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What virtual reality technologies could provide to specialized healthcare in Finland?

Helsinki Metropolia University of Applied Sciences

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Forewords

In 2017 when this thesis work was started, the VR technology was not widely used or known in Finland and in HUS. I personally had no experience of the technology. Not until an enthusiastic colleague, whom had a huge interest towards VR technology arranged a company visit to see and try it. After the visit, I quickly understood that this is something new and big that needs to be further studied. Suitably, I just had started my masters' studies and was looking for a thesis subject.

In the beginning, I had no idea what was the relation between healthcare and virtual reality. As it turned out, virtual reality and related technologies are really useful in many areas for the healthcare sector.

Soon after the initial company visit, I got involved arranging a technology pilot in HUS-ICT called a Virtual Reality Test Lab. The idea was to gather VR applications for testing and introducing its potential to different HUS personnel. Afterwards the VR laboratory became a constant part of HUS campus area and moved to its own premises. The idea is to have open doors for anyone interested. This provides possibilities for companies to meet with hospital professionals and vice versa. The business confronts hospital in practice.

Since the beginning, there have now been many projects around VR technologies in HUS. Personally, I am not involved in these projects on my daily work, but I am following this new and interesting technology branch. I also see that sooner or later these tools will be more common in our everyday life.

I want to thank Toni for the inspiration to the subject. My principal lecturer Ville for professional and encouraging guidance to support the work to be finalized. And of course, my family that have supported me during the journey and taken a lot of the burden keeping the wheels rolling.

Hopefully this thesis work will open the possibilities to its readers and encourage spreading the VR technology to the clinical treatments and other use cases proposed by this thesis study.

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This Master's thesis explored the emerging new technology of Virtual Reality (VR) for healthcare industry. The purpose was to introduce the possibilities and studies what have been done in this field. Secondly, the aim was to evaluate the usability and maturity of the VR healthcare solutions. The goal was to create a road map for a Finnish specialized healthcare provider HUS.

In the beginning the study presents the VR technology hardware and software and what components does it comprise of. The study drew an overview to the current VR market situation to emphasize the importance why VR is booming to main stream.

Thesis searched literal sources of healthcare related VR solutions and introduced those. Main categories presented were VR solutions for psychotherapy, pain reduction, rehabilitation, simulation, education and surgery. Found use cases were evaluated by the evaluation criteria. The selected criteria were effectiveness, patient amounts, cost and other criteria. Combining the technology characteristics with found research studies and evaluating these formed the study output.

The result of the study recommended the most cost-efficient and useful VR solutions for the healthcare organizations. This provided broad scale of information of the VR solutions that should be further studied to introduce it to the clinical practices.

Secondly, the study provided information concerning researched fields of VR in healthcare for anyone interested. The VR solutions for the healthcare industry will change the way how the patients are treated in the future.

Keywords	Virtual reality, VR, augmented reality, AR, VR glasses, specialized healthcare, hospitals, HUS, VRET, VR-CBT, VR analgesia

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List of Abbreviations

360 video	Video recorded with several cameras to visualize viewers environment in all directions in 360 degree angles.
6DoF	6 degrees of freedom (6DoF), VR user possible movement positions: left/right, up/down and forward/backward and other 3 movements for users view point, head movements.
Analgesia	Not-feeling pain, the absence of the sense of pain while remaining conscious.
AR	Augmented Reality. Enhanced vision of real world where information is added to user glasses to provide extra information.
ASD	Autism Spectrum Disorder
Avatar	Avatar is a virtual person or profile representing user from the real world.
CAVE	Cave Automatic Virtual Environment
CBT	Cognitive Behavior Therapy
CT	Computed Tomography, uses computers to create tomographic images or slices of scanned object or human body
EEG	Electroencephalogram, measure human brains electric signals
EMG	Electromyography, measure muscle activity from electric signals
FASD	Fetal Alcohol Spectrum Disorder, a condition caused by a pregnant mother's alcohol abuse for the fetus.
fMRI	functional Magnetic Resonance Imaging, a method to study how brains function.
HMD	Head Mounted Display or Head set
Immersion	Used in VR to emphasis that virtual world experience feels authentic and real. User is immersed in virtual world.
MDD	European Union Medical Device Directive
MR	Mixed reality, a combination of AR and VR.
PTSD	Post-Traumatic Stress Disorder
RFVR	Reinforced feedback in virtual reality
VAS	Visual Analogy Scale, a pain measure test
VE	Virtual Environment, the content inside virtual world, a person in VR is looking and feeling the virtual environment

VH	Virtual Human, see avatar
VP	Virtual Patient, see avatar
VR	Virtual Reality. A vision of a virtual world that is created with computer aided glasses or projectors.
VR analgesia	VR treatment for pain control
VRCBT	VR cognitive behavior therapy
VRET	Virtual Reality Exposure Therapy
VRS	Virtual Reality Simulation
VRSCT	Virtual Reality Social Cognitive training
XR	Extended Reality, an umbrella term meaning all different VR, AR and MR technologies

1 Introduction

Virtual Reality (VR) has been used in science fiction for a long time. The idea of virtual reality was first described in 1955. The first prototype was a machine called Sensorama. The machine had mechanically built stereoscopic picture, odors, fans and sound. Its prototype was built in 1957 and patented in 1962. The inventor of VR was Morton Heilig. [1]

In the late 1980s the term virtual reality was firstly used by Jason Lanier. The VR technology was getting public hype in the early 1990s, but the technology was not matured enough and interest slowly faded away. The early VR solutions were complicated technologically, enormous in physical size and impractical to use. [2] [3]

As technological evolution brought better screen technologies and smaller and efficient computers, the revolution of VR can now really take place. The VR solutions are going main stream on many business areas: home users, gaming, education, military, healthcare, marketing and many more. Virtual Reality is one of the hottest new technology trends in 2017 by Gartner. The year 2017 can be said as one of the breakthrough years of Virtual Reality. Now the time is right for scaling up for masses in various applications. [4] [5]

In Finland, the VR technology in healthcare sector has not been widely used or studied. There is a need for studying this subject and to gain information and insight, what can it offer for the healthcare sector.

This work studies the new area of VR technology for the hospital district of Helsinki and Uusimaa (HUS) hospitals. There have been started a few pilot studies within the VR technology in 2017. The big picture is still quite fragmented. This thesis gathers different VR use cases from literal research papers and studies and combine these with a technology aspect in an evaluation. The evaluation is used to show which solutions are the most useful and effective. Secondly, this study researches what VR treatments exists and how they have been used. The purpose of this work is to spread information of VR in healthcare and to create a roadmap for HUS. [6] [7] [8]

1.1 Hospital District of Helsinki and Uusimaa

The Hospital District of Helsinki and Uusimaa (HUS) is a joint Authority formed by 24 municipalities. The aim is to offer patients in all member municipalities a timely and equal access to specialized medical care. [9]

HUS is the biggest specialized healthcare provider in Finland due to its location in the capital area and surroundings. In this role is important to be the leader of studying new technologies and adapting these into clinical practice.

Figure 1. HUS geographical area surrounding the capital Helsinki.

Finland is geographically widely spread. It is not reasonable to have all specialized medical services provided everywhere in Finland. HUS has some special clinical responsibilities for medical services that are not provided elsewhere in Finland. Different HUS specialties are listed below in the Figure 2.

Figure 2. HUS special branches in medical treatments

Allergology	Medical Imaging and physiology
Anesthesiology	Neurology
Children and adolescents	Neurosurgery
Dermatology	Obstetrics
Ear, nose and throat diseases	Oncology
Emergency medicine	Oral and maxillofacial diseases
Eye diseases	Phoniatric
General medicine	Physiatry
Gynecology	Psychiatry
Heart Diseases	Respiratory Medicine
Internal medicine	Surgery
Laboratory specialties	

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An important new branch is also the virtual hospital concept. Virtual hospital is lowering the barrier between the hospital and patient homes. The purpose is to provide medical aid for out-patients at their homes. If needed patient is guided to a healthcare professional in hospital. All Finnish university hospitals are developing this service together. It has grown to a national co-operation project. There is a huge need for Finnish healthcare sector to provide its services on its large geographical area. All remote and digitalized telemedicine services should also be covered from this aspect as well. The VR solutions can provide remote services due to virtuality and mobility.

This thesis work is done for HUS and its ICT department, HUS-ICT. HUS has its strategies and visions in new innovative solutions and being high in on competitive and international level. In this contrast, it seems that virtual reality should be a part of HUS future innovation strategies.

1.2 Thesis Structure

This research was conducted as following: Introduction chapter explain current situation of VR and its relevance to healthcare industry in general.

In the methods and materials chapter, the study scope and work is explained in more detail. Study outcome and evaluation criteria are described here.

In the third chapter VR technologies, the study will look in to the VR hardware and software. Thesis will cover the main VR concepts and tools from technical aspect. What is needed to create virtual experiences or treatments?

In the VR applications in healthcare chapter, the thesis gathers research studies and knowledge from literature regarding VR in healthcare. This provides an understanding of what VR solutions have been implemented and studied before.

The evaluation of VR in healthcare chapter scores the found solutions. The results were evaluated by the selected criteria and scored. These were presented in a matrix format. Results gather a good and easily comparable view of VR solutions.

At last the results and findings were discussed. The outcome from this study was to recommend which VR solutions and use cases would be most beneficial to start considering and further studying by the evaluation criteria.

2 Methods and Materials

This chapter explains how and why the thesis work was done and what study methods were used.

The first chapter explain the technology and literature study methods more thoroughly. After that the evaluation criteria are described. The chapter ends defying the study scope.

2.1 Study Setup

At first the VR industry and markets are studied to emphasize the importance and change this new technology is causing.

Followingly, the key components of VR are presented. These are different hardware and software components. The components are used to create virtual environments (VE). Focus is on general concepts, what makes an VR experience. These include different virtualized senses, such as visuals and sounds.

In literature analysis the current knowledge and research studies, using VR in healthcare, was searched from e-libraries, research databases and sources. The starting point was Metropolia's MetCat e-library and Finna services that contain broad international research study base and links to other scientific research papers.

Source material were searched with key words "Virtual Reality" and "healthcare". After the initial source materials were found, the search was focused to a specific solution or treatment. For example, "VR" and "analgesia".

Gathering from these sources, the main VR treatment categories were found. The main categories in this study were psychiatry, pain management, rehabilitation, simulation, training, education and surgery.

Different categories and their use cases were described in their own chapters. A few use cases per field were represented in this thesis. This provides a good overall view of what VR treatments exists for specific category that already had been studied.

In the evaluation part of this study, the results were evaluated by the defined criteria. The evaluation was done using qualitative method and scoring. The scoring was used to put the solutions in order by the evaluation criteria. This makes it easy to compare, which solutions have been researched before and what were the evaluated cost-efficiencies.

Study outcome includes suggestions and a roadmap, what to look for in VR healthcare technology, if not already applied by HUS.

2.2 Evaluation Criteria

Evaluation criteria focus on which VR solutions should be further studied to be taken into use by healthcare and clinical practices. The evaluation criteria in this study were decided to be effectiveness, patient groups, costs and other criteria. These criteria are explained in the below chapters.

The evaluation criteria were formulated to 3-step scale from 1 to 3. Also, an extra point was evaluated for each solution. This allowed summarizing the scores together, making the score range to be from 3 to 10. Bigger score equals the solutions with better characteristics. All scoring and evaluation factors were also briefly commented to show where the scoring was based on.

2.2.1 Effectiveness Criteria

Effectiveness criteria was examined on the perspective, how does the VR solution change the current treatments. Effectiveness can be looked from different angles. Is this a new treatment? How much it has been studied? Does it provide an alternative treatment to current practices? Does it provide better results than traditional treatment? These are the factors that are considered in the effectiveness criteria.

This criterion was scored on a scale from 1 to 3. The higher number is, the more effective the solution was. For this criterion, the score characteristics were estimated followingly:

1 = No benefit compared to traditional treatment.
2 = Provides improved results or alternative option for a traditional treatment.
3 = Totally new treatment that has not existed before.

The effectiveness criteria scores were estimated from the found literature sources and materials presented in chapter 4.

2.2.2 Patient Group Criteria

Secondly the evaluation aim to study the most useful tools for most patients. This factor was looking for effectiveness on masses of patients. There is quite minimal interest to create VR solutions for each single patient need. Nor that is not possible due to the costs.

This is a matter of ethics, to discuss if the society and its healthcare service providers like HUS, should develop a treatment to patients that are only few per year. This has to be a point for decision makers to evaluate such case-by-case. Much easier decision is to develop a treatment that concern thousands of patients or even national diseases and mortality rates.

The patient groups criteria evaluate how many patients does the solution provide aid for. There are some patient groups that are not so many on yearly basis.

The patient group scoring was evaluated on scale from 1 to 3. The higher number represents more people that can benefit from the treatment. For this criterion, the score characteristics were estimated followingly:

1 = Few hundreds or less patients per year
2 = Thousands of patients per year
3 = Hundreds of thousands of patients per year

The patients amount yearly affected were searched from Finnish medical databases and articles. The estimates of yearly patients are presented on each use case study in chapter 4.

2.2.3 Cost Criteria

Costs factor criterion evaluate the costs related to the solutions in question. The costs of new technology can be high. Not all technology and solutions are feasible to implement.

The costs factor evaluates the solutions hardware and software costs. It also includes other cost related matters, such as if other additional stimuli were required by the treatment. The VR software and content depend on the treatment. Some treatments are made individual and some are generalizable to masses. The content has to be able to modify in some of the treatments, which is more expansive. Advanced systems with additional hardware also require more expertise from the developers. This also was considered in the cost evaluation.

The costs score was evaluated on a scale from 1 to 3. Higher number represents a cheaper solution. For this criterion, the score characteristics were estimated followingly:

1 = Expansive hardware and software with other special requirements
2 = Expansive hardware or low-end devices with expansive software's
3 = Low-end hardware device with simple app or content without extra features.

Different use cases presented in the chapter 4 describe the general VR technology that was used. The VR technology features were described in the chapter 3.

2.2.4 Other Criteria

The other evaluation criteria notes, if there are other factors that concerns the solution and should be taken in to account. The range of technology providers and solutions are expanding quickly and not all evaluation aspects could not be taken in to account. Therefore, the other criterion factor was evaluated on scale from 0 to 1. This provides an extra point to the solution, if seen adequate.

The other criterion scores were mainly looked from the presented use cases in the chapter 4. If the solution had an extra impact on general level, there was granted an extra point.

2.3 Study Scope

The presented evaluation scores are not directly comparable between each other. The evaluation needs to be seen in the context of what the healthcare practitioners or patients need. A specific treatment might have a huge impact on a single patient's wellbeing and health, even the cost factor might be relatively high. The evaluation of any new VR treatments, considered to be taken into clinical use, need to be done by the medical doctors. This study provides useful knowledge and collection of existing and studied VR treatments, that can be used as a base for further research studies in this field.

All medical devices and solutions need to be verified to comply with the Finnish law and legislation, if used for treatments. This also concern the VR hardware and even software. Legal aspects are important to cover. Otherwise one may compromise the patient security or introduce unwanted lawsuits, which is no intention of any healthcare professional. This study does not focus on these legal matters, but notices that these are important matters to comply, if the technology is taken in to clinical use.

This study is not in anyways suggesting medical treatments or solutions. The purpose was to present the studies that has been done with VR for the healthcare sector. The study explains some medical treatments from public sources as background information and for evaluation purposes. All VR treatments and solutions should be evaluated by the specialist medical doctor on the specialty field.

The VR related researches were exponentially growing. Not to expand the scope too much, it was decided to focus on VR technology and the selected categories. As in most technology the earliest studies are a good basis to understand the later evolution. Also, there was no point to compare different VR surgery studies. Instead one or two separate solutions were presented. These are of course relevant to the field of study itself. For this work the scope was to identify the main VR solution categories that had been researched.

Other Realities AR, MR and XR

The Virtual Reality technologies are evolving rapidly. New technologies, such as Augmented Reality (AR), Mixed Reality (MR) and Extended Reality (XR) have emerged from the VR technology in the past years. The AR enhances the real-world vision adding an extra layer of virtual images on top of it. In practice, a user is looking a see-through headset and the AR reflects a virtual image on top of it. It can also be used on a tablet device or phone to add virtual graphics to real world screen image. The MR is similar in definition than AR is, mixing the real world with virtual images. The terminology between these is confusing. This is partly because it has become a branding strategy between some of the competing companies. The XR is the combining umbrella term. It means all the different technologies: VR, AR and MR. The XR can be used to discuss the branch in general.

The base technology, VR, and its studies are in the focus of this thesis. The other XR technologies are out of scope for this work. However, the findings in this work could be used in a context with the AR and MR technologies.

3 Virtual Reality and Technology

This chapter starts from VR business and markets, explaining why it is getting popular. Later, the chapter looks into general hardware and software components that are used in VR. What tools are used to create a VR experience? Chapter ends summarizing the technology benefits and limitations. These are used in the study results evaluation criteria.

3.1 VR Markets

VR technology is going to have impact on many sectors and businesses. Overall market estimates by Goldman Sachs forecast VR and Augmented Reality (AR) growth to reach 20 billion USD (16,2 B€) in 2019. By 2025 it is estimated to reach almost 80 billion USD (64,8 B€), as seen in Figure 3. [10]

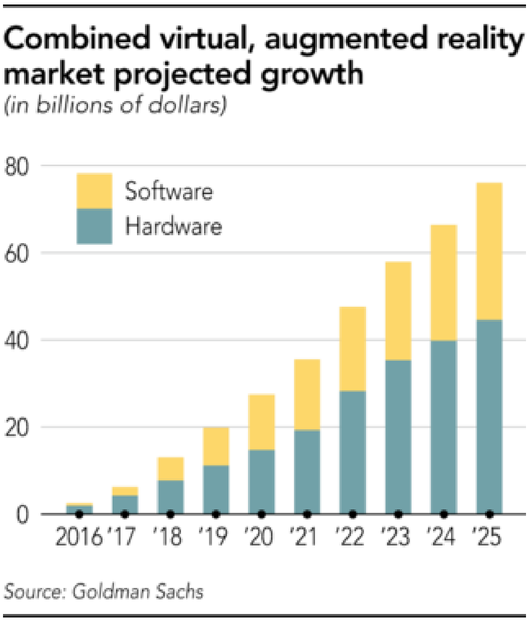

Figure 3. Estimated VR and AR market growth.

For healthcare industry, a market analysis company, Global Industry Analysts Inc., estimated that VR healthcare market will be 3,6 billion USD (2,9 B€) in 2020. Another company, Research and Markets, estimated healthcare market to be around 5 billion USD (4,0 B€) in 2023. This means that roughly ten percent of VR/AR industry is going to be healthcare related by different estimations. [11] [12]

The reason for the growth and breakthrough of VR is lowered pricing of mass market products. Big technology companies such as HTC, Samsung, Sony, Google, Facebook and Microsoft are all involved in innovating this new technology and gaining their share of the growing business area. The market consists of hardware and software components. It is estimated that after the market growth is filled with hardware, the software components will be taking bigger share by 2025. [13]

Business Finland's report mention that in 2017 the market size was estimated at 5.5 billion dollars (4,4 B€), which is in line with Goldman Sachs estimate. The growth pace is though estimated a lot higher, reaching to 150 billion dollars (121,6 B€) by 2020. The report also notes the important role of medical related development by quoting Digi Capital study stating: "According to Digi Capital technology and medical applications seem to be the driving forces in AR and VR In Q4 2017". [14]

In Finland, this VR evolution can be seen in the rise of new VR/AR companies. Majority of the Finnish VR/AR companies (77%) have been founded after the early 2016 by the Finnish Virtual Reality Association (FIVR). The older companies in the field have been working on industries such as 3D design, film making and gaming industry that have lots of similarities to VR technology. This is also noted in Finland on governmental level by the Business Finland, former Tekes, that is funding new VR and AR companies by 30 million euro in 2018. [15] [16]

It is clear, that healthcare is one big segment where VR shows a lot of promises. These are cost savings, gaining more efficiency on operations and even provide new treatments. The new VR solutions in healthcare sector and industry has a lot of potential to gain from this technology. VR can substitute expensive and difficult or impossible-to-create training scenarios and treatments.

3.2 VR Technology in General

Virtual reality can use several stimuli to create sensation of being part of the virtual world. There are 5 basic senses that humans can experience. These are: sight (vision), sound, haptic (touch), smell (olfactory) and taste. To create VR experience for users, the basic senses are created on computer applications and apparatus as stimuluses.

Applications control different stimuluses as inputs and outputs. According to user reactions the virtual environment (VE) correspond to the user actions (inputs). User looks around the virtual world and system updates the visual output accordingly in 360 degrees (visual output). User listening surrounding sounds in VE. Based by the user positioning the volume and source are updated (sound output). When user touches a virtual object, the object moves and provide touch sensation to user (haptic input and output). These stimuli create a sensation where person feels to be inside the virtual world. [17]

The user's experience of VE depends on the visualizations quality and stimuluses. Feeling of virtual world and its depth, is called immersion in the VR terms. The more realistic the VR application is, deeper the immersion is. The deeper immersion can be created with more high-quality visualizations and using several stimuli. [17]

VR technologies have reported to cause motion sickness for some. There can be symptoms of nausea, headache, disorientation and other unpleasantness. The level of sickness depends on individual differences, the time spent on the VR application and the quality of the VR implementation. There are some theories that are trying to explain these symptoms. But the physiology behind this is currently not clearly understood. [17 p.10] [18]

Some of the theories causing motion sickness are sensory conflict, refresh rate of the screens, resolution of software animation. Sensory conflict means that the brain is getting visual information, that doesn't match the person sensations to the real world. For example, a person is flying in a VR application, but is actually sitting on a chair, our brains get confused. The vision and body feeling stimulations are not matching. Refresh rate of the screens can also be one cause of motion sickness. As well as lagging animation, that doesn't follow and update the users head movement for visualizations. Most of these quality issues are no longer caused by hardware limitations. The most motion sickness issues are due to poor software implementations. [17] [18] [19]

3.3 Stimulus

Following chapters describe the VR stimuli that are used to create the virtual experiences.

3.3.1 Visual Output HMD

The main tool for VR applications is to use visual outputs. A Head-Mounted Display (HMD) or simply head-sets show stereoscopic images to create 3D virtual world. Headsets are monitoring user head movement with gyroscopes and other sensors to adjust the vision accordingly to show surrounding environment in VE. [17 p.46-47]

It has been studied that stronger immersion are accomplished by better and faster graphics. Also using more stimuluses makes the experience more authentic. These can be 3D sound environment, odors that match the virtual world or haptic feedback that gives users a touch response, once touching an object in the virtual world. [22, p120]

Challenges in the high-quality visualizations are data bandwidth and latency. Bandwidth for a low quality 360-degree video requires 25-30 Mbps continuous bandwidth connection. HD quality resolution stream requires above 100 Mbps. UHD resolution and above resolutions might require as high as 0,5-Gbps bandwidths. [23]

The latency for comfortable VR solution should be under 15ms. If system doesn't accordingly refresh the view to the user HMD, there can be feeling of motion sickness. The challenge is that latency needs to be end-to-end latency including network traffic. [17 p.10, 23]

Current mobile network bandwidths and latencies are not meeting the need of high-end VR visuals. These requirements tie the high-end solutions to physical cabling and fixed premises. The VR head-sets are blocking the view from the real world. User can only see the virtual images from the HMD. This is annoying for the users, since the real-world cables are not visible in VE. User might fall to the cables or immersion might be disturbed by watching out the cables. The solution for these might be provided when the 5G mobile networks became available. Before that high-end VR/AR solutions over mobile network are not possible to do. [23] [24]

Wireless LAN (WLAN) networks could meet the bandwidth and latency requirements to provide free movement. There remains the need for powering the HMD and its sensors. Wireless high-end HMD will be one of the next evolution phases for the manufacturers to solve.

There is evidence that better high-end VR graphics are not necessarily needed for all cases. In a study by J. Gutiérrez-Maldonado et al. the finding was that comparing a low-end and a high-end VR HMD were not having a statistical difference on a training for eating disorder diagnosing skills. [25]

Similar findings are supported in a study by P. Gamito et al. The team tested neurologic rehabilitation with HMD compared to a desktop screen based VR. The test measured 17 participants memory and attention after a VR training. The finding from this study showed that both VR solutions gave the same results. This suggests the use of non-expansive

VR equipment, since they provide the same results as high-end VR. The study also noted that using VR HMD caused sometimes nausea and dizziness to users. The 3D monitors like Cave does not have similar issues. [26]

The quality of visualizations is depending on the application in question. High quality resolution provides deeper immersion. Low quality resolutions are still enough for some applications.

3.3.2 Visual Output CAVE

The Cave Automatic Virtual Environment (CAVE) is a VR application output, where several images are projected on the walls around users. Maximum of 6 walls can be projected, but usually 4 is used. Users need specific goggles to see the stereoscopic 3D images. User in CAVE environment in figure 4. [17 p.50] [27]

Cave provides a good way to collaborate with projected 3D images. Several users can be using it at the same time. The Cave support movement in the environment. Because of the multiuser possibility, the Cave is driven by a main user. The main user is controlling the movement and sight in VE. [17 p.50]

Figure 4. User in a Cave environment.

One benefit of the Cave is that users are not blindfolded as in the VR HMD. VR HMD could also be liming factor for some patients since VR can cause motion sickness. The downside for the Cave are relatively high cost, space requirement, static installation of the system and possible viewing errors that are correct only for the main user.

The Cave has been used in building projects to evaluate designed building spaces and premises. It also has been used in some VR group therapy sessions.

3.3.3 Haptic

Tactile perception can be felt by pressure, vibration, temperature and pain. For the VR systems, there have been developed many haptic systems. Only few of those have made it to the mass markets. Commonly there are control units, gamepads or joysticks as haptic inputs that can react to virtual objects. These are versatile to use. Other haptic systems are made for more specific needs. These are virtual gloves, haptic tools, training devices and other custom-built solutions. [17 p.79]

The common high-end VR solutions has hand-held controls that's position are monitored by the VR system. This allows the system to locate users' arms and movements that are reflected to the virtual world and to the users view in HMD. In the low-end HMD, the controls are implemented via Bluetooth controllers, integrated buttons in the HMD or pointing the users view to the spot that needs to be activated for a few seconds.

Surgeons training can be made with VR tools such as virtual scalpel. The virtual scalpel produces pressure sensation, that is crucial for surgeon to practice knowing how much force to use. With these tools a surgeon can practice the surgeries in more realistic ways.

The VR tools can also be used in a robot surgery. The surgeons can practice as much as needed without risking the patients. The robot surgery trainings can simulate real surgeries and the knowledge can be directly used in real life. The robot surgeries could be used remotely, if the latency and bandwidth issues would be solved as discussed previously. In a figure 5. can be seen an image of DaVinci surgery robot and its controls. [17 p.123] [28]

Figure 5. DaVinci surgery robot.

For physical rehabilitation, there are hand-held controls that are integrated to the training device. These provide immediate feedback that can be seen during the rehabilitation session. These are motivating the users for better results.

3.3.4 Olfactory

Humans have olfactory receptors cells that detect chemical odors. Cells signal to our brain for a certain reaction. The odors can be produced by releasing a small amounts of odor samples in the air via an additional hardware. Olfaction is a strong sense that can affect human feelings. This was olfaction can affect strongly for the virtual immersion. [17 p.149]

Olfaction is rather difficult to manage. There are some issues to overcome. The released odors can stay in the ambient room. This might affect badly to the wished result. Other challenges are controlling the dosing, release of the scents and storing the scents. There are some commercial products that can provide certain odors for VR solutions needs. [17 p.151]

Olfaction has been used in Post-Traumatic Stress Disorder (PTSD) treatments to create foreign scents for combat veterans and in addiction rehabilitation to stimulate cravings, e.g. smoking. [17 p.158]

3.3.5 Sound

Humans use sound to locate and detect the sound source. The sound has properties such as pitch, volume, timbre and tempo. Hearing mechanisms are complex and adjusting the volume is not sufficient to create virtual sound environment. Hearing can have a huge impact on the VR experience.

The sound environment for the VR are produced by headphones or loudspeakers. The headphones are the most often used and combined with the HMD. It is important to track the head movements to replicate the sound sources correctly. The loudspeakers enables to create sound environments for a multiuser VR.

Many factors need to be considered when planning a good auditory environment. Auditory environment need to match the visual outputs and other sources to be realistic. Otherwise the immersion feelings can be compromised.

3.3.6 Taste

Taste is the ability to detect different flavors and textures, such as food and drink. Taste is sensed by the taste cells in a mouth. Humans can taste 5 different flavors: sweet, sour, salty, bitter and umami. The flavors are difficult to mimic virtually. The taste also relates to other human senses such as haptic and auditory. Like odors, the taste can affect persons mood and feelings. [17 p.156]

Due to technological evolution in the past years, researchers have learned to mimic different tastes. The researches can create virtual tastes for sweet, sour, salty, bitter, mint and spicy. These sensations are made with controlling the temperature and electrical stimuli to a user tongue. The different tastes depend on the electric amplitude and frequency going to a tongue. [29] [30]

Another stimulus is needed to mimic the texture. In a recent experimental study by A. Niijima et al., the team tested a new method to attach an electrode to a jaw muscle. This method provided a way to feel the virtual texture of food. A test user had a feeling of chewing hard or soft, once they bit this virtual stimulus. The study result encourages that electric muscle stimulation can affect feeling the virtual texture. [31]

The virtual taste is not just for entertainment. It has some use cases to cut down salt consumption of elder people, cut down the sugary food and drinks consumption or help in other eating disorders. [32]

The virtual taste in one of the evolving ways of VR technologies that hasn't been studied a lot. This might provide interesting new treatments and methods in the future.

3.3.7 Movement in VR

Moving in the VE is important to support the immersion and freedom of exploring the environment. The VR systems need to be able to provide 6 degrees of freedom (6DoF). 6 DoF means the 3 movements in the viewer position, left/right, up/down and forward/backward. The other 3 movements come from the users viewing point. In other word, the users head movement that can also move to 3 directions. These need to be actively monitored and refreshed to the visual output. [33]

For a VR system to see user movement, moving objects and forces, the system need to use different sensors as input devices. The sensors can be potentiometers or use different electric-, magnetic-, ultrasound- or optical methods. Even physiological signals can be used as inputs, such as EEG, EMG, pulse or thermometer. These signals are translated to the VR system that can correlate these to VE. [17 p.14]

Commonly in a high-end VR solution there are ultrasound beacons, infrared lights or radio frequency beacons, that monitor user movement and position from the real world. Hand movements are monitored from the control units or joysticks that a person holds. Head movement are monitored from the head-set that user wears. [17 p.15-19] [22 p.176]

3.4 VR Content

An essential part of the VR solution is content. The content controls different virtual stimuluses that was presented in the previous chapters. The visual content for VR is made by software tools and software development kits (SDK). Process is close to programming games visualizations. The VR applications need smooth real-time engines to run. Several development platforms exist that are free to use. Common tools for development are products called Unity and Unreal. Depending on the VR device and its attributes, the software content need to be designed accordingly for a certain device and model. [34] [35]

Another visual content type is 360 videos that can be used with low-end VR glasses or advanced HMD. The 360 videos are recorded in real life with several video cameras. The separate videos are patched together seamlessly. A user can look around to the 360 video and get visual immersive feeling of being present in the virtual environment. This is a relatively cheap content creation solution, compared to 3D programming that must create the whole visual content from a scratch. The 360-video solution however needs some coding to manage the content and controls inside the application. For example, an app can give control options to play, stop, exit application or choose an action built-in to the application.

In some use cases, the 360 videos could be used by patients themselves. This could be for example a relaxation video for stress relief. Some treatments need medical professionals to aid the use and monitor the progress. The VR content can be realistic and show detailed graphics. These might not be suitable for all healthcare use cases. For example, a PTSD patient treated with realistic VR immersions could be too scary for the patient and worsen the treatment. For this purpose, the content should to be possible to adjust the level of details and showed scenarios. Another best practice is mirroring the HMD content for the supervising medical professional. This way the doctor can also see and control the process of the treatment.

3.5 VR Products

The common available general VR solutions can be separated into two categories: low-end and high-end devices. They differ by quality and features, which correlate with price. Followingly the most common products and their properties are presented.

3.5.1 Low-end Devices

Simplest and the cheapest solution is using mobile phone as a HMD. These are the modern world commodities that most people possess. The mobile phones today can provide the technology for VR graphics display, sounds and gyroscopes. These are an easy and cheap solution to be used as a full VR solution.

A simple head-set could be even made from a cardboard. Google carboard solution is a one example of this as seen in figure 6. These are one of the reasons why VR solutions are booming to the bigger audience. Anyone with a proper mobile phone can also afford to have a cardboard HMD. [20]

Figure 6. Google Cardboard headset for mobile phone.

A more professional and comfortable solution for mobile phones HMD are made from plastic. The main differences in these are the materials. The HMD fastening and durability are better on the plastic versions. User comfort and design has also a big impact to the user experience.

Some plastic HMD models have also built-in input controls. Another control option is a separate Bluetooth controlling unit. These can communicate with the mobile phones Bluetooth connection as an input device, if the application supports it. Either of these controls need to be coded into the application, depending on the selected control mechanism.

Samsung Gear VR is an example of plastic HMD with better design and comfortable paddings and straps. It also has adjustments for viewing lenses distances. The Samsung gear VR cost around 150 € in 2018. Samsung Gear VR can be seen in figure 7. A lot of other cheap plastic HMD are also available on the markets. [21]

Figure 7. Samsung Gear VR head-set with control buttons on a side and a lens adjustment on top.

According to user head movements the view is refreshed to the screen. On the mobile phones, this is done by the phone's accelerometer and gyroscope. For the low-end VR HMD, the costs are a benefit to reach high volumes and masses. The downsides are limited extension possibilities, limited calculation power in CPU and GPU and lower immersion experiences than in high-end devices.

3.5.2 High-end Devices

There are some high-end VR vendors that are trying to provide the most immersive experiences and easy to use solutions. Currently the high-end market is dominated by manufacturers HTC Vive, Oculus rift and Sony PlayStation VR. First two providers suit for general VR solutions and Sony is focusing mainly on gaming. Oculus and HTC HMD can be seen in figures 8 and 9.

Figure 8. Oculus Rift and controllers.

Figure 9. HTC Vive virtual reality system and controllers.

HTC and Oculus uses regular PCs and video cards to provide the required graphical computing power. They all have physical cabling attached to the head-set. The cables are needed for powering the HMD, transferring video graphics to the HMD and connecting to movement trackers and sensors. The movement sensors on HTC Vive and Oculus rift can follow user on a limited area. This provides the user a possibility to walk and move inside the room and VE accordingly. For such setup, there needs to be enough space to allow the movement. The disadvantage with the cables is the discomfort for the user that cannot see the real world obstacles while wearing the HMD.

The cost for high-end devices are consumer friendly, which is essential to get the mass market and consumers interested. The prices for the high-end HMD setups with accessories start from 400 € for Oculus and up to around 600€ for HTC. One must keep in mind that this is only the HMD system price. A powerful workstation is also needed, which easily doubles the pricing. The software content is another cost factor to consider the full system cost.

3.6 VR Markets and Technology Summary

First barrier for a new technology to gain popularity are the cost factors. How much does it cost for a single person or treatment? What is the cost-efficiency compared to current treatments? Do the new treatments provide better results or provide an alternative treatment to existing ones?

Today the costs have sunk from the early days of VR due to new VR manufacturers and competition. The current VR hardware solutions are affordable and technologically sufficient for many medical uses. The requirement is still to verify the effectivity of the VR treatment. Also, the main stream VR devices are not usable in all medical treatments. For some uses there is a need for customized solutions. These special VR solutions cost a lot. For example, the DaVinci surgery robot costs are in six figures. The market indicators though show that there is plenty of room for the VR solutions to grow in the healthcare markets in the upcoming years. [36]

Another end of the VR solutions are the low-end devices. Due to the rapid evolution of the mobile phones they are also able to provide full VR experiences with proper headsets. This opens possibilities to provide VR service and treatments to bigger masses. The services could be provided for patients at their homes and possibly even at globally, if the treatment is suitable for such remote usage. The mobile VR platforms are not suitable for all VR treatments. Since the technology is constantly evolving this might not be an issue after few years.

The current technological evolution shows that VR and other XR technologies are quickly becoming common. This means that more knowledge, researches, studies and pilots are needed. Especially in the healthcare field this is mandatory. Today it feels bit further away, but we are on the edge of these new VR services to became generally available.

4 VR applications in Healthcare

This chapter covers a background study of VR researches and findings in healthcare sector. It provides information of different use cases and field studies that has been done. Different chapters describe VR related studies from psychotherapy, pain management, rehabilitation, simulation, training, education and surgery.

4.1 Psychotherapy

Virtual Reality solutions provide new tools for psychotherapy disorders. These include post-traumatic stress disorders (PTSD), phobias, anxiety disorders and other cognitive behavior disorders. In some cases, VR applications provide new tools for psychotherapy treatments that has not existed before.

The current treatment guideline for phobia and post-traumatic stress disorder are cognitive behavior therapy, exposure therapy and EMDR-psychotherapy with proper medication, if the conditions are severe. [37] [38]

4.1.1 Post-Traumatic Stress Disorder and VR

In Finland PTSD disorders are affecting refugees, peacekeeper or crisis forces, domestic violence and rape victims, accidents and other shocking situations like mass crisis situations. By estimates there are 100 000 events yearly that match PTSD criteria, where 20-30% can cause PTSD symptoms. For refugees, the numbers are even higher. Trauma events concern approximately 57-78 % of refugee immigrants. [37]

War veterans are sometimes suffering from post-traumatic stress disorder, PTSD, after experiencing exceptional and horrendous situations during the war. The PTSD can also occur after a terrorist attack, kidnapping or other exceptional situation. These conditions might follow a person in normal civil life causing the PTSD.

It has been reported that 1 out of 6 Iraq war veterans are suffering from PTSD and other similar stress disorder conditions. In a study conducted by A. Rizzo et. al were using VR exposure therapy (VRET) to treat the PTSD. The VRET was simulating stressful situations via means of VR technology. The situations were those that person had been exposed to, such as disastrous combat environments. These were re-created and simulated in the Virtual Reality. Details and different properties could be adjusted by the operating clinician. The system included several stimuli such as VR HMD, 3D audio, vibrotactile and olfactory. A group of test persons suffering from the PTSD were guided through the re-generated trauma situation in the treatment sessions. Using the VR technology, the trauma disorders were treated with very promising results. 16 out of 20 patients were no longer meeting the PTSD criteria. The effects were also seem to last on long term. Other similar studies have also shown to correlate with this study. [39]

A study was done after the 11.9.2001 World Trade Center terrorist attack by JoAnn Difede et al. In a VRET study Difede and her research group showed a significant difference in clinical and statistical difference between VR group compared to control group. The results showed that 9 out 10 patients had improved their condition in the VR group, where the control groups condition had stayed the same or worsen. Also after 6 months follow-up the VR treatment results remained. A notable remark was also that the VR treatment provided aid for some patients whom earlier wasn’t successful in a traditional exposure therapy. [40]

These studies show promising results of new treatment tools that are benefiting the VR technology. It was noted by both studies that the treatments need to be run by experienced therapeutics. In general, the VRET tools are not purposed for self-treatment and always needs proper guiding and healthcare professionals to support the treatment. Another issue pointed out by the studies was that the researches patient groups were rather small and more controlled studies are needed. [39] [40]

A benefit in these studies noted was that the VRET as a treatment is easy to approach by the patients. These psychotherapeutic conditions are sensitive issues and could be a cause of a stigmatization. Therefore, the VRET was seen interesting new tool for treating the trauma causes, rather than the typical exposure therapy. [39]

The PTSD treatments can be used to other similarities, if the patients have experienced matching conditions. Otherwise the software needs to be altered to match a specific trauma event and experience. Therefore, the patient amounts for the VRET are limited. For the PTSD, it might be better to use other psychotherapy treatments, if the patient amounts are small. [22 p.59]

4.1.2 Phobia Treatment

Different phobias concern almost 10% of all population so that it causes some disturbance to normal life. There can be various symptoms like panic disorder, anxiety and other stress reactions besides the common phobias. [41]

Similarly to PTSD study, VR exposure therapy (VRET) can be used to treat phobias. The VRET has been used to treat various phobias. These include fear of heights, flying, needles, spiders, dental phobias and claustrophobia. [22] [40]

In a study by Raghav, Kumar et al. a randomized control trial study was made to see effects on treating dental phobia with the VRET. In the study patients were exposed to virtual dental visit. Study start the treatment by introducing a dental clinic in virtual environment. Step by step more accurate stimulus were added. These included drilling sounds and clinical odors. The patients also had to open their mouths while wearing a headset to simulate the dental visit. In the end, the study showed statistical significance in results compared to a normal exposure therapy. For all treated patients 6 out of 9 completers had no longer the dental phobia after the 6 months follow-up period. 4 patients were from the VRET group and 2 from control group. 4 out 5 VRET patients had scheduled a time for dentist. In the control group none did this. [42]

In a randomized controlled trial study by K. Meyerbroeker et al., a team was treating patients with panic disorder and agoraphobia. In the study, there was no difference between VRET and traditional exposure therapy. [43]

Virtual Reality Cognitive Behavior Therapy (VRCBT) can also be used to treat many different phobias. It has been used in social phobia, flight phobia, claustrophobia, fear of driving, arachnophobia among others. This can be adapted to almost any kind of phobia treatment. [22]

A follow-up study by MP. Safir et al. showed that using VRCBT in public speaking phobia, there were no differences compared to Cognitive Behavior Therapy (CBT) group. Both treatments were effecting equally. The results also remained during the one year follow-up period. The study also compared the therapies to patients on a waiting-list. It showed that both the VRCBT and the CBT were improving the patients' conditions. Even there were no differences in effectivity, the VRCBT participants had fewer dropouts during the study. Another improvement was that the VRCBT provided more control to the therapists.

This encourage the VRCBT treatments to be more appealing than traditional treatment, even the effects are the same. [22 p.35]

VRET and VRCBT have proven to be effective on treating phobias. It might not be a silver bullet for all phobia cases, but at least an optional treatment method. The underlying mechanisms are still uncertain. More studies are needed for treating phobias such as social phobia, panic disorder and agoraphobia. For these phobias, the patients might be too scared to even get involved with any treatments. A remote treatment from patient’s home, using the VR solutions, might a suitable way to lower the barrier to start the treatment in a safe environment. [22 p.59]

4.1.3 Cognitive Behavior Therapy for Children with Autism

Children with Autism Spectrum Disorder (ASD) are lacking communication and verbal skills and have other behavioral impairment. The ASD children are at higher risk on disaster scenarios such as fire and earthquake. Strickland et al. studied the evolution of Virtual Reality cognitional training with ASD and Fetal Alcohol Spectrum Disorders (FASD) children. These included studies of fire safety and road crossing skills via VR tools. The initial studies were started in 1996 and developed from there on. A study in 1997 showed promising results where 11 of 14 child performed 100% accuracy in virtual world fire safety steps. Challenges mentioned in these studies were communicating with the ASD children, designing the controls and visual instructions. The evolution study also told of following trial studies between 2001 to 2005 by Padgett, Coles, & Strickland. The results from these studies taught FASD children to cross-roads with success rate of 72%. A week later the children’s retention was 69%. The Strickland’s evolution study results showed that VR education to ASD and FASD children were significantly improving their skills. [45]

A study by Ke et al. taught autistic children to improve their social skills and practice behavior in a virtual world via an avatar. The study taught social manners like greetings and making an eye contact with confronted persons. The study results significantly improved the children abilities in the virtual world. The behavior also followed up to the real world. [46]

Another study by N. Didehbani et al. were studying young ASD children with VR Social Cognition Training (VR-SCT). The study measured emotion recognition, social attribution, attention and executive function. The study setup was using Second Life game version 2.1 and its avatars. In this study no HMD were used, since some studies have shown to cause motion sickness, especially for ASD persons. The visualizations were done using three 24” monitors. An audiobox was used to instruct and interact with the patients in different voices. The voices matched to a confederate clinician’s avatar figure. The intervention included several challenging social scenarios for adolescent participants, such as cheating or meeting a new friend. The confederated clinician played different avatar roles, such as a child whom had lost her puppy with the audiobox voices. After each session a lead clinician, called also VR coach, advised and educated the participating patients and gave feedback from the tasks. This study, as some other previous research work on the field of VR-SCT, supported that VR education can offer effective treatment for improving social skills of the ASD impaired. [47]

A study by Y.J.D. Yang et al. showed that using VR-SCT has implications to brain activity. The study reported to be the first time such impact was looked by a functional Magnetic Resonance Imaging (fMRI) brain scanning device. The fMRI is a brain scanning tool that can be used to study brain activity. The evidence showed that VR-SCT affected brains neural circuits that handle social emotional experiences and language comprehension and interpretations. [48]

4.2 VR for Pain Reduction

What is pain? Pain comes from the nerve receptors that’s send signals to brain via spinal cord. The brains identify the type of pain, location and strength and compares it to previous feelings of pain. A body and mind react to pain by interrupting other tasks. This has been a vital process for the human survival. Physical factors play a huge role of how a person experience and feel pain. The pain feelings are affected by different individual factors such as age, culture, thoughts, mood and earlier pain experiences. [49]

An acute pain is treated by removing the cause of pain. The pain feelings are reduced by medication such as opioids and pain killers. Other non-medical treatments are cold treatments, relaxation and turning focus away from the pain by reading or listening to music. [50]

The Virtual Reality could be a great tool to turn pain focus away using visualization, sound, olfactory and sensory feedback. One assumption for VR analgesia’s function is a gate theory. The idea is that the more different stimulus and senses sent to the brain closes the gates for a person to focus to pain stimulus. This way the patient would be feeling less pain. [51]

Another aspect for Virtual Reality during the clinical treatment, is that the patient doesn’t see the actual treatment care happening. This usually creates strong anxiety towards the procedure that is been accomplished. Using a HMD to block out these visual expectations, can help to reduce pain feelings. [51]

Following chapters goes through different studies that have been made for handling the pain with VR.

4.2.1 Burn Wound Patients

In Finland in 2018 burn wound patients have lowered to half from some decades ago. Yearly there are roughly 1 000 patients that require hospital care, where 50-70 are considered serious conditions. [52]

Burn wounds covering a patient’s body are extremely painful. Typically, when a body is covered with burn wounds, the pain is reduced by medication and opioids. The medication can cause unwanted side-effects such as drowsiness, affect nutritional intake and cause addiction to drugs, if used for longer periods. Other bad symptoms could be caused for limbs rehabilitation. The burn wound patient limbs should be stretched and mobilized to improve the healing process and minimize long-term disability. Virtual reality solutions for pain reduction provide a good way to re-focus the pain feelings and reduce the amount of medication needed to avoid the unwanted side-effects. [51]

The first applications for VR pain relief was made for burn wound patients. This work was started by a scholar Hunter G. Hoffman in 1996. He and other professionals together created a VR game called SnowWorld. The game took place in a cold winter world, where a player was moving through a wintery scene. The player had a possibility to shoot snowballs to penguins, snowman and other objects to gain scores. The idea behind this was to keep the patients focus to stimulus provided by the SnowWorld game and not focusing on the pain feelings. There have been many studies using this game, SnowWorld, and other 3D VR solutions to study their mechanisms, trustworthiness and effectiveness for VR analgesia. In these studies Hunter G. Hoffman et al. noted that virtual reality offers many stimuluses sound, visual and touch that provide immersive experience. This reduces the patients pain input. [54, 55]

In 2001 a study by Hunter G. Hoffmans, Patterson, Sharar and Carrougher a repetitive VR analgesia was studied. The reason was to find out, if the effect was only for first time users experience or long-lasting mechanism. If the effect was vanishing during treatments, there was only minor use for practical clinical work. Typically burn wound patients go through several physical therapy sessions and other treatments, such as daily bandage changes. Another aspect was distinguishing from placebo effect, where one could show potential at first, but slowly the real effects might vanish.

The study found out that the VR analgesia effect lasted through the seven days experiment. It provided promising results for more comprehensive studies. The authors also noted that the burn wound injuries are usually the most painful to suffer. If these techniques prove to be effective, it will most probably work with many other painful procedures. These procedures include painful cancer treatments, medical procedures where patients should remain conscious, avoiding opioids during treatments, stroke victims and many others. The study results showed that the pain experiences on Visual Analogue Scale (VAS) test was lower. Also time the patients were focusing on the pain was shorter during the VR treatment than without VR analgesia. [51]

4.2.2 VR Analgesia for Chronic Pain

Chronic pain is a common symptom. It is estimated that every fifth person is suffering from pain in Europe. It roughly means 100 million persons. Chronic pain is not as widely studied as acute pain. [53]

In a case study by Hoffman et al. a team created an optical HMD. Purpose was to use it during a hydro tank treatment. Hydro tank is tank filled with water, where burn patients are treated with wound care. In the study, the treatment was successful for a single patient. Such method drastically allows more VR pain treatments during the most painful treatment phases, such as the hydro tank wound care. [54, 55]

In later studies, the VR analgesia have been studied with a fMRI machine. It can be used to see how our brains react to pain feelings. The studies have confirmed that the VR analgesia reduces brains pain-related activity in all main parts related to pain feelings. It is worth to mention that the optic HMD device was also needed to study the VR analgesia in the fMRI machine. The fMRI machine uses strong magnetics, where no metal objects are allowed inside it. Therefore, an optical HMD was needed, similar to the hydro tank study. [55, 56]

Other controlled trials have also confirmed the effects of VR analgesia. A study by B. Kipping et al. tested VR analgesia with off the shelf VR. Adolescents in the study reported systematically lower pain feelings, even the difference was not statistically significant. Study noted that a customized VR equipment might provide better results. [57]

VR studies have proven to be effective tool to decrease pain feeling inside the clinics with proper VR HMD technology. In 2014 a study by Wiederhold et al. tested a low-end mobile HMD and compared it to a high-end HMD technology in VR analgesia. The results showed that mobile phones were useful tool that provided significant difference treating the pain. However, the low-end solution was not as effective as in the high-end HMD setup. The low-end mobile solution could be an easy way to provide the VR pain management for bigger masses in the future. The study concluded that large scale studies and longer-term follow-up studies are needed for confirming the effectivity. [58]

Another study by H. Hoffman was looking at the differences of equipment used in the VR analgesia. The finding was that high-quality HMD is mitigating more pain than low-quality HMD. [59]

In a comprehensive literature review study by Li et al., the team found several researches of VR and pain management. The VR analgesia has been used for burn wounds patients, painful cancer and chemotherapies, lumbar punctures and routine medical operations. All the studies had systematically similar findings supporting that the VR analgesia can be used to attenuate pain. Even some of the studies did not find a statistical difference, other benefits were attached to VR analgesia. In the VR analgesia, the patients were reported to be more relaxed, spent less time thinking about pain and had reduced unpleasantness feelings. Healthcare professionals also reported increased cooperation with the patients and decreased anxiety and stress. These will ease the treatment procedures to go more smoothly and faster. The review studies generally dealt with acute pain and only few chronic pain studies had been done. In the Li's report, a few chronic pain studies had had similar VR analgesia reducing effect than in acute pain. [60]

4.3 Rehabilitation

VR rehabilitation in this chapter covers stroke's physical and neurological training. Secondly the chapter presents VR rehabilitation for different addictions.

4.3.1 Stroke and Physical VR Rehabilitation

Stroke is globally one of the main causes of death and disabilities for men and women of all ages. In Finland, the most common causes of deaths are related to blood circulation conditions, such as the stroke. The stroke affects yearly for over 10 000 people in Finland. The most people that survived the stroke, suffer from a left- or right-sided hemiplegia. The stroke impact to large patient groups and their relatives. It is effecting the patients motor and social disabilities. [61] [62] [63]

An ageing society is a global challenge. The statistics predict that globally the amount of 60 years old peoples will be doubled by 2050. This is challenging the healthcare system and specially the elder people, whose risk for stroke grows drastically as they age. [64]

Post-stroke rehabilitation uses physiotherapy and rehabilitation therapies to activate the patient’s movement or other disabilities caused by the damaged part of the brain. The exercises depend on many factors and how the conditions had emerged. A neurological training might be needed, if the patient has lowered observation skills, memory issues and other cognitive problems. [65]

A study by L. Piron et al. used Reinforced Feedback in Virtual Reality (RFVR) and compared it to conventional therapy. The study used 3D motion-tracking system and high-resolution LCD projector. In the therapy, physical therapist could create tasks for the patient. While doing the given tasks, the patient could see measured exercise feedback on the screen. This was compared to conventional therapy, where therapist advised the patients for the exercise tasks. The finding in the study was that RFVE scores were systematically higher than in conventional therapy. An observation by this study mentioned that the patients were more engaged to the RFVR rehabilitation than to the conventional therapy. Visualizing the results and gamification can improve the patient motivation for rehabilitation. The study noticed, that it was auto-motivating for the patients to improve their rehabilitation scores and rehabilitation development. [66]

A meta-analysis study in 2011 by Gustavo Saposnik et al. found that virtual reality in stroke rehabilitation enhances the potential for upper arm limb’s stroke rehabilitation. The results indicate that VR rehabilitation might offer more improved results compared to conventional therapy. [67]

Another meta-analysis study by Lohse et al. concluded that stroke rehabilitation is more effective than conventional therapy. The study included 26 research studies covering the VR therapy for stroke patients that were compared with the conventional therapy. [68]

In 2017 Kate E Laver et al. did a Cochrane review study comparing the research works related to VR efficacy compared with alternative intervention. The material included 72 trial studies. Interestingly, the results showed no statistically significant improvement compared to usual care. Some of the studies had combined the usual care together with VR therapy, which resulted to statistically significant improvement. This was expected to result from increased overall therapy time. The quality of the review analysis was reported to be low or moderate. This was due to analyzed studies, which typically had small number of patients that can bias the results. Laver's study showed that upper limb rehabilitation does not improve the rehabilitation effect compared to the conventional therapy. It can be a good alternative and supportive tool in rehabilitation to increase motivation and therapy time. It is good to keep in minds, that for some people, the VR training might not be suitable to use due to patients age, nausea or other conditions. [69]

A. Hughes et al. studied what are the barriers that block new technologies, like the VR in stroke rehabilitation, to spread into common practice. Even there are a lot of evidences of the VR technologies power and cost-efficiency, the key findings were that professionals and patients were lacking knowledge, awareness, access and education regarding the new technologies. The study noted a need for improvements for designing new technology, in pragmatic clinical evaluations, in service provisioning, in better awareness and knowledge. [70]

4.3.2 Stroke and Neurological VR Rehabilitation

In addition to the physical training there are also solutions for cognitive and neurological trainings leveraging the VR technologies.

A systematic review study was used by Ogourtseva et al. to study the effect of virtual reality for unilateral spatial neglection. That is a condition where the stroke patient has difficulties to detect spatial distances and spaces. The group found 23 studies, where the results showed limited evidence that the VR is more effective than a conventional therapy. In addition, the study found the VR to broaden the treatments to safer environment than the conventional treatment. The VR treatment also provided ways to collect data and outcomes that were not possible in the conventional therapy. The study also noted that some of tested VR systems might be expansive. It would be relevant info to practitioners to know what kind of efforts these VR solutions require. Besides the costs, there are other requirements, such as know-how and staff trainings, that need to be considered, if one would like to start deploying the VR treatments in practice. [71]

One of the means in neurological VR rehabilitation is using gamification. The gamification in these are called the serious games. It is important that the serious games are well designed and the game flow is suitable to the patients. The game flow means that the game is not too easy, but also not too difficult. The game flow and difficulty need to be adapting to the patient’s skills. This requires some expertise from the serious game creators or professionals designing such solutions. [22 p.180]

A reviewing study in 2016 by S. Valladares-Rodríguez et al. found 57 studies that were handling neurological and cognitive rehabilitation with VR. This included 54 serious games. The study results noticed that there were different ways that had been used in neuropsychological evaluation. Those were mainly testing different approaches for the evaluation. The study noted that the research work in this field had grown a lot during the past three years. The research work showed a good potential for conventional neurologic testing. For clinical use, these tools need more researches and testing. [72]

In an article of a Finnish company, Peilivision, the story explain the benefits of the VR rehabilitation. The company has created a solution for stroke patients and elder people. In the solution, the therapeutics can create tailored tasks for the patients. The tasks could be practicing vocabulary, training memory or other customized rehearsals. Out of these practices, the application provides useful information of reaction times and patient conditions. Using gamification, the patients see immediately the training results in the game scores. This is motivating for the patients. One advantage mentioned in the article was possibility for remote usage. The solution can be easily used in clinics, hospitals or at patients’ homes. It eases the lack of therapist personnel resources. Devices used in these treatments were low-end mobile HMD and tablets. The therapists can follow the treatment progress from a tablet and guide the use of the HMD. This external support is important, since most of the patients are elder and not familiar with the technology. [73] [74]

4.3.3 Addictions VR Rehabilitation

Addictions to alcohol, drugs, smoking, eating disorders and others affect a lot of people. These addictions cause globally a lot of direct and indirect problems. By the World Health Organization (WHO) report alcohol is the sixth leading cause of death. [75]

In Finland alcohol and drug related costs to society has been calculated to be over 1,1 billion euro in 2010. The harmful substance addictions cost a lot for the Finnish society, in addition to the high mortality rates. Of course, the VR therapies does not solve these issues, but the more treatment options are available, the better the results will be. [76]

Treatments for different substance addictions are detoxification together with individual or group therapy. The detoxification is used to remove the physical addiction to harmful substances. One of the main problems in these treatments are patient relapses to old habits. It is estimated that the completers of alcohol and drug rehab therapies fails for 40-60% of the participants. The relapses are typically caused by addiction triggers. A trigger could be an advertisement for cigarettes for a smoker or just a stressful situation. VR rehab therapy is focusing to change the patients behavior patterns to overcome the addiction triggers with better behavior and coping mechanisms. [77] [79]

In a study article by Dr. Bordnick et al. tells that there is a lot of evidence that VRCBT can be used to treat various addictions. The VR pioneer Dr. Bordnick's work was started in 1995. In his study regarding the addictions, he sees it might be used to study obesity and eating disorders. Besides the VRCBT and learning for coping skills to resist the triggers, it is also possible to educate patients to make good choices for example in grocery shopping. Motivating the patients to the good behavior via VR tools is more engaging than just handing out printed leaflets. [78]

The problem in the traditional rehabilitation therapy is that the created treatment scenarios are too simplistic or unrealistic. For example, to an alcoholic the traditional rehabilitation therapy has shown a bottle or images of a bar to cause craving for alcohol. These treatments are missing the realistic life-like surroundings. Virtual world can offer a whole range of stimulus like alcohol odors, visualizations of a bar or party and sound environment for social contacts in one package. [78]

A benefit using the VRCBT for addictions is research work. The VR provide tools to study the patient's cravings in laboratory settings. Earlier these have been difficult or impossible to arrange. The patients have different triggers to launch the cue or craving symptoms. In the VR, these cues can be studied and created to the application with a click of a button. It helps both the patient and therapist to acknowledge the issues and situations that launch the disorders for the patient. [78]

A study project by Liam North, Chris Robinson, Adrian Haffegee et al. piloted to see how Virtual Reality Exposure Therapy could be used to identify triggers for alcohol and drug abuse. The study found out that participants were more activated to group discussion concerning the triggers of which they were talking in the therapy session. Though the participants feedback from the study were mixed, the team saw that the patient’s confidence in understanding the triggers slightly improved. [79]

A more comprehensive study by Patrick Bordnic et al. used a VR setup with visuals, sounds and odors. In the controlled trial 40 participants with alcohol use disorders were exposed to VR alcohol cue environments. The study showed that VR cue tools can generate more alcohol craving compared to neutral VR cues. The finding in this study was that VR based cue reactivity environments can be used to further study the alcohol and other addictions treatments and research. [80]

The substance addictions treatments with VR technology seem to be very promising and working on many areas. Later addiction research work has been done with heroin addicts. Another new area is treating addicted internet game players with VR treatments. [81] [82]

4.4 VR Simulation and Education

Virtual reality training and education is useful since there can be virtual patients and different training scenarios as much as needed. In traditional education, these would need to be simulated or created with substitute solutions or learning by following mentors work.

This chapter covers educational use cases for simulations trainings, therapeutics and stereoscopic 3D trainings. In the end, surgical training cases are also presented. In general, it is notable that almost any kind of practical work could be educated via the VR tools.

4.4.1 Simulation Based Training for Mass Disaster

Training for mass disaster events are difficult to arrange. The trainings are limited in realism or are costly and difficult to arrange. Virtual reality can provide cost-efficient, easily accessible and modifiable tools for the mass disaster training. A study by Philip Pucher et al. validated a model for virtual simulation training for mass disasters. By the study, they showed that expert groups performed better than novice groups in speed and trauma non-technical skills. All test users thought that VR simulation was realistic and provided better options for training than in traditional training methods. [83]

A study by S. Farra et al. found out that Virtual Reality Simulation (VRS) training for disasters is a significant tool to be used for educational purposes. The study outcome was that learning is long lasting compared to comparison group after 2 months follow-up testing. The results showed that VRS improves learning retention and reinforces learning. [84]

4.4.2 VR Anatomy Education

Virtual reality education for anatomy has benefits studying the human anatomy. In virtual education, there is no need for cadavers, animals or other real-life samples. Assuming this provides excellent tools for teaching medical doctors, this isn't necessarily the case. In 2007 a controlled trial study by Anthony Levinson et al. found that in some circumstances computer aided education may slow down the learning process for some participants. [85]

A study by L. Mendoza Oropeza et al. compared fourth year dental bachelor's students in 3D training and compared to traditional training. The traditional training was done with presentations and chalk board. The finding was that students with the 3D training have significantly better capabilities and skills compared to the traditional way of teaching. In the 3D training students learn to identify and diagnose more anomalies, which the students needed in their fifth-year clinical training period. [86]

A later study in 2017 by Susan Jang et al. saw the difference on gaining the optimal viewing compared to the passive viewing. In the study students were either using 3D visuals of inner ear anatomy or passively viewing the same images. The study showed clear advantages for direct manipulation beyond passive viewing. [87]

The anatomy training has notable benefits for replacing old substitutes. The optimal education methods using virtual reality is still unclear.

4.4.3 Therapist Training and Virtual Patients

Training new healthcare professionals is not an easy task. A novice practitioner need several years of academic studying and learning from professional doctors. In a book by Sheryl Brahnam and Lakhmi C. Jain, researchers had studied a new way of teaching psychotherapists. The solution used interaction with virtual patients, a computer based avatars. The novice therapeutics could interact and practice with simulated but realistic patient conditions. The virtual patients could simulate resistant clients, sexual assault victims, PTSD patients and many other scenarios. The solution showed huge potential to educate better professionals with improved skills for their craftmanship. [22 p.39]

Another benefit for the training was that the teacher or older professional could see and instruct how the novice was performing. This also build more knowledge to the learner, whom could practice interaction with the virtual patients, before meeting the real situations. This method is important in this sensitive area of psychotherapy, where the patients can have huge barriers to even meet with a doctor. Unlike any other medical area, the new psychotherapists must be ready for the real patients, once they start practicing their craftsmanship. In other medical doctoral educations, the supervisors can take over, if needed. [22 p.39]

The interviewing skills are the main competency of psychotherapists to diagnose the patients. Part of the therapist education are typically accomplished by hiring an actor or other students to present psychological disorders that the trainees must diagnose. The problem in the conventional way of teaching is standardization of the patients and diagnosed symptoms. These might depend of the available actors or monetary issues. Virtual reality tools could provide and offer challenging scenarios that would improve the training. In a study by Parsons et al. the group created a pilot of virtual patient (VP). The VP was male adolescent with conduct behavioral symptoms. The Parsons study conducted that the created VP was realistic and had a lot of potential in the therapists' trainings. [88]

A lot of development has been made for the U.S. military in the VR therapies field. One solution for soldiers is an online tool called Simcoach. Simcoach is a low level contacting platform to talk about stressful situations with virtual therapist. Virtual Human (VH) agents are build using artificial intelligence to interact with real users on the platform. These tools provide the patients to take the first step in seeking advice and help. The platform was designed for military persons and their families. The same system can also be adapted to other localizations. Even the main development work has been done for the military needs, the results are also transferrable and usable in many other therapies forms. [89,90]

There are also open source development platforms available for anyone to participate. VR pioneer Albert Rizzo mentioned in his presentation that development kits are available to localize the virtual therapist sessions for different kinds of therapy needs. Using a prepared platform helps to start deploying these new VR therapy tools. [91]

4.5 Surgery

Medical errors cause a lot of mortality and indirect costs. In 1999 Institute of Medicine estimated that there were 44 000 deaths caused by medical errors and 8,8 Billion USD of indirect costs. [17 p.3]

In Finland, there are estimated to be 700 – 1700 deaths yearly, related to medical treatment errors. Indirect costs are evaluated to be over 1 B€, besides other caused symptoms and humane suffering. Approximately half of these would be preventable. These situations are a sum of many different things, false medication, infections, false diagnoses, humane error, device malfunction and surgical errors. Improving the training and diagnosing with latest knowledge and education is important. [95] [96]

Traditional training methods for surgical education are apprenticeship, using animal cadavers and plastic mock-ups. Surgical training is a big area that could leverage VR technology. VR and surgical education has many benefits: it can be made without real patients risk-free, it reduces costs in saving operation room time and costly samples, training availability is better, variability and complication training are all possible to arrange when needed. Despite the many promises there are some risks involved using the VR surgery education. The risks are unclear training targets, transferring knowledge to real world is unknown, missing knowledge compared to conventional method, possible negative learning and required level of realism is unknown. [17 p.182]

Virtual reality applications for surgery are divided for three categories: surgery training, surgery planning and augmented reality for surgery sessions. The first two are in the scope of this work and presented in the following chapters. [86]

4.5.1 Surgical Training

Surgical VR training has mainly been studied from laparoscopic surgery point of view. Other areas where surgical VR solutions has been used are neurosurgery, endoscopic (arthscopy), open surgery, orthognathic, plastic surgery, robot surgery and telesurgery. [17] [21]

Eugenia Yiannakopoulou et al. had studied laparoscopic surgeries using VR simulators and training. The study showed that basic laparoscopic surgeries can be learned from training simulators. This knowledge can also be transferred to an operation room. This is noted as a one alternative training method for laparoscopy students. The study notes that there is no knowledge, if the same applies to advanced surgical procedures. These have totally different levels complexity. A risk-free simulator with VR compared to operating an advanced surgery with real patients that might cost the patient lives. [92]

A systematic review study by Gurusamy et al. found that VR training supplement laparoscopic surgery. The study was found 23 trial studies including 622 participants. [93]

Another systematic meta-analysis in 2014 by Alaker M. et al. studied the same laparoscopic surgery with 31 randomized controlled trials. The result by this analysis clearly showed significant differences. VR training improves operative performance, operation times and outcomes. This is a strong indication that virtual reality should be part of laparoscopic surgery education. [94]

4.5.2 Surgery Planning

Traditionally surgeons use 2D gray images from computerized tomography (CT) scanner. These images are important for planning an operation in a pre-operation phase. By these images, the surgeon decides if and how to perform the surgery. The surgeon forms the 3D image in their minds from the 2D CT images with the help of a professional radiologist. 3D visualizations with VR tools provide more precise picture and data of organ details and other variables in the pre-op planning phase. These are crucial details especially when operating with cancer cells in a liver or with other sensitive organs. Virtual reality tools can visualize the CT images to a real 3D image that the surgeon can explore and study with proper HMD. [97]

A study by Wang Shou-Sen et al. used VR planning tools for brain tumor resection. Nine out of eleven participants saw that the VR tools were superior compared to conventional method, the CT images. Still regular images are needed to complement the VR tools. The study concluded that virtual reality seems to be promising tool for brain surgery in the future. [98]

A study group Kim Y et al. did a meta-analysis regarding VR/AR related studies in field of plastic surgery. They screened for 3 surgery planning areas: 13 studies of surgical planning, 7 studies of surgical navigation and 11 studies of surgical training. The study claim that VR is currently lacking enough realism, but it will be eventually fixed. There are several technological tools available that provide benefits. The benefits are improved view of radiologic data, more realistic pre-operative prediction of outcomes, better learning and training systems and improved surgery results. In the future plastic surgery and planning tools has lots of possibilities with the VR technology. One possibility would be doing remote surgeries. [99]

Meta-analysis by Mazur et al. was studying a brain tumor related evidence for VR simulators. The study accepted 9 studies that were divided into a pre-surgical planning and VR training categories. The study saw that VR technologies enhanced these surgery sections. Still more precise evidence and studies are needed. [100]

5 Evaluation of VR in Healthcare

This chapter presents the thesis outcomes and evaluates each VR treatment types that were presented. They represent the ground work studies related to healthcare and VR that were found in the literature search.

The results are scored to a matrix format to show the results in clear and comparable format. Maximum score for the evaluated treatments is 10.

5.1.1 Psychotherapy Evaluation

This chapter evaluate the findings from the VR and psychotherapy treatments that were presented in the chapter 4.1. Evaluation for the psychotherapy treatments are presented in the figure 10.

Figure 10. VR psychotherapy treatments evaluation matrix

VR treatment	Effectiveness	Patient groups	Cost	Other	Summary
4.1.1 **PTSD**	3	1-2	1	1	6-7
Scoring	✓ Lower the barrier for participating to treatments ✓ More realistic scenarios and stimulus enhance the conventional exposure treatment results ✓ Interactive treatment to support treatment intensity per patient needs	✓ PTSD concern quite large population ✓ In Finland growing number of refugees might get help from PTSD VRET ✓ Treatment is limited to similarities only	✓ High-end devices and many stimulus are needed for good immersion ✓ Need good design and control software that raise the solution costs ✓ Cannot be generalized to masses	✓ Can provide totally new kind of treatment method for those that hasn't got aid from traditional methods.	

4.1.2 Phobia treatment	2-3	3	2- 3	0-1	9
Scoring	✓ Provide totally new type of therapies ✓ Proven to treat many phobias such as dental phobia, fear of heights, spiders and flying ✓ Some phobias could not be treated with VR such as social- and agoraphobia.	✓ Affect a lot of different phobias and disorders. ✓ Patient amounts are in hundreds of thousands.	✓ Low-end devices are enough in some cases. ✓ Same phobias can benefit the same software ✓ Some phobias need extra stimulus and more expertise	✓ Mobile treatment could be possible	
4.1.3 CBT for children with ASD	3	1	2	1	7
Scoring	✓ Provides new treatments for people with special needs. ✓ Effectivity was proven in the presented studies	✓ Limited number of patients	✓ Expertise is needed for designing the solutions ✓ Software can be reused for similarities	✓ Remote sessions are possible	

5.1.2 VR Pain Management Evaluation

This chapter summarize the findings from the VR analgesia treatments presented in the chapter 4.2. The VR analgesia evaluation matrix for different treatments are presented in the figure 11.

Figure 11. VR analgesia evaluation matrix

VR treatment	Effectiveness	Patient groups	Cost	Other	Summary
4.2.1 **Burn wound patients**	3	1	1	1	6
Scoring	✓ Improved treatment results ✓ VR analgesia reduces the unwanted side effects of drugs ✓ Ease the treatment procedures	✓ Low amount of burn wound patients yearly	✓ High-end devices and several stimuli are needed to reduce pain ✓ Special equipment might be needed, like optic HMD	✓ Improving the burn wound treatment quality compared to traditional	
4.2.2 **VR analgesia for chronic pain**	3	3	2-3	0	8-9
Scoring	✓ Proven effects on pain management ✓ VR analgesia reduces the unwanted side effects of drugs ✓ Ease the treatment procedures	✓ Provides aid for many different types of pain	✓ VR analgesia can be done with low-end and low-cost devices, but better quality provides better immersion and results ✓ Pain management software development can be done once and used for many similarities ✓ Solutions could be easily deployed on the clinics with basic VR equipment	✓ Some people might get nausea from using VR. This might not be a solution for all pain patients	

5.1.3 Rehabilitation Evaluation

This chapter evaluate the findings from the VR rehabilitation treatments that were presented in the chapter 4.3. The evaluation for the psychotherapy treatments are presented in the figure 12.

Figure 12. VR rehabilitation evaluation matrix

VR treatment	Effectiveness	Patient groups	Cost	Other	Summary
4.3.1 Stroke and physical VR rehabilitation	1-3	3	1	1	6-8
Scoring	✓ Conflicting meta-analysis studies for and against ✓ New tools and treatment that engage patients	✓ One of the most common cause of death and disabilities globally ✓ Population ageing is a future challenge in western countries	✓ RFVR need integrating external input devices to VR application that can be costly ✓ Gamification and software development require expertise	✓ Improve the treatment outcome ✓ Provide measurable data of rehabilitation	
4.3.2 Stroke and neurological VR training	3	3	3	1	10
Scoring	✓ Rehabilitation concerns patients and their social connections ✓ VR Rehabilitation increases patient engagement ✓ Improved treatment outcome	✓ One of the most common cause of death and disabilities globally ✓ Population ageing is a future challenge in western countries	✓ Can be used on low-end HMD devices ✓ Same software content can be reused for others ✓ Possibility for telerehabilitation	✓ Improving the patients' social abilities that affect even bigger audience, such as the patient relatives	

4.3.3 Addictions	3	3	2	1	9
Scoring	✓ Provides new treatments for many addictions ✓ Lower the barrier for starting a therapy ✓ Good alternative for conventional therapy methods	✓ Many people are affected with addictions ✓ Many different addiction types can be treated	✓ Might require many stimuli such as odors, which can be costly to arrange and implement ✓ VR tools provide easy to use tools and adaptability for many needs	✓ Provide new research tools for therapeutics to study addiction cravings	

5.1.4 Simulation and Education Evaluation

The new virtual reality simulation, education and training tools are becoming more common and advanced as the evolution goes on. This chapter is summarizing the finding for VR simulation and education use cases presented in the chapter 4.4. The virtual reality education and simulation evaluation matrix can be seen in figure 13.

Figure 13. VR simulation and education evaluation matrix

VR treatment	Effectiveness	Patient groups	Cost	Other	Summary
4.4.1 Simulation based training for mass disasters	2-3	2	3	0	7-8
Scoring	✓ Improved results for participants ✓ Strong indication that VR trainings and simulations benefit the education for better results.	✓ Mass disaster events are rare. ✓ Casualties depend on the event	✓ Cheap and easy solution compared to arrangeing traditional training scenarios ✓ Training can be provided to all personnel		

	✓ Different roles can be practiced by each trainee		✓ Content can be re-used		
4.4.2 **Anatomy training**	2	3	2-3	0	7-8
Scoring	✓ Some education methods work and others don't. More studies are required to find the best practices ✓ Advantages are educating rare anomalies ✓ No need for cadavers	✓ Not directly concern patients, but as a basic anatomy training new VR training methods could concern all medical education ✓ Education can be made for almost any kind of activities from nursing to virtual therapy session with avatars.	✓ Can be done on both low-cost and high-end equipment. ✓ Reusing is possible		
4.4.3 **Therapist training**	3	2-3	2	1	8-9
Scoring	✓ VR education for psychiatrists are important before the actual field work ✓ Trainees can practice with anomalies and rare symptoms ✓ Improves the skills of therapist trainees	✓ Can be used on many different therapies education ✓ Education can be made with avatars ✓ Virtual persons can also be used for online patients to seek aid	✓ Doesn't need costly equipment ✓ Development kits are available to modify open source tools	✓ Improve the therapist educations	

5.1.5 Surgery Evaluation

This chapter summarize the finding from the VR surgery use cases that were presented in the chapter 4.5. Virtual reality surgery use cases evaluation matrix can be seen in figure 14.

Figure 14. VR surgery use cases evaluation matrix

VR treatment	Effectiveness	Patient groups	Cost	Other	Summary
4.5.1 Surgical training	3	3	2	1	9
Scoring	✓ Studies indicate that VR training will be the future of laparoscopic surgery education ✓ Benefit to practice with the most special anomalies and rare symptoms ✓ Provide risk-free training and improves the trainees' skills	✓ Concerns great amounts of surgeons and surgeries ✓ Has huge effect improving patient safety and reducing medical errors	✓ Costs for surgical training devices are relatively high ✓ No need for cadavers or other costly or ethically dubious solutions	✓ VR has impact on the future telesurgery and robot surgery fields	
4.5.2 Surgery planning and imaging	3	3	2	1	9
Scoring	✓ 3D imaging will help surgeons a lot in the planning phase ✓ More precise data available ✓ VR tools help the doctors to easily understand the CT images and radiologist findings	✓ Many surgery areas benefit the VR tools ✓ Has huge effect improving patient safety and reducing medical errors	✓ Requires high-end devices that are expansive ✓ Huge savings in time planning the operations	✓ VR has impact on the future telesurgery and robot surgery fields	

6 Summary and Conclusions

This thesis study presented the general background of VR, market trends and technology concepts. After that VR related medical studies were searched and presented. The study found out that the main areas for VR related medical treatments that had been used and studied were psychotherapy, pain management, rehabilitation, education, and surgery.

The selected VR research areas represent the foundation, where the medical VR treatments have started. Same areas were found from many literal sources. The study used both technological qualities and other attributes for evaluating the different factors related to VR technology in healthcare. The target was to find out the most useful and beneficial VR tools that had a scientific research basis. This evaluation and thesis work can be used to find useful VR solutions for healthcare professionals. The study outcome and results are discussed in the below chapters.

6.1 Study Outcome

In this chapter, the different use cases were summarized based on the study findings and evaluation criteria. The scoring was used to indicate the most useful and cost-efficient tools for Finnish specialized healthcare. These evaluations won't necessarily correlate with the medical treatment effect.

PTSD VRET

VRET for post-traumatic stress disorder (PTSD) had been studied a lot and mentioned in several research studies. The studies had shown it to be effective, at least as an alternative option to the traditional exposure therapy. VRET was also lowering the barrier to seek help and avoid stigmatization. It had also shown promise to help patients with long term PTSD symptoms where conventional treatments did not provide aid. Due to relatively small number of patients in Finland and the fact that the PTSD VR treatments would be needed to be personalized to rather small patient groups, the treatment was not proposed to be in the front row. However, one patient group that might benefit the new tools could be refugees with PTSD symptoms. Currently the PTSD patients can be treated with conventional therapies with similar results. VR is a good alternative and enchantment to conventional methods.

In the evaluation, the score of PTSD VRET was 6-7 points.

Phobia VRET

Phobia treatments use VRET. It has proven to cure common phobias: fear of spiders, fear of heights, dental phobia and some others. Still there are areas, where it doesn't work. These include agoraphobia and a fear of social situations. These mechanisms need further research studies and evidence. Still general phobias concern many people and these new tools could provide aid for many.

The same software's and hardware's could be reused to any phobia treatment. It is also possible to use low-end devices, which makes it even easier to start deploying VRET services. Therefore, VRET phobia treatment might have a huge potential for Finnish specialized healthcare professionals.

The evaluation score for VRET phobia treatments was 9.

Autism VR-CBT

A cognitive behavior therapy for autism spectrums disorder (ASD) patients can benefit a lot from the VR-CBT. It offers totally new kinds of treatments for people with special needs. Virtual reality tools can provide new ways to communicate with ASD people that have difficulties in communication and social interactions. The studies presented showed that VR can teach ASD persons important skills from social interaction to disaster survival skills and other. These skills were shown to transfer from the VR to the real world. Also, a fMRI scanning confirmed that the brain interaction changed after the VR training.

The challenge in this is how to develop the user interfaces and how to communicate these to the ASD patients. For this thesis, the ASD VRCBT represents a niche area where VR certainly has an impact to patient outcomes. Looking at the bigger picture, including effectiveness and cost efficiency, the solutions concerns only a small amount of people.

The evaluation score for this Autism VR-CBT was 7.

Burn Wound Patients and VR Analgesia

Virtual reality pain management research, VR analgesia, was started with the burn wound patients. Burn wounds were mentioned as one of the most painful types of pain. The pain treatment has been conventionally done using opioids that causes many disadvantages such as drowsiness, drug addiction and low nutritional intake. These harm the patient's rehabilitation. The VR analgesia treatment improved the patient recovery and reduced the unwanted side-effects.

The VR analgesia can require special equipment and high-end products that are more expensive. On the other-hand these tools can be reused, making it a one-time investment. Even with the proven benefits to the pain treatments, the burn-wound victims in Finland are less than a hundred per year. This is a notable and meaningful treatment method, but from the cost-efficiency perspective, it is not the first VR solution to invest into, if one had to choose.

The evaluation score for burn wound patient's VR analgesia was 6.

VR Analgesia for Chronic Pain

Unlike the burn-wound analgesia, a general VR analgesia concerns a huge amount of people. The pain mechanisms were attenuated when using VR analgesia. The actual pain mechanism for the VR analgesia are unknown. One assumption was the gate mechanism where other stimulus such as visuals, haptics, and odors take more focus and pain stimulus is left attenuated, lowering the pain sensations.

The studies showed that brain activity for feeling pain was lowered during the VR analgesia. Some studies also showed that even low-end devices might be enough to be used in the VR analgesia treatment. This could be easily deployed to the clinics or even to home users. Another benefit was that the same software could be used in all similar cases, making it a one-time investment.

The VR analgesia shows a lot promise and proven effect. Low costs to take it into clinical use and possibly for homecare, makes it an interesting new treatment to consider deploying.

The VR analgesia evaluation score was 8-9.

Stroke and Physical VR Rehabilitation

This study found researches using an upper-limb VR rehabilitation. VR stroke rehabilitation promises a lot, but due to reviewing studies, it seems that the promises are not necessarily met. This is the reason why such studies of effectivity are needed. Even some new tools or treatments seem to be interesting the effects need to be proved to get the best results and tools into use and not to waste resources in the less effective ones.

A good thing of the VR stroke rehabilitation was engaging the patient more in to the treatment. The new VR tools digitalize the rehabilitation results. Using the RFVR tools in some studies showed to excite into more training amounts. Some studies showed that same results could be reached by conventional treatments. This mean the improved results could be a result from a technology enthusiasm. But does it matter, if the new treatments are improving the results. More studies are needed to find the best practices.

A stroke is an important component from the national healthcare aspect. Aging societies in the western worlds are growing the patient amounts. All new tools and solutions are welcome.

The physical VR rehabilitation requires special equipment to be integrated with the VR tools making it moderately expansive. If the integrated technology prices lower or becomes available to mobile devices, this would most certainly make it viable tool for physical stroke rehabilitation.

The evaluation score for physical VR rehabilitation had a spread scale from 6 to 8. The score was depended on the conflicting treatment effectivity data and the VR technology pricing. This technology is worth to pilot or at least follow the evolution of available solutions.

Stroke Neurological VR Rehabilitation

For neurological stroke rehabilitation, it seems to be a different story. They are on their way to the clinical practices. More thorough and clinical testing is needed though. This thesis study found many researches and meta-analyses supporting the fact that neurological VR rehabilitation improved the treatment outcome. As in physical rehabilitation, the VR tools engage people more into this treatment type. The neurological issues affect also the patients’ social abilities. The treatments effects are also important to the patient relatives. The strokes impact to the general population is huge.

The VR treatment for stroke neurological rehabilitation can be done with a low-cost hardware and HMD. It is still good to remember that some people do get motion sickness using VR. Especially this should be considered for the elderly people. The VR rehabilitation treatments design and gamification needs a solid and professional software development. This is increasing the costs of the solution.

The thesis found data encouraging the use of remote rehabilitation for stroke. This would provide more therapist resources for remote locations. This is notable point especially in Finland, where the geographical distances are long.

The stroke neurological VR rehabilitation is one area that can leverage the new VR technology. The VR training is improving the conventional methods in neurological testing and rehabilitation. The evaluation score was maximum 10.

Addiction VR Rehabilitation

Addictions comes in various forms and effect on many levels directly and indirectly. The VR rehabilitation tools had been used to treat alcohol, smoking and drug addictions. Later studies also include using the VR rehabilitation in eating disorders, internet and gaming addictions.

The found research studies report more engagement towards the VR treatments than for the conventional therapies. The VR therapies were found to improve the treatment results and outcome. Addiction treatments using VR CBT tries to change the bad behavior of the patient. In practice, this means creating a virtual environment like a bar with the smell of patient’s favorite drink. These situations create cravings for the patient. The therapists are educating better coping mechanisms and identifying the bad behavior habits. The benefits compared to conventional treatments are more realistic environments that are easily adjustable to different patient’s needs.

The new VR tools had provided the researchers new ways to study the patient cravings and other behavioral mechanisms in a way that has not been possible before. An interesting new area was also found by studying an eating disorder patients using virtual taste sense. This research work was looking ways to create a virtual taste stimuli that could be used to cut down salt or sugary foods consumption. These new tools have an unimaginable potential in the future, once the technology evolves.

The addiction treatment with VR will have a lot of potential and a huge patient base. The evaluation score for VR addiction treatments was 9.

Simulation VR Training

Training for mass disasters is not directly a healthcare treatment type and could have been left out from this study. The training for a disaster is still in an important role for hospitals to keep and improve sufficient skills in these rare occasions.

The found researches from this area indicated improved results for the VR training participants. There were other benefits as well. Different personnel could train different roles and scenarios. The virtual training tools are cheaper to arrange than conventional trainings.

The evaluation score for VR mass simulation training was 7-8.

Anatomy Education

Virtual education has undisputable benefits of replacing conventional training methods, such as cadavers, animal samples or other costly artificial tissue samples. It also provides a great tool for educating rare anomalies that students can learn. In a conventional master-student teaching method, these might not be covered or could only be studied from the text books.

Based on the found studies teaching benefits were not obvious. There are certain cases where the conventional method provided better learning results. Opposite studies could also be easily found. The point is that not necessarily all new VR tools provide the best results. The virtual anatomy training has clear benefits, but more studies are needed to find the best practices.

The evaluation score for anatomy education was 7-8.

Therapist training

Psychiatrist and doctors' education are not comprehensive. Once the student starts practicing the skills learned, there is big leap to the unknown. In other medical doctor's world, there are usually supervisors that can take control, if needed. The psychiatrists are not having such safety net, it is a sink or swim situation. For this purpose, there have been developed virtual patients that use artificial intelligence to mimic real life scenarios. The studies showed that even the virtual patients could be seen unrealistic, the training improved the skills of the learning student. This provided important tools to practice different psychiatric conditions and diagnosing skills. The teacher could also advice and give feedback to the students based on the virtual training scenarios.

Virtual Humans (VH) can be used as a discussion platform for the patients. By this tool the patient could contact an online avatar to discuss bothering symptoms. The VH can advise the patient to seek help or provide information about the conditions.

Therapist training solutions and VHs are not relatively expansive, mainly the software development and AI are the cost factors. Some general development kits and open source VH projects has been reported to exists for anyone to participate. These tools were not accessible during this thesis work and could not be verified.

Virtual patients and therapist trainings show a massive potential. This is worth considering by specialized healthcare professionals. A virtual human platform would be useful for the HUS virtual hospital concept.

The evaluation score for virtual therapist training was 8-9

Surgical Training

Surgical training with VR tools has the same benefits as in anatomy training, replacing conventional training methods and provide means to study anomalies as part of a standard education. It is also a risk-free tool to practice challenging surgeries or train new surgeons.

The research studies in this field strongly support the VR training method for laparoscopic surgery education. The VR surgery tools also serve the needs of telesurgery and robot surgery. These tools are using remote visualizations anyways.

Despite the high cost of realistic and customized VR surgery tools the return of investment might decent. One of the studies mentioned a 6 months payback time for a medical school. Hospital surgeries have a big impact to the patient safety issues. Improving the education is mentioned as a one way to improve the patient safety. The VR surgery training tools might be one tool to improve the matter.

Surgery trainings with VR will be one of future tools that improve the healthcare industry. The evaluation score for VR surgical training was 9.

Surgical Planning

Surgical planning with VR tools helps the surgeons to visualize the CT images to 3D visualizations. The VR surgery pre-op tools are improving the patient outcomes and improving the surgeries by the found research studies and meta-analyses. These will save a lot of time and improve the surgeons work.

The equipment and software are moderately costly to provide precise image quality. The evolution for surgical planning to become a common practice seems inevitable after more research studies have been conducted.

The evaluation score for surgical planning was 9.

6.2 Study Recommendations

Based by the scoring and findings in this study, the recommendation is to further study VR treatments in the following order:

1. Stroke Neurological VR Rehabilitation, 10 points
2. Surgical Training and planning, 9 points
3. Addiction VR Rehabilitation, 9 points
4. Phobia VRET, 9 points
5. VR Analgesia, 8-9 points (mean 8.5)
6. Therapist training, 8-9 points (mean 8.5)
7. Anatomy Education, 7-8 points (mean 7,5)
8. Simulation VR Training, 7-8 points (mean 7,5)
9. Stroke Physical VR Rehabilitation, 6-8 points (mean 7)
10. Autism VR-CBT, 7 points
11. PTSD VRET, 6-7 points (mean 6,5)
12. Burn Wound Patients, 6 points

The evaluation criteria were based on the most cost-efficient solutions for the most patients amounts as explained in the evaluation criteria chapter.

6.3 Thesis Evaluation

At the end, the study outcome did meet the original focus of creating a roadmap for most cost-effective solutions. The evaluation criteria and how the work was implemented was decided during the writing. This made the right focus sometimes to disappear. Digging deeper and reading more about the VR subjects and solutions did eventually form the proper evaluation criteria. After that was decided, it was easier to do the hard work. The study objective, creating a roadmap for HUS VR, was reached. The secondary object, to study available VR related healthcare applications, did provide a lot of new and interesting information.

Challenges during the thesis work were the literal studies that were difficult to find in the beginning. Later there were too many sources to choose from. The amount of research studies per year had almost doubled in the last two years (2015-2017). During the finalization and confirming the thesis references in 2018 there were, if not daily, but at least on a weekly basis new research work added to the library database. It was tempting to start digging into those latest research works and drawing the scope here was difficult. Better planning for the source material might have helped to overcome this challenge.

Another challenge was how the subject was selected. The original idea was to study and gather knowledge of VR related studies from the healthcare sector. During the time when the topic was selected in early 2017, there was basically nothing going on in the HUS and VR. At least not publicly available. A year later, there had been started several VR researches and projects. Including own AI & VR seminar and a virtual reality laboratory premises. The timing for this study most probably occurred in well ascending trend curve of the VR technology.

Interestingly, some AR related surgical tools, neurological VR stroke rehabilitation and VRET psychotherapy projects were started in HUS in 2017. These correlate to the study outcome recommendation of the most cost efficient and useful VR solutions. This thesis study also encourages HUS to consider VR analgesia, addictions rehabilitation and more phobia related VR projects.

Currently, the VR solutions are expanding drastically. New areas and researches of VR were noted, but not included in the thesis. This was to keep the thesis scope in reasonable limits. These studies and projects were related AR, VR psychotherapy treatments for schizophrenia, specific surgery areas, eye diseases and a lot more. Any following research studies considering VR in healthcare might be reasonable to limit the scope into a specific field and a solution to study it more deeply.

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