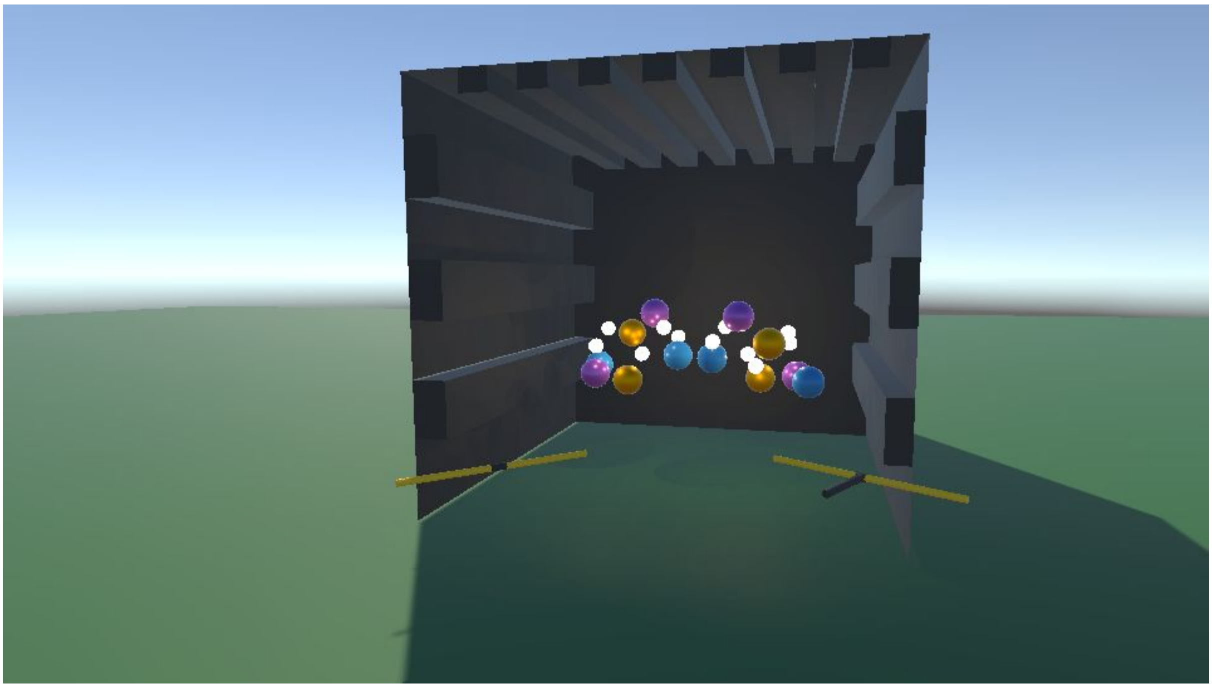

Figure 4. Orbiters (background). Wrist rotation tools (foreground)..

Sword

The sword is a tool inspired from the stick present in the 9th semester interaction environment. The sword is using a free model from the Unity Asset store, under the form of a stylized katana. The sword can be used to topple stacked cubes, poke at orbiter spheres and smash breakable cubes. In fact, the conception of the sword is tied to the conception of the breakable cubes; the sword was initially a tool designed to break the cubes. After the breakable cubes evolved into a later iteration, where any force can break them, the sword took up its own role as a general tool for poking and prodding.

Adjustable tables

Inspired from the similar item from the 9th semester, the adjustable table provides a raised surface area for playing or placing interactables. The first variant is a small table, suitable for several throwable cubes or a single tool. A larger variant exists, that has a larger surface area. This table is suitable for holding the cube pyramid, multiple tools, or larger interactables such as the breakable cube. The last variant of the table offers ample surface area, as well as having a unique shape: that of an arc. In this way, the surface area can best be used from a single point in the center of the table. This table can hold multiple interactables and tools, but it can be used as a divider between a pickup point and targets placed behind it. The example usage of this table has cube dispensers on both sides, and breakable cube targets placed behind.

All the tables are height adjustable via controls on one of the desktop screens, which is also mirrored on the tabled. The height adjustments are necessary to accommodate various sitting and standing positions (due to frequent cases of HMD users being restricted to wheelchairs), as well as different degrees of mobility.

Wrist rotation tools

The wrist rotation tools are interactables that are built in a fashion that encourages wrist rotation to use them. Their conception stems from the stakeholder’s description of wrist pronation and supination exercises that some patients perform. The first variant is a simple stick, with the pickup point being in the middle. Whilst holding this stick from the middle, rotating the wrist rotates the stick. As simple as it may sound, by doing so this interactable discourages poking and encourages spinning instead. The second variant has a small handle in the middle, distancing the pickup point from the player, allowing for the same interaction but with more reach radius. These wrist rotation tools emanate a colorful particle trail through the air when moved, encourading spinning them. These tools are intended to interact with other interactables, such as orbiter spheres, throwable cubes and breakable cubes. In one example scenario, two sets of orbiter spheres are placed in a confined area, and the two version of the wrist rotation tools are placed at the entrance. These tools float in midair at a comfortable height, locked in their place. Once picked up, they will return to that place. As such, the tools can not be lost. Particle effects are added on impact with the orbiter spheres, which along with the particle trails on the rotation tools offer a pleasant cue for interaction (Fig. 4).

Wrist rotation system

The wrist rotation system is a more complex implementation than that of the wrist rotation tools, but it is designed to accomplish the same goal: that of masking wrist pronation and supination exercises. The wrist rotation system consists of a remote control, a sliding sphere and two elastic targets. The remote control is a small red cube that floats in space and will return to the same spot if dropped. While the remote is picked up, it translates the local rotation of the Vive Wand on the axis relevant to wrist pronation and supination into linear movement of the sliding sphere. The sliding sphere is constrained on a single horizontal axis, and can be moved to the left or right by rotating the wrist appropriately while holding the remote. The two targets on the sides, represented by large capsules, are anchored to the ground with an invisible spring, allowing them to sway back and forth as they are being hit by the sliding sphere. This, along with impact particle effects, offer visual feedback to encourage rotating the remote, and thus the wrist. A notable aspect of the exercise is that the range of wrist rotation necessary to reach the goals with the sphere is adjustable with a UI slider on the secondary screen and tablet. This allows for wrists with various levels of limited mobility to reach the goal, as well as offering the possibility to increase the difficulty of the task.

Cannon aiming

This interactable uses a stylized cannon asset from the Unity Asset store. This cannon can be aimed on the up-down and left-right axes by twisting two knob-like controls on its base. These controls can turn clockwise and anti clockwise, and are also meant to mask wrist rotation exercises. The vertical adjustment knob has a turning limit, as the cannon itself has upper and lower limits for aiming. The horizontal adjustment knob can turn freely forever, since the cannon can rotate freely. This interactable would eventually be able to fire a projectile at a target, but at the moment of writing this functionality was not implemented.

Exercises as requested by stakeholders

There were two exercises requested by the stakeholders, and their design was informed from all forms of data gathering used in the meetings: an exercise dedicated to patients with neglect (wall exercise) and an exercise dedicate to upper arm rehabilitation (flex exercise).

Wall exercise system

As part of a stakeholder meeting, the therapists described a type of exercise they would envision being adapted to VR. This exercise is aimed at patients with neglect, hemianopsia or similar conditions, and consists of a wall with paper squares placed on it at regular intervals (both vertically and horizontally). The object of the exercise is for patients to reach out with their hands and touch specific squares indicated by the therapist. The targets are selected in such a way as to force the patient to look towards their weak side (the side with neglect, for example), thus training both their perception and their motor skills. However, the exercise in its analog form requires the therapist to constantly select and describe a new target for the patient, and offers no visual feedback upon successful completion. This is why a VR alternative was thought to be a good choice.

The exercise was implemented in the VR system as a semi-cylindrical wall covered in square buttons, one of which would light up (a different color than the rest) and require the HMD user to physically reach with controller in hand and press it. The target button would be randomly selected by the system, based on a set of parameters adjusted by the therapist using the tablet interface. This facilitates the use for patients with neglect and similar conditions, by allowing the therapist to choose which side, and how far to the left or right target buttons appear. Once a button is successfully pressed and released by the patient, visual and audio feedback is provided (the button changes colour to green, a sound effect is played, a flower grows at the patient’s feet). Immediately after, a new target button is randomly selected allowing the process to continue seamlessly, for as long as needed. The settings can be modified by the therapist at any time without pausing the exercise and without alerting the patient in any way.

The technical implementation consists of 45 identical button prefabs distributed evenly on the semi-cylindrical wall, in 9 columns and 5 rows. Each button prefab is fully independent, handles its own functionality (being pressed, changing color, creating sound effects) and does not communicate with other buttons at all. Instead, a manager script it present on an empty game object, to which all buttons are parented. The manager script handles the randomized selection of target buttons, keeps track of the current target, and allows settings to be adjusted via the interface on the tablet. The selection can be done by choosing which of 5 groups of buttons can be potential targets: from left to right columns 1&2, 3&4, 5 (the middle one), 6&7, or 8&9. The selection is not mutually exclusive, with any number of groups being selectable at once (including all 5). This modular constructions allows for quick changes (in mere hours) to the number of buttons, their placement on the wall, their spacing, or their grouping (Fig. 5).

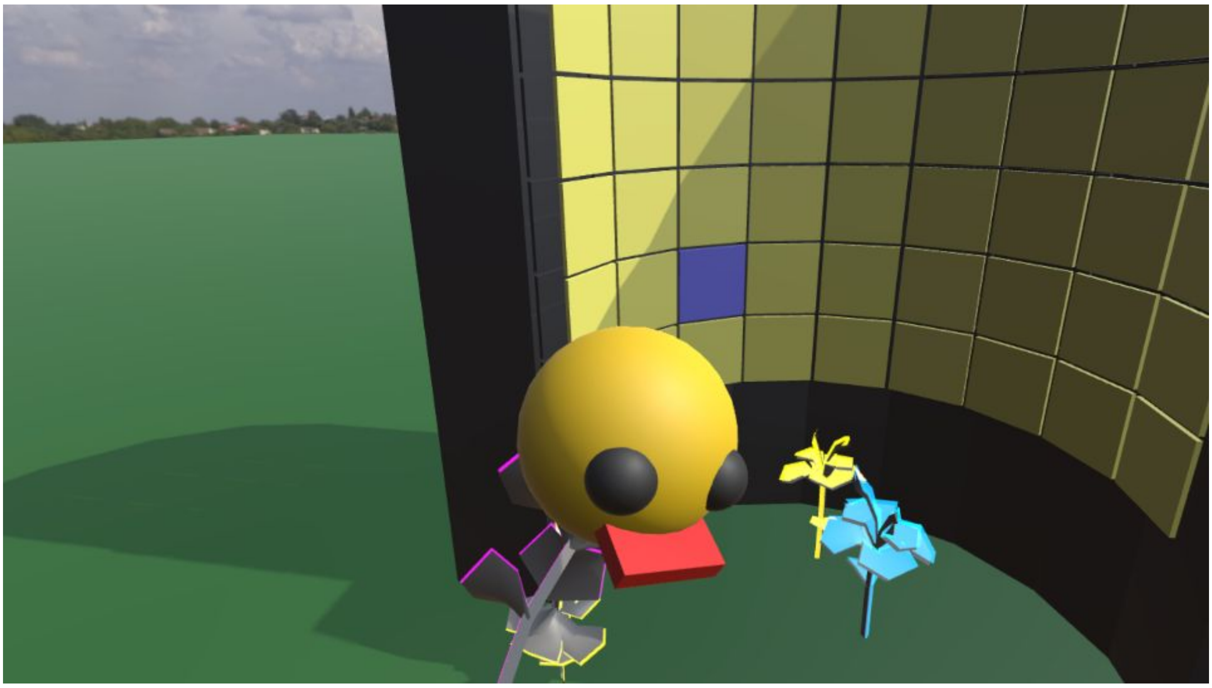

Figure 5. Wall exercise (background). Avatar duck (foreground).

Neglect exercise (wall v2)

After the first play session using the wall exercise described immediately above, feedback and observations led to a set of changes which eventually spawned an entirely new version of the exercise. This second version is also aimed at patients with neglect and similar conditions. However, instead of being a direct adaptation of an analog exercise performed by therapists in Lunden, it is instead an abstraction making better use of the potential of this VR system. The overall goal is the same: create a series of targets which HMD users must reach for and touch (using the Vive controller), focusing their appearance on the side the patient's weak side to encourage them to look and move towards that side. Instead of being a wall filled with buttons, this second version of the exercise is instead a single target at a time, spawning in a circular pattern around the user. The targets are coloured spheres which explode with particle effects when touched (i.e. they pop like balloons). A new target then spawns.

The targets only spawn with horizontal variation on a single line, which can be moved up-down using the tablet interface. This is in contrast to the previous version where there are buttons on the wall at various heights. The change was made based on direct feedback and suggestions from the stakeholders. Other adjustable parameters are the start and end point of the area in which targets may spawn: essentially an arc on the circle. This is done by moving two arrows using the tablet interface. Finally, the visual feedback for when targets are reached can be toggled between low and high. To better facilitate this setup process, the tablet UI has a new component for this exercise: a static top-down view (coined as a minimap) placed above the exercise. This third camera shows the entire area (including targets, controllers, HMD, duck, and static surroundings). The aforementioned arrows are clearly visible on this minimap, making it much easier for the therapist to adjust the target area. The minimap is in a corner of the tablet interface, in addition to the existing camera view guided by the Vive tracker (Fig. 6).

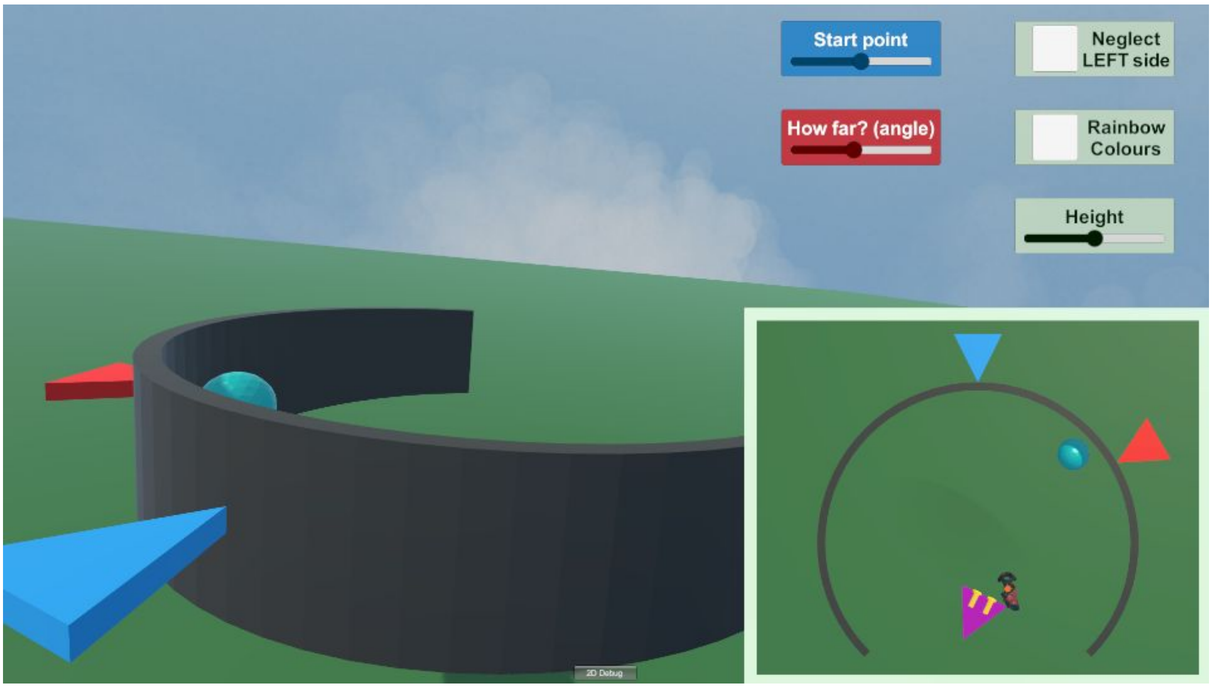

Figure 6. Wall exercise version 2 as seen from behind (center and left). Minimap (bottom right).

Flex exercise system

As part of a stakeholder meeting, a rehabilitation exercise consisting of placing the patient’s arm on a table and asking them to slide it forward within marked straight lines to reach a goal was described.The therapists are still responsible for ensuring the proper posture of the patient and correct execution of the exercise. The flex system consists of a hardware part in addition to the custom interactable in the VR environment. The hardware part is a wrist strap with a Vive Tracker mounted on it, intended to be worn by the user performing the exercise. The interactable is comprised of a virtual table, the wrist tracker representation, a sliding cylinder, and two guidelines. The virtual table resembles the kind of table the exercise takes place on traditionally, which is still meant to be present. The cylinder is a representation of a target prop that a patient might have traditionally. The difference from a regular prop lies in that the cylinder is locked to the axis between the guidelines, representing the ideal movement trajectory. The wrist tracker representation is a diegetic 3D model of the tracker that the patient is wearing, and its position follows that of the worn tracker. The guidelines are similar to the guidelines on the real world table. While the real guidelines can only indicate what the correct movement trajectory is, not respecting the virtual guidelines can stop the cylinder from being moved, thus requiring readjustment to the correct trajectory keep interacting with it. This entire setup results in the user being able to see the misalignment between the worn tracker and the target cylinder; the visible effect of the flex system is that when this misalignment is too large, progress cannot happen anymore, as it is considered to be incorrect. In the VR scene, the wrist tracker is the reference point of the interaction. Specifically, with the press of a button on the keyboard, the entire setup of the exercise can align with the user, once their starting position has been determined by the therapist. This is done to facilitate the required setup, as the table in the virtual scene may not coincide in placing, height and rotation with the real table in the play area. Instead of moving the patient and the table around, everything readjusts in VR.

Tools Available to Stakeholders

The stakeholder refers to a user that interacts with the system, but not from the HMD. Typically, this will be a therapist or facilitator. These are the parts of the system that benefit the facilitator of the session the most.

Portal

The portal is akin to a mobile “window” that the observer can use to look into the VR scene from any angle, allowing them to operate more easily within the scene, and even interact with the user wearing the HMD. Work has been done on several versions of this, at different levels of complexity. The last iteration, which is the one being used, is also one of the simpler ones. Nonetheless, this section presents the full progress on the possible features of the portal.

Wired version

The early version of the portal consists of a 19 inch desktop monitor mounted on a wheeled office chair. The monitor contains a mount which holds a Vive tracker, placed at the top. This tracker records the position of the monitor relative to the HMD and the play area. As such, the observer can have a real perspective into the VR scene, and with proper setup, the HMD user can diegetically see the position of the real monitor from within VR. The office chair allows the monitor to be horizontally moved and rotated freely within the play area, and the tilt functionality of the monitor itself allows for some vertical angle adjustment of the view.

The monitor is wired via HDMI cable to the computer, and is also powered by an extension cord. As such, there are two cables trailing behind it, limiting the full mobility of the monitor.

Motion parallax

This is one version of the implementation of the virtual camera as displayed on the mobile monitor described above. In this version, the system simulates the effect of motion parallax in order to induce depth perception cues to the viewer (Gibson, Gibson, Smith, & Flock, 1959; Rogers & Graham, 1979), with the intent of emulating the behavior of a physical window into another world. This version uses one Vive tracker on the real monitor (M) and one Vive tracker on the human viewer (V). The V tracker is required to correctly calculate the projection matrix that the virtual camera employs to display its output on the monitor, as part of the rendering process of the application. This is necessary because the parallax effect is viewpoint dependent (Gibson et al., 1959; Rogers & Graham, 1979). As a consequence, the effect only works correctly for a single viewer at a time. The V tracker was planned to be worn easily with a customized cap or headband, however the implementation of this idea did not go past the working prototype stage.

The first variant of this version uses a custom projection matrix and a static virtual screen. The position of the virtual screen coincides with the position M of the monitor. The camera form v is projected through the virtual screen. As expected, changing the position between V and M affects the image displayed on the monitor, skewing it to emulate motion parallax as viewed from the perspective of V. All other perspectives appear as skewed images. The results of this variant were unsatisfactory however, because the it lead to occasional moments of confusion where the perspective looked uncanny. Particularly, the perspective of the view on the monitor becomes very skewed when V is very close of very far from M. This feels wrong to the eye probably because the monitor is too small, thus taking up only a minor segment of the observer’s field of view. As such, it behaves more like looking through a pinhole rather than a window. A much larger screen would be required to further test this aspect. The authors speculate that the simulated motion parallax effect would be much more acceptable if the monitor occupies the majority of the field of view of the viewer. However, at this point, the mobility aspect of the screen is hindered due to the size. In the end, this idea was suspended.

The second variant of this version also uses the same custom projection matrix and virtual screen as the one above. The virtual camera from V is still projected through the virtual screen at position M. However, the difference lies in the fact that the virtual screen can now dynamically change in size. Using the same pinhole vs. window metaphor as before, in this case the behaviour simulates a pinhole that can dynamically change its size based on the distance from the viewer. This is designed to counteract the skewed perspectives in the extremities of the viewing range encountered before. While this still allows for some motion parallax, particularly on vertical and horizontal translation, in heavily diminishes the depth cues that come with the phenomenon, to the point which its utility becomes questionable. While the use can still peek “behind” the borders of the monitor, the effect becomes redundant given the mobility of the monitor.

A final variant consists of the same hardware setup, but without the custom projection matrix and screen. Instead, on the software side, the camera from V always points at the position of M. In the real world, the viewer wearing tracker V sees on monitor M the image from the virtual camera at position V that points at position M. The resulting effect is very similar to the one obtain in the previous variant (variant 2), but with a much simpler implementation. As such, this variant possesses the same limitations.

Overall, the motion parallax effect, while interesting and having the potential to better engage the facilitator with the content of the VR world, is deemed too complicated given the little benefits in brings. Most notably, the high mobility of the monitor, which is further increased in the following section, offers the necessary flexibility instead.

Wireless version

The later version of the portal consists of a 10.5 inch iPad Pro tablet with a Vive tracker mounted on it (M). In this version, the video feed was mirrored from a computer monitor to the tablet via game streaming software at a resolution of 1920x1080 pixels. The main limitation of this solution is the lack of direct touch input. Specifically, the touchscreen of the tablet acts instead as a touchpad. In this role, the tablet surface is used to move around a screen pointer relatively, instead of acting on the screen at the absolute position of the finger. This inconvenience, although minor, is a limitation of the software solution used for streaming the video feed from the desktop to the tablet. The chosen solution was an open source game streaming software, Moonlight Game Streaming (“Moonlight Game Streaming: Play Your PC Games Remotely,” n.d.). This solution, despite limited input capability (i.e. restricted touch input), is desirable because it supports low latency, high quality streaming, by employing newer standards of video compression compatible with the fast hardware of the newer generations of mobile devices (i.e. the HEVC/H.265 video codec). The streaming takes places across a wireless network supported by a conventional 5GHz WiFi router. A better network setup might alleviate the performance issues, thus opening the possibility for other, less optimized streaming software that supports better touchscreen input. However, within the resources available at the time, this was the desired solution, allowing the authors to focus on the development of other parts of the system.

In this implementation, the tablet is hand-held and the viewer can move it anywhere and point it in any desired direction. There have been several short internal trials with motion parallax and an improvised head-mounted secondary tracker. However, these features were not used because the high degree of mobility of a hand-held device was deemed to be sufficient on its own. Ultimately, the simple implementation prevailed.

In order for the HMD user to see where the tablet is in the play area, a small avatar under the form a a symbolic 3D model of a duck is present on the tablet tracker game object. This helper avatar has multiple roles. Firstly, the HMD user is unaware of the area outside VR and may accidentally bump into the tablet or the tablet user during play sessions. Since the helper avatar is an accurate representation of the position of the tracker in VR, the HMD user can be aware of where it is placed. Secondly, the duck can be (and has been) used to guide the attention of the HMD user towards a specific location or object in the virtual world: By moving the tablet around, the therapist can quite literally point towards an area of interest using the duck. This ended up being used by therapists at Varde Lunden for example when guiding patients with neglect, helping them to look towards their weaker side.

User interface tools

Besides acting as a portal into the VR scene, the handheld tabled that the facilitator has contains several user interface elements that offer additional control over the VR scene. Several versions of this user interface have been implemented, and each is meant to serve a particular build of the system (as it was previously established, custom builds are used depending on the use case).

The first version of the user interface is a general version. This version contains a slider for adjusting the light level of the scene, in case the HMD user may find it too bright or too dark. In addition, the slider can be used to enhance the visual impact that the luminescent orbiter spheres have by lowering the rest of the ambient lighting. Another slider controls the height level of the adjustable tables in the scene. A third slider is used to control the range of wrist rotation required in the wrist rotation system. Another slider contains a release velocity multiplier parameter. This parameter artificially increases the release velocity of a thrown object, and is meant to assist users that cannot throw hard enough. A reset button is also present, which rearranges the interactables in their original state and position in the case of a pre-made scene. This allows for restarting the experience without breaking the immersion of the user. This functionality requires for the scene to be authored in the appropriate way so as to allow for a stable reset behavior. A toggle button for grabbing type is also present. This is intended to determine whether the trigger on the Vive Want needs to held or pressed once in order to pickup and hold an interactable. However, at the moment of writing, this functionality was not complete. At the top of the screen, there is also a timer, with a start/pause/stop functionality. This eases the stakeholder's role if required, by replacing any external timing devices.

A more specific variant of the UI exists for the custom build containing the wall exercise. This variant contains the required buttons that allow the therapist to adjust the parameters of the exercise by setting preset target areas (in the case of the first iteration), or specific target angles (in the second iteration).

Features of development process

Initial development

Development resumed from the the previous semester's work, and firstly consisted of updating the development tools to the most recent stable versions. Unity Engine 2018.3 ("Unity," n.d.) and SteamVR version 1.4 ("SteamVR," n.d.) are the fundamental pieces of software required for implementation. The SteamVR plugin ("SteamVR Plugin - Asset Store," n.d.), version 2.2.0, from the Unity Asset store is used as the basis for many core functions of the system, including interactions and tracking.

In previous semesters, a third party plugin was used in addition to this, namely VRTK ("VRTK - Virtual Reality Toolkit," n.d.; "VRTK Virtual Reality Toolkit - Asset Store," n.d.). Many of the additional functions of VRTK were eventually not used. Furthermore, VRTK brings its own class structure and toolkit documentation on top of SteamVR Plugin. As such, for this semester project VRTK was omitted, and development was based solely on the SteamVR Plugin. However, this was not free of difficulties. While the SteamVR plugin comes with an inbuilt interaction system, intended to facilitate the job of developers and to provide examples of use, the latest version of the plugin introduces considerable changes in how the interaction system works (*SteamVR Unity Plugin*, 2017/2019). With the latest software came incomplete documentation, which brought challenges to the implementation. For example, a much desired feature of grab mode toggling (pressing the Vive Wand trigger once instead of holding it to grab objects) was suspended.

For a period of three weeks during the development process, a wireless adapter module for the HTC Vive ("Wireless VR - TPCast," n.d.) was used with the intention to eliminate some mobility limitations arising from the wires trailing behind he HMD. The power cable is replaced by a battery mounted on the waist. The video signal cable is replaced by a transmitter tethered to the computer, a small receiver mounted on the HMD and powered by the same battery on the waist, and a 5GHz wireless router that enables the communication between the components. This solution is more desirable than having trailing cables between the user and a computer. However, in this group's experience, the additional complexity introduced by the intermediary components of the wireless adapter system decreased the reliability of the connection. Specifically, the wireless signal would often be masked by interference with people and objects in the area. In a real use case scenario, the system's play area would be populated with at least another person performing therapy who acts around the HMD user, which is an increased risk factor for signal masking. Furthermore, the added benefits of not being tethered by a wire are mitigated by the fact that in most use cases, the interaction happens from a sitting position. As such, the setup was reverted to the original, wired approach.

Vive Trackers

The portal for the therapist was present early on in the conception of the semester project. For this reason, an additional hardware component was required to facilitate the implementation and interaction of such a feature: the Vive Tracker (“VIVE Tracker,” n.d.). Vive trackers are motion tracking accessories which can attach to regular objects and allow them to make use of the HTC Vive’s Lighthouse tracking system (Brown & Holly, 2017). This piece of hardware accelerated the implementation of the otherwise complex task of bringing a real object into VR interactively. Hardware aspect aside, the tracker required software integration with the project’s applications. SteamVR plugin contains a class responsible for tracker management, although this was not very obvious from the start, given the limited documentation at the time. This caused a few delays in development.

Within the SteamVR Plugin, the hardware components of the HTC Vive system have a device index. When adding additional trackers to the system, the order in which they are indexed differs depending on the collection of devices connected at the time (i.e Vive Wands and other trackers). As such, it is difficult to identify which device index is a tracker after the system is relocated and reinitialized, or if devices are unpaired are re-paired. Fortunately, all the components of the HTC Vive ecosystem (HMD, Wand controllers, base stations and trackers) have hardware IDs. Hardware IDs are unique identifiers for each component, and the key concept is that they do not change over time. A custom script was implemented to identify these hardware IDs, which were then used to correctly assign given roles to the tracker. The most important role was the secondary camera (for the facilitator). In consequence, instead of relying on trial and error after every system re-initialization and rebuilding the project into an executable application every time, tracker-specific behavior can be pre-programmed using the hardware ID. At this stage of the process, a basic VR environment consisting of a floor, teleportation mechanics and trackers was ready to be populated with interactables and novel systems.

Prefab Workflow

In organizing its assets, Unity can use the concept of prefabs. Prefabs allow the content creator to do the time consuming work of making and configuring a particular game object only once (i.e. an interactable), and the save that work as a reusable asset (Unity Technologies, n.d.). The power of prefabs comes in the fact that changing the original prefab changes all the other instances (inheritance), and that they can be spawned from code (instantiation) (Unity Technologies, n.d.). With the use of inheritance, the content creators can make substantial changes to prefabs even after they have been used in the scene, and everything will be properly updated (Unity Technologies, n.d.). Furthermore, instantiation allows behaviours like the cube dispenser, the breakable cube and the reset function to exist. That is because all of these components make use of spawning (instantiating) prefabs as part of their core behaviour.

Unity version 2018.3 supports nested prefabs. This feature allows for prefabs to have other prefabs as part of them. With that comes the option to have prefab variants, which are prefabs that share the same asset parent, but have different configurations (Unity Technologies, n.d.). These behaviours allow the content creators to iteratively increase the complexity of interactables by building up behaviors step by step, while keeping all the intermediary prefabs to be used interchangeably. For example, when working with Vive trackers for this project, a basic prefab containing an empty gameobject (can not be seen in the scene) and hardware ID was made as a reusable asset. Prefabs that build upon this include variants with a camera, a 3D model and combinations of both. The most complex tracker prefab is the duck, which contains the SteamVR Plugin tracker management script, the custom hardware ID script, a game view camera and the symbolic 3D model of a duck.

Reset Function

A scene can be pre-configured during authoring to use a manager class to keep track of specified objects/interactables (their position, rotation, scale, source prefab). A custom class coded for this project, the manager communicates with the UI, and can receive the command to reset the scene from the appropriate UI button. During a scene reset, the manager class destroys all the interactables it kept track of, and instantiates the respective prefabs at the positions, rotations and scales it remembered. The visible effect of this is that the scene is ‘tidied up’: broken cubes are repaired, tossed interactables are back in their original place and the orbiter is set back into balance.

In addition the throwable and breakable cube interactables contain a custom class allowing them to self-destruct if they have fallen through the floor, or have risen 100 meters above ground (applicable to zero gravity elements). This is a measure taken to prevent clogging up the memory of the computer with unnecessary items that can no longer be interacted with due to being out of reach.

Display setup

This project’s latest configuration of the VR setup also contains two desktop monitors. The application is built to run on two screens, one mirrors the view in the HMD, while the other displays the view from the tracker camera. As such, any external observers can view the interaction from the perspective of the HMD user and from the perspective of the tablet user.

Alternatively, the tablet user can leave the tablet in a fixed place, thus pointing the camera in a desired direction, and watch the interaction from that angle on the desktop monitor. From the software side, this is the extent of the display behaviour, as the remote tablet aspect is handled by the third party streaming software, as described in section Portal.

Besides the game view camera feeding into the HMD, the scenes in the project contain an additional camera (within a prefab made with the workflow described in section Prefab workflow) which follows the position of the Vive tracker mounted on the tablet in the play area.

Results

Visits to Lunden

The visits to Lunden (described in Chronology) resulted in plenty of observations under the form of notes, as well as many informal conversations between the authors and the therapists. All of these observational notes can be found in original format in the Appendix.

Conversations

Throughout the meetings, data was gathered from conversations as well. During the meeting with the section leader, the leader explained a wrist repetition exercise, which became the basis for some new features presented in the following visit alongside previous work. There were also a focus on the VR environment not becoming a replica of of real life, and still exploring playful elements in the virtual environment. The differences from the previous collaboration with the same leader were discussed, establishing focus on the therapist for this project. The leader presented the idea at a staff meeting the next day, which eventually led to the interest of the therapists that took part in the sessions.

During the play sessions, several points were made from the conversation with the therapists. Firstly, more granular control over the targets of the wall reach exercise was desired, as in its state at the time, the targets could appear in too few position. In the case of patients with neglect, the difference between a point in the neglected zone and a point in the non-neglected zone was much smaller than the size of the target. This resulted in the minimum adjustable step of the exercise not being fine enough to accommodate the patients beyond a general left-right level. There were discussions on implementing features to guide the attention of the user from the healthy side to the side with neglect, such as lines, frames, arrows or moving objects. In addition, a desire to isolate a horizontal area crossing the two zones of the patient's perception was expressed. These features would have to be adjustable by the therapists. These suggestions especially informed the update of the wall reach exercise for the second play session. Secondly, the therapists stated that customizability is always welcome, and they desired as much control on the variables of the interactables of the system in order to adapt them into exercises on the fly. Customizability was also desired in conjunction with more goals in general, that should be adjustable and satisfying to reach by any user, irrespective of their level of impairment. The therapists explained that it is important for the motivation of the patients that they can benefit from positive feedback at every step. Scoring systems were also mentioned as part of motivation, as well as part of logging for reviewing performance.

Observation Notes

The second meeting enabled the authors and two therapists to exchange information and further delve into the methods employed at Lunden, as well as the technology used for VR.

In this meeting, the therapists tried the interactables and systems already present in the system as part of previous work, as well as tentative implementations following previous discussions with the section leader (see Implementation). Feedback on these features was shared, informing the design of any future changes. Afterwards, the therapists described the rehabilitation exercises that they commonly use, and presented several props utilised in traditional exercises. One of the authors was submitted to a mock arm flexion exercise, complete with posture adjustment and isolation of movement. Resulting from this meeting were the two exercises rapidly implemented and iterated upon throughout the play sessions that followed: the wall reaching exercise and the arm flex exercise.

During the first play session, in which patients were present, observations were made on the therapists interacting with the system while performing therapy with their patients. The first main observation is the loose approach of the therapists, that did not follow a strict protocol with the patients, as everyone was becoming familiar with the novel set of tools the VR system introduced. The therapists helped the patients familiarize themselves with wearing a HMD and being in VR. As the authors were present, the role distribution with the therapists was not entirely clear from the beginning. The technical expertise that the authors bring on the system made them naturally fulfil some roles relating to the VR system, including equipping and unequipping the HMD and using the Vive controllers. However, the therapists were responsible the rest of the interactions with their patient, and sometimes this would overlap with handling the HMD and controllers as well.

Another observation from this session was that the patients exhibited various degrees of mobility and dexterity, some having obvious neglect, others motor impairments, others combinations of both. Both of the exercises were used in the play session, each with patients in the corresponding area of interest: the first exercise mainly for neglect, and the second exercise mainly for motor rehabilitation of the arm. At the time of this visit, the second exercise was less developed that the first. This resulted in less features, and consequently less customization and interaction from the therapists. However, this permitted for more improvisation from the therapists, leading into emergent behaviours described in the Interaction Analysis. During this session it was first observed that bringing the ergonomic table, foam packs and other props into the rehabilitation exercises did not interfere with the usage of the VR system. Some of the observations from the first session, when corroborated with the informal conversations, and led to focusing on and updating the wall reach exercise for the next session a week later.

During the second play session, an updated version of the wall reach exercise was used. Again, the play session was conducted loosely, with little protocol from the part of the therapists. The observations from this sessions are similar to the first session, with the added note that the therapists were this time more confident in using the system and took the lead on some technical aspects more, especially updating the exercise goals during the interaction. Furthermore, a technical difficulty of the tablet being separated from the tracker was managed.

Interaction Analysis

As described in Methods, interaction analysis was used to interpret video footage recorded during visits at Lunden. Approximately three hours of video footage resulted from these visits. This section presents the common themes observed by the authors across the key aspects (positive/negative interactions of the therapists with the system, emergent interactions of therapists with the system and interactions between the therapists and the patients.

Positive Interactions of Therapists With the System

- Therapists observing the interaction from various angles, both in the real world and through the tablet.
- Therapists observing the interaction directly, on the tablet, and on the desktop monitors (1st person from HMD and roaming camera from tablet tracker). In most cases, there is at least one way for the therapists to see into VR, depending on the placement of desktop monitors and tablet.
- Therapists using UI controls on tablet to customize parameters of the experience before play session. After several times being exposed to that, therapists use UI controls on tablet to customize parameters of the experience during the play session.
- System easily accommodates additional props and techniques used in the rehabilitation process: tables, low friction cloth, foam pads.

Negative Interactions of Therapists With the System

- Therapists encountering difficulties with the limited input mode of the tablet (touchpad behavior instead of direct touchscreen).
- When using the tracked tablet, and when acting upon the VR play area with a controller, therapists encountering difficulties orienting themselves in relation to the patient. For example, it was challenging to move the avatar (duck) with the tablet tracker in the desired direction (e.g. towards an exercise goal) while being able to see the 1st person perspective on a desktop screen, the local perspective from the avatar on another screen and the tablet, and navigating around the patient.
- All body visual cues that therapists give to the patients (e.g. pointing at a location, smiling) are now lost because the patient is wearing the HMD. Some of this is

mitigated by new cues that emerged in the play sessions (described in emergent behaviours).

- Therapists need to navigate the moving patient who can not see them, especially if they are not carrying the tracker tablet. This requires additional care as therapists operate mostly in close proximity with their patients.
- When a therapist cannot hold the tablet because they are interacting with the patient, there are limited cases when one or both desktop monitors are obscured from the view, requiring another person to guide the interaction. In general, the current version of the system operates best with two therapists present for a patient, whereas in the day to day operation it is common that a single therapist is present.
- Software bugs can lead to the exercises being performed in a wrong way.

Emergent Interactions Between Therapists and System

- The avatar duck became a central tool in the activity of the therapists, who used it to replace the missing visual cues they give to the patient when their vision into the room is not obscured by the HMD. The avatar is used to grab and direct attention of the patient, although initially developed only to act as an indicator for the position of the therapist using the tablet.
- The avatar duck is used to gauge the limits of the area of neglect of patients.
- In some cases, the second controller is used by the therapist instead of the avatar to grab and direct attention of the patient.
- The view on the tablet is shared with other observers/therapists.
- Randomized color of targets, implemented as a customization for visual preference, is used as a tool to check whether patient with neglect actually sees the target instead of guessing that the target is in their area of neglect.

- Software bugs can also lead to useful interactions. P3 was encouraged to keep playing to train the impaired arm when a software bug in the 'reach' exercise caused multiple targets to appear.
- Flowers spawning as a visual indicator of a reached goal were used as interactables for physical training of impaired arm.
- Second version of wall reach exercise was configured by therapists to work as a different exercise (flex).

Interactions Between Therapists and Patients

- Plenty of verbal communication between therapist and patient, especially praise and instruction.
- Common instructions are to use the impaired arm, to direct attention towards side with neglect, to direct attention towards target, to switch to other arm.
- Other communication is to enquire about state of patient (e.g. tired, happy) and state of interaction (e.g. difficulty, fun).
- Often the therapists would touch the patient as a mode of ensuring the quality of movement, correcting posture, instruction and praise.
- Common touches are used to set the limb in the correct position in preparation for the exercise, to correct the posture when the patient is compensating with the rest of the body, to correct the movement when the limb is straying. Also common are touches to draw and direct attention, especially in patients with neglect. Sometimes pats and rubs are given for praise.
- There is also casual conversation.

Questionnaire

Two of the several therapists present in the play sessions at Varde Lunden answered the set of questions presented in Methods. For the original responses in Danish, and the translations in English, refer to Appendix. The answers for seven of the questions agreed or were similar for both respondents, and the other eight responses, while not in disagreement, different too much in content or quality to be considered analogous.

Both respondents suggest adding to the system the features of counting repetitions and recording time, in order to better observe improvement. When asked about the visual aspect, the therapists mention focus as the prime factor being influenced: colors and movement can capture and maintain the attention of patients. The respondents agree that using verbal and visual feedback and guidance are the most common ways they instruct and communicate with the patient. Furthermore, both respondents suggest that more audio feedback would be a welcome addition to the system. The therapists also state that their role can not be completely replaced by a system, with one of the respondents elaborating that the therapist is responsible for determining the type of exercise for the patient, as well as ensuring the correct execution of the exercise. The most common methods they use in daily rehabilitation with their patients are repetitive training on specific tasks, regular strength and cardio training, stretching and massage.

The respondents mention that they also use the Affolter model (used for patients with impaired perception), and the Bobath concept (for motor training) as starting points for therapy and move on to more evidence based training practices. When asked about the choice of methods, both therapists state their education as the source, and one of them adds that manuals, articles, conferences and work experience are additional origins of their knowledge. In terms of props and equipment used in daily rehabilitation, respondents refer to ergonomic, height-adjustable tables, foam packs (observed to be used in supporting or restricting certain movements), low friction cloth (observed to facilitate repetitive arm movements on a surface), as well as gym equipment (stationary bike, gym balls), office supplies (tape, markers, elastic bands) and mundane objects (cups, glasses).

One respondent mentions that in VR their patients reach further in their range of movement, and do exercises for longer, when asked about novel aspects brought in by the system. When asked specifically about focus, the therapist states that distraction is greater if the patient is not wearing the HMD and there is more focus in the VR environment. However, the other respondent mentions how some patients become confused in the VR world. The full responses are found in Appendix.

Discussion

For this project the implemented system is destined as a tool for the therapist, the main stakeholder of the work. This is distinguished from the end user, which is the patient. The focus lies on the therapist using the tools available in the VR system to address the requirements encountered in each unique session with their patients. Perhaps more research in the field should focus on the therapist and their experience with the system during the therapy session.

The software used in this context should be flexible enough to accommodate the requirements of therapists in their work. These therapists are applying their knowledge and skills in a holistic manner as part of the rehabilitation process, building on theoretical expertise from their education with additional material throughout their development in their profession. This process includes looking at the overall progress of the patient, measuring specific markers of mobility, and using their ingenuity to perform a tailored form of therapy suited to each individual’s needs. As such, there is no recipe to follow that is generalizable to all therapy sessions, because these sessions are not entirely what the theory makes them to be. For example, the therapists at Lunden start from education, professional expertise and established approaches (e.g. Affolter is mentioned in Results), but extend to each patient the required support by involving them in daily activities, traditional physical exercises, rehabilitation therapy and novel approaches (such as this system).

In the case of these novel approaches, it is important to give the therapists the bridge to translate their skills into the new medium freely and without much being ‘lost in translation’. To illustrate an example, the stakeholders of this semester soon readjusted to using an avatar within a virtual space to compensate for the loss of direct visual cues they could offer to patients using the HMD added by the system. We discovered that doing so successfully means allowing for the system to respect well known requirements, and occasionally mold to unexpected ones. Some of these conditions arise from specific limitations of the medium, while others emerge in conjunction with new behaviors and possibilities. For example, a first person perspective, a top down perspective, and a free perspective are all possible simultaneously in the system for the therapists to observe the interaction space, but this introduces new issues of orientation for both parties involved, usually leaving it to the therapists to address the inconveniences that would affect the patient. Fortunately, as illustrated by using a variety of specialized and mundane equipment in their daily work for traditional rehabilitation practices, therapists can shape the tools available into an adequate solution. In the case of virtual tools, this flexibility is arguably ampler, masking some shortcomings brought by the field of VR rehabilitation being less developed than the one of rehabilitation in general.

Addressing the Research Questions

What tools and methods do therapists utilise in rehabilitation exercises with patients?

As the main focus of this study was to provide the therapists with a set of virtual tools to use in rehabilitation sessions, a good starting point was to find out what physical tools they already use, and for what type of exercise. Some of the exercises initially described by the therapists did not necessarily rely on any tools other than a table to rest an arm on. Such was the repetitive wrist rotation exercise where the patient in need of that specific exercise might sit at a table with an arm resting on it, and just rotating the wrist back and forth. The same with the arm extension exercise where the user pushes and pulls their arm back and forth, sometimes with a physical object to connect with in front of them. These kind of exercises are well suited for adaptation to a VR system.

Another exercise that the therapists explained was meant to get patients with neglect to practice searching for objects on the neglect side. The exercise consisted of several colored targets taped to a wall, and the patient would be asked to locate and touch a target with a specific color. There being no other feedback than that from the therapist means that it can become a boring task to do after a short time. Adapting this exercise for VR not only had the potential to make it more engaging and rewarding for the patient, but it also gave the therapist a much more convenient way of adjusting the exercise in various ways, some of which would not be possible with a physical, paper and wall setup.

Although not implemented in this project, doing exercises while a VR system is tracking the movements of the user could be used for logging data more precisely and efficiently, than what the therapist are able to do. For example when a patient is doing repetition exercises, the therapist sometimes counts the repetitions using an analog click counter. Also when recording how far a user is able to stretch, the therapists use masking tape on a table and then mark on the tape how far the patient is able to stretch. A proper implementation for logging such data would be very useful for both the therapists and the patient.

Which aspect of rehabilitation could be enhanced by VR?

A big part of ABI rehabilitation is the use of repetition exercises to strengthen connections in the patient’s brain with regard to a specific task or movement, according to the therapists at Lunden. Patients are often required to repeat a set of movements hundreds of times, sometimes daily, with little to no visible progress or visual feedback. This is prime example of how a VR system can improve upon conventional methods: By enhancing the experience with a virtual environment, tied with better feedback (visual, audio, haptic), these repetitive task become more bearable. A chore can become a fun game, or at least an enjoyable experience. This project’s VR system tries to achieve this by using a set of visual effects such as sparks on collision of objects, particle effects when objects explode, trails left by fast-moving tools. The tasks themselves are masked as something else: A simple arm extension turns into popping a colourful balloon.

Then, once each end user’s preferences with regard to play style are determined, it is possible to further increase motivation by adding the appropriate type of gameplay elements and rewards. This group’s previous work resulted in a model with (among other categories) three types of playstyles which also match Bartle’s taxonomy (Bartle, 1996). Social users benefit from the option to interact with the therapist by throwing cubes to one another, interacting with the duck, or even having the therapist use a second controller. Goal-oriented players would benefit from a scoring system and progression, such as levels and set goals.

Users in the sandbox category are perhaps the least suited for the strict targets of rehabilitation exercises.

A second potential benefit of using a VR system is automation, whether it be to log data or to setup and adjust exercise settings. The inherent nature of a computerized system allows for capture of massive quantities of data, while the HTC Vive has multiple trackers and sensor to provide the necessary data to be captured. Much of this can be done in the analog world as well, by using clickers and markers on paper, but a VR based system could take this burden off the therapists. Automation can also be used to set up exercises in a specific way, for example based on a profile for each patient. Adjusting settings is much easier with a VR system because anything can be moved and changed: colours, shapes, position, rotation, size of virtual objects can be changed with just a few touches by the therapist. Feedback of all kinds is also automated in this semester project’s VR system: sounds play automatically when a target is reached, objects change color based on if they were a target or not. New targets are spawned automatically as well, in a randomized fashion, further alleviating the burden of therapists.

Which aspect of rehabilitation should not be substituted by VR?

The therapists at Lunden mentioned on several occasions how important it is that when a patient is performing a physical exercise, the quality of the movements is important to ensure that the right neural connections are being stimulated and the correct muscles are used. In many cases the patients need guidance both verbal and physical in order to do the exercises right, as there is often a tendency to compensate when the required movement is too difficult. The therapists at Lunden have shown an impressive resourcefulness when it comes to figuring out ways to make sure that the exercises are useful for the patients. Sometimes the therapist can make the patient adjust a movement by verbally instructing them, and other times the therapists bring in different objects that can be used to physically constrain the movements of the patient. Knowing the individual patient and their condition is also important when deciding how to approach an exercise. So the therapist seems to play a crucial role in making sure that exercises are done right which will not be replaceable by an automated system any time soon. Even if a much more automated system were to be implemented, the data from the play sessions at Lunden still indicate that trained professionals should at least configure the system for each participant's needs.

What can a computerized VR system offer to rehabilitation that traditional methods can not?

One of the major benefits of using VR in this context is the different perspectives that can be available for the facilitator. In this project the therapist had a portable camera into the VR world that could be viewed through the tablet or one of the desktop monitors. On the same screen was a top down view of one of the exercises. Additionally the possibility to have a first person view of the patient is something that would never really occur in traditional rehabilitation. Many parameters of the system can be adjusted on the fly, and for deeper customization, new exercises altogether have been authored at the request of therapists. Furthermore, not only does the VR system not interfere with the props of traditional rehabilitation, but it can complement them. In the cases where interference does happen, such as visual contact being broken by the HMD, the system can offer alternative way of communication. There is also big potential for computerized systems to automatically log much more information that therapists can manually, in order to review improvements and a later stage. The therapists at Lunden observed that some of their patients would spend more time on a task in VR than they would otherwise, indicating a potential in increasing focus.

How does the conventional approach of therapists transfer to a virtual reality toolset.

Using VR technology in rehabilitation brings some of the limitations of the medium into the therapy session. The principal aspect observed in this project in regards to introducing VR to the therapists at Lunden is that they could no longer be seen directly by their patients. Since the vision of the patient is obscured by the HMD, natural visual cues from the therapist that instruct or communicate with the patient are obstructed. It seems, however, that the therapists quickly employ the new tools that come with the medium, especially the avatar on the tracker to mitigate this limitation and introduce new communication channels to the patients. They make use of the avatar and controllers to reach into the VR play area of the patient and redirect their attention towards the goal.

Guidelines are required for such situations, where the alliance between therapist and patient depends on implicit and explicit communication. Both the therapist and the patient would benefit from constant cues to remind them of the way VR works. The chaperone system integrated with SteamVR and the avatar for the therapist are just two solutions. More precise positional indicators from additional trackers could allow the HMD user to identify the exact placement of the therapists limbs. Alternatively, the HTC Vive contains an inbuilt camera that could display a view of the outside world, although how this is best overlayed and whether it is left at the control of the therapist are valid new questions.

At least in the case of Lunden, therapy sessions involve a single therapist for a patient during a session. Throughout this project, however, multiple therapists took part in the play sessions, perhaps in part due to the novelty aspect. Nonetheless, with the new devices, perspectives and controls introduced by the VR system, its handling without sacrificing attention to the patient was in some cases only possible with the intervention of at least two therapists. If this type of system changes the nature of the sessions at this fundamental level, it is desirable to do so in the direction of minimizing the workload on the therapists instead.

While it has been observed that the therapists are adaptable enough to handle the new modes of interaction while still attending to their patients as usual, and that the system supports an adequate degree of alteration serve the spontaneity of the therapists, the role of the authors in the interaction does introduce some biases. Most importantly, the installation and troubleshooting of the system was left to the authors. The therapists might require additional training to address these aspects themselves, in a similar way in which the authors themselves cannot perform physical therapy. As such, even though in general the skillset of therapists is translatable given the new tools, there are medium-specific considerations that raise the question of how much more complex does a system have to be in order to seamlessly integrate with the rehabilitation process like any other tool.

Weaknesses of study

While all efforts were made to identify and compensate for weaknesses present, there are a number of elements that could not be addressed. Some of these arise from lack of time, while others are outside the project group’s control. The most prominent weakness is the continuing difficulty in gathering information about individual patients at Lunden. This has been the case ever since collaboration first began in the 9th semester. The group was unable to find out any details about the specific conditions and disabilities of patients, with the reasons cited by staff there being simply ‘privacy’. While some shreds of information were offered by therapists during various sessions, these are restricted to generic statements and terms (e.g. neglect), or a brief description of symptoms exhibited. Generally, the project group was told how a patient was able to move and what some of their limitations were (both physical and cognitive).

Another weakness of this study is the difficulty in generalizing any conclusions. This stems from not only the use of a case study approach, but also from the inherent nature of therapy sessions at Lunden, which are unique. That is to say that each combination of rehabilitation center (like Lunden), therapist, and patient create a unique context which must be treated as a separate case. Common patterns can be discerned, and a limited set of conclusions are drawn in this paper, but generalizing further would not be possible without further research using other methods. Another point of contention here is the very low sample size of data gathered from the questionnaire, where only two therapists answered at the time of writing. This is of course limited by the actual number of participating therapists, but nevertheless is a weakness.

Ethical and Safety Concerns

There are a number of ethical concerns within the context of this semester project that must be addressed. The first and foremost is privacy, both for the patients and the therapists at Lunden. The data protection regulations (a combination of EU’s General Data Protection Regulation and the Danish Data Protection Act) state that anyone working with personal data concerning other people is under legislation to handle the data under certain rules that are meant to protect the privacy and safety of whom the data is referring to. Furthermore, one requirement is for the data handler to have a legitimate purpose to do so. As a student, handling data for the purpose of a study is a legitimate purpose. In most cases consent can be used as legal basis for handling personal data, and although verbal consent is technically valid, a physical consent form is recommended. For these reasons all the subjects that data has been collected on in relation to this project have signed a consent form (Appendix) that explains the circumstances of the project group's handling of their data.

When designing and developing VR experiences it is important to know about best practices and safety recommendations. Companies such as Oculus and headsets such as HTC Vive have design guidelines to follow for ensuring safe, meaningful and comfortable VR experiences. However, most of the problems that existed some years ago are of less concern today because of the improvements in hardware and software. For example, latency used to be common problem which could cause discomfort in the user. The hardware and software used in this project takes care of many of the problems that could arise if certain features were excluded. HTC Vive combined with SteamVR and OpenVR make sure that there is low latency and with good tracking it ensures a one to one mapping of the physical and virtual movement of the user. Safety systems such as the chaperone system (warns HMD vearer if they are about to walk out of traced area) and fade to gray if the headset loses tracking, are example of inherent safety features. Another thing that is important is that the VE "behaves" naturally. Creating VEs in Unity engine makes sure that the proper depth cues and physics behaviours are present for the user. Generally content creators need to familiarize themselves with the best practices and safety guidelines before creating VR experiences for anyone.

Conclusion

This paper set out to explain how the behaviour of therapists during ABI rehabilitation sessions would change and adapt when a VR system is introduced, as a supplementary tool to their existing analog exercises. For this purpose, a VR system was created which contained a series of virtual interactable objects forming alternate version of existing exercise setups used by the therapists at Lunden, or original setups aimed at fulfilling some of the same goals as these exercises. The VR system was tested at Lunden over the course of several play sessions, and data collected in a case study approach. The video footage was analysed using interaction analysis, resulting in a series of themes. A set of five research questions was answered.

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