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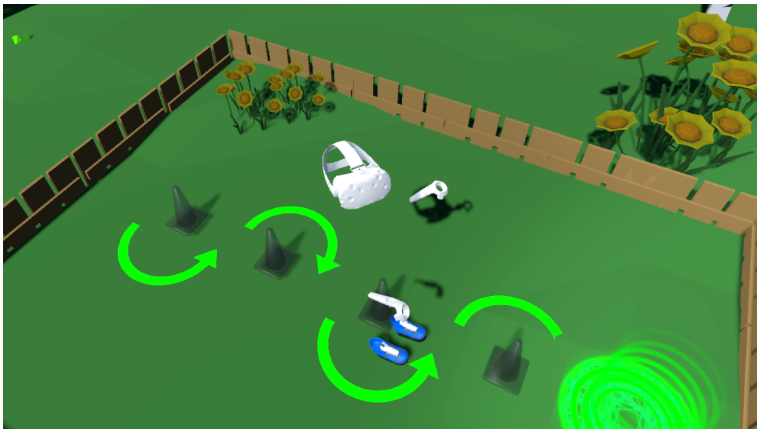

Virtual Reality for Locomotion Rehabilitation

Alexandre Martins Braga Gordo

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Supervisor(s): Prof. Dr. Hugo Miguel Aleixo Albuquerque Nicolau
Prof. Dr. Daniel Simões Lopes

Examination Committee

Chairperson: Prof. Dr. João António Madeiras Pereira
Supervisor: Prof. Dr. Hugo Miguel Aleixo Albuquerque Nicolau
Member of the Committee: Prof. Dr. Alfredo Manuel Dos Santos Ferreira Júnior

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Resumo

A locomoção é uma habilidade muito importante para o nosso bem-estar. Infelizmente, existem cada vez mais condições e doenças, como o AVC, que tendem a afetar essa capacidade e degradam a nossa qualidade de vida. Nos últimos anos, o impacto dessas condições tem vindo a aumentar e os pacientes têm tido uma maior necessidade de recorrer à reabilitação física. Existe, portanto, uma necessidade urgente de melhorar e desenvolver melhores soluções na área da fisioterapia. A realidade virtual (RV) é uma tecnologia promissora e tem vindo a comprovar que confere uma série de benefícios à fisioterapia. No entanto, ainda pouca implementação de sistemas de RV específicos para reabilitação locomotora e, por consequência, a própria adoção dessas alternativas. Neste estudo, desenvolvemos um sistema de RV imersiva, chamado Locomotiver, que suporta exercícios para reabilitação de locomoção com base nas necessidades e expectativas de nossos fisioterapeutas parceiros. Além disso, realizámos uma experiência em que vários terapeutas testaram o protótipo e deram o seu feedback, fizeram comentários e responderam a perguntas numa entrevista semi-estruturada. Os participantes também respondem a um questionário com questões assentes em conceitos associados a teorias de adoção de tecnologia. Por fim, fizemos uma análise temática qualitativa do rescaldo da experiência e relacionamo-la com os resultados do questionário. Concluímos assim que os fisioterapeutas tinham, de facto, intenção de adotar o Locomotiver como solução de RV e de a aplicar nas suas práticas diárias.

Palavras-chave: Realidade virtual, fisioterapia, reabilitação, locomoção, adoção, tecnologia imersiva

Abstract

Locomotion is a very important ability for our well-being. Unfortunately, there are many conditions and diseases, such as stroke, that can affect this ability and degrade the individual's quality of life. In recent years, the impact of these conditions has been increasing and patients have a greater need to resort to physical rehabilitation. Therefore, there is an urgent need to improve and develop better solutions in physiotherapy. Virtual reality (VR) is a promising technology that has been proven to have significant benefits in physiotherapy. However, there is little implementation and subsequent adoption of VR alternatives in locomotion rehabilitation. In this research, we built an immersive VR system, called Locomotiver, that supports exercises for locomotion rehabilitation based on the needs and expectations of our physiotherapists partners. We also conducted an experiment where several therapists used the prototype and provided feedback, commentaries and answered interview questions. Participants also responded to a questionnaire based on concepts inherited from theories of adoption. Finally, we made a qualitative thematic analysis on the results of the experiment and correlated them with the outcomes of the questionnaire. In the end, we concluded that the professional physiotherapists had indeed the usage intention and will to adopt the Locomotiver as a VR solution and apply it in their daily practises.

Keywords: Virtual reality, physiotherapy, locomotion, rehabilitation, technology adoption, immersive technology

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Chapter 1

Introduction

Locomotion is one of the most significant abilities of humans beings. It enables people to move around and it is very important to maintain our quality of life. However, over the last years, there has been an increasing number of diseases and conditions that affect people's locomotion abilities. These can be associated to our sedentary life habits and poor choices of eating, among other factors. One of the main conditions that can affect the ability of locomotion is stroke [5]. Stroke has become one of the main medical concerns in modern societies as it can profoundly change someone's way of living, especially when it affects directly the individual's ability of walking and/or balance. According to the Stroke Association's statistics of 2017, it is estimated that there is a first-time stroke occurrence worldwide, every two seconds, to which half of the survivors will probably have some kind of long-term disability. This enhances the importance of physical therapy for stroke victims that has been shown to be paramount to the patient's partial or full recovery from this disease. The advances of science and development of new technologies have allowed the creation of more motivating and effective treatments in the physiotherapy field.

One technology that has been established as one of the most influential of the future is virtual reality (VR). VR utilizes computer technology to create immersive 3D environments where the user has a sense of spatial presence [20]. The recent launch of first-generation VR consumer products, such as the Oculus Rift and HTC Vive, has generated even more interest and investment in this area and people see a lot of potential in it. There has also been many studies conducted on the benefits of VR in medical context including physical rehabilitation and recently, new progresses on the development of VR systems to be used as a complement or substitution of standard therapy.

1.1 Motivation

Since we have established the importance of the locomotion abilities for people's well-being, it is very important that the recovery processes behind physical rehabilitation related to it improve at a fast pace.

Despite the numerous studies on the benefits of VR as a viable solution to improve the experience and results of physical interventions, there is still an issue with the slow adoption of this technology in

real clinical environments. This phenomena is even more evident in locomotion therapies as, due to its complexity, there are almost no VR systems that support this type of rehabilitation.

There may be several reasons for this to happen, but we can break them down in two main categories: technology and people. Regarding the technology category, we currently have VR equipment, used in physiotherapy, that is relatively expensive, hard to set up and requires some knowledge to be put in practice. Furthermore, to address locomotion rehabilitations, most VR options cannot function as a stand-alone system, meaning that they must use many peripheral devices like motion trackers, treadmills or cycling devices to work properly. The integration of these multiple technologies increases the complexity of the setup and adds up to the cost which ultimately reduces VR adoption. However, the most important issue, is related to the people, namely the physiotherapists and the seeming lack of support given to them.

As VR is a recent technology, there are many challenges associated with its usability and functionality and VR adoption will not improve unless these challenges are approached.

1.2 Objectives

In this work, we had the goal of helping physiotherapists to include VR in their locomotion rehabilitations.

In order to do this, it was important to consider the details of the therapists practises, in locomotion rehabilitation, and take those in consideration when we were developing our VR solution. Since VR is also considered to be an innovative technology, we needed to analyze the nuances of usage intent state of art.

We proposed the Locomotiver system as an immersive VR complement to locomotion therapies which included exercises for lower limb recovery. After the development phase, we wanted to assess the physiotherapist's will to adopt it as an alternative or complement to their daily practises.

1.3 Contributions

This research presents several contributions to the medical and scientific community in a lot of aspects:

- We established a clear understanding of the state of the art on the application of VR in physiotherapy and the relationship of professional clinicians with such technology.
- Development of a VR system prototype capable of deploying exercises for locomotion rehabilitation, based on meetings with professional clinicians.
- Conduct a study with professional physiotherapists that included a qualitative thematic analysis on the clinician's opinions about implementation of a VR system in these therapies.
- Results from a questionnaire with 20 statements regarding the usage intent of physiotherapists to adopt our prototype as a VR solution.

1.4 Thesis Outline

The rest of the document is organized as follows. The chapter that follows will provide the background context on the theories of adoption and technology acceptance models. These are necessary to have a better understanding of the whole work. On chapter 3 we present the related work and a series of analysis on projects related to the domain of VR in physiotherapy, how therapists deal with technology and VR systems. Chapter 4 describes some of the context from our meetings and encounters with physiotherapists prior to the development of the prototype. Everything related to the implementation and features of the Locomotiver prototype is described on the Chapter 5. This chapter is heavily illustrated with screenshoots from the application itself which are accompanied by the respective functionalities description. The following chapter 6 depicts the evaluation phase. In it, we include the research questions, participants profiling and the details of the experiment conducted. Chapter 7 reports on the results of the evaluation and contains both the qualitative and quantitative analysis. Finally, chapter 8 points out the conclusions and provides suggestions for future work.

Chapter 2

Theories of Adoption and Acceptance Models

Technology advancement is a constant product of innovation in human history. As humans, we are always looking for new and innovative ways to explore our resources and build better tools and systems that help us progress and live a better life. In a way, is this incessant search for better technological solutions that has allowed us, as a specie, to evolve and proliferate throughout the ages. But in the midst of all that, new technological solutions do not usually reach the masses all the at once. People take time to discover, explore and get used to certain developments, especially if they promise to have a significant impact in their lives. Not only that, but people tend to adopt these advancements only when certain conditions are met.

Over the last decades, the phenomena of people adopting new types of technology has been the subject of multiple cross-field studies. From social psychology to information systems, multiple researches have been conducted to better understand what drives people and societies to include innovative technology in their daily lives. This subject is often called technology acceptance or adoption and it refers to the voluntary intent of individuals to use a particular technology.

One kind of research that has been tested multiple times and has great acceptance on the scientific community regards the technology acceptance models [34]. These models specify a series of concepts and structures with the purpose of establishing a foundation that promotes technological use and facilitates its adoption. In this section, we briefly cover some of the technology acceptance models and theories of adoption and the guidelines they offer. We will also cover important factors that support those theories.

2.1 Theory of Reasoned Action

The Theory of Reasoned Action (TRA) is a theory that is used to predict how humans will act based on their previous attitudes and behavioral intentions. It is deeply rooted in social psychology and, since it has been reviewed multiple times [9], is still one of the most influential models of human behavior.

According to the authors, there is a subjective way that influences the individuals behavior based on his perception of what he believes his family, friends and social circle think he should do [16] . The key constructs of the TRA are attitude toward behavior and subjective norm.

2.2 Technology Acceptance Model

The Technology Acceptance Model (TAM) is one of the most established theories of adoption in the scientific community. It has been a widely accepted model to explain why people use and adopt new technologies. The TAM is often associated with the information systems field and its research context [38]. It is built upon two main key concepts: perceived usefulness and perceived ease-of-use. The first one regards the degree to which an individual believes that using a particular system would improve his or her activity and job performance.

This model has also been used in several researches related to the health information technology area. These studies have proven multiple times that user intent of adopting a system is strongly influenced by the concepts that constitute the TAM. One study by Lim et al. [25] investigated Singaporean women acceptance of using mobile phones to seek health information. The associated findings revealed that perceived usefulness and self-efficacy influenced directly the intent of women to use the mobile devices for the given activities.

2.3 Motivation Model

The Motivation Model (MM) deals with motivational theories to explain human behavior. Vallerand [42] explores that MM makes clear that intrinsic and extrinsic motivation are important concepts to be considered in order to better understand how people act. Extrinsic motivation can be defined as the perception that individuals want to perform an activity as that may involve a valuable outcome such as improved job performance and promotions. On the other hand, when such activity provides feelings of joy, engagement and overall satisfaction, we can consider that intrinsic motivation. In this case, individuals would want to perform an activity with no apparent reason than that of their own personal progress.

Davis et al. applied the MM to understand the adaptation of new technologies and usage intent associated with it [13].

2.4 Theory of Planned Behavior

The Theory of Planned Behavior(TPB) extends the previously mentioned TRA. However, the TPB adds the construct of perceived behavioral control [1]. Therefore, in addition to the subjective norm and attitude towards behavior, the TPB sustains that perceived behavioral control has an important effect on the acts of the individual. This perception is related to the degree to which a person believes they control any given behavior.

2.5 Model of PC Utilization

This model of PC utilization (MPCU) expands the idea of adoption of new technologies with the key constructs of job-fit, complexity, long-term consequences, affect towards use, social factors and facilitating conditions [39]. The first relates to the extent to which an individual believes that adopting an innovation can improve his or her job performance. The complexity is associated with the perceived difficulty to understand and use the given technology. The consequences and long-term outcomes also have a weight in the MPCU. Affect towards use is related to the feelings of the user. Those can be translated in joy, pleasure, depression, hate, etc. The social factors are related to the individual's group and social culture and the facilitating conditions are provisions of technological support that may influence the usage intent. This model presents an opposing position to the previous TRA and TPB and it is suited to predict user acceptance and adoption of information technologies.

2.6 The Innovation Diffusion Theory

The Innovation Diffusion Theory (IDS) or Diffusion of Innovations is another theory proposed by Rogers, that dates back to 1962. It has been reviewed several times. The IDS is based on sociology and seeks to explain how, why and at what rate new technologies are adopted across a certain scope. The IDS has also been a subject of a study by Hess et al. [18] on adoption with VR technology. Another study conducted by Ash et at. [4] expanded that the IDS was a useful framework for analyzing the desirable and undesirable consequences of adopting, in a hospital, a computerized provider order entry system.

This theory states that there are four main concepts that influence the spread of new ideas: innovation, communication channels, time and social system. The innovation relates to ideas or practises that are recognized as novelty by an adopting party. On the other hand, the communication channels stand as a key concept as the factor that influences the diffusion and spreading of the ideas. The time concept regards the estimation necessary for innovations to be adopted. IDS stipulates that adoption is rarely instantaneously and usually takes a fair amount of time to occur. Finally, the social system accounts for the influencers such as media, organizations and opinion leaders that take a role of guiding the adoption of the given innovation.

IDS determines that, in order for an innovation to be self-sustained, it requires wide adoption to the point of hitting critical mass. It also identifies five categories of adopters as innovators, early adopters, early majority, late majority and laggards. Innovators are the individuals that are willing to take the risk of spending more money and trying new technologies first. These people are not only more risk tolerant but also tend to nurture high social status and prestige as a result of being the first ones to adopt something new. Following this group, the early adopters are often the leaders of opinion among the adopter categories. They share some of the characteristics of the innovators such as resources disposal, social forwardness and closure to innovation sources, but are slightly more discreet in adoption choices. They can also be responsible for taking the innovation to the tipping point of reaching the next category of adopters, the early majority. At a time where an innovation has already proven to be useful for their

lives, the individuals in the early majority will start to adopt such solution. In contrast, the late majority is composed by people with higher levels of skepticism. According the the IDS, this groups tends to adopt a certain solution only after the majority of the population. Lastly, the laggards are typically very resistant to change and tend to be focused on traditional methods.

2.7 The Social Cognitive Theory

The Social Cognitive Theory (SCT) is one of the most powerful theories of human behavior. According to the SCT, the behaviour of users, regarding a technological system, is heavily influenced by their expectations of such system's performance and the related gains either for job improvement or personal gain [6]. These key constructs can be declared as outcome of expectations-performance and outcome of expectations-personal.

Sell-efficacy is also a key construct of this theory. As we have seen before, sell-efficacy related to the person's judgment in regards to their abilities of applying or doing a certain task. The SCT states that this is a crucial point to improve adoption in the information technologies field as users are required to have the confidence in their capabilities to use the system.

The SCT also focus on the key constructs of affect and anxiety, which have opposite influences. While affect has a clear positive connotation regarding the individual's interest on his or her job, anxiety has a more negative influence. According to the SCT, anxiety is related to the distrust from the user that he or she will be able to correctly use the system and, therefore, produce worse results at the job.

This has been a very popular theory in adoption studies.

2.8 Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology (UTAUT) is a technology acceptance model that integrates elements from many other models. This theory was formulated from the empirical comparison and review of the previous models presented, with the purpose of identifying differences, similarities and unifying the key constructs under a single theory. This way, the UTAUT presents itself as a very versatile and comprehensive model that can be applied in a multiple range of fields [28]. Is also a great model to be utilized with the information systems field and user behavior.

The authors of the UTAUT have compiled and tested all the previous key constructs used in the adoption theories and concluded that there were four constructs that are most significant as determinants of intention to use information technology. They have also come to the conclusion that the UTAUT is is able to explain 70% of the variance (dispersion of data) while the earlier theories were only explaining about 30-40% of the variance when it came to usage intent and adoption behaviour [43].

The four key constructs that build this model are: performance expectancy, effort expectancy, social influence and facilitating conditions. The performance expectancy is driven by the previous constructs of perceived usefulness (TAM), extrinsic motivation (MM), job-fit (MPCU) and outcome expectations (SCT). This key construct relates to the degree the user thinks the technology will help him or her at the job.

The next concept, effort expectancy, has its source on the previously mentioned perceived ease of use (TAM), complexity (MPCU) and ease of use (IDT). It regards the perceived ease of use by the individual. The social influence is derivative from the subjective norm (TRA, TPB) and social factors from the MPCU theory. Finally, the facilitating conditions regard the user's beliefs that his or her organization have the technical infrastructure to support the innovation. It is a derivative of the previous perceived behavioural control (TAM, TPB) and facilitating conditions (MPCU).

This model has been used in multiple studies to assess the usage intent of users regarding certain technological systems. A research by Schaper et al. [32] examined information and communication technologies acceptance and utilization by Australian occupational therapists. They have proven the utility of the UTAUT model in the given case.

Chapter 3

Related Work

In this chapter we present some scientific readings on four main thematic related to our research. Each section explores some nuances of the given theme to expand the context of the field.

We start by presenting research on VR in physiotherapy. Then we proceed to analyze research related to physiotherapists and studies on how to empower the clinicians to help them use and adopt new technologies. We also cover some of the VR systems currently on the market and research associated with those. Lastly, we present a brief table analysis of the research projects discussed during this chapter.

3.1 Virtual Reality in Physiotherapy

Virtual reality (VR) has been one of the most promising technologies to soon revolutionize physiotherapy. According to a SWOT study [31], VR systems may not only help individuals enjoy more their rehabilitation processes, but also increase the clinician's confidence that their patients will actually benefit from these.

VR is the term used to describe a technological system that creates a simulated world or environment for the user to experience usually by the means of a head mounted display (HMD). It is important to note that, while many studies mention VR as any system that reproduces a virtual environment, like a screen or a projection, we will refer to VR as a representation of an immersive system where the user must use an HMD device [10]. This way, the user's vision sense is confined to the virtual world, which increases his immersivity and focus and will, ultimately, better trick the brain into thinking he is in a totally different environment.

Over the last few years, many studies have emerged on the possible applications and benefits of VR in medical fields such as physiotherapy. The raising number of cerebrovascular accident occurrences and increase importance of these treatments has also motivated the research of VR as an alternative and/or complement to standard interventions for stroke survivors. Furthermore, a conducted systematic review [12] compared the difference between the addition of VR, as a complement, to standard therapy and the complete replacement of later with virtual reality based rehabilitation (VRBR) applied in a locomotion rehabilitation program. The patient's recovery was evaluated by the measurement of

three important metrics related to gait abilities: walking speed, balance and mobility. What they verified is that the en-tire substitution of standard rehabilitation with VRBR produced better results in all motor rehabilitations variables. In the end, participants that went through VRBR only showed an increased walking speed, balance and mobility. The addition of VRBR as a complement also produced benefits to the mobility but nothing was concluded regarding the walking speed and balance of the individuals. This suggests that VRBR is more effective, produces better results and increases the benefits in after-stroke patients doing motor rehabilitation.

As VR is being proven, over and over, to be a valuable asset in physiotherapy, some VRBR systems are starting to be built to be used in this context. Kaminer et al. developed a prototype that integrated the Oculus Rift, the Microsoft Kinect and a pair of haptic gloves to create a VRBR solution for after-stroke hand's strength [21]. The Kinect was used to track the movements of the user's body and the gloves permitted finger motion capture and pressure sensing. These devices would function as an input to a simple exergame inspired by real physical therapy exercises, and would also record the data to be posteriorly analysed. The game would be displayed on the Oculus Rift which fully immerses the player and increases its focus. AlMousa et al [3] also established a good VR system for upper limb treatment. In this one, they did a requirements assessment of therapists and patient's needs and developed a prototype to be used in immersive VR arguing that it increases the immersion and engagement.

3.1.1 VR for Locomotion Rehabilitation.

Most research related to VR in physiotherapy addresses upper limb rehabilitation. In fact, much of the research regarding VR gait rehabilitation focuses on small pilot studies or specific tests and there are little insights on the potential of immersive VR in this field. This may be a cause of the increased complexity of gait rehabilitation VR systems compared to the upper limb ones. Patients may simply interact more easily with upper limb systems that do not require much hardware or interfaces to function properly [30]. Locomotion systems often impose additional challenges as they usually require treadmills or cycling devices and other peripherals that increase the overall cost of the system. Despite all of this, locomotion is still one of the most influential abilities in people's lives and VR may take a crucial part in establishing better gait rehabilitations.

One platform that addresses gait and locomotion rehabilitation is the GRAIL (Gait Real-time Analysis Interactive Lab) [8]. The system has been used for the rehabilitation of walking abilities in the development age of children suffering from cerebral palsy (CP) which affects the person's coordination and regulation of muscle tone. While the GRAIL is not technically immersive VR, as it does not leverage the use of an HMD, it takes advantage of a dual -belt treadmill on a motion-frame, a motion capture system and a 180° degree projection. The study conducted, using this system, had very positive results particularly on the improvement of walking patterns of children affected by CP. The GRAIL was also used in a recent study [19] that assessed the feasibility of VR training during earlier stages of rehabilitation. Both balance and gait abilities were tested in stroke survivors and results showed that VR training was beneficial for patients within 12 weeks after stroke.

Keime et al. explored another treadmill system that used the Oculus Rift to immerse the user in a city environment [22]. By using a modified treadmill that had a micro-controller that read the speed and send it to the VR system to update the position. However, the researchers report that this implementation was quite difficult which corroborates the challenging aspects of developing systems with treadmills as peripherals. The user's movement data was collected by the means of a Qualisys motion tracking system and a 20-marker placed on the participant's lower body. The user would then be immersed in a city block via the Oculus Rift. Although the prototype did not include any kind of challenge or exergame beyond the freely exploration of the city, the results were still satisfying.

3.1.2 Specifications for VR Systems in Physiotherapy.

Physical therapy has many requirements that need to be addressed to justify the conception and inclusion of VR systems in these interventions. Furthermore, VR systems must be adapted to the physiotherapy context, not the other way around.

We have explicit before that physiotherapy exercises need to be goal-oriented and address specific tasks. As everyone's condition is unique the concept of personalization is also very important. For example, if a patient is trying to recover his walking ability, the intervention exercises should be narrow enough to target that individual's walking deficits. VR technologies can be programmed with a high level of abstraction that allows the creation of multiple types of exercises that map a large number of issues. This enables the creation of viable interventions that can target specific needs.

Accuracy is also extremely important when performing physical exercises and VR systems can be a great way to check whether the exercise is being perform correctly or not. This is may be particularly effective to minimize compensatory movements that interfere with the patient's progress. For example, it is very common to submit patient's through cycling training as this is a great option for lower limb functionality rehab. While going through the training, patients tend to compensate the affected limb with the unaffected one, pedalling harder with one leg than the other. This will ultimately result in sub-optimal rehabilitation. VR systems can help patients to correct their behaviour as it was demonstrated in a study [46] that used a VR cycling training system. To minimize the pedalling disparities, the system would sense the patient's cycling force in real-time and give immediate feedback. The user would then be aware of the compensation and would adjust his behaviour which improved the final results. It can also be the case that the system offers an exergame or challenge that can only be completed if the movements are being performed correctly which functions as a motivator for the patient.

Another important principle in physiotherapy is the repetition. Physical therapy exercises usually need to be practised over and over to better establish the neural connections required to perform a certain activity. This can sometimes be a long and tedious process that demotivates patients from going through with the program which may be very bad. If patients are unmotivated and do not finish their exercise sets, their intervention will probably be compromised, and their recovery delayed. VR can play an important part in solving this issue. Multiple studies mention that patients felt very motivated in doing their exercises when using VR systems and games. There are multiple factors that may explain

why this happens. First, VR takes advantage of abundant visual and auditory feedback. This creates a more pleasant experience and it enhances the patient's capabilities of learning as well. The novelty of the technology may also be a factor for the increased motivation in patients going through VRBR. Most of them have never tried VR and the curiosity and eager to try new things adds up to their motivation. Finally, VR systems often leverage the use of exergames to establish engaging and stimulating experiences. This provides the user with sense of accomplishment and it keeps him/her much more entertained than standard therapy.

3.1.3 Exergames as a Physiotherapy Option.

Exergames are related to the activity of playing video games that require some form of physical exercise. They have seen the subject of multiple studies not only in physical therapy context but also a way of promoting healthier lifestyle habits in children [44]. These games offer a more fun and challenging environment that motivates the player to complete the given tasks and provide a sense of accomplishment. These exergames are usually built on top of platforms and consoles such as the Wii, Kinect and PlayStation Move as they utilize the technology of motion capture, depth sensors, accelerometers and gyroscope enabling the input of the user's movement.

Exergames have a lot of influence in physiotherapy rehabilitation interventions. In almost all the studies we found, the participants going through interventions that included exergames were more motivated and engaged which had a positive impact on their recovery.

VR is a technology that is taking exergaming to the next level. The immersion factor emphasizes the player's feeling of presence in the game and it enhances the experience. The project "VRun" [49] compared how the interaction of a running game on the Google VR would differ from the ones on a laptop display and a large projector in terms of user preference. The participants were more interested on the VR version as it was more engaging. However, the accuracy of the movement and the inability to move backwards were mentioned as liabilities of the project. The fact that the player would "run-in-place" caused players to unintentionally and unsafely move around the room. "PaperDude" [11] is another example of a VR exergame. "PaperDude" required a Trek FX bicycle attached to a Kickr power trainer to allow movement on the game. The player would see a virtual city on the Oculus Rift and deliver newspapers by performing a throwing gesture that would be captured by a Kinect camera. As this type of movement seems natural to the player the effect of motion sickness is almost eliminated which is very important for a great VR experience.

While the previous exergames are not associated with any clinical practises, Motion Rehab AVE 3D (MRAVE) is. This exergame was developed for post-stroke rehabilitation with the primary objective of increasing the patient's motivation to execute the program [40]. MRAVE uses a Kinect as a motion tracking device and it supports HMD's such as the Oculus Rift and the HTC Vive. The exergame is meant to be used in upper limb motor and balance rehabilitation by proposing a set of activities that stimulate those areas such as flexing and abduction of the elbows and shoulders. The player is supposed to stay in orthostasis and perform the activities to hit the ball. The game also gives immediate feedback

to the player by displaying the score and whether the movements are correct or not. This feedback is also supported by sound effects that enhance the experience. Some motivational messages were also included. The preliminary tests have proven the MRAVE to be a useful tool to motivate the patients in their rehabilitations.

Figure 3.1: Screenshots from Motion Rehab AVE 3D gameplay [40]

When it comes to locomotion or motor exercises, one of the consistent problems with VR was that the player could not move around. The exergames, in VR, would almost always need peripheral hardware like a rowing machine, a treadmill, a bicycle or even multiple integrations of devices. Otherwise, they could only perform exergame that did not require any kind of movement from player.

3.1.4 Designing an exergame for physiotherapy.

Producing a great exergame can be a challenge and it becomes double important when it is meant to be used in the post-stroke physical therapy context. In general, an exergame should not feel like an exercise. The more engaging and fun the game is, the more likely it will motivate players to engage with it. The gameplay should be designed around the user movements and it is important to keep in the mind the players limitations. For example, if the player is required to be stationary and extend the arms to catch a thrown ball, then the object should not be out of reach anytime.

Gamification is also an important concept. Users usually benefit from the integration of gamification elements just like it was implied in the project Rift-a-bike [41]. This project focused on the application of gamification techniques on immersive VR exergames. They found that there were three important concepts to be feature in an exergame in VR. The concept of challenge, which represents a specific task the user must accomplish to earn experience, was the most relevant for their immersive game. “Levels” also helped to maintain a progress plan and provided the player a better understanding of the

difficulty of the following task. Lastly, the “points” provided an immediate reward and affected positively the motivation and fun implying that the player benefits from being able to track its data in real time. The information can be the time left for next the beginning or end of an exercise, the number of points or current level. However, as the player is using an HMD system, this may interfere with the immersion factor, so a trade-off must be considered. At the end of each session, the state should be saved to enable the tracking of long-term progress. It has been shown that people tend to be more motivated when they can see their progress. Moreover, this stored information will help to establish each user’s personal profile. Yoo [50] has demonstrated a methodology to create personalized exergames based on user modelling. The personalized exergame would be influenced by several variables including the user preferences but mostly, game play performance. This is one method that probably should be translated in a VR system for physiotherapy as personalization is one of the most important requirements mentioned before.

We have also previously established the benefits of VR visual quality. Smeddinck et al.[36] studied exactly how the exergame graphics can influence the experience. The conducted study compared the effects of different levels of visual complexity and their impact in player’s exertion and experience in exergames meant for physical therapy for old adults. Participants were presented four versions of the same game, to which the only variable was the graphics level of detail. It was possible to verify that older adults preferred high-fidelity graphics. They also concluded that visual complexity did not had an impact on players experience as participants did not rate the experience that included better artwork any higher than the others. They did, however, notice that visual complexity influenced the way exertion was perceived. People reported higher levels of exertion after playing a game with much less visual complexity. This indicates that the more engaging the experience is the less likely it is to be perceived as physical effort which may or may not be desirable in a physical therapy scenario.

It is important to establish the difference between a regular exergame and the one to be used in physiotherapy. While some of the components of the second may inherit from the regular one, others should be modified to fit the player’s conditions and meet therapist’s expectations. For example, Yoo et al. did not design ”Snowballz” [47] to be used in a physical therapy session rather than a regular exergame. This means that while some of its components can be translated to the therapy context, others may not apply. ”Snowballz” has some interesting mechanics regarding the personalization of the game and how to tailor the experience to each player by collecting session’s information in a user model. The game would dynamically adjust the difficulty to the player as he performed better. While we have mentioned the importance of creating personalized exercises for the patients, this mechanic needs to be adapted to fit the physical therapy context. The user profile will be useful for the therapist to track, manage and support decision-making. Another mechanic that would need to change is the dynamically change of difficulty. The games can and should probably become more difficult over time, to endorse the progress of the rehabilitation, but that arrangement should be handed over to the physiotherapist in charge of the patient. A systematic review [7] conducted to investigate the safety, feasibility and effectiveness of exergaming for motor rehabilitation of people with Parkinson’s disease (PD) concluded something similar. Although the preliminary studies established that the use of exergames seems promising for

the rehabilitation of these patients, the use of commercial games would not be the best option as they were not tailored to the patient's specific clinical situation. They also recommended that exergames for debilitated patients should be a little easier than commercial ones, include clear instructions and avoid negative feedback to the player.

Figure 3.2: Snowballz - an example of a VR exergame that uses the HTC Vive [47]

3.2 Empowering Physiotherapists

Physiotherapists are some of the most important stakeholders in rehabilitation interventions, therefore it is fundamental to have their perspective on the implementation and introduction of VR as an intervention option. In this section, we will research the therapists' opinion on virtual reality technologies and understand the main factors responsible for the adoption and rejections of VR in a clinical environment.

3.2.1 Therapists' Opinions on VR.

As VR is becoming a potential component in the treatment of patients in physical therapy, it becomes important to understand the opinions of physical therapists regarding these technologies and what they think it needs to be done to put these projects in practise.

Schmid et al conducted a study [33] that collected very good insights on experiences and expectations of physiotherapists (PT) and occupational therapists (OT) specialized in the rehabilitation of after-stroke patients. The experiments were conducted using a non-immersive VR system for the rehabilitation of the upper-limbs called YouGrabber (YG) with real patients. Each therapist would use the YG system for some time with a group of patients and answer a few questions related to the use of the

system during an interview process. The system leveraged data gloves and infra-red arm tracking to capture the patient's upper limb movements that allowed the interaction with an exergame. The game was displayed on a screen and consisted on directing a car on a road using the hands. Some therapists mention that this game was slightly immature for adult people and did not quite match up to daily life orient-ed training, but that did not seem to affect the patient's motivation levels which were very good.

Overall, most PT's and OT's felt very confident on the effectiveness of the VR system in the context of their therapies. Some therapists mentioned that they felt motivated by applying VR even though they were not playing along with the patient.

Therapists also pointed out important topics that may influence future development in this area. Some felt that VRRB's purpose should not only be about providing a fun experience to the patient, but it would also need to enhance the rehabilitation training somehow and provide more information to the therapist. It was also discussed the importance of allowing the therapists to appropriately manipulate the game. Luque-Moreno et al provided a good study on VR used in lower extremity disorders that enabled the therapists a good control of the session [26]. By controlling and adapting the systems variables, therapists would be able to provide the best training for each patient accordingly to their unique conditions. This corroborates the need for personalization features on a VR system.

Regarding the implementation of VR in clinical context, Schmid et al [33] concluded that there is an importance of combining the PT's and OT's knowledge of the patients and the VR development teams and that communications between engineers and therapists would have to improve to raise their confidence levels in VR and put these systems in practise.

3.2.2 Barriers and Facilitators for VR Adoption.

The novelty of virtual reality technologies can impose some difficulties on its adoption in therapies. VR systems can be somewhat complex and faulty at times.

In the previous study by Schmid et al [33], one the major identified problems were the possible failure of the equipment. Therapists in general believed that if the system would fail during one of the rehabilitation processes, they would not be able to keep using it for the session, which may be a strong demotivating factor both for the therapist and the patient alike.

Self-efficacy seems to be one of the most dominant issues among therapists regarding VR. According to a study by Glegg et al [17], to identify influential factors for therapists' VR adoption, the self-efficacy aspect had the lowest scores. In addition to the perceived lack of knowledge, they identified that the lack of time was the also a big barrier. Even though therapists have shown much interest in applying these technologies, they do not seem to have the time to learn how to put these systems and applications in practise. We consider this a very important constraint for the design of a VR system in this area.

Another recent online survey [24] on the clinical use of VR and exergames by Canadian physical and occupational therapists was conducted to identify barriers, facilitators and determine the learning needs of the physicians. The predictive factors of using VR in clinical environment included the technology's usefulness and therapist's confidence in conducting the interventions with those systems. The

barriers that came out of this study refer to the lack of funds to implement this technology, not having a dedicated space for the practise as well as supportive staff and appropriate patients. However, most respondents answer affirmatively when asked if they were interested in learning more about the subject. The study also covered some interesting statistics about the implementation of VR in physical therapy. Regarding VR practise settings, most respondents answered rehabilitation centres (33.2%) and hospitals (30.7%). They also checked the population whom was provided with VRBR to which stroke (25.8%), orthopaedic/musculoskeletal diagnoses (15.3%), brain injury (14.9%) and cerebral palsy (10.5%) were the main subjects. It was also established what the therapists considered as a priority to focus VRBR on. Balance (39.3%) was the most important followed by exercise/physical activity (19.8%) and mobility/gait training (12.1%). Unfortunately, this study did not include immersive VR in the group of systems used by the therapists.

To apply these VR systems, therapists need to have not only the necessary requirements fulfilled but need to understand as well how to use, interact, setup the systems and be able to adjust it accordingly to the patient's situation.

3.3 Virtual Reality Systems

In this section, we will take a brief look to the current state of VR systems, their features and how they can be applied to physiotherapy. We have previously established that most researches prior to 2014 often refer to virtual reality as any kind of system that can generate a computer simulation, regarding of utilizing an immersive HMD. These studies have utilized systems such as the Nintendo Wii [27] and the Microsoft Kinect to create viable solutions for rehabilitations, and while most of their results have been proven to be viable solutions they do not provide an immersive experience.

The basic idea of VR is to use a headset to substitute the person's sense of sight with a virtual computer-generated environment [20]. The user is then confined to that VR world and interact with scenarios that otherwise would be very expensive or impossible to replicate. The concept has been around since the 1950's, but the industry took some time to take off due to technological limitations. VR systems were almost exclusively made for research or military purposes and used to be very expensive to manufacture. In addition, graphics quality was bad, motion-tracking inaccurate and users usually felt motion-sickness when using such devices. While some of these deficits still have some form today, VR seems to be mature enough for major companies to invest in it and launch some of the first commercial VR consumer products. Nowadays, those products can be divided in two main categories: mobile VR and desktop VR.

3.3.1 Mobile VR

The technological advances in newer generations of smartphones, has made possible the appearance of mobile VR. Mobile VR works by using the smartphone as the screen. The user plugs in the phone on the headset and it renders a stereoscopic image that can be seen through the device's lenses. The

inclusion of gyroscopes and accelerometers, included in the smartphone, allows the detection of head movements to which the VR environment adapts accordingly. Google and Samsung introduced their respective Google Cardboard [29] and Gear VR establishing some of the first consumer products in this area. These are also the cheapest products in the industry. However, because they use the smartphone, the experience very limited especially when compared with the more robust desktop VR. Moreover, these mobile systems lack the motion-tracking solutions necessaries for body tracking.

3.3.2 Desktop VR

In the last few years, powerful systems have emerged and establish a new era for virtual reality. These take advantage of top range computer processors and graphics to create immersive experiences that users love. Desktop VR systems like the Oculus Rift and HTC Vive are already familiar to many consumers, but lately have been introduced in a variety of studies that want the leverage their unique capabilities. For the first time, it is possible to provide extremely good VR experiences at a fraction of the cost of the older systems.

3.3.3 Oculus Rift

The Rift is one of the most well-known VR systems and ones of the best VR options as a consumer VR product. The headset if considered to be very light weighted, relatively cheap and leverages a very good head tracking system that constantly analyses the user's head movements and adjusts the visualization accordingly [15]. The Oculus DK2 also utilizes position tracking which enables the user to per-form actions such as lean in for a closer look at an object or peek around a wall and it can even be used in a room-scale configuration to allow physical movement around the virtual environment. The Rift has already been used as a tool in many researches in the medical field such as bio-mechanics [45] and physiotherapy [46].

3.3.4 HTC Vive

The Vive is a very high-quality device that can produce great virtual scenarios. This system enables the movement as well in a room-scale configuration because of its good tracking which has been proven to be a more immersive experience com-pared to a stand-up only [35]. Just like the Rift, the Vive is composed by an HMD, external sensors for position tracking and extremely accurate handheld wireless controllers that allow interaction with the virtual world. Unlike the Rift, the HTC Vive provides not just one but two motion sensors that detect and track both controllers and the HMD positions which helps as well to create a very good "room-scale" con-figuration. However, to run properly, Vive requires a computer with some specific characteristic. The machine should have an Intel™ Core™ i5-4590 or AMD FX™ 8350, equivalent processor or better and a NVIDIA GeForce™ GTX 1060 or AMD Radeon™ RX 480 graphics card among other requirements [14] . Many applications and researches have taken advantage of this system to build interactive VR experiences and exergames as well. In fact, the Vive offers a

freedom of movement so good that exergames build for it have proven to deliver enough exertion to be considered physical exercise [48]. Unfortunately, during our research, we could not find any studies related to the application of the HTC Vive in a physiotherapy context.

3.3.5 Rift vs Vive.

Suznjevic et al [37] compared the performance and quality of experience of both the Oculus Rift and the HTC Vive. The assessment evaluated the frame rate by having the same application running on each system on the same computer for 5 minutes. Then, both systems were analysed under different lighting conditions to estimate which motion capture system would adapt better. Finally, they tested the systems' behaviour when their sensors were obstructed. They also collected user feedback regarding the quality of experience on both devices to get a sense of the testers preferences. In the proposed game, the player would have three cubes marks and respective marks disposed on a table. The player would have to pick up each cube and put it in the right place to complete the task. The overall results gave a slight advantage to the Vive as this one maintained a better frame rate and its robust tracking system outperformed the Rift when the sensors were obstructed. Neither of systems had performance issues under any light conditions except for the infrared which interfered with the tracking sensors. The users rated a better quality of experience on the HTC Vive, mainly due to the freedom of movement they had over the Oculus Rift.

3.4 Discussion Table

In this section, we established a comparative table to evaluate the similarities of the works stated previously. We specified some factors for the system and technology as well as the support given to the therapists. We have filled the table with our objective and subjective appreciation of each work and how they match the expectations. Each entry may be either described as Yes/No according to the presence of that element on the source or it can state the device. For each entry, we have also coloured in green the elements we consider to be more beneficial and desirable. The last five entries are related to exergames. Based on the presented studies, there seems to be a lack of implementation of VR in locomotion rehabilitations. Most of the studies apply VR to upper limb rehabilitation which has a complex system setup that involves at least one external motion tracker or peripheral device and therefore increases the complexity of the system. Some exergames streamline the use of VR by applying the HTC Vive, which does not require any peripheral devices and has its own motion tracking sensors included. However, we did not find any studies that utilized this system as a physio-therapy option. Regarding the therapists' support, only one of the studies stated, clearly, that they had included physiotherapists in the design process. In other words, most systems were not build based on their users' specific needs. Most systems allow the therapists to control its games while also monitoring the patient's activity. However, most of the solutions did not include enough exercises and options that enabled the therapists to customize a session for patients.

	System and Technology					Therapists support			
Articles	**Locomotion therapy**	**VR**	**Motion tracking**	**Peripheral devices***	**Exergames**	**Inclusion on the design**	**Therapist control**	**Exercises personalization**	**Patient activity monitoring**
[21]	No	Rift	Kinect	Sensor gloves	Yes	No	No	No	Yes
[46]	Yes	No	No	Cycling device	Yes	No	Yes	No	Yes
[9]	Yes	No	Vicon	Treadmill	Yes	No	No	No	No
[4]	No	Rift	Leap Motion	No	No	Yes	Yes	No	Yes
[26]	Yes	No	P. Fastrak 3Space	No	No	No	Yes	Yes	Yes
[22]	Yes	Rift	Qualisys	Treadmill	No	No	No	No	Yes
[12]	-	Rift	Kinect	Cycling device	Yes	-	-	-	-
[41]	-	Rift	Kinect	Cycling device	Yes	-	-	-	-
[48]	-	HTC Vive		No	Yes	-	-	-	
[49]	-	Cardboard	Mobile	No	Yes	-	-	-	-
[50]	-	HTC Vive		No	Yes	-	-	-	

Chapter 4

Understanding Physiotherapists

This work aimed to understand some of the potentialities of VR adoption in physiotherapy, particularly in locomotion rehabilitation. Therefore, there were multiple fronts we wanted to cover in order to have a better understanding of the nuances such technology integration had in those environments. Based on the scientific readings on technology adoption in medical fields and the application of VR itself in the same context, we would design a study to test the willingness of professional physiotherapists to integrate a VR prototype solution made specifically for locomotion rehabilitation. Before anything else, we had to collect valuable information from professional clinicians and understand their needs.

The study would have two main phases. One for the development of the VR prototype and a second for the evaluation and analysis of the results. In both cases, the participation of therapists was crucial.

The VR prototype was one of the most important aspects of our research, so we decided to build our own custom solution, which we called the ”Locomotiver”. The Locomotiver was built with both the technological and people components in consideration. This means that every feature would be developed upon the necessity of the stakeholders, particularly the physiotherapists, that regularly conduct rehabilitation sessions, and patients that would theoretically utilize the VR devices. In terms of technology, we would try to take the maximum advantage of VR aspects and limit the presence and perception of common referred VR restrains such as latency. This way, we had the objective of providing the best VR platform for physiotherapy of locomotion possible.

We took advantage of our partnerships to develop a collaborative and iterative process of prototype development. We started out by making some field research to have a greater sense of the therapists practises and learn more about their needs and expectations. Afterwards, we would come back to the lab and develop some of the discussed ideas. Thus, the prototype evolved in a cycle with alternating phases of development and feedback from the partners.

4.1 Preparation Phase

Since our team did not have a lot of experience in the field of locomotion rehabilitation, we had to prepare some introductory questions in a semi-structured interview format. These questions would serve as a

baseline during the field research that would come about.

Note that the questions were opened to allow the therapists to expatiate their conversation and provide information they thought was useful. They are also very related to their own practises and had the purpose of providing us the knowledge to better understand their practise. We did not want to start from our presumptions or even from the findings of the scientific readings. These questions included:

- What king of locomotion rehabilitation do you usually conduct?
- Could you provide us some generic or specific exercises related with locomotion interventions?
- Do you leave patients alone or do they always need someone looking out for them?
- How much time do these exercises take?
- Can you describe your daily routine with a regular patient, during a locomotion rehabilitation?
- What are the mains differences you can point out, between neurological and musculoskeletal patients?

As the conversations unfold, we took the change to expand on some of these accordingly to their responses. Once we were confident we had a good base of questions we decided to meet the physiotherapists.

4.2 Field Research

Before we even started to code anything on the Locomotiver, we went out to do some field research with the objective of establishing some initial requirements. We partnered with professional physiotherapists from “Instituto Superior de Ciências da Saúde Egas Moniz” and “Hospital Prof. Doutor Fernando Fonseca, E.P.E.” and paid them a visit on their premises. Since we had no prior knowledge or experience on the field of physiotherapy, we made use of the questions to drive the conversations and asked many more according to what we watched on the gym where therapists were working. These meetings were very important to initiate the project.

On the first meetings, we started by creating a good relationship with the physiotherapists and explaining our initial vision of what the project, based on the scientific readings and related work, could be about. We observed the therapists working with several neurological and musculoskeletal patients performing a variety of exercises related to their locomotion therapies. We registered these exercises and also managed to speak with the therapists that would elaborate and explain some of the processes behind the rehabilitations. Over time, follow-up meetings took place to iterate on the Locomotiver’s functionalities and also to explore fresh ideas and needs that could be included.

4.2.1 Observation of Patients

We had the chance to observe multiple patients performing some of their routines during our field research.

The very first observed exercise required the patient to walk in a straight line across the room using squared tiles on the floor as a visual reference. The course had about 10 meters in length and 50cm width and the performing patient was guided by the therapist along the way. It was explained to us that this type of help is a regular practice on early stages of intervention or when the gym is full of people, as it happened to be that day. In that particular case, the recovering individual did the exercise twice, once from one side to the other and then back again. Shortly afterwards, the patient performed a similar exercise but that time, she had to walk sideways, from one side of the room to the other. According to the therapists, the interpolation between walking forms on the exercises is very common in order to have a greater sense of the patients progress.

We also observed an exercise where the patient was required to circumvent some obstacles (coloured sponges) placed on the floor by the therapists while also taking a zigzag course. The obstacles were distanced from each other by 40 to 50 cm. Once the patient reached the final obstacle, she had to make a u-turn and get across again. The patient did the exercise thrice back and forth as the therapists indicated the way.

We did not get to see any orthostatic exercises being performed by the patients during our visit. However, therapists still informed us about some common ones in these rehabilitations, as an answer to our question regarding which exercises were performed. Orthostatic exercises do not require the patient to move around the room. In these, the patient is merely required to stand in place and only move one foot forward, back or sideways at the time accordingly to instructions. Also in this category, there are exercises such as climbing on top of a wooden block or a step which we did not consider practical for VR.

Therapists explained to us that most of these physical exercises allow them to understand some gait patterns on the patients. Over the years, they start to get a good sense of the cadence of the feet, the load on each leg and whether or not the patient is performing compensations at any given time. However, some of these informations are not easily quantifiable with current technology.

4.2.2 Initial Conversations

After the initial observations, we talked with the therapists about the possibilities of our project and how it could be included on their daily-basis practises. We also took the change to ask some of our prepared questions.

Fortunately, most professionals we talked to, already had a good understanding of what immersive VR was about and shown good will to help by providing more information and ideas. We specified some important concepts and limitations regarding the hardware and software that would be used, specifically the immersive goggles from HTC Vive and tracking systems. For example, because the tracking lighthouse system could only track correctly an area of about 2x3 meters, the exercises included on the Locomotiver could not require more than the available space. By providing these informations, the therapists would be able to better conceptualize the possibilities of the project.

Overall, they were very excited with the application of VR. The therapists agreed that it provided a

more enriched and engaging experience than the traditional therapies and we should make use of that to create beautiful environments where the patients could feel good. Since in VR we had full control of the environment, they justified that we should make use of that to create a more escapism experience for the patients. They also supported the idea of creating some mini games that would map real life exercises.

After exploring a couple of ideas on the patient experience, we wanted to know more about the clinician's opinion on this matter of the metrics of the system. According to the scientific readings, in order to improve the adoption of such technology, it was very important to include valuable assets not only to the patient using VR, but also to the therapists conducting the session from afar. The metrics could be a solution for the extraction, analysis and delivery of quality information to the therapists. These would improve the professionals' perception and understanding of each exercise being performed.

Therapists liked the idea of having reliable data on each patient's performance very much, so we took the opportunity and decided to raise some metrics that they look for on every given exercise execution. We already mentioned, in the previous section, metrics such as the cadence of the feet, leg weight and compensations. Some of the most important included the number of steps on each exercise, the number of mistakes made on a given activity and the correspondent speed of the movement. In addition, therapists often try to estimate if the overall quality of movement, that refers to the ability of the patient to not only finish a given task but also to perform it correctly. Other metrics referred were the alignment of the feet relatively to the course, the spine movement and also the coordination between arms and legs during the gait. Despite the hardware limitations, we still had a lot of room to collect some of those metrics and facilitate the therapist's analysis.

Most important, the therapists disclaimed that it was paramount that the system and the exercises could be as customizable as possible. We have already studied on the related work section the importance of allowing the clinicians to control as many variables as possible to deploy custom solutions for each patient, so this was a very important factor to considered when building the system.

In general, the initial meetings were very productive and extremely important for us to better understand the therapists' needs and expectations. By taking the time to observe the nuances of the physiotherapy practises, we were able to have a good starting point to develop a first iteration of the prototype with some clear goals.

4.3 Design Implications for the Prototype

After the meetings, we started to better understand not only some of the physiotherapists practises, but also how could we improve them by recurring to VR. By taking both the scientific readings and the initial meetings learning's, we had some base design implications for the development of the Locomotiver.

4.3.1 Exercises

On the meetings phase, we managed to observe a variety of exercises, so inevitably, one of the early decisions was related to which exercises would actually be included on the prototype.

We started by discarding any orthostatic exercises since the scope of the project was primarily related to walking ones. On the other hand, we had the technological leverage to provide exercises in virtual reality that required some open space to walk on. So we would focus on building these propositions.

One of the early decisions, regarding the exercises, defined that we would try to map the exercises on the Locomotiver as much we could to the real ones. With that in consideration we would start by translating the very first exercise we saw, in which the patient would walk forward in a straight line to the other side of the room and then back.

4.3.2 Locomotiver for Patients

The Locomotiver aimed to provide a better physiotherapy experience for patients and ultimately improve their locomotion abilities. It is important to note that these individuals, that would be the users of the VR equipment, constitute a sensible focus group. Therefore, we had the responsibility to develop a system to be as safe and comfortable as possible.

By taking the scientific readings and the partners feedback, we identified some key components for the Locomotiver, as it would be used by physiotherapy patients. The system had to:

- Be comfortable, safe and easy to use;
- Provide motivating and fun experiences;
- Have engaging and immersive 360 environments;
- Present some kind of gamification.

To provide the most comfortable experience, we needed to analyze some of the limitations of the VR systems available on the market and choose one that could minimize these collateral effects as much as it was possible.

In addition, we would design the Locomotiver to fit the new paradigm of immersive 3D content. This means that the system would be designed with VR design practises such as having minimalist elements and low poli 3D assets. As an example and safety measure, the Locomotiver would translate the boundaries of the real play area into the virtual environment by having elements that worked as visual frontiers in VR. This way the user would know exactly where he can perform the exercises safely. Other optimization features, like the appliance of occlusion culling and LOD (Level of detail), would also be considered to ensure an optimized system that reduced latency and therefore increased comfort and safety.

Regarding the easiness and intuitiveness of use, we decided to choose to reduce the patients interaction to the bare minimum. We had the intention of providing a solution where the patient would put on the VR devices and be ready for the session, without having to push buttons, fill-in forms or any other

actions that required at least some experience with VR technology. Therefore, the patient would only interact with the system by means of his own body by utilizing full body tracking technology. This allowed the patient to see his/her body parts (hands and feet) in VR, as well as to interact with any elements around him. Besides, this would provide a more natural, free and fun experience.

On the other hand, VR offers endless possibilities to providing motivating experiences, especially when compared with traditional therapies. On the Locomotiver, the patient would be immersed in a virtual world with a full 360 point of view (POV) on its surroundings. That environment was only limited to our imagination. We would create different environments to increase the felling of novelty, but most importantly, we would leverage exercises as a driver for the patient engagement.

Each session would be composed by a set of exercises deployed by the therapist. These exercises are direct translations of real ones that the patient is probably already familiar with. As each exercise occurs, informations related to it, such as timers and progress, would be displayed for the patient have an understanding of the development.

Ultimately, we would design an enriched experience that could improve the patients motivation and well-being in physiotherapy.

4.3.3 Locomotiver for Therapists

It is important to note that the most important stakeholders of the Locomotiver system would be the physiotherapists. They are the ones who conduct the rehabilitation processes and decide whether or not the system is worth to apply. This increased the attention to the implications that regarded the therapists.

The implications related to the therapists included:

- Require little effort to learn and understand the use of the system;
- Provide a useful experience for their daily practise;
- Provide reliable data from each session;
- Function properly with limited systematic errors;
- Allow customization of exercises;
- Utilize unique features related to VR.

One thing that was clear, after the meetings, was the overwhelming amount of work the therapists had on a regular basis. There was always a patient that required some kind of attention either because he needed help with an exercise or simply because it was his turn to be assisted. This was an important thing to note and affected the level of complexity we could include on the system. The therapists do not seem to have the time to learn very complex user interfaces and systems, for that reason we decided to imply the design to be minimalist and easy to use. Note that, this is also congruent with the UTAUT theory of adoption previously stated.

The prototype should also provide value to the therapist, in a sense that it should simplify some of the current processes performed by the professionals. One way to do this is to optimize some of the customization of exercises. This would reduce the time spent preparing the exercises that are different from patient to patient. In fact, therapists emphasized the need of personalizing the treatments according to the patients, as each individual has an unique condition.

The Locomotiver also needs to promote the trust of the physiotherapists. This means it should provide reliable information that would otherwise be difficult to account. On the other hand, the system should not contain systematic errors that require technical knowledge to resolve. This is also related to the simplicity of the system. In a way, the Locomotiver should be able to be put in practise by every therapist that is already familiar with general technology.

We also establish the intent to provide the therapists with tools that are unique to the VR realm. These include the possibility of exploring the point of view (POV) of the patient, in real time, by taking a look at the POV camera that sees the virtual world. A third-person camera should also be included to allow the therapist to analyze the movement of the patient immersed in VR.

All the system should be highly configurable with multiple settings that allow more information to be displayed on the screen such as metrics, assets and other particular functionalities related to the included exercises.

With all of this in consideration, we were able to start developing our Locomotiver prototype.

Chapter 5

Locomotiver

As the medical field of physiotherapy still lacks the practical implementation of VR systems, we propose the Locomotiver as a platform to deploy exercises that leverage that technology specifically for the treatment and rehabilitation of locomotion disabilities.

In this section, we specify the tools and technologies used in the buildup of the platform, while also explaining how the frequent contact with our physiotherapists partners heavily influenced the design decisions and features implementation.

5.1 Architecture

The Locomotiver prototype was built with hardware and software technology provided by the HTC Vive. In this section, we present the hardware and software tools we used in the development of the Locomotiver system. We chose the HTC Vive to build the application on as it was very easy to use. It also already included all the hardware necessary to make VR work. The Locomotiver run in the SteamVR that allowed the deployment of software and games on the HTC Vive.

The Vive's headset is very precise, with 360-degree tracking, realistic graphics and directional audio. It has a refresh rate of 90 Hz and a 110 degree field of view, and each OLED panel (one per eye) has a resolution of 1080x1200 pixels producing a final display of 2160x1200. For safety reasons, the system includes a mechanism called "Chaperone" that automatically displays a virtual wall that prevents the user from hitting obstacles or getting out the play area. The headset has dozens of infrared sensors that make it detectable by the base stations, and it also includes an accelerometer, gyroscope and proximity sensor.

The Vive controllers have an incredibly rigorous tracking. Each one has multiple input methods suck as a track pad, grip buttons and triggers making it very intuitive to use. Their lifetime per charge is also quite reasonable, being about six hours which covers almost a full working day at a rehabilitation establishment.

These devices are being tracked by the Vive base stations, also known as the lighthouse tracking system. The tracking system emits infrared pulses at 60 per second that detect the headset, controllers

and trackers with milimetric precision. These small devices are placed on opposite sides of the room and allow the creation of a 360 degree virtual area called the play area. In this area players can physically walk around in a recommended space of about 5 meters of diagonal. Having that, we took the 3,5 m x 3,5 m as a standard as a physical requirement for the use of the Locomotiver.

Users would be recommended to use a pair of headphones to improve the immersion and therefore the VR experience.

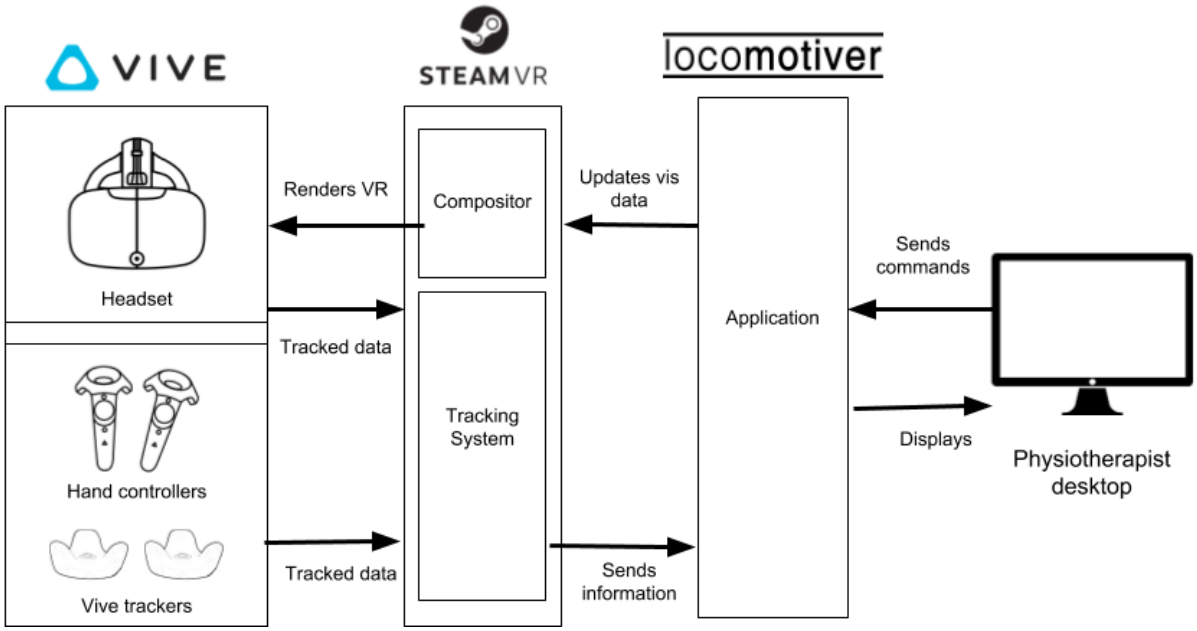


Figure 5.1: Locomotiver's system architecture

5.2 Vive Trackers and Full-body Tracking

In addition to the included HTC Vive essential parts, we decided to included Vive Trackers and Track straps to increase the capabilities of the Locomotiver. On a regular session, each patient is required to attach two trackers, on its feet, that function as markers and allow the system to recognize their position and consequent movement at any given time. The Vive Trackers are attached via the comfortable Track straps that wrap around the patient's legs, feet or shoes, accordingly with the therapist's desire. A third Vive Tracker may also be optionally used to see the pelvic area of the patient. The inclusion of these devices allows a full-body motion and visualization in a regular session, increasing the reliability of the Locomotiver.

5.3 Unity 3D

The Locomotiver was built using the cross-platform game engine Unity3D. Unity has become one of the most popular platforms for VR development and so it brought a lot of advantages to the development

Figure 5.2: Setup of the Vive Trackers on the patient's feet

of the prototype. Some convenient factors associated with the use of Unity include not only a large availability of assets but also open-source code, tutorials and sample projects.

SteamVR was also launched with native support for Unity, making these applications relatively simple to integrate with the existing hardware. Furthermore, Unity also had an already significant community of VR developers which allowed us to minimize errors and optimize some processes. The scripts for the Locomotiver functionality were written in C#.

5.4 Locomotiver - First Version

Having some initial information collected from the therapists, we started building the Locomotiver prototype.

We started by creating a very simple VR environment including the HTC Vive essentials to allow the deployment of the application. We proceeded to separate the visualizations by including two different cameras, one integrated with the Vive for the patient to experience the 360º environment as a POV (point of view) and a main one for the physiotherapist to have a 3rd person view and an user interface that controls the sessions. The patient did not have a user interface since he would be wearing the headset. Instead, the UI elements would be physical objects like displays and tablets that showed information to the patient at any given time. On the first iteration we included a TV screen that displayed a top view of the player so that he could have a sense of his movements without having the need of looking down to his feet all the time. This would later be changed. Regarding the physiotherapist UI, we started by including some options to control the environment. We also included the possibility of the physiotherapist to see the POV of the patient by making a split screen, if it is desired.

Then, we started to build the first exercise - walking forward. This exercise consisted in a small corridor that extended from one side of the play area to the other and had two borders. The main purpose of the exercise is to allow the patient to go from the starting point to the other side of the corridor and back without touching the borders. The corridor was set by the ground level and would be interacted with two game objects, with respective colliders, mapped by the Vive controllers (and later by the Vive trackers). The borders would emit a red smoke, if collided with, to indicate that the patient had made a mistake and the overall floor of the corridor would turn green according to the player's feet

position.

We also included some customization controls on the therapist user interface (UI) on the first iteration of the prototype. Regarding the walking forward exercise, the therapist could set the width of the corridor, by means of a slider. This feature allowed the clinicians to have a good control of the level of difficulty of the exercise. The bigger the width of the corridor, the easier it would be for the player to go from one side to the other without colliding with the borders. On the other hand, if the width is very small, the patient needs a much greater control over his lower body to complete the exercise with minimal mistakes recorded. By providing this level of customization, therapists should be able to deploy the same exercise to many patients and adjust it to fit their capabilities. For example, patients in earlier phases of the rehabilitation will need a bigger area to set their feet in, than the ones at the end of their recovery.

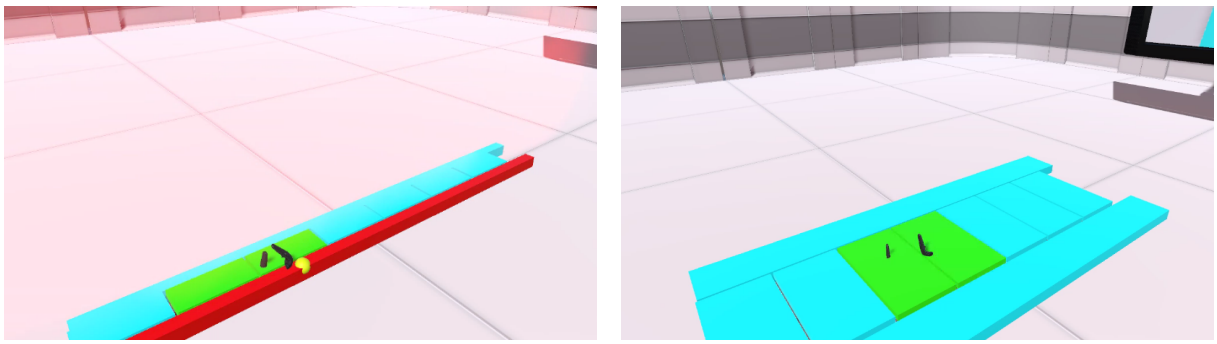


Figure 5.3: Locomotiver's first iteration of the Walking Forward exercise

The first prototype was also capable of recording some important metrics regarding the exercise being performed. First, we returned the number of steps by calculating how many times each foot was in contact with the floor since the beginning of the exercise. The number of goals achieved was also returned to the therapist to keep track of the progress of the exercise.

Each walking exercise has a starting point and a goal on the other side, indicating the patient to move towards that goal. Once the patient arrives at the goal location, the goal moves to the opposite side and so on. The number of goals, or repetitions, is also customizable and determined by the therapist on the initial setup. This way the level of difficulty is also determined by the therapist in charge. It is presumed that the more advanced the patient is on their recovery the more repetitions he/she is able to perform on the given exercise. Finally, we recorded the amount of time the patient took from the beginning to the end of the course.

As the project advanced, we sent out a video of the Locomotiver prototype to our partners and scheduled a second meeting with them to improve it.

5.4.1 Second Iteration

Once again, we had a meeting with the partners at the "Instituto Superior de Ciências da Saúde Egas Moniz". They had already seen the video where both the hardware setup and the walking exercise were displayed, so they had a greater sense of the purpose of the project and the possibilities. This was a very important milestone for us to understand what would need to work in the future and how we could

expand the exercises and functionalities to better serve the clinicians needs.

One of the very first and important take ways was related to the possibility of the therapist to see the POV of the patient in VR. The therapists loved the idea as that was a completely new paradigm. For the very first time, they would be able to see exactly what the patient was seeing and make sense of their motor responses relatively to the presented stimuli. In real life, the therapist only has a 3rd person view of a given exercise performed by the patients, but in VR they have the possibility of steeping in the patient's shoes and better induce their decision making.

Physiotherapists also gave us feedback on the VR aesthetics and visual content. Although we had only one simple VR environment, therapists endorsed us to explore more creative ones by saying that "by using this platform patients could still go outside while staying comfortable and safe all the same". This would also justify our motivation to create more compelling visual scenes on the system.

These validations were very important to sustain the development of the Locomotiver prototype.

5.4.2 Exercises

Having seen and approved the first exercise, we started to explore more exercises that were done in traditional rehabilitation programs and could be translated to VR. Once again, the importance of exercises in VR being the same as in traditional programs was very emphasized by the professionals. Despite the fact that VR can enhance the characteristics of an exercise in terms of engagement or visual effects, it was still paramount that the mechanics and goals were very close to reality to make the rehabilitation relevant. One of the exercises we agreed that made sense to translate to VR was related to barriers and obstacles. These are often made to study the step alternation and ability of the patients to overcome blockades. We were shown a video recording of a related exercise where the patient had to walk from one side of the room to the other, while surpassing a couple of padded barriers spread across the floor. This type of exercise made sense in VR not only because it was an interesting experience to gamify for the patient, but also because in VR the therapists could more easily parameterize the height, distance and number of barriers.

Another exercise we considered was the zigzag. We had previously seen, on the first iteration, a version of this exercise, and since it came up again we strongly considered translating it to the Locomotiver. Just like the obstacles, in VR, the zigzag seemed an interesting gaming experience for the patients.

The therapists also enlightened us about the differences between simple tasks and multiple ones. It is common in physical rehabilitation to submit patients to tasks where they need to perform a regular exercise while being distracted by a concurrent activity. That may be counting up numbers, talk freely about a subject or identifying object colors. The purpose of this relates to the plasticity of brain cells and automation of the movement despite the distracting factors.

5.4.3 Mirrors and Parallel Bars

We also explored the subject of the environment where the exercises were performed. Here we found an interesting concept. There were a lot of walking exercises performed between two parallel side bars

on a short distance of about 2.5 meters long. These bars are very common in lower limb rehabilitations and serve as safety for the patient. The recovering individual is required to hold on to the bars as she advances on the course. The setup consists in having the parallel side bars and two mirror on each extremity to allow the patient to see his movement. According to the professionals, this is used specially with patients that lack the autonomy to perform the exercises on an open room.

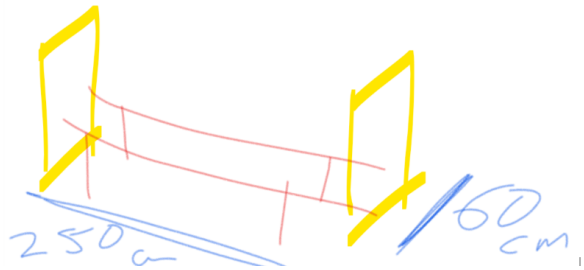


Figure 5.4: A draft of the parallel bars and mirrors to implement in VR

Curiously enough, the maximum play area on the HTC Vive corresponded very well to this area where the parallel bars sit. We talked with the therapists about translating this to VR for several reasons. Firstly, the VR parallel bars could be easily customizable for each patient for example according to their height. Secondly, the use of a mirror in VR was very important. At that time, the Locomotiver had a TV screen that displayed a top view for the player. This was made as a work around the limited field of view that induced players to be constantly looking at their feet when walking on the Locomotiver's environment. It worked fine but the interaction did not feel natural. The inclusion of mirrors in VR would not only solve this issue but also reflect the real setups in physiotherapy gyms very well.

5.4.4 Metrics

While the metrics we presented already offer some insights on the walking exercise being performed, the therapists reinforce the importance of extracting as much data as possible for posterior analysis. One of the mentioned metrics was the general speed of the patient during the exercise. This was something a bit more complicated to induce in traditional therapies but relatively simple in VR, since it is possible to calculate distance over time for each exercise.

Another important metric was related to the sizing of the steps. The clinicians would like to have a better sense of the differences of length, width and height between two steps at any given time. By having this data, they would be able to better understand the progress of the patient and whether or not they were compensating certain movements. They also suggested the establishment of a profile for each patient and record the evolution of a given individual over multiple sessions. Those profiles could also include an history of the exercises the patient had done so far and the results associated with. All the ideas would be considered on the following iteration of the prototype development.

5.5 Locomotiver - Final Version

By the time the second iteration of the prototyping took place, we already had the bulk of the information that would serve as a base to the project. This was a very important phase where we put our efforts in developing a couple more exercises as well as extending the functionalities of the software.

Overall, most of the look and feel of the Locomotiver would be set by this iteration and verified later on by therapists on the lab.

5.5.1 Exercise - ”Walking Forward”

We have described in the previous section the ”Walking Forward” exercise. The final version of this exercise was very similar to the first version. We simply decided to remove the red smoke effect that had a negative effect on the systems' optimization. Now, everytime the patient collided with the borders they would simply turn red and account one mistake.

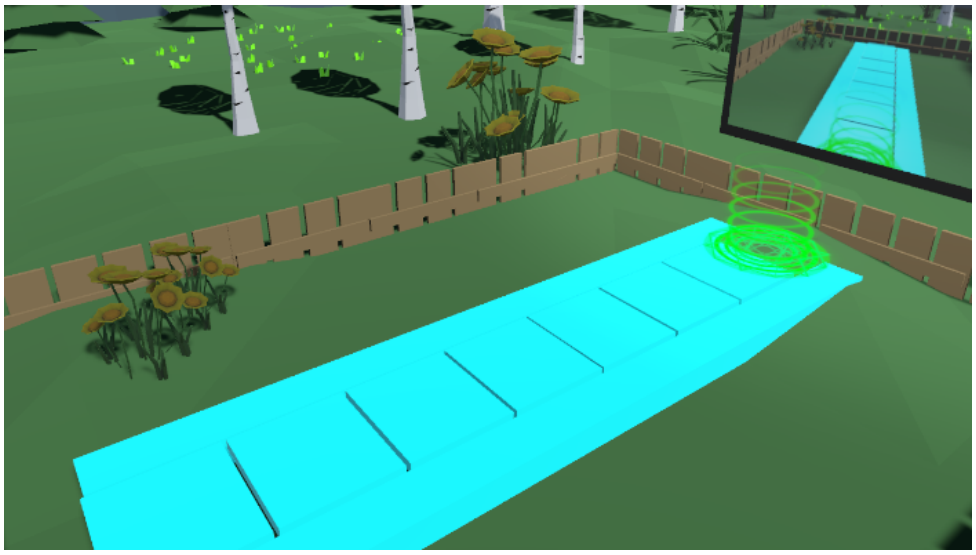


Figure 5.5: ”Walking Forward” exercise on the Locomotiver

5.5.2 Exercise - ”Barriers”

Following the previous explored ideas of the obstacle course, we decided to implement a version on the Locomotiver. This exercise was similar to the walking forward one, as it had a beginning and end goal to which the player would need to get across. However, in this one in particular there would be obstacles in the form of barriers. The barriers were customizable by the physiotherapist at the start. This way, the clinician would be able to decide how many barriers would be on the course, between the minimum of one and the maximum of four, and their respective height.

The barriers were made so that they would turn red if stumbled upon and would emit a sound effect as feedback. On the other hand, the player would hear another sound when surpassing it successfully. The system would also record how many barriers were hit and surpassed to keep track of the patient's

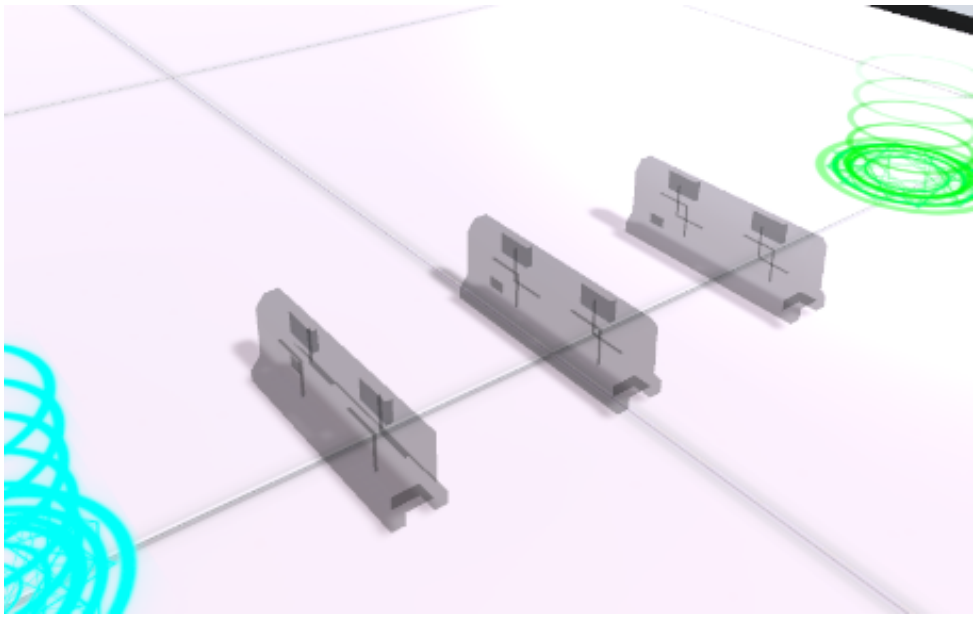


Figure 5.6: ”Barriers” exercise on the Locomotiver

progress on the exercise. As a design decision we decided to limit the height of the barriers to 50 cm, as we felt it was a maximum value already too hard to reach even by an healthy individual. The minimum height was set to be 12 cm. These values were approved by the partners in following meetings.

5.5.3 Exercise - ”Zigzag”

We based ourselves on the feedback from the meetings to design our own zigzag exercise using cones as obstacles over a course. The purpose of this exercise consists in working around each cone without touching it and reach the goal to complete the sets. Similarly to the barriers exercise, the cones light up red when hit and emit a sound effect noticing a foul. A similar sound effect is heard when a cone is successfully bypassed. The Locomotiver would also record how many cones were hit and bypassed to demonstrate the progress.

However, contrarily to the barriers exercise, the therapist lacked some customizing options on this exercise. The number of cones was set in 4 and there was no option to alter the cones height or width. We felt that there was no significant difference on the difficulty and the number of repetitions was enough to establish the level of complexity on this exercise.

5.6 Physiotherapist’s User Interface

We designed the therapist interface to be very intuitive, minimalist and easy to understand. We also made it so it enabled the most control and customization as possible over the system.

In general, the UI is divided in three major components: the top bar, the visualization area and the bottom bar. Elements displayed on the top and bottom bar open windows with different functions associated. The visualization area is where the therapist is able to see the action occurring in the virtual

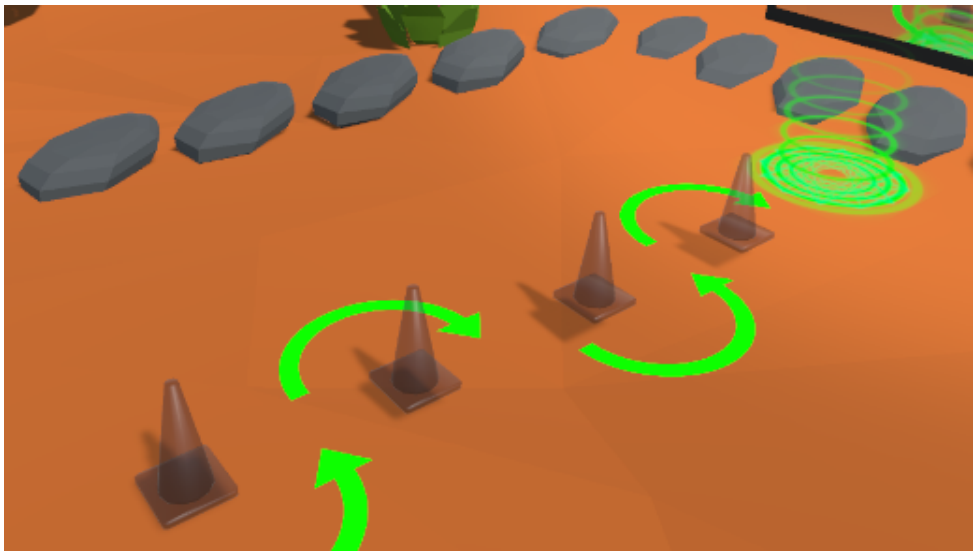


Figure 5.7: ”Zigzag” exercise on the Locomotiver

environment and analyze it. On certain occasions, the system deploys some pop-up windows that require the attention of the user. We applied a fluid design with minimalist icons and color schemes to create a good user experience. In this section, we describe the elements of the UI and the functionalities associated with it.

5.6.1 Patient’s POV

On the right corner of the top bar, there’s an icon with a VR headset. This one switches on and off the POV of the VR headset allowing the therapist to see what the patient is seeing. The screen will then be split in two displaying the 3rd person view on one half and the patient’s POV on the other.

This was one of the most important functionalities that introduced the possibility of the clinicians to see what their patients were seeing, in their daily practises.

5.6.2 Locomotiver Settings

The settings are located right next to the patient’s POV icon, on the top right corner. These settings can be changed at any given time, by the therapists, to correct some behaviors in the system or to display different views and functions in it.

The first button in this menu is the ”Calibrate Floor”. This option serves as a shortcut for an eventual bad calibration of the HTC Vive system. On the Locomotiver, the main functionalities are directly correlated with the player’s feet. In other words, the player’s feet have to collide with the floor elements, may those be the barriers, cones and floor itself, for the system to behave correctly. For that reason, we offer the possibility to correct the ground level of the Locomotiver to be directly in contact with the current player’s tracked feet. This menu will open a separate window where it is possible to see the current position of one tracked foot and the ground level. By using the slider on the left, the therapist is able to quickly correct the ground level and proceed with the session without the need of re-calibrating the Vive

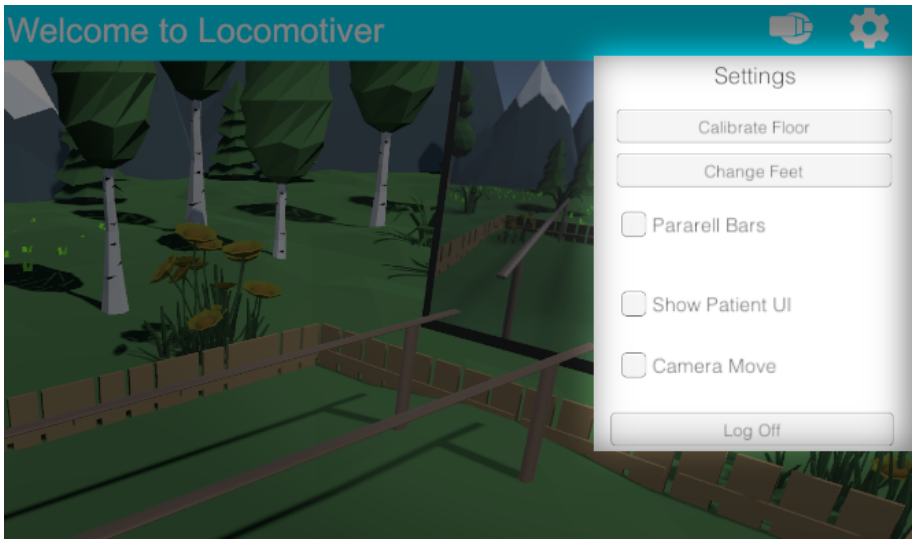


Figure 5.8: Locomotiver's settings menu and respective components

system completely.

Above the floor calibration, sits the "Change Feet". This option is a direct response to a physical exchange of the trackers from one player to the other. The trackers are identical, so the chance of a player putting the tracker for the left foot on the right one are not that low. In that case, this option will exchange the functionalities of one tracker with another, making it changing feet and therefore correcting the situation.

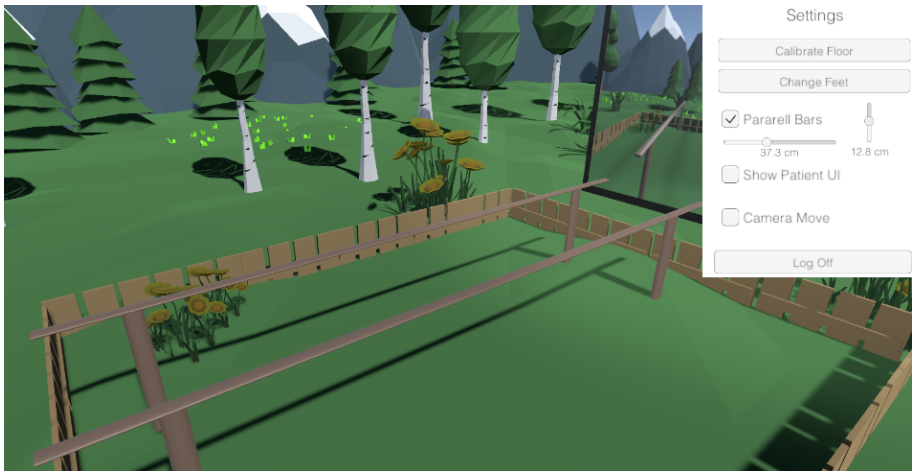


Figure 5.9: Customization of the parallel bars on the settings menu

The Locomotiver also includes a set of customizable parallel bars, similar to the ones we observed in the gyms and meeting with the partners. By means of a checkbox, included in the "Settings" menu, it is possible to make them visible to the patient or not. By default, the bars are set to be hidden. When turned on, two new sliders pop up on the menu to adjust both the height and the width according to the therapist's decision.

Bellow the parallel bars options, there is a second checkbox to toggle the display of the patient's UI elements. As mentioned before, it is not a good practise to put static UI elements on a head mount

display type of interface. For that reason, the patient has in-game objects that display informations. However, the therapist already had access to those informations in a different window. There was no need to clutter the visualization area with those elements, therefore they are hidden from the therapist by default. If, for some reason, the therapist wants to see in the 3rd person view all the elements, he/she can use this checkbox to make them visible at any time.

The last check box relates to the 3rd person camera movement. By default, the Locomotiver has a static camera that points in the direction of the elements on the play area. This functionality allows the therapist to much more control over that camera. It is then possible to rotate around the room by using the mouse and fly over the play area. Zoom in and out is also available by using the mouse wheel. Zoom out is limited to a certain boundaries of the play area. Finally, it is possible to freeze the camera position wherever it stands. While locked in place, the camera does not allow rotation anymore but zoom in/out is still available to allow a better analysis of the elements.

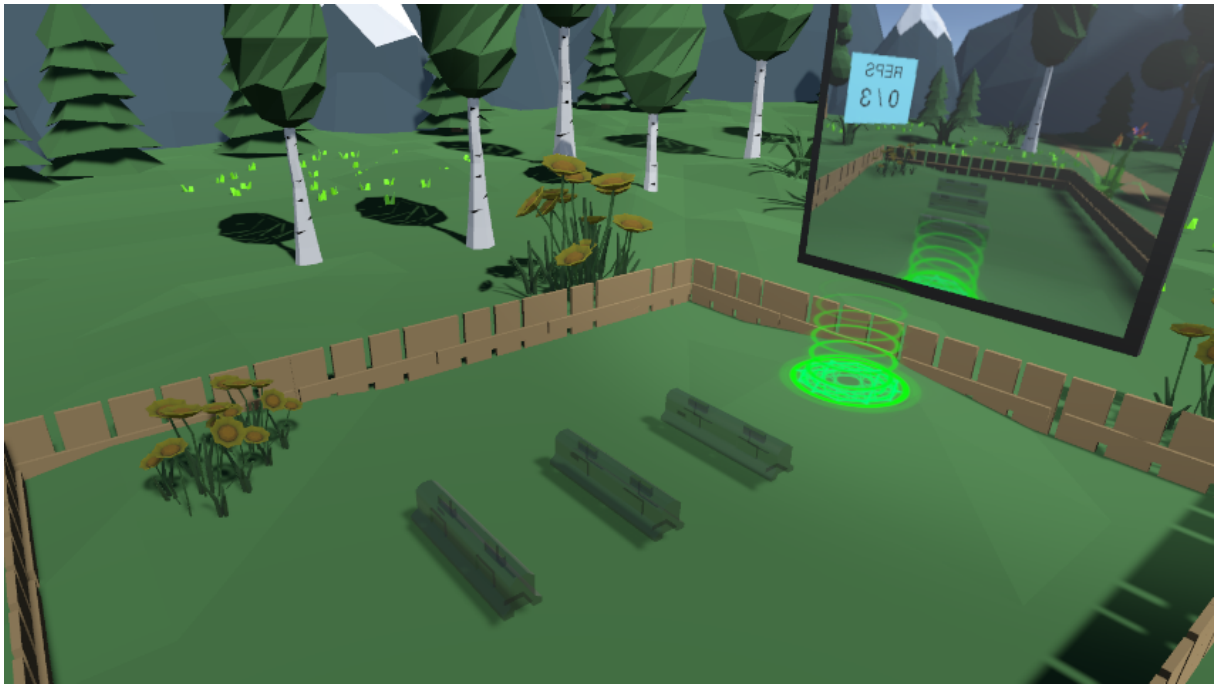


Figure 5.10: Third person view of the visualization area with a static camera

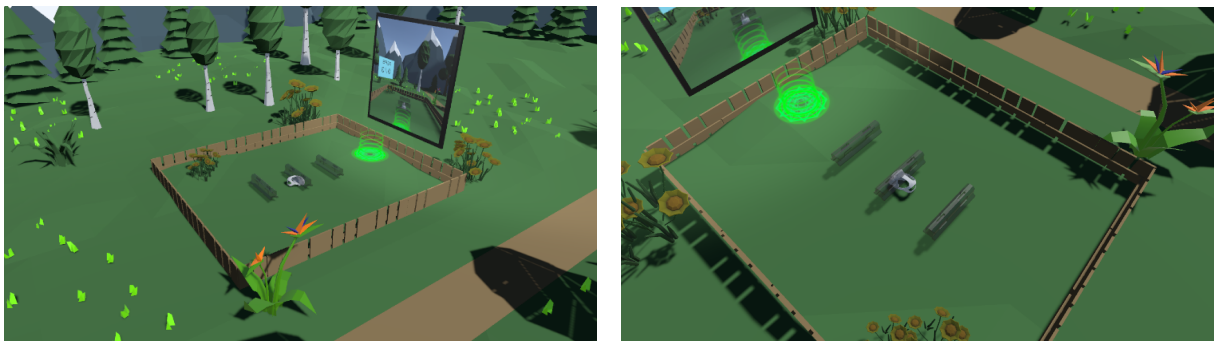


Figure 5.11: A moving camera allowing different perspectives on the VR environment

This functionality requires slightly more practise than the static camera. Because of that, we decided

to leave this option turned off by default, giving the more curious therapists the option to explore it whenever they want.

Lastly, there's a "Log Off" button to exit the session to the main screen.

5.6.3 Exercises Setup

The exercises are the main focus of the Locomotiver. Based on the scientific readings and the preceding meetings with the professionals, we established that the physiotherapist would have as much control as possible on the exercises. The exercises are launched singularly from the menu on the bottom right corner of the UI - "New Exercise". Each exercise has a set of values that need to be customized by the therapist before it begins. While some of the parameters are generic for every exercise, some have own unique definitions to work properly. When an exercise is selected, its menu opens with the correspondent options. In order to keep the UI consistent, the parameters are specified via sliders that range between specific values. All three exercises share the specifications for the timer and repetitions. The "Walking Forward" exercise has a specific customization for the width of the corridor while the "Barriers" exercise has custom values for the number of obstacles and their respective height. A preview of the exercise is displayed on the visualization area while the therapist is establishing the variables.

Figure 5.12: Setup of a "Barriers" exercise's custom variables

At any given time, it is possible to go back to the previous menu by choosing the back button. Otherwise, when all the variables are set, the therapist can click on the start button (play icon) to start off the exercise.

5.6.4 Deployment of Exercises

When an exercise is deployed, it doesn't start automatically. Instead, there is a pop up window that reminds the physiotherapist that his/her patient needs to be positioned at the starting point, before the

exercise begins. This prevents possible confusions and miscommunications in a regular session. The starting point of the exercise presents itself as a light blue portal. It is important to note that, if the patient is already on the starting point by the time the deployment takes place, this warning will not be shown. Once the patient is in the correct position, a button to start the exercise is unlocked. Right before it begins, a countdown from 5 to 0 is displayed on both the therapist UI and the VR environment.

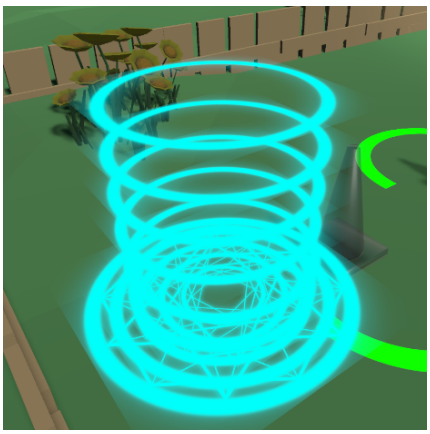


Figure 5.13: Starting point indicator that indicates the initial position of the exercise

Once the countdown reaches zero, the pop up window closes, freeing the visual space and the metrics side window opens up.

5.6.5 Metrics Window

In every exercise, there are many informations emerging in real time. Those may be the number of steps increasing, the number of goals achieved or even the mistakes made.

Because of their importance, metrics have their own separate menu on the bottom left of the screen. This menu can be toggled as well to hide or show the results according to the user preferences. By default, every-time an exercise begins, this window will pop up.

Evidently, different exercises register different metrics in real time. For example, the exercise ”Barriers” is the only one that accounts for the variable ”Surpassed barriers”. All the metrics are automatically updated as the events occur during the session, until the end of the exercise.

5.6.6 End Screens

Each exercise ends either because the player accomplished the objective (number of repetitions) or because the system reached an ending condition like the time is up. As each practise finishes, a window pops up on the therapist UI. This ending screen states if the player achieved his goal or not and the results associated.

The therapist then has the opportunity to save the data of the session in the tracking records or continue and disregard the outcomes.

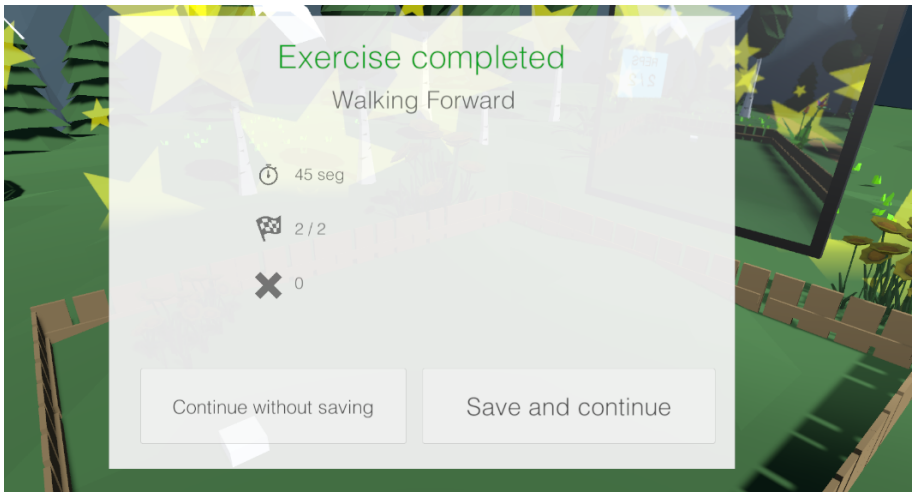


Figure 5.14: End screen of a successfully accomplished exercise

5.7 Patient's Interface

As we covered before, the patient interface was made to be as simplistic as possible to promote the best VR experience possible. Nevertheless there are significant components we describe in this section.

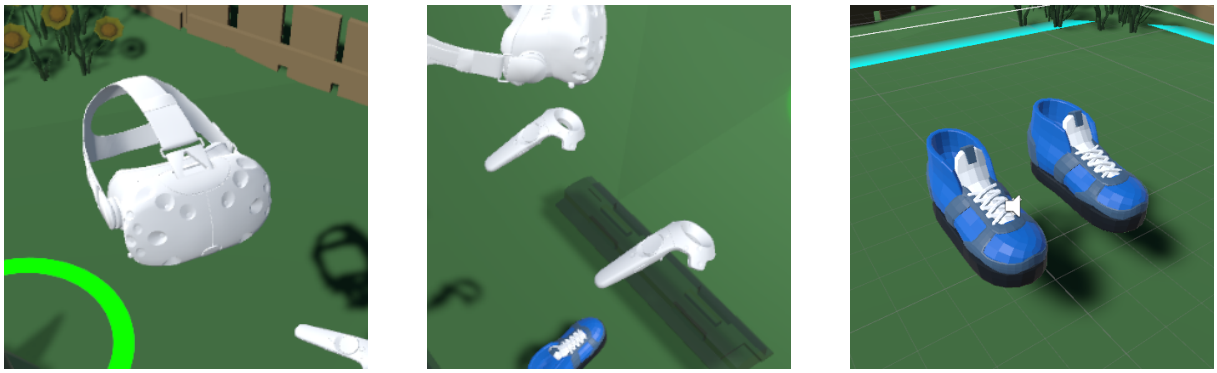
5.7.1 Virtual Body

The representation of the user's body immersed in VR has been a subject of many studies. Since the technology requires the substitution of the sense of sight, developers and scientists have wondered what was the best solution to provide context to players in VR. Those can vary from the most simple invisible player to a full-body tracked avatar. On the Locomotiver, the ability to provide a reliable visualization of the players limbs was very important on the context of rehabilitation. According to a study on the illusory body ownership of an invisible body interpolated between virtual hands and feet, the presence of those references is sufficient to provide a sense of reality to the user [23].

We established visual components for the feet of the player. Two low-poli 3D models of shoes on the same position as the HTC Vive trackers (required to be used on the subjects feet). The player's hands are represented by the HTC Vive's controllers included on the Vive's library. At last, the head is presented in VR as a 3D model of the Vive headset to keep a level of visual consistency.

5.7.2 Information Elements

We have settled before that, to create a great VR experience, there is a need of keeping the visual content, for the user, as clean as possible. Fixed elements on the UI are also very troublesome. Therefore, the informative elements of the Locomotiver are in-world objects like signs and displays. We also made it so these elements are only active when and only as they are needed. This way we avoid overwhelming the patient with too much information. As an example, before an exercise begins, there is a temporary sign with the countdown from five to zero. Once the exercise begins, that sign disappears and a smaller one with the current time of the exercise shows up.



(a) Head (b) Hands (c) Feet

Figure 5.15: Player's body parts representation in the VR world

We also made so that, the important information is redundant. Since the player is involved in a 3D environment, he/she can easily lose the track of the spatial positioning of the objects. To minimize that effect, important elements of display, such as the signs with the number of repetitions or timer, are duplicated on opposite sides of the play area. This increases the chances of the player to not lose the track of that information.

5.7.3 VR Environments

In order to create a good VR experience for the immersed patient, it was crucial to develop some great visual compelling environments. On all three environments we preferred to use simplistic assets and objects. Note that the environments do not influence the functionalities of the system. The exercises are independent from their surroundings. The main purpose of the Locomotiver to offer different environments is to introduce novelty and create different experiences. So, we designed three different spaces: "Locomotiver VR Gym", the "Forest" and the "Oasis".

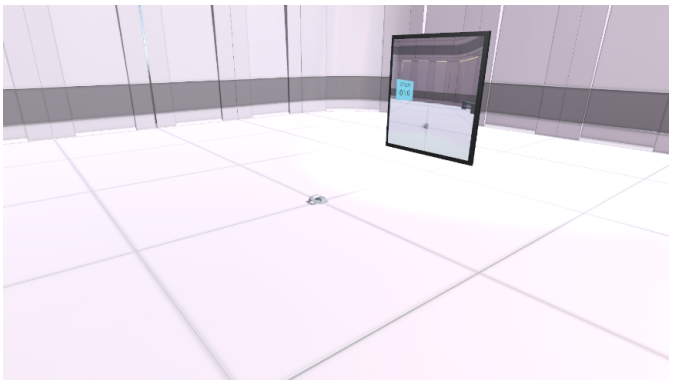


Figure 5.16: VR environment - "Locomotiver Gym"

The "Locomotiver VR Gym" is the system's default minimalist environment. This environment was made to be very simple in order to avoid distractions and allow the therapist and patient to focus on the work rather than the VR experience itself.

The environment consists on an open white and fairly empty room with a window for an outside

exterior. We removed almost all the shadows from this environment to allow more light inside the room.

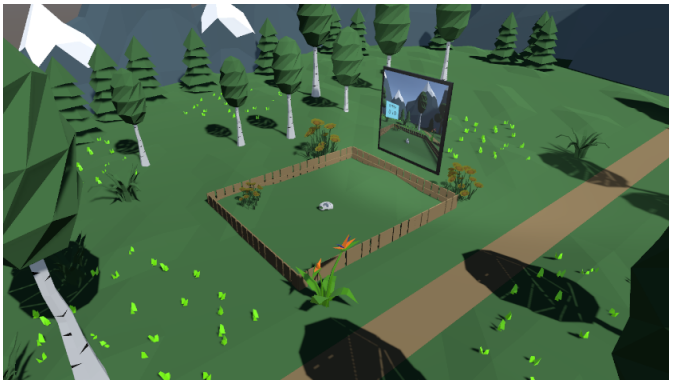


Figure 5.17: VR environment - ”Forest”

The second environment is the ”Forest”. This environment was created to provide a more engaging and enriched experience to the player than the ”Locomotiver Gym”. We also intended to provide a more relaxing environment that has the purpose of functioning as a small escapism for the player.

We placed several elements of nature on the surroundings of the play area such as a large variety of trees, plants, flowers and grass. We also surrounded the area with mountains to have content in all 360 degrees of VR. The VR play area is limited by a wooden fence which the player should not cross. All the exercises take place inside the fence that works as a more appealing visual boundary than the default one.

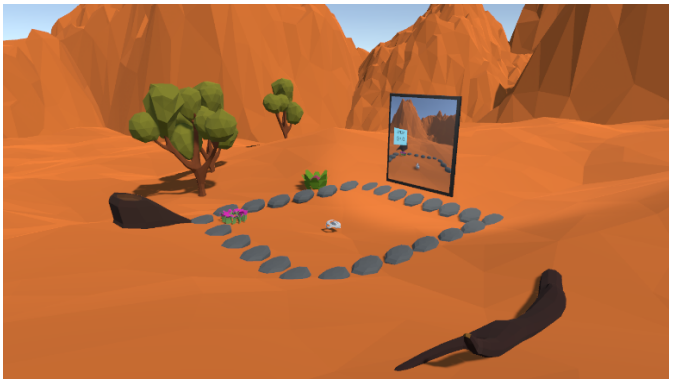


Figure 5.18: VR environment - ”Oasis”

The third environment we included is the ”Oasis”. The ”Oasis” is a simple desert environment with arid sands, desert vegetation, rocks and stones.

Similarly to the ”Forest” environment, the ”Oasis” is also limited by mountains to hide the horizon and create a more immersive experience. The play area is also limited by rocks disposed in a squared shape around it that create a visual boundary.

Once the prototype was ready we moved on to the evaluation phase of the research.

Chapter 6

Evaluation

Once the Locomotiver prototype was finalized, we proceeded to the evaluation phase. During this stage, we settled several objectives. These included the assessment of the quality of the Locomotiver and the search to understand the usage intent of the physiotherapists to adopt it in their daily activities.

We started by establishing some research questions related to the adoption of our VR solution as well as the impact and implications associated with it. Afterwards, we prepared a semi-structure interview and a questionnaire supported on principles and concepts of theories of adoption. We reunited with professional physiotherapists and conducted an experiment with them at our partner's facilities where they had the change to use the Locomotiver and provide feedback. Posteriorly, we did a qualitative thematic analysis on interview answers and comments to which we correlated with the quantitative results of the questionnaire responses.

In this section, we describe the preparation of the evaluation process and provide details on the decision making behind each step of it.

6.1 Research Questions

The main research question we had related to the usage intent and adoption of the proposed prototype and stated:

- Do physiotherapists have the intent to adopt the Locomotiver, as a VR locomotion rehabilitation option, in their daily practices?

By answering this main question, we can have a sense if the processes we took during the previous phases actually improve the intent to use this technology. But we also wanted to assess some of the nuances that regard the Locomotiver and its impact. We had other research questions such as:

- Do physiotherapists believe the Locomotiver will motivate their patients and bring benefits to their rehabilitations?
- Is the system easy to use and understand? If not, what can be improved?

- Do therapists believe that the system can improve their activities?
- What are the biggest barriers to the immediate application of the Locomotiver in a real life scenario?

These research questions cover some of the most important aspects of the impact and usage intent related with the Locomotiver, and they allowed us to guide the evaluation process to the goal of understating if our prototype could be adopted by the professionals.

6.2 Participants

The evaluation was carried out with our partners from the ”Instituto Superior de Ciências da Saúde Egas Moniz” and also professional clinicians from ”Hospital Garcia da Horta”. It was crucial that the participants were active and knowledgeable individuals on the subject as we would induce their interest and perceived ability to put in practise our solution.

The 9 participants were all active in the physiotherapy area, whether as being an active physiotherapist or as a current professor on the subject. From these, 8 were women and 1 was male. All the participants had previously performed rehabilitation that included locomotion therapy, lower limb recovery and gait training, similar to the ones the Locomotiver provided. Regarding the use of VR, 44,4% had never experienced a virtual reality device up until the date of the experiment.

All the participants shown great interest in collaborating with our team by providing as much information and detailed opinions.

6.3 Methodology

The experiment we conducted was comprised by some key stages. All participants followed each one, in order. In this subsection we describe each of the stages conducted and their purpose. They were:

- Briefing
- Using the Locomotiver as the Patient Persona
- Using the Locomotiver as the Physiotherapist Persona
- Semi-structured Interview
- Questionnaire
- Conclusion

6.3.1 Briefing

Before the experiment begin, all participants were given informed consent forms that outlined the purpose and goal of the study as well as the information that concern their privacy, safety and personal

data. These consent forms can be consulted on the Appendix B. All participants would participate by their own will and they were free to withdraw at any time during the experiment. The participants' names are not used in this document in order to protect their privacy. For the same reason, the following images presented on this document hide the participants face behind the VR headset. Participants were also informed that the audio of the session was going to be recorded for posterior transcription and analysis. We would started recording as soon as the experiment began and the consent forms were duly signed. During the experiment, the participants were not exposed to greater risk of harm than smaller rare issues associated with VR that included motion sickness or nausea. Participants were informed that this research would contribute to the scientific progress and could bring future benefits for their own profession. Information gathered for this study was confidential and not shared with any third parties and was only used for this study. In addition, each participant went through the same experiment and performed the same task as all the others. The full script of the experiment can also be consulted on the Appendix A.

We started every session by greeting the participant and introducing each other. We proceeded to transmit the purpose of the project regarding the creation of a virtual reality system specific for locomotion rehabilitation and the potential of adoption of such technology. It was also made clear that the product had been developed with close collaboration of their professional colleagues.

After the initial briefing, we would advance to explain the various phases that would come about. The participant would try the Locomotiver first as if he/she was the patient herself (patient persona) and then in0 his/her own professional clinician role behind the screen (physiotherapist persona).

Think aloud protocol

Since we wanted to collect as much feedback as possible on the utilization of the Locomotiver prototype, we decided to include the think aloud protocol on the experiment. Therefore, we would kindly ask the participant to verbalize her own thinking process as each event occurred in VR or anytime during the test. This could include what they are looking at, thinking, doing, feeling or intending. This would allow us to better understand the therapists' cognitive processes behind every action and aspect of the prototype. If a therapist seemed quiet at times, we would kindly remind her to verbalize her thinking process or ask her what was happening.

During the experiment, the participants comments ranged from amusement, curiosity, doubts, immediate suggestions and criticism, among others. We specifically stated to each participant that every opinion they had was valid and a likely contribution to the research itself. Since all the session were being recorded, these commentaries would be then be apart of the transcripts and constitute an important foundation of the research results. This protocol allowed us to collect very good feedback and concepts that would be analysed posteriorly. When all informations were properly given and comprehended, we started the second stage of the experiment.

6.3.2 Using the Locomotiver as the Patient Persona

Before advancing any forward, we would ask the participant if he/she had ever worked, used or experiment with virtual reality in general. If it was the case we would expand the question and assess which devices or systems (Oculus Rift, Google Cardboard, etc) had he/she experienced before. This would give us a better understanding of their own opinions regarding the Locomotiver and the VR experience it provided. Either if it was the participants first contact with VR technology or not, we would always take a few moments to briefly explain the hardware components and their role on the system. Therefore, the participant was made aware of the equipment that powered the whole experience:

- VR headset: to visualize and experience the VR environment
- VR devices: hand controllers and trackers mapped the participants hands and feet accordingly with respective 3D models in VR
- Motion tracking cameras: track the devices and map the room to VR

We started by holding the tracker straps around the participants feet with the Vive tracker attached as displayed on the figure 6.1. Then, we would help him/her to put the headset on and adjust it to fit her properly. Finally, when the participant was already in VR would we give her the hand controllers.

When the participant was set in the VR environment, we would typically take between 2 to 3 minutes to leave her to freely explore the environment (figure 6.2). Depending on the immediate feedback we would suggest her to walk across the room and look around in 360 to see the ambience. It was often the case that the physiotherapist was very engaged with the experience and would comment on the details of the environment. We constantly encouraged commentaries to be made. They would usually give opinions on the mirrors, the fence (forest environment), the tablets that displayed the number of repetitions, the parallel bars and so on.

Shortly after the freely experimentation, we as researchers would assume the physiotherapist persona and launch the exercises from the Locomotiver user interface for the participant to fully experience the patient point of view, as depicted on figure 6.3. The participant would then experiment all three exercises presented on the prototype - Walking Forward, Barriers and Zig Zag. For each exercise, the participant was asked to try to complete it and provide some insights and feedback. This time they would comment on the new elements on the world such as the barriers and cones. They would start to complete each course of obstacles and at the end we would let them walk around and analyze the obstacles freely. This produced some interesting commentaries that will be analysed in further sections.

At the end of this stage, we would help the patient to remove the VR devices and ask them if they were feeling well. Neither of the therapists had any issue after trying the VR experience which was very good. Then we proceeded to the following stage.

6.3.3 Using the Locomotiver as the Physiotherapist Persona

By this time, the physiotherapist already had a good notion on the Locomotiver's experience and functionalities. Since the participant had experienced the system from the point of view of one of his/her

Figure 6.1: Researcher helping a participant to setup some VR devices

patients, it was time to actually test the prototype from the persona that she would play in a real life scenario.

The physiotherapist persona relates to the clinician that is conducting the VR intervention. This persona does not wear any VR devices. Instead, he stays either on the computer or nearby the patient that is performing the exercises and manages the session. On this phase, we started by siting down with the participant on the computer. One of our colleagues would pose as the patient persona and simulate the interaction of a patient similarly to what the therapist had done before. This way, the participant could have a sense of what a real session with the Locomotiver would look like.

We proceeded to briefly explain the user interface and its elements. However, we did not explain everything as we wanted to let the participant explore the system at will. We started by explaining the area of visualization since it was the more apparent element on the screen. In it, the physiotherapist can visualize what is happening inside the VR world and we explained each patient that that was how we could accompanied what was going on in VR. We also showed the POV button that displayed what the patient was looking at.

After a short explanation about the menu for launching new exercises we would let each participant setup some exercises and conduct his/her own session with our colleague (posing as a patient). Each participant would behave differently in this phase. Some would start clicking around and changing

Figure 6.2: A professional physiotherapist experimenting the Locomotiver as the patient persona

the default options of the timer and repetitions to launch an exercise while other would ask a lot of questions related to each step of the process. Once a therapist launched an exercise, our colleague would complete it as a patient so that the participant could analyze all components of the system, including the ending screens of each exercise. We would often ask the participant if he/she had any doubts and for his/her thoughts on the user interface and processes. This part of the experiment would usually be one the longest as the therapist had a lot of components to analyze. At the very end of the experiment we would show some of the nuances of the Locomotiver that included the settings and calibration and ask the participants for their feedback on the implementation and importance of those. Overall, most therapists seemed confident in using the Locomotiver system, which would be verified later on.

This was the phase that took the longest time of the whole experiment, mainly due to the time spend by the therapists explaining their suggestions and comments. We gave the participants total freedom to experiment the boundaries of the Locomotiver and explore new possibilities that could be implemented in the future. Their feedback would be extremely useful to establish what the factors promote the adoption of these technologies in this field. Furthermore, in order to have a greater sense of their opinions, we took the opportunity to ask a variety of questions for posterior analysis.

Figure 6.3: Researcher launching exercises on the Locomotiver

6.3.4 Semi-structured interview

From the beginning we had a set of questions prepared to gather as much information about the quality of the system and the experiment itself. Since we were promoting the use of the think aloud protocol, the therapists were already providing us a lot of feedback on the given activities. However, we wanted to explore many subjects related to the use of the Locomotiver such as the impact and the possible benefits of it, to try to answer the research question as best we could. For those reasons, we utilize a series of questions to promote these conversations. While some of the questions are very direct and concise, others are more open to discussion. The interview included the following questions:

- What did you like the most about the Locomotiver?
- What did you like the least about the Locomotiver?
- What are the benefits you foresee to the use of this system?
- Can you point out some of the limitations you believe this [Locomotiver] has in regular physiotherapy interventions?
- Do you believe this can facilitate your job in any matter? Why?
- Do you believe VR can bring benefits to patients? If so, what kind of benefits?
- Do you think this system can help improve the accompaniment and progress of the patients?

- Do you think this system can help improve the accompaniment and progress of the patients? If so, in what way? If not, why?
- How do you expect patients to react to VR?
- What group of patients is more adequate to use the Locomotiver?
- What are some of the risks for patients that you foresee?

It is important to note that these questions were not asked neither in a particular order nor all patients were asked the same questions. Sometimes, during an experiment, the participants would comment on things that were a direct answer to these questions. For example, multiple physiotherapists would comment on the things they liked the most, well before we had the change to actually ask them. Another common commentary regarded the type of patients that were inadequate to utilize the Locomotiver. Those commentaries would come up often when the therapists were experimenting as the patient persona. However, most of the time, the therapists would not comment on these subjects directly, so we would take some time at the end of the experiment to focus on some of these points.

6.3.5 Questionnaire

At the end of each experiment, participants were asked to fulfill a questionnaire. Our questionnaire was heavily influenced by the research work of Alaiad et at. who employed the UTAUT model to do an empirical investigation on the adoption of home healthcare robots [2]. The questionnaire was composed of a list of 20 statements which the therapist had to evaluate with a 7-point likert type Scale. The values ranged from 1 to 7, 1 meaning the therapists disagreed completely and 7 they agreed completely with the given statement. The full questionnaire and statements can be consulted on the Appendix C

This questionnaire was constructed based of some key concepts that support some models of technology adoption as we reviewed in previous sections.. The concepts were therefore chosen based on the scientific literature and would provide the foundation for the research findings. The concepts we considered most relevant for the adoption of VR technology were: ”Performance Expectancy”, ”Effort Expectancy”, ”Social Influence” (Social), ”Facilitating Conditions”, ”Trust”, ”Ethical Concerns” and ”Legal Concerns”. In addiction we categorized the concept of ”Usage Intention” to map determined questions directly to the purpose of the research related with the adoption of VR.

Performance Expectancy

We define performance expectancy as the extent to which the physiotherapists believe that VR, particularly the Locomotiver system presented, can help them improve their daily activities and job performance.

To map this concept we wrote statements related to the ability of the Locomotiver to be useful as a VR intervention, the robustness of the prototype to cover multiple types of therapies and also the capacity to streamline some of the therapists practices.

Effort Expectancy

Effort expectancy is also a fundamental key concept that supports the UTAUT model. In the context of our research, we defined this concept as the degree of facility the physiotherapists feel regarding the use of VR and the Locomotiver. There has been multiple studies confirming empirically that effort expectancy has a direct influence on usage intention and technology adoption. Subsequently, the intent of adopting the Locomotiver as a VR rehabilitation option would be greater if the system turned out to be easy to use and understand. Therefore, if the participants perceived the system to required to much effort to learn, they would be more likely to cast it aside.

For those reasons, we indicated two statements related with the therapists perception of their own capabilities to use the Locomotiver and their own opinion on the difficulty of operating the system.

Social Influence

The social influence, is the third construct that builds on the UTAUT model. However, we have adapted this concept to match our own research. We defined the social concept has the extent to which therapists believe their patients will benefit and enjoy the appliance of such alternative as VR.

Since therapists work really close to their patients, the perceived benefit and accountability regarding the utilization of the Locomotiver should be a factor on the usage intention. Because of that, we wrote two statements that answer to this concept and evaluate the therapists view on this matter.

Facilitating Conditions

This concept is one we consider to be very important in the context of VR. Facilitating conditions is the fourth and last construct of the UTAUT model and we defined by the degree which the therapists believe they have the organizational, knowledgement and technical structures to deploy this type of technological solutions.

These facilitators can be considered the conditions on the gyms and clinics where the physiotherapists usually work, the technical support offered during the setup of the system or even the knowledge and resources to accommodate the system. By taking the previously studied UTAUT model in consideration, this concept is one of the most influential on the decision making processes and usage intention by the therapists regarding VR, we wrote three statements that reflect it. One regarding the conditions on the workplace, another for the actual opportunities to deploy the Locomotiver and a third for the professionals own beliefs on their knowledge to use and adopt the VR system.

Trust

Trust is a very important concept to promote usage intention of technological solutions [2]. In the context of our research, we define trust as the positive perception of the therapists on the reliability and capabilities of the VR system. In a sense, trust can be viewed as a faith and confidence that the system will work properly. Therefore, the increase of trust levels on a certain technology should also promote its

adoption. Users tend to create expectations upon newer systems and functionalities and we can only expect adoption levels to rise when their beliefs are met.

We proposed two statements regarding the therapists trust on the Locomotiver's results and whether or not they believe it would work properly.

Ethical and Legal Concerns

Every society has its own code of ethics. This concept distinguishes between what is right and what is wrong in a given situation. On the other hand, there are are also rules of conduct formally recognized and enforced by an authority that we consider legal matters. These two concepts are important to notice as they can have a reducing effect on the usage intention. Since VR is a recent technology there are still multiple factors to be considered regarding not only the future of professionals that work with it, but also the legalities surrounding this area.

We proposed four statements with a negative connotation to assess some of the concerns that may or may not preoccupy the professional therapists. These include the future of their profession, the safety of their patients, the side-effects of malfunctions associated with the Locomotiver and the apparent lack of formal regulation and safety standards. All these would give us a good idea on what do future implementations need to worry about and what not.

Usage Intention

The final concept regards the usage intention and adoption of our Locomotiver solution itself. We define usage intention by the expectation of the professional therapists to adopt and use the presented prototype on their daily activities.

This was a very important concept as it focused directly on the findings of this research. For that reason, we posed four statements regarding the will and desires of the participants to adopt the presented prototype.

Each participant answered the questionnaire alone at the end of the session. We would resolve any doubts or questions they had regarding the statements. The results were then analysed.

6.3.6 Conclusion

At the end of each session, we would, once again, thank the participant for her time and kindness in helping the research. Most participants seemed to enjoy the experiment and would comment on the overall experience.

Chapter 7

Results

In this chapter, we present a thematic analysis of the semi-structured interviews and feedback collected during the experiments with the professionals. We also exhibit the results obtained from the questionnaire and establish a correlation between the collected data.

7.1 Thematic Analysis

Following the procedure mentioned in the previous section, each experiment, with the therapists, lasted between 25 and 45 minutes.

Following the first step of the thematic analysis procedure, we transcribed the audio recordings from each session and read them several times to have a broad understanding of the results, as a whole. We also added some notes about our impressions on the data that would help later on.

On the second stage, we identified and labeled relevant words, sentences and expressions to establish 46 codes on the analysis of the transcripts. From those, only two were not used to construct a theme.

7.1.1 Theme 1 - VR: A new and more motivational experience in physiotherapy

This theme focus on how the professional physiotherapists perceived the VR experience as a better way to provide not only more motivational and fun rehabilitations but also introduce some of the benefits of this technology.

Overall, when trying the system as the patient persona, participants were very confident in using the VR devices. Most would start walking around the room, with the VR headset on, as soon as they were allowed to, without any hesitation. Many therapists described the use of the headset as comfortable and no one felt either nausea, motion sickness or any kind of effects during the whole process.

The VR environments were one of the most popular responses to the question: what did you like the most about the Locomotiver? In one example, one therapist responded:

> ”I think that the environments are very interesting. I particularly liked the one with the forest

and nature."

Other therapists often described the VR environments as being: "fun", "beautiful", "calm" and "fascinating". One participant added that the fact that there was a lot of apparent free space in the virtual world was good to make the user feel a sense of liberty. Another therapist reinforced the idea that the VR environments were very appealing and explored why she thought that was important:

> "Patients are usually accommodated on an unpleasant environment such as a clinic. I believe that experimenting with the Locomotiver would be a new engaging experience that would, in a sense, pull their imagination out of the hospital. That would be very beneficial for them."

When we asked the therapists about the possible benefits of this solution for their patients, most argue about the evident promotion of escapism and playful experiences that are not as easy to advocate on their daily basis. They also pointed out the importance of patients feeling good in their environment, which is often not an easy task to achieve. Gyms and clinics are often full of other individuals awaiting their turn to participate in the interventions and can be "dull and boring".

The boredom of patients seems to be a general concern among the participants. One therapist told us about how hard it can be to motivate patients on their interventions at times and how VR can be a solution for the problem:

> "This is a more playful, entertaining way to motivate patients to participate in their rehabilitation. I can see that it is much more interesting than some of the exercises we provide. Sometimes, when we use a similar exercise like your 'Zig Zag', they seem very into it at the start, but after two or three times performing the same exercise, they get bored.

Another professional spoke about her own impressions on the patients engagement during interventions and her opinion about the inclusion of technology to make physiotherapy more interesting:

> "I believe in VR we can provide multiple fun challenges to patients and make interventions more entertaining and motivational. I have the impression that most patients get tired after a while when performing the same routines.
>
> One time, I brought the Nintendo Wii for my elderly patients to play a little bit, while doing some exercises. They loved it so much, they keep asking me to bring it again.
>
> This Locomotiver seems to provide a very interesting novelty factor to our practise."

As it we stated, some therapists also explored the possibility on introducing novelty in their patient's daily routines and how that can help them improve their activities. One specialist works directly with neurological patients and explained:

> "The introduction of novelty, in terms of our neurological system, works as an important stimuli. In a sense, we are much more aware of any situation when it presents something out of the ordinary, therefore we, as clinicians, have a constant need to find creative ways to adapt the exercises in order to keep the patients engaged."

To this point, therapists agreed that the Locomotiver provided a much better way to innovate their interventions and introduce novelty factors in their patients routines. These factors could be new environments, exercises, objectives, games and many more.

It is reasonable to assume that therapists enjoyed their experience with VR, particularly with the Locomotiver prototype. Not only did they show confidence in VR as a possible technological solution for future rehabilitations as it provided a more motivational and fun experience for their patients, but also as great tool for their practise as it will be further discussed in subsequent themes.

7.1.2 Theme 2 - Locomotiver: Limitations, Improvements and Suggestions

As each experiment took place, participants often commented on the Locomotiver's functionalities and expanded their views on the limitations, improvements and suggestions. This theme describes some of those opinions and feedback from the participants.

The first major issue that came up during the experiment, was related to the physical cable that connects the HTC Vive headset to the computer interface. Most participants either felt less confidence in walking around by feeling constrain or slightly scared they would be wrapped in the cable like it was told us by one therapist:

> ”The cable is a bit troublesome. I was afraid I would get wrapped in it and because of that I was a little uneasy when I walked around.”

Some participants expanded on the issue and imagined how the patients would react to it:

> ”I did not think the cable was functional. It somewhat muddled my movements. I can see a patient having problems with it for example during the ’Zig Zag’ exercise.”

Another frequently mentioned limitation regarded the customization of the exercises themselves. As the therapists explored the user interface of the Locomotiver they wanted to know more about certain actions they could or could not do depending on the situation. One of the most common issues raised was related to the customization of the distance between barriers on the ”Barriers” exercise. One therapists detailed the issue:

> ”I would be interesting to allow us (the therapists) to customize the distance between each barrier. I mean, the distance between these barriers conditions the size of the step required by the patient to surpass each set of obstacles. By personalizing these distances, we would technically be able to to work different types of steps.
>
> I could, for example, work smaller step sizes by shortening the distance between barriers, or work bigger ones with the obstacles much further apart.”

Similarly to the barriers, some therapists also indicated their interest in manipulating the position of the cones on the ”Zig Zag” exercise and have more control over the obstacles:

> ”I think the therapist should be able to edit the obstacles. Maybe I should be able to display them in different positions across the room, make them bigger or smaller, longer or wider according to each patient.”

This participant believed that functionality would decrease the chances of establishing a standardize walking pattern on the patient’s intervention and therefore would improve their recovery as well as introducing more novelty factors (as seen on the Thematic 1 section). In addition, she also suggested that the obstacles changed somehow at a given time, meaning that the obstacles did not have to be necessarily only cones or barriers but could vary according to different environments or depending on the patients or therapists’ choices. On the other hand, she also agreed that by providing the same obstacles, in the beginning, it made the exercises easier to understand.

The third issue relates to the apparent lack of progression of the exercises and patient profiling. Although this was not mentioned by the majority of the participants, the ones that pointed it out gave it a lot of relevancy. When asked about what did they like the least, some of the comments could be associated with this topic. One of the participants answered:

> ”It is not clear to me that there is a progression of the exercises. I mean the level of difficulty does not seem to significantly increase over time.
>
> When we are dealing with a patient, his routine often needs to have a clear evolution. Otherwise he will not develop new competences.”

He goes on exemplifying that a patient with a knee injury requires different treatments on the first day and last, and it was not clear to him how the VR system solved that issue. He added that the solution could pass by providing new objectives:

One of his colleague extended the answer by providing her own suggestions:

> ”I think the system should provide some kind of database or profile where each patient session was stored. Then, we could analyze, in detail, the progress of the patients and what type of intervention and exercises should we proceed with.”

Despite the implemented functionality of exporting the data from each session as a CSV file, the therapists wished the system was able to do a further analysis and registration of the data produced.

Lastly, there were multiple small improvements mentioned by some therapists. Overall, they were very curious of the possibilities of the application of VR in their interventions and some of the suggestions had not come up on the previous conversations with the partners.

One participant was interested in putting the Locomotiver in practise for rehabilitation specialized in the sports field. However, he understood that some of the mechanics would have to improve a little bit. Instead of the purpose of the exercises being limited to the timer and completion of goals, he hinted that the system could utilize hand controllers to establish a more gaming experience or even multitask exercises:

> ”I think the goal of the exercise should be extended. For example, in my interventions we often do multitasking. On the Locomotiver it would be fun to include some exercises where I needed to touch the floor with the controller, or grab some objects.
>
> The idea was to do gait training while also doing something with the hands to make it a bit more interesting.”

He also gave more ideas on how he believed the Locomotiver could be applied in sports, if the progression level of each exercise was adapted:

> ”Regarding the appliance to sports, for example, the cones could be displayed across the room, instead of inline, to do some lateral running. Then we could add the idea of the hands touching the cones. That would be amazing.”

These indications show us the interest of the physiotherapist to collaborate in the development of a technological advancements that can better serve their own needs and those of their patients.

7.1.3 Theme 3 - Patients fit for VR

This third theme outlines the therapists views on the patients that would be fit for this kind of interventions.

One of the questions we asked each participant, during the experiment, was: Which patients do you believe would benefit to use VR?

Most of the participants seem to agree that VR was still a very complex technology and not made for everybody to fully experience without some kind of risk. Although they acknowledged that VR could possibly benefit a larger group of people, neither of the participants would compromise the security and well-being of the patients. The sensibility of the patients was a clear and constant concern among the physiotherapists.

Despite all of that, almost all the therapists concurred that patients with musculoskeletal disorders or orthopedic conditions were the group of individuals they would feel more comfortable to work with VR over the neurological ones. The first participant predicted that her colleagues would probably be less resistant to adopt that type of VR systems with orthopedic patients over neurological ones. She argued that:

> ”As physiotherapists, we need to be extremely careful with the care we provide to the patients. I cannot imagine my co-workers performing any type of intervention that carries any risk of hurting them. You will probably find therapists that work with neurological patients uneasy with these applications.
>
> On the other hand, I can see the benefits of performing some of these exercises with patients that can stand on their own in a free type of scheme. I would personally feel more comfortable experimenting this [Locomotiver] with patients who do not have any leg load issues.”

This participant's initial expectations would be matched by her colleagues opinions. When asked the same question about the individuals that could use the system, one responded:

> ”The patients I think would benefit the most would be the ones that are, for example, recovering from operations and need to strengthen those body parts. Basically, patients that need to regain their gait abilities because those have been weakened during procedures. However, I think they should have a fair level of autonomy.”

Another therapist extended her own views on the matter, according to what she had experienced:

> ”As you presented the system, I believe it is more fit for patients with musculoskeletal problems.
>
> I think the system would work better for patients that can stand on their own. That being the case, orthopedic individuals that have for example a knee prosthesis, have fewer dysfunctions than those that have neurological conditions.
>
> We must be very careful with patients with neurological conditions. These individuals have far more complex conditions and often have issues with posture and balance which immensely increases the risk of fall.”

Over the experiments, many therapists gave their own perspective on why the thought neurological patients were not as fit for VR. One of them justified:

> ”Regarding the neurological patients, this may not be adequate. Some of them do not have a clear perception of their body in real life. From what I experience, that effect would be accentuated, for sure, in VR, making it too exigent for them.”

But the body perception was not the only argument against the use of VR with neurological patients. One specialist, that works directly with these patients pointed that VR could also provide an excessive of visual stimuli.

> ”I think we need to consider that this visual stimulus may not be beneficial to certain neurological patients. We need to keep the interventions as safe as possible and I do not know if we will be able to tell which neurological patients could adapt to these stimuli and which would not. That is why I also defend that patients with simpler pathologies are fitter to use your system.”

This argument was supported by another participant, but this time with emphasis on the elderly people:

> ”I do not think that patients that have sensitive alterations should use this system. For example, older people rely heavily on their weakened senses for balance and orientation. By exposing them to VR, I fear their nervous system might conflict and cause imbalances.”

However, other participants did not agree with the previous opinion. In fact, their impressions on this matter diverged. Some therapists encouraged that older individuals would be potential patients that could benefit from this type of interventions. One therapist explained:

> ”I actually think this would be very good for elderly individuals. They usually do not get the chance to play with these games.”

We also took notes on the mentioned groups of individuals that could benefit from this system and are not necessarily related to either neurological or musculoskeletal categories.

We already covered on a previous thematic that one participant mentioned that we would like to apply the Locomotiver to sports medicine and recovering athletes. When trying the system he made sure to test the speed of the system and reaction times to made sure it could match real movements well enough. He sustained his views:

> ”I tested the speed of reaction in VR and it seemed to me quite reliable to apply it in sports practise related therapies.”

He extended his response by providing some exercises that could already be done with the elements provided by the Locomotiver and continued by suggesting some more that could be included in the future. These suggestions included some adaptations to the ”Barriers” and ”Zig Zag” exercises.

Lastly, one curious matter that was raised was the benefits of adopting the Locomotiver for individuals that suffer from dementia. Despite being a neurological condition, the participant argued that, given the proper resources, it would be possible to reconstruct the patient’s specific environment like, for example, their own home. These ideas are not directly related to the scope of the project, but nevertheless it was interesting to register that the professionals would be able to, in a way, extend the use of the VR system to other types of rehabilitation.

7.1.4 Theme 4 - Potentialities and Benefits of VR for Physiotherapists

This last theme covers the potentialities and benefits of VR identified by the participants relatively to their daily activities. We also mention some of the functionalities that pleased most the participants during the experiment. Some of the covered topics had already come up multiple times during the development process, but it was interesting to verify, on the evaluation phase, the reliability of that previous information.

Since the experiment started with the therapist experimenting VR as the patient persona, the first benefits that were pointed out were inevitably related to the hardware itself. We already described some of the weaker points recognized by the professionals, but overall they found that the amount of hardware and devices needed to make VR work was quite few. Most commented that the setup of the patient was fast and easy, especially compared to other common technological systems in their practises. One therapists simply said:

> ”The system is easy to setup and actually really comfortable. I also think it is good that we do not need that many devices to make it work. I think it will help more therapists to get interested in this.”

Regarding the software functionality, one of the first benefits that was proven useful was the allowance of the therapist to see the patient’s point of view. Most therapists found it relevant and an innovative functionality that also should help to conduct the rehabilitation process.

One of the most beneficial concepts pointed out relates to the optimization of the physiotherapists practise. Almost everybody that participated in the experiment had something that can relate somehow to the optimization either of the exercises setup or even the amount of people that are exercising at any given time.

After using the Locomotiver, one therapist concurred that the system would definitely help her setup some exercises more quickly and therefore making the therapies more efficient. When asked if the system would make her job easier, she answered:

> ”For me it would make many of my tasks a lot faster. Almost everyday, I have to take some time to setup the exercises. That can be drawing marks on the floor, limits or spread obstacles on the way. By using this system, I can setup and change the exercises very quickly and it gives back an exercise ready to be used.”

One of her colleagues gave a similar explanation:

> ”Yesterday, I had to do the exact same barriers exercise. I had to waste a lot of time to prepare it compared to your setup.
>
> I believe this allows us to optimize our time and adapt each exercise very easily.”

The topics of optimization and efficiency improvement of some processes on the daily lives of the physiotherapists are some of the more important points from this theme. These clinicians have a very busy schedule and often do not have the time and resources to provide the best solution to every patient. One participant clarified precisely that when asked if the Locomotiver would help her in her daily practise:

> ”I can really see this being very helpful. It would be interesting to have more patient doing more exercises for greater periods of time. In a gym full of patients, this [Locomotiver] would allow some of the self sustained ones to perform more exercises, which I would just take a look from time to time.
>
> Nowadays, I have little more than 20 min to work with a single individual before someone else requires my attention, so there is a great need to have systems in place to put more people to work simultaneously.”

One of her colleagues mentioned the same issue regarding the amount of patients that are put on hold before they can actually start their routines. She also added that gyms are ”getting smaller” for the amount of people that need these therapies:

> ”Oftentimes, I have too many patients in the queue for the parallel bars. By using a system like this, I believe it would be easier to put more patients performing exercises at the same time, since we can simulate very similar exercises.
>
> Besides, in our gyms, we are starting to lack the space to accommodate different types of equipment. This system allows not only to have multiple setups but also to add new ones without the need of expanding the physical space.”

It is reasonable to assume that the therapists looked confident that the VR system would provide a great benefit for the optimization of their practises.

Another important matter that was covered relates to the exercises themselves. In previous comments, therapists already touched this point and the fact that the exercises are direct translations of the real ones already in practise. This was one of the requirements that frequently came up during the conversations with the partners during the first stages of development. Some participants iterated on that opinion and mentioned the benefits of the exercises:

> ”The chosen exercises are easy to understand and are some of the most used ones in our daily practises. Although it is a more futurist way of doing things, I think the exercises are very similar to the ’real ones’ and that is very good.”

Another participant added:

> ”The prototype contains exercises that we use on the regular basis. We often train change of direction, walking in straight lines and support base variations. These are all factors that we are accustomed to use with multiple patients.

Following up on the previous comment, some therapists pointed out particular benefits on each exercises that was presented. For example, relatively to the ”Walking Forward” one participant commented:

> ”The fact that it contains a form of visual limitations (squares) gives us the possibility of alternating the intervention. For example, we could ask the patient to walk on with the feet between each square. By changing the support base, we can work different sizes of steps according to each patient.”

This allures, once again, to the importance of customization of the provided system.

Lastly, there were some very interesting comments about the interest of the therapists in using the Locomotiver as a diagnosis tool in addition to an intervention one. One participant mentioned:

> ”From what I experienced, I think it seems not only good enough to provide exercises to the patients but also a good tool for future diagnosis. I could for example, evaluate the base level of gait capabilities of the patient by utilizing the customization of the ’Walking Forward’. Instead of using a tape on the floor and do multiple versions to measure the walking patterns, we could simply to change the variables of your [Locomotiver] exercises and analyze in real time the reaction to those.”

In fact, the Locomotiver was build with the primarily function of providing an alternative solution for interventions. For that reason it was curious to get these responses.

Professional therapists seem to be always looking for new innovative ways to improve their practises, and using the VR system as a diagnosis solution as well as intervention is a very interesting point to discuss. On this matter, a therapists argued:

> ”I think your system is more focused on the intervention area. However, I think it would be very good, in the future, to adapt it to be a more efficient tool for diagnosis. In our daily practises we are always trying to diagnose new conditions on the patients. In a way, the diagnosis is a constant.
>
> The Locomotiver has the benefit of proving many stimulus that can be tested with different patients and we do not have reliable methods to infuse and analyze those stimuli. I think you should definitely think about the focus on the evaluation and diagnosis area.

In general, therapists could understand the benefits and potentialities of the Locomotiver as a VR system in their daily practises. Not only did they seem enthusiastic with the solution but also provided a lot of useful feedback for future attempts of development and adoption of VR technology in physiotherapy.

7.2 Questionnaire

In this section, we present the results of the questionnaire handed at the end of each experiment. We also establish a connection between these answers and the findings of the previous thematic analysis. We started by converting each entry of the likert type scale to numbers ranging from 1 to 7. Values closer to 1 lean to the ”strongly disagree” opinion while greater numbers tend to ”strongly agree”. By converting the scale to numeric values it is easier to understand the data and perform some statistical analysis.

All participants answered all the 20 proposed questions. For each question, we calculated the following statistical variables: mean, standard deviation, minimum and maximum values, median and interquartile range (IQR). The table of results can be consulted on the Appendix D. We proceeded to create box-and-whisker plots that are displayed on 7.1 and 7.2 separated in two groups, all colored differently, to facilitate reading and analysis. The graphs helps us to understand the distributional characteristics of the scores attributed by the participants to each answer.

Each plot has a middle box that represents the IQR ranging between the lower quartile to the upper quartile values. This accounts for 50% of scores of the group. At the exact mid-point of the box sits the median (middle quartile) of each dataset. The mean value is also marked on each graph with an ”X”. Note that median and mean do not always coincide hence why the latter is often marked away from the mid-point of the box. Whiskers represent the scores outside the middle 50%. These can sometimes stretch over a wider range than the middle quartile values. However, on some of the graphics that will follow, either the upper, the lower or even both whiskers will not be visible. Outliers are also displayed as single dots outside the whiskers spectrum.

7.2.1 Responses Analysis

The very first statement (Q1) was directly correlated with the objective of the research and regards the intent of the physiotherapists to adopt a VR system in their daily practise. It stated:

Q1: Given the opportunity, I would use the Locomotiver on my daily activities.

By analyzing the figure 7.1, we can observe that the answers were overwhelmingly positive. Only one therapist's answer is not included on the range of 5 and 7. In addition, the mode value was 7. Therefore, we can assume that most participants strongly agreed they had intentions to use the Locomotiver in their interventions. This result may be a product of the positive feedback of the therapists, relatively to the Locomotiver and VR, particularly on the topics covered by the themes 1 and 4 of the previous analysis.

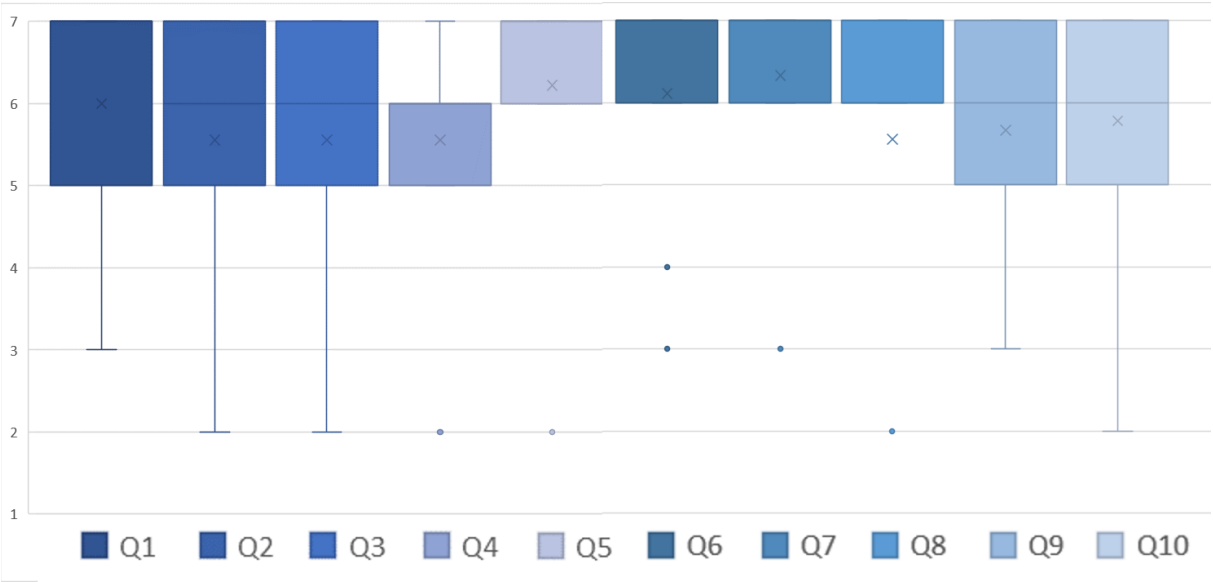


Figure 7.1: Questionnaire Results (Q1 - Q10)

The second (Q2) and third (Q3) statements were related to the topic of the "Performance Expectancy" and indicated respectively:

Q2: I consider that the Locomotiver would be useful in my job.

Q3: Using the Locomotiver would make my job easier.

Once again, the answers were very clear. Curiously, while the answers to the phrases were not exactly the same for every therapist, the results ended up matching with a median value of 6 and IQR of 2. The mean was also the same at 5,56. These results are also congruent with Q1 as the therapists would probably not have intent of using a system that did not provide any clear value to their practise.

Statements four (Q4) and five (Q5) corresponded to the topic of "Effort Expectancy" and affirmed:

Q4: The Locomotiver is easy to use.

Q5: Learning how to use the Locomotiver would be easy for me.

These results are very interesting as they imply the confidence of the participants in the utilization of the Locomotiver and VR. According to the results, the therapists think the system was easy to use and did not anticipate major difficulties in learning how to use it.

In particular, the Q5 was the second most agreed statement of the whole questionnaire with 6 participant attributing the maximum score. With a median of 7 and IQR of 1, Q5 represents an important discovery that points not only to the ease of use of the presented prototype but also the perceived ability of the participants to put it in practise. These results may be driven by some of the decisions made during the development process, related to the minimalist design of the user interface and iterative development with professional clinicians.

The following three statements related to the topic of ”Facilitating Conditions”.

Q6: I have the necessary conditions, on my workplace, to use the Locomotiver.

Q7: I will have the opportunity, on my workplace, to put the Locomotiver in practise.

Q8: I have the knowledge necessary to use the Locomotiver.

This was the group of statements that had the best score across the questionnaire. In fact, Q7 was the statement with the best one from all the questionnaire with a mean of 6,33, median of 7 and an IQR value of 1. This seems to indicate the confidence of the professionals on their opportunity to apply the Locomotiver as a VR solution.

In addition, if we discard a couple of outliers, Q6 and Q8 also produced some interesting outcomes. Most therapists strongly agreed with the statements which suggests some interesting findings. The participants believed they had some facilitating conditions associated with their environment. These can range from higher level concepts such as working with people that are eager to try new innovating technologies, but it can also mean the professionals are familiar with the means and resources of their workplace.

Q8 results correspond very well to the previous Q4 and Q5 and could also help to explain those. In fact, the perceived ease of use of the system may be directly related to the knowledge the user accounted. However, the influence may work backwards meaning, since the therapists found the system easy to use, they feel confident they already possess the abilities to make it work. Either way, the simplicity of the VR system and user interface seemed to play an important role on these results as it was suggested several times on the scientific readings on this matter.

The next statements Q9 and Q10 are centered around the ”Social” component, namely the therapists' opinions regarding the patients and the benefits they can retrieve from the VR system:

Q9: My patients would like to use the Locomotiver.

Q10: My patients would benefit from using the Locomotiver.

By taking the previous commentaries on the thematic analysis regarding the increment of motivation and engagement (Theme 1), it is clear that therapists believe their patients would like to use VR. The results of this question confirm that. More than two thirds considered they strongly agreed with the Q9

statement, resulting in a median of 6 and IQR of 2. Q10 produced slightly better results since the most chosen value for that statement was the 7 and the median and IQR values coincide with Q9.

These two results support the idea that the therapists believe the Locomotiver would not only motivate their patients but also expect improvements following those interventions. However, we did not cover other stakeholders influence that could be apart of the ”Social” key construct, so more research would provide clearer answers on this regard.

Q11 is related to the ”Usage Intention”:

Q11: I would be able to use the Locomotiver almost every day.

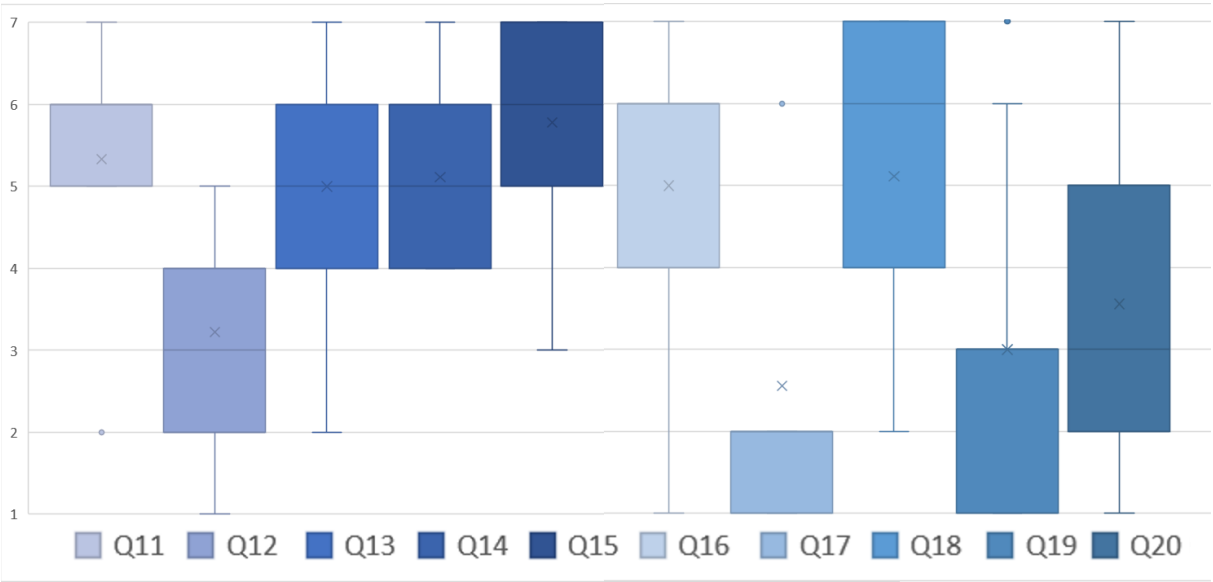


Figure 7.2: Questionnaire Results (Q11 - Q20)

This one seems to support the therapists will to adopt such technology and the Locomotiver in particular. We have already established on Q7 that the professionals would have the opportunity to use the system. Also, on Q5 and Q8, therapists revealed confidence on learning the usage of VR. This statement was focused on the specific application on their daily routines. The responses were positive as the majority of participants agreed they would be able to apply this technology daily (IQR: 1). This may be associated with the theme 4, discussed on the previous section. Since the theme was associated with some of the potentialities of VR for therapists, one of the topics was the optimization of their practises. It makes sense that therapists make an effort to push these solutions in order to improve their routines, which may also be a motive for the results of Q11.

The next statement (Q12) was the one that fell short in comparison to the rest of the questionnaire. From the presented positive assumptions, this was the one that therapists disagreed the most. Q12 had an mean of 3,22, median of 3, IQR of 2 and stated:

Q12: The Locomotiver has all the necessary exercises for my daily practises.

Overall, the participants did not feel the Locomotiver provided all the exercises they would use in their rehabilitations. Their answer can be explained by multiple factors.

If we take in account the theme 2 raised on the thematic analysis, we can note that the therapists felt that some exercises could have been extended and the system could have provided more customization. This question is related to that theme, in the sense that physiotherapy interventions are very specific to the individual. For that reason, there is a need to supply different types of exercises and configurations to maximize the amount of patients that can benefit from using VR.

During previous previous development phases, there was a great amount of exercises observed that could be translated to VR, but we decided to keep the number of exercises limited to avoid the escalation of the prototype complexity. A more complex system would probably be too overwhelming for the physiotherapists during the evaluation process. However, according to the previous scientific readings, we were expecting the therapists to be much more willing to adopt the presented solution if such prototype covered as many use cases as possibly, so we were not surprised by the response of the therapists regarding the relatively small amount of exercises contained on the Locomotiver.

Nevertheless, the decision of keeping the amount of functions smaller had a positive impact on the previous statements Q2 and Q3 of the same ”Performance Expectancy” category, as we expected. By first concentrating in establishing a good foundation on to apply VR in physiotherapy of locomotion, we will not only improve the odds of future adoption but also make it simpler to add new exercises.

In the end, the Q12 statement was the one therapists did not agreed the most, but it served the purpose of verifying and sustaining the necessity of expanding the system's functionalities and exercises in order to establish a good understating on how to improve VR adoption in physiotherapy in the future.

The next couple of statements are related to the concept of ”Trust”, specifically the physiotherapists trust in the Locomotiver system:

Q13: I trust in the Locomotiver's results.

Q14: I trust the Locomotiver will work well without any issues.

We have previously established the importance of the information reliability in the medical field. Since therapists deal with sensible people on their daily basis, the quality of the information is particularly important to be as accurate as possible. That data facilitates the decision making processes that ultimately affect peoples' lives, sometimes in very significant ways. For those reasons, it was crucial that therapists trusted the results provided by the VR system. These results can be interpreted either as being lower level data reliability provided the system in the form of metrics, or a more higher level confidence that the Locomotiver as VR application in physiotherapy interventions will actually produce better results for patients. Either way, the Q13 results sustain fairly well the reliability of the participants regarding the Locomotiver.

Q13 had a median value of 5 and IQR of 2. It is fair to say that, for the most part, therapists trusted the application of the Locomotiver would have good results in their practise, which suggests a better possibility of adoption of such technology.

On the other hand, we covered in the state of art the importance of the technological systems to function properly. This means that, for clinicians to adopt newer technological systems, these cannot be faulty or stop working for no apparent reason. Medical professionals and physiotherapists are not

as familiar with technological systems as engineers and their knowledge of technology is limited on this matter. This was a very important consideration during development process and we prompt Q14 to verify the participants confidence level on this.

Q14 had very similar results to the previous statement (Median = 5, IQR = 2) which suggests the therapists felt confident that the Locomotiver would work properly. Since we have establish that trust is an important factor for technology adoption, these results may also sustain the following Q15 and Q16 statements regarding the usage intention.

Q15 and Q16 regarded the participants core beliefs on VR adoption both as a current and future option for physiotherapy rehabilitations. In a way, these questions were a direct challenge to the participants to project their own practises into the future and visualize the utilization of VR and whether or not they would apply it.

> Q15: A system like the Locomotiver is the future of rehabilitation and physiotherapy.
>
> Q16: Given the opportunity, I would rather use the Locomotiver instead of traditional physiotherapy methods.

Q15 had an overwhelming positive response (Median = 6, IQR = 2). This corroborates the findings on themes 1 and 4 on the thematic analysis. While most participants had their first experience with VR technology during our research experiment, most were amazed with quality of the application, its capabilities and future possibilities. Although, some commented that it still had some important limitations (theme 2) they believed these could be easily mitigated and adapted to provide a good quality type of intervention. It was very interesting to verify that therapists believe that one solution such as the Locomotiver could soon be a part of their daily practises.

Furthermore, we were surprised with the positive response to the Q16 statement. Contrarily to the Q15, Q16 mentioned the use of the Locomotiver at the present time rather than the future. The range of responses was obviously different as some therapists did not fell ready to adopt the Locomotiver yet, but the majority of respondents actually agreed with the statement (Median = 6, IQR = 2). Once again, this supports previous findings on themes 1, 3 and 4 since therapists recognize the benefits for both parties (clinicians and patients) of applying this technology today, at least with musculoskeletal and orthopedic patients.

Finally, we will analyze the results of the last four statements. Q17, Q18, Q19 and Q20 differ from the previous statements as they have a negative connotation. These regard some important concerns and preoccupations that, accordingly to the scientific readings on technology adoption, if verified, may have a negative impact on the adoption of newer solutions.

We will start by analyzing separately Q17, Q18 and Q19 that are related to the key concept of ”Ethical Concerns” previously identified.

> Q17: It concerns me that this technology (VR) may substitute the work of physiotherapists (like myself).

The fact that technology may substitute certain human activities is often a regular concern among society and very discussed as an ethical issue in the engineering field. When a new kind of technology

is proposed as a better alternative for a certain practise, there is also the argument that the level of optimization that it brings may affect the lives of professionals and, sometimes, even threat their job prospects. For that reason, we wanted to know our participants opinion on that matter.

It was very interesting to analyze that this statement was the most disagreed with. Q17 had the lowest overall score from all the questionnaire. The median value was only 2 and IQR of 1. In fact, 77% of the participants answered 2 or lower on this question and only two professionals were concern with this matter. It is fair to say that, in spite of some popular opinions regarding the substitution of human professionals with technological solutions, when these professionals were presented with better alternatives to their practises, they were open minded and receptive to the ideas.

However, some concerns were still raised, as we could confirm on the answers to the Q18 statement. This one said:

> Q18: It concerns me if the patients will be safe by utilizing the VR devices necessary for the Locomotiver.

We have mentioned the hardware necessary to put these VR interventions in practise in previous sections. In fact, during the evaluation phase, several participants raised some concerns regarding the use of devices like the VR headset and verbalize limitations such as the cable that connects the headset to the computer. Most of these concerns were categorized on the theme 2 of the thematic analysis and while some of them already have some kind of practical solution, it is worth to take note of the general concern among therapists regarding their patients safety.

It is part of the therapist's role to be concern with the health and well-being of the patient he/she is in charge of. It is important to reinforce that the individuals going through physical rehabilitation often constitute a sensible population which require care and attention. Since the earlier meeting we knew that therapists would never compromise the safety and security of their patients, no matter the benefits that the technology may provide the practise.

This Q18 was the concern which, unsurprisingly, reunited the most advocates among the participants (Median = 6, IQR = 3) and therefore the one with the major impact on the research. Although it was not a clear consensus among the participants, the most respondents agreed that some of the devices could comprise the safety of the patients, especially the groups mentioned in the theme 3 of the thematic analysis. While these answers do not depress the recognition of value of the Locomotiver, by the therapists, it is important to note that the dependencies on some of the VR hardware and their intrinsic limitations may be a delay factor for VR adoption in this area.

Having this in consideration, it is even more interesting to analyze the following Q19 statement:

> Q19: It concerns me that the Locomotiver system might fail and prejudice my patient's rehabilitation.

Since we verified the general concern among participants about the safety of patients and the utilization of VR devices, it seemed logical that the answers to this Q19 statement were close to the previous one. However, that did not turn out to be true. Q19 had a lower median than Q18 of just about 3 with an

IQR of 2. While there was still some level of concern of therapists regarding the safety of the patients, it is far less when compared to the previous statement.

We have previously analysed in the Q14 that the therapists seemed to find the Locomotiver reliable in terms of functionality and stability. It is reasonable to assume that, when it comes to the safety of the patients, the participants did not believe the main issues would come from the application itself rather than the hardware and devices. This is an important finding and may help future developments in terms of attention to the hardware setup process.

Lastly, we will analyze the final statement (Q20) that regards the concept of ”Legal Concerns”:

Q20: It concerns me that the system quality may not be legally verified.

During the evaluation, therapists raised a few questions, regarding this question, as some did not quite understand it. The reason behind it regards the lack of current legalities and verification of procedures that concern the utilization of VR in this scenarios. During our investigation process we could not find clear guidelines for VR control in this area. It is often the case that technology develops so quickly that administrations and regulations do not keep up with its progress. Since there seems to be a reduced regulation when it comes to quality of VR systems and applications we wanted to assess the professionals opinion on the matter and analyze if this could also be considered a barrier for adopting these solutions. In fact, this was the answer that was not consensus at all. Most therapists that participated in the study answered with a neutral response while the rest had opposing answers. Q20 had a median of 3 and IQR of 3. This does not clarify the general opinion of therapists on the legal matters, so future research is needed. From all the statements, that regarded the concerns and preoccupations, the most notorious is Q18 that heavily influences the physiotherapists in terms of adopting VR as a physiotherapy rehabilitation technology.

7.3 Discussion

After the analysis of both the thematic analysis and the questionnaire results, we can verify some of our findings and relate them to the previous research questions.

The main research question we posed was: ”Do physiotherapists have the intent to adopt the Locomotiver, as a VR locomotion rehabilitation option, in their daily practices?”. When we analyze the themes 1 and 4, we can see that participants recognized a lot of value in utilizing VR in their practises. Not only it provided a more fun and motivating experience for their patients, but it also permitted certain processes, in locomotion rehabilitation, to be optimized. We can also extract valuable data, that corroborates the assertion to the main research question, from the questionnaire. The statements based on the concept of usage intent (Q1, Q11, Q15 and Q16) had a very high agreement level. Furthermore, many key constructs such as facilitating conditions (Q6, Q7 and Q8), effort expectancy (Q4 and Q5) and performance expectancy (Q2 and Q3) had positive outcomes that strengthen this conclusion. All things considered, it is reasonable to assume that physiotherapists would have the usage intent to apply the Locomotiver in their daily practises.

The theme 1, raised in the thematic analysis, directly answers the research question: ”Do physiotherapists believe the Locomotiver will motivate their patients and bring benefits to their rehabilitations?”. From the engaging environments, to the escapism and novelty factors, therapists pointed out multiple reasons for why they believed our system would improve patient’s motivation. The results of the statements on the social key construct (Q9 and Q10) help to support that finding, since they presented also strongly agreement values.

We also had a research question regarding the Locomotiver’s impact on the physiotherapists activities: ”Do therapists believe that the system can improve their activities?”. The theme 4 previously indicated suggests that the participants admit a lot of benefits in using this system. From quicker setups to better customizable options, therapists can improve their daily practices by using the Locomotiver. This is also supported by the two statements related to performance expectancy (Q2 and Q3) who had very high values of agreement. However, there seems to be a lot of improvement to be made, especially on the metrics analysis and confidence in the results. This may partially answer the following research question: ”Is the system easy to use and understand? If not, what can be improved?”. The effort expectancy statements (Q4 and Q5) suggest that therapists find the system easy to utilize, but they also indicated a lot of suggestions that cannot be dismissed. These are taken in account in the analysed theme 2. Furthermore, we could argue that theme 3 also points out some needs of expanding VR systems to other types of patients, since there was a consensual agreement that neurological patients would probably not be fit to benefit from VR rehabilitation.

VR is still in its infancy as a technology. There are still many factors and limitations that pose as barrier to the mass adoption in sensitive cases such as physical therapy. To answer the final question: ”What are the biggest barriers to the immediate application of the Locomotiver in a real life scenario?” we did not get enough data to clearly establish an answer. We can argue that there are still a lot of improvements to be made in terms of number of use cases and exercises (Q12) and there are still many concerns in terms of safety and well-being (Q18). The hardware still posed limitations to the freedom of movement and the conducted experiment did not cover a lot of scenarios that occur in real clinical context. Further research is needed regarding this topic.

In summary, the physiotherapists seemed very interested in utilizing the proposed prototype, Locomotiver, as a VR locomotion rehabilitation option. We collected a lot of commentaries and we measure the willingness of therapists to adopt this type of technology. In the end, the data supports our goal of helping clinicians to adopt VR as a more motivating and engaging experience in physiotherapy.

Chapter 8

Conclusions

In this research we explored the impact and adoption of VR in locomotion rehabilitation with professional physiotherapists. Societal problems like the aging of population and poor lifestyle choices tend to increase the effects of limitations, such as neurological and orthopedic conditions, that require physical rehabilitation. Therefore there is an increasing importance of improving therapeutic practises in the physiotherapy field in order to respond more effectively to the demand of people that resort to these interventions. Innovative technology, like VR, has been the subject of multiple studies that prove its positive effect in physiotherapy. However, there was a lack of adoption and practicality of these solutions, particularly in locomotion rehabilitation.

To face this problem, we partnered with professional physiotherapists to build a VR system that could deploy exercises, in a virtual environment, related to the rehabilitation of locomotion abilities. The Locomotiver was build based on an iterative process where therapists would provide their needs, wants and feedback. According to the scientific readings this process would help improve their ultimately adoption of the developed solution. The Locomotiver included very customizable exercises that mapped real ones from traditional interventions. We have verified that it also provided a very engaging and motivating experience for the users.

After the development of the prototype we posed a research question regarding the usage intent of professional therapists to adopt the Locomotiver in their own clinical practises. We designed an experiment where professional therapists would use the system and provide feedback on it. Using a qualitative thematic analysis of the collected opinions, commentaries and interview responses, four themes emerged. These four themes were: ”VR: A new and more motivational experience in physiotherapy” that related to the therapists perception of VR as a better way to involve and engage their patients and motivate them to participate more actively on the rehabilitation; ”Locomotiver: Limitations, Improvements and Suggestions” described some of the hardware and software problems that may limit the usage intent of the therapists and require further implementations; ”Patients fit for VR” indicated the types of patients that professionals considered apt to start using this type of solution, namely more autonomous musculoskeletal and orthopedic patients instead of individuals with neurological conditions; ”Potentialities and Benefits of VR for Physiotherapists” stated the advantages physiotherapists identified such as a better

optimization of their practises, easy customization and possibility of diagnosis. In addition, we conducted a questionnaire supported by following adoption theories key constructs: performance expectancy, effort expectancy, social influence, facilitating conditions, ethical and legal concerns and usage intention.

The results of the research have shown that professional therapists would be interested in adopting the Locomotiver as a VR rehabilitation tool in their daily practise. This suggests that the process behind the development enhanced the positive outcomes of the research. We believe that this research contributes to establish this a baseline to develop and introduce immersive VR technology, that significantly boosts the motivation of patients, optimizes intervention processes and improves the overall locomotion rehabilitation.

8.1 Future Work

The Locomotiver was proven to be a good starting point to introduce VR in the daily practises of physiotherapists. There are, though, many possibilities to be explored on the expansion of these systems functionalities.

As it was suggested in previous sections, therapists would be very interested to cover more types of interventions and rehabilitations. This would increase the number of possible use cases which would certainly raise the possibilities of adoption. This way, in the future, it would be interesting to provide many more exercises and further improve the customization settings of each of them.

Another thing that should be considered is the inclusion of an information system associated with the Locomotiver that organizes and displays the systems' data. This way, physiotherapists could more easily do the profiling of patients and keep track of their progress.

We also consider that it would be very good to promote a research where the physiotherapists used the Locomotiver with real patients for a certain period of time, in a real life scenario. This would provide more information on the actual practicality and consequences of appliance of this type of intervention.

Regarding our own research, we believe that we were limited by sample size of therapists that tested our solution. A bigger sample size would provide more information and possibly new findings. The previous material that included both the semi-structured interview and questionnaire could also be expanded to more detailed and specific questions to assess other results.

Finally, additional research could be transposed to other areas of physiotherapy and rehabilitation scenarios.

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Appendix A

Evaluation Script

Guião do Estudo

(Introdução)

2 - 3 min

***Bom dia*.** Antes de mais gostaria de agradecer a disponibilidade e a gentileza em ajudar. *Eu sou o Alexandre e estou a acabar a minha tese de mestrado*. A sua contribuição é muito importante nesta altura.

Vou começar por explicar brevemente um bocadinho do **objetivo** deste projeto no âmbito da minha dissertação. Acho que vai achar bastante interessante.

Durante os últimos meses, com a ajuda dos seus colegas que foram dando ideias, construímos um *sistema de realidade virtual* para fisioterapia de locomoção - particularmente dos *membros inferiores*.
O objetivo seria sempre criar algo inovador não só para o paciente que vai fazer a reabilitação mas também para o terapeuta que a conduz:

Paciente: ambiente mais imersivo e interativo, jogos;
Terapeuta: forma dinâmica de recolher dados do paciente e analisar a sua evolução;

Antes de começar, tratemos dos pormenores a nível legal:
(Entrega do Consentimento informado)

Vou deixar o gravador ligado para tratar os dados relativos à sua opinião. Peço que dê a sua opinião em qualquer instante - **todos os comentários são válidos** e vão ajudar-nos a compreender melhor como melhorar estes sistemas e melhor servir as vossas expectativas.

Vamos começar então por dar uma olhadela ao equipamento - e passo a explicar como funciona.

(Demo do VIVE)

1 - 3 min

Começando por mostrar os óculos e como encaixa na cabeça do paciente. Passando à explicação das câmaras e tracking. Seguida o espaço e a possibilidade de se movimentar no espaço real / virtual.
Mostrar como os Vive Trackers funcionam nos pés para que o doente os veja na RV.
Deixar claro algumas limitações como os fios e afins.

Pode agora experimentar um bocado do ponto de vista do paciente para ter uma noção do sistema.

(DEMO do Locomotiver - Paciente)

10 - 15 min

Como pode ver, existe alguma liberdade criativa para criar exercícios na realidade virtual. Esses exercícios são “lançados” pelo terapeuta através do computador.

Já exploramos a visão do doente, vamos ver agora o que seria a utilização pela parte do terapeuta.

(DEMO do Locomotiver - Terapeuta)

12 - 15 min

Agora o nosso colega será o nosso modelo do paciente, e está na realidade virtual enquanto exploramos a interface do terapeuta.
Vamos repetir o processo de preparação do paciente, com os marcadores nos pés e os óculos ajustados.

Aqui é o nosso ambiente do Locomotiver. Há várias opções e menus. Vamos explorar um de cada vez.

Na área de visualização - esta grande aqui - temos uma visão do que se está a passar na realidade virtual em tempo real. Conseguimos ver aqui o nosso colega a mexer-se de um lado para o outro.

(DEMO)

Vemos portanto o que o paciente está a fazer e como está a correr a sessão.

Na barra de topo temos dois ícones principais:
Ponto de vista do Paciente e *Definições*

--

No POV do Paciente, podemos ativar se queremos ver o que o paciente está a ver no momento.

(DEMO)

Nas definições podemos alterar algumas variáveis do ambiente. Vamos dar uma olhadela mais tarde.

Na barra de baixo, é onde lançamos **novos exercícios**:

Demonstração de cada um dos exercícios:

- *Andar em Frente*

Aqui o objetivo é o Paciente ir de um lado ao outro do quarto, sem tocar na fronteira - ou seja mantendo-se dentro do corredor. Quando o paciente bate nas fronteiras, acede-se o vermelho e indica que houve um erro.
O terapeuta é que controla o *tempo do exercício* e o *número de repetições*, ou seja o número de vezes que o paciente tem de ir de um lado ao outro do quarto.
Também é possível escolher a largura do corredor para para facilitar ou dificultar o exercício.

- *Barreiras*

O Paciente ir de um lado ao outro do quarto, **ultrapassando as barreiras** - o terapeuta é que controla o *tempo do exercício* e o *número de repetições*, ou seja o número de vezes que o paciente tem de ir de um lado ao outro do quarto. Neste caso é possível escolher *quantas barreiras* é que se quer no exercício e a *sua altura*.

- *Zig Zag (Cones)*

Neste exercício o paciente deverá contornar os cones - o terapeuta é que controla o *tempo do exercício* e o *número de repetições*, ou seja o número de vezes que o paciente tem de ir de um lado ao outro do quarto.

(DEMO)

Vamos lançar um exercício:

1. Escolher as variáveis - tempo, número de repetições, e personalizar ao paciente
    a. Introduzir valores simbólicos (1 min; 2 REP)
2. Carregar no PLAY;
3. Agora é **importante**, guiar o paciente para o ponto de começo - aquele **portal azul** - o exercício só pode começar no ponto de começo;
    a. Se o paciente já estiver no ponto de começo, pode dar início ao exercício imediatamente;
    b. Se o paciente NÃO estiver, cabe ao terapeuta dar indicações para tal
4. Quando estiver pronto, pode clicar “Começar”
5. A partir de agora há uma contagem decrescente que o paciente também vê para começar a andar em direção ao objetivo - **portal verde**.

6. No final há uma indicação que o exercício foi completo e abre-se um menu com os resultados do exercício.

Alguma dúvida até agora?
De certeza? De qualquer maneira, a seguir vamos lançar mais uns exercícios.

Como reparou, no final do exercício - até mesmo a meio, abriu-se uma janela com as MÉTRICAS.
Para cada exercício conseguimos analisar se está a correr bem ou mal de acordo com estas métricas.

As métricas do sistema incluem:

- Tempo que falta para o exercício acabar;
- Repetições concluídas;
- Número de passos total;
- Número de erros (caso exista);
- Número de barreiras / cones ultrapassados;

--

Finalmente, nas definições temos algumas funcionalidades extra:

Podemos mudar a vista da câmara, fazendo zoom e rodando para ver melhor o paciente.

(DEMO)

Podemos adicionar ou remover as barras paralelas para dar mais uma indicação visual ao paciente - ou caso queira realizar os exercícios apoiando numa barra lateral paralela real.
Podemos ajudar também para ficar do mesmo tamanho da realidade.

(DEMO)

--
Vou deixa-la explorar um bocado da Interface à sua vontade. Alguma funcionalidade que não tenha ficado clara?
Alguma questão no que toca ao sistema?
--

(Questionário e Entrevista)

10 - 15 min

Vamos agora, fazer o rescaldo da situação.

Tenho aqui um pequeno questionário para averiguar a utilidade do sistema em si. Gostaria que tirasse 5 min para responder.

(Entrega do Questionário)

Finalmente, e se não se importar gostaria só de lhe fazer algumas perguntas adicionais para completar o estudo.

(Entrevista)

(Agradecimento Final)

1 min

Chegamos assim ao fim.

Resta-me agradecer pela sua colaboração. Espero que tenha sido uma experiência interessante e cativante - e que tenha dado uma perspetiva do que o futuro possa trazer.
Deu um feedback bastante bom e estou sinceramente grato por ter contribuído.

Muito obrigado!

Appendix B

Consent Form

Consentimento Informado

Código | IMP:EM.PE.17_02

Oeiras, 3 de Setembro de 2018

Caro participante,

Está a ser convidado para participar num projecto de investigação acerca do uso de realidade virtual em fisioterapia de locomoção. A informação aqui disponibilizada é relevante para que possa decidir a sua participação.

A participação neste estudo é voluntária e a não participação não lhe trará qualquer prejuízo.

Este estudo não lhe trará benefícios imediatos, mas contribuirá para o progresso do conhecimento científico que poderá beneficiar futuros tratamentos de reabilitação motora.

Os riscos associados a este projecto são mínimos. Os dispositivos usados não são capazes de causar danos físicos ou cognitivos. No entanto, o uso de realidade virtual, em alguns indivíduos, pode causar leve indisposição, náuseas, suores frios, arroto e/ou perigo de queda. Se em algum instante se aperceber que se sentem indisposto ou cansado, por favor termine a sessão de imediato.

A informação recolhida destina-se unicamente a tratamento estatístico e/ou publicação e será tratada pela equipa de investigação. Todos os dados serão anonimizados e confidenciais. Comprometemo-nos a guardar os dados durante 5 anos. Após este período, toda a informação será eliminada. Caso deseje, poderá pedir a remoção dos dados em qualquer altura.

Mais se informa que a sua participação é voluntária e poderá sempre desistir a qualquer momento sem qualquer penalização ou consequência.

Cada experiência consistirá na simulação de condução de sessões de terapia, usando realidade virtual. No final de cada sessão ser-lhe-á pedido para preencher um curto questionário e ser-lhe-ão feitas algumas perguntas.

Consentimento Informado

Código | IMP:EM.PE.17_02

As sessões poderão ser gravadas em vídeo e áudio caso o participante o permita. Todos os dados recolhidos serão mantidos em sigilo e serão analisados, exclusivamente, pelos investigadores deste projecto. Os dados processados poderão também ser utilizados para apresentação ou exibição de resultados em publicações científicas, conferências ou eventos semelhantes. Somente após a sua autorização específica para o fazer, poderão os dados recolhidos ser utilizados para divulgação online (por exemplo, no youtube, vimeo, etc.).

(Riscar o que não interessa)

ACEITO/NÃO ACEITO participar neste estudo, confirmando que fui esclarecido sobre as condições do mesmo e que não tenho dúvidas.

Nome (escrito de forma legível)

_____

Assinatura do participante ou, no caso de menores, do pai/mãe ou tutor legal

_____

Quais dúvidas acerca deste projecto poderá contactar:

Prof. Dr. Hugo Nicolau
Departamento Engenharia Informática,
Instituto Superior Técnico,
Email: hugo.nicolau@tecnico.ulisboa.pt

Appendix C

Questionnaire

QUESTIONÁRIO

Assinale, numa escala de 1 a 7, se concorda ou não com as seguintes afirmações:

1. Tendo oportunidade, **eu utilizaria** o *Locomotiver* no meu dia a dia.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

2. Considero que o *Locomotiver* seria **útil** no meu trabalho.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

3. A utilização do *Locomotiver* **facilitaria** o meu trabalho.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

4. O *Locomotiver* é um sistema **fácil de usar**.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

5. Eu teria facilidade em **aprender a usar** o Locomotiver.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

6. No meu local de trabalho, tenho as **condições necessárias** para usar o *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

7. No meu local de trabalho, tenho **oportunidade para usar** o *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

8. Eu tenho **conhecimento suficiente** para usar um sistema como o *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

9. Os meus doentes **gostariam** de usar o *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

10. Os meus doentes **beneficiariam** do uso do *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

11. Eu conseguiria usar o *Locomotiver* **quase todos os dias**.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

12. Acho que o *Locomotiver* tem **todos os exercícios** necessários à minha prática clínica.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

13. Eu **confio nos resultados** do *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

14. Eu acredito que o *Locomotiver* **funcione bem** e sem problemas.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

15. Um sistema como o *Locomotiver* é o **futuro da reabilitação** e fisioterapia.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

16. Dada a oportunidade, **preferia** usar o *Locomotiver* em vez de terapia convencional.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

17. Preocupa-me que esta tecnologia possa vir a **substituir o trabalho** dos profissionais de saúde (como eu).

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

18. Preocupa-me se os pacientes estarão em **segurança** a usar dispositivos de realidade virtual usados no *Locomotiver*.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

19. Preocupa-me que o sistema possa falhar e **prejudicar** a reabilitação dos meus doentes.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

20. Preocupa-me que a qualidade do sistema não esteja **verificada** a nível legal.

discordo totalmente ○ ○ ○ ○ ○ ○ ○ concordo totalmente

Appendix D

Questionnaire - Results

Questão		P1	P2	P3	P4	P5	P6	P7	P8	P9	Mean	SD	Mode	Mediar	IQR
Tendo oportunidade, eu utilizaria o Locomotiver no meu dia a dia.	**Q1**	5	7	7	7	7	6	7	5	3	6	1,41	7	7	2
Considero que o Locomotiver seria útil no meu trabalho.	**Q2**	6	4	6	7	7	7	5	6	2	5,56	1,67	6	6	2
A utilização do Locomotiver facilitaria o meu trabalho.	**Q3**	6	4	5	7	7	6	6	7	2	5,56	1,67	6	6	2
O Locomotiver é um sistema fácil de usar.	**Q4**	6	6	5	7	6	7	6	5	2	5,56	1,51	6	6	1
Eu teria facilidade em aprender a usar o Locomotiver.	**Q5**	7	7	7	6	6	7	7	7	2	6,22	1,64	7	7	1
No meu local de trabalho, tenho as condições necessárias para usar o Locomotiver.	**Q6**	7	7	7	7	7	7	4	6	3	6,11	1,54	7	7	1
No meu local de trabalho, tenho oportunidade para usar o Locomotiver.	**Q7**	7	6	7	7	7	7	6	7	3	6,33	1,32	7	7	1
Eu tenho conhecimento suficiente para usar um sistema como o Locomotiver.	**Q8**	7	6	2	7	6	7	7	6	2	5,56	2,07	7	6	1
Os meus doentes gostariam de usar o Locomotiver.	**Q9**	5	6	4	7	7	7	6	6	3	5,67	1,41	6	6	2
Os meus doentes beneficiariam do uso do Locomotiver.	**Q10**	5	6	7	7	5	7	6	7	2	5,78	1,64	7	6	2
Eu conseguiria usar o Locomotiver quase todos os dias.	**Q11**	6	5	7	6	6	6	5	5	2	5,33	1,41	6	6	1
Acho que o Locomotiver tem todos os exercícios necessários à minha prática clínica.	**Q12**	2	4	5	4	3	5	2	3	1	3,22	1,39	2	3	2
Eu confio nos resultados do Locomotiver	**Q13**	4	4	7	6	6	7	2	4	5	5	1,66	4	5	2
Eu acredito que o Locomotiver funcione bem e sem problemas.	**Q14**	4	4	4	7	6	7	5	5	4	5,11	1,27	4	5	2
Um sistema como o Locomotiver é o futuro da reabilitação e fisioterapia.	**Q15**	6	7	7	7	7	4	6	3	5	5,78	1,48	7	6	2
Dada a oportunidade, preferia usar o Locomotiver em vez de terapia convencional.	**Q16**	5	4	6	6	7	6	7	1	3	5	2	6	6	2
Preocupa-me que esta tecnologia possa vir a substituir o trabalho dos profissionais de saúde.	**Q17**	1	6	1	2	1	6	2	2	2	2,56	2,01	2	2	1
Preocupa-me se os pacientes estarão em segurança a usar dispositivos de realidade virtual usados no Locomotiver.	**Q18**	4	6	2	7	7	7	2	4	7	5,11	2,15	7	6	3
Preocupa-me que o sistema possa falhar e prejudicar a reabilitação dos meus doentes.	**Q19**	3	2	1	3	6	1	1	3	7	3	2,18	3	3	2
Preocupa-me que a qualidade do sistema não esteja verificada a nível legal.	**Q20**	3	5	1	2	6	7	2	2	4	3,56	2,07	2	3	3