DM

Virtual Reality Environments as a therapeutic technique in Rehabilitation of physical and cognitive training in soccer players

MASTER DISSERTATION

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INTERNATIONAL MASTER OF INTERACTIVE MEDIA DESIGN

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Este trabalho é dedicado à minha querida mãe.

RESUMO

Um dos principais problemas dos jogadores de futebol são as lesões que sofrem durante a carreira. Por isso, os clubes profissionais investem em equipas médicas especializadas para contornar esse problema. Com a evolução das tecnologias interativas, têm sido muito os estudos para resolver esse problema e trazer mais opções para o campo científico. Apesar desse esforço, ainda faltam estudos sobre a introdução de tecnologias interativas nesses contextos. Desenvolvemos um sistema para testar se o uso dessas novas tecnologias, mais especificamente a realidade virtual, poderia trazer mais motivação e evitar a monotonia de atletas profissionais na realização de exercícios de reabilitação. Ao longo desta dissertação, iremos explicar todos os processos que foram realizados até chegar ao sistema atual. A explicação do processo inclui os exercícios de reabilitação física escolhidos, bem como o desenvolvimento do software que os envolve. Os estudos realizados durante esta tese revelaram feedback positivo entre os atletas e há potencial de trabalho futuro em termos de utilidade do sistema.

Palavras-chave: Interação Humano-Computador, realidade virtual, atletas, futebol, treino físico, treino cognitivo.

ABSTRACT

One of the main problems of football players is the injuries they suffer during their careers. For that reason, professional clubs invest in specialized medical staff to overpass this problem. With the evolution of interactive technologies, many studies have been made to address this problem and bring more options to the scientific field. Despite this effort, there is still a lack of studies regarding the introduction of interactive technologies in these contexts. We developed a system to test whether the usage of these new technologies, more specifically virtual reality, could bring better motivation and avoid monotony in professional athletes when performing rehabilitation exercises. Throughout this dissertation, we will explain all the processes that were performed until reaching the current system. The explanation of the process includes the physical rehabilitation exercises chosen, as well as the software development entailing those exercises. The studies performed during this thesis revealed positive feedback among athletes and there is future work potential in terms of the usefulness of the system.

Keywords: Human-Computer Interaction; virtual reality, athletes, soccer, physical training, cognitive training.

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Acronyms

SPA – specialist in the sports area.

1 INTRODUCTION

1.1 MOTIVATION

Throughout their careers, professional athletes are affected by injuries of various types. The main objective of the various agents involved in a player's career is the rapid recovery of these injuries. Besides the physical injury, the psychological of a player can also be affected, and the athlete may have long periods of immobility, depending of the type of the injury. This leads to life changes, since the athlete suspends habits (training, nutrition, rhythms, and mental hygiene). On top of that, the separation from the sporting environment can lead to a loss of their social role and even social life, inducing changes in self-image and self-esteem. This negative psychological condition makes physical recovery much slower [30]. Training in its most diverse forms is the fundamental basis in the player's evolution, whether in decision making, recovery from injuries, or even in maintaining the physical and mental shape of any professional athlete. All rehabilitation plans involve the repetition of certain body movements, and most utilize certain hardware that can aid or apply resistance to these movements, focusing the affected body parts. As in rehabilitation, the use of devices is almost always the same and always in the same environment. Also, an athlete going through a long and exhaustive rehabilitation can become unmotivated for performing the same type of exercise over and over [22].

1.2 OBJECTIVES

The introduction of Virtual Reality (VR) allows the presentation a virtual scenario that is appealing to the patient performing rehabilitation. Challenging the player or promoting exploration makes the plan of rehabilitation more exciting and more enjoyable than the traditional rehabilitation plan [22].

Systems that use Virtual Reality (VR) have been increasingly explored in the area of sports, as tools to simulate, analyse and train situations too complex to reproduce in the field [12]. Despite this focus in VR systems for athletes, there is currently limited scientific evidence of rehabilitation for injured athletes in professional sport using VR systems and the scenarios applied to it.

The introduction of Virtual Reality in a context of rehabilitation for injured athletes in professional sport is the main objective of this thesis, where we intend to maximize soccer player's, especially soccer's performance to support cognitive and rehabilitation training. The intention of using VR in soccer players is based on its exceptional features. The possibility of creating different scenarios with an infinite number of repetitions where it is possible to manipulate the visual environment, for example, brightness of objects, their location, different perspective, temporal and spatial distortions of the movement trajectory, and feedback, may influence the performance in a way that is hard to achieve in the real world [11]. Besides that, VR can invoke embodied simulations of the human in the world, used to represent and predict actions, concepts, and emotions [3].
For this thesis, we used full-body tracking technology allowing more tracking range. This gave a more immersive and realistic experience [4]. This type of interaction was necessary in some rehabilitation exercises provided in this study.

1.3 PUBLICATIONS

The system developed in this dissertation led to a blind-reviewed publication being evaluated by a panel of experts. The publication, Appendix D – Publication, was:

1) Cristiano França, Michael Sousa, Frederica Gonçalves, Élvio Gouveia, Bruna Gouveia, Pedro Campos, "Pilot Implementation in Virtual Reality: Pitfalls, Tensions and Organizational Issues" (2021), Pilot4HWID, INTERACT, Bari, 2021.

The project was also presented on the Macaronight 2021 [40], where was presented and explained the project as well shown some demos of exercises.
There were also some public presentations, namely, for students of different ages, athletes, and others.

1.4 THESIS OUTLINE

This dissertation was structured in several main chapters for a better understanding of the system implemented. Each chapter was also divided into multiple sub-chapters that helped to order the document. The main chapters were Related Work, Development

Methodology, Prototypes, Evaluation Methodology, Conclusion, and Future Work. Below is the description of each chapter:

2) Chapter two, the related work, describes what was already done regarding this theme. It will be shown several studies that used virtual reality as their technology.

3) Chapter three, the development methodology, defines all the processes involved in the development of the system including all the hardware and software used. This chapter will describe in detail how the virtual reality system was developed.

4) Chapter four, the prototypes, several prototypes, which will be shown and explained, were accomplished considering each phase of development.

5) Chapter five, the evaluation methodology, describes the evaluation process to validate this dissertation. It will be explained all the metrics, the participants, and the results arrived.

6) Chapter six, the conclusion, will focus on the conclusion that we arrived with this thesis.

7) Chapter seven, the future work, describe the future work that can be done if the development of the system would continue as well as new studies.

2 RELATED WORK

This chapter will focus on presenting projects that used virtual reality for rehabilitation as well the application of virtual reality in sports.

2.1LITERATURE REVIEW

To understand what was possible to do in this thesis was searched what was done previously with virtual reality focusing rehabilitation. It was found several projects that used Virtual Reality for rehabilitation but still there is a lack of scientific evidence of rehabilitation with Virtual Reality in sports context.

2.1.1 Rehabilitation with Virtual Reality

Activities done in daily life, for example climbing stairs, walking, carrying an object and even other activities require functioning of certain parts of the body. Neurological disorders, strokes, aging and life events decrease movement ability, which results in difficulties for carrying out such simple day-to-day tasks. For this reason, researchers have sought to improve rehabilitation. All the rehabilitation plans involve using the affected body parts and performing exercises, some of these repeated multiple times. As in rehabilitation, the use of devices is almost always the same and always in the same environment. Generally, rehabilitation programs are boring and repetitive since the programs are based on repeated behaviours making the patient less motivated. The introduction of VR that allows presenting a virtual scenario that is appealing to the patient makes it more fun and interesting, thereby leading to more positive reactions [22]. Many studies [34] [24] [37] and clinical trials have been done using VR for these pathologies. In the first study, a 3D scenario called Caren was developed, which simulates a supermarket scenario, and the objective of the participants was to interact with the products that were placed on a shelf. To match the upper extremity training, rehabilitation exercises involve repetition of movements to enhance motor skills. The authors concluded that rehabilitation with virtual experiment was more successful than physical experiment [34].

Another example is the case of IREX VR, where the main purpose was to handle virtual objects when using multiple VR games that induce reaching and lifting motor skills of the upper limb at various angles. The main objective of this system was to be a complement to the current and most common rehabilitation therapies. Authors concluded there was improvement during the VR training [24]. In another study [37], the authors used the Virtual Reality Rehabilitation System (VRRS) including a computer workstation connected to a 3D motion-tracking system and a high-resolution LCD projector displaying the virtual scenarios. The main objective of the therapy involved performing different motor tasks with the patient holding a real manipulable object in their hands while interacting with a virtual scenario. The study was made in order to evaluate the effectiveness of non-immersive VR treatment for the restoration of the upper limb motor function concluding that this type of rehabilitation seemed more effective than the conventional interventions [37]. In the StrokeBack project, rehabilitation is done at home with a telemedicine system and defined by the medical team according to each patient's case, making human intervention minimal. Medical staff use an editor interface to customize the rehabilitation plan. All these games that use immersive VR and AR technologies created for the StrokeBack system were meant to be used for rehabilitation purposes [41].

Many conditions and diseases such as stroke can affect your physical abilities, more particularly the locomotion degrading the individual's quality of life. Because of that a study was made [21] to try to recover this ability damaged. The study used virtual reality as its main technology and developed a full body application called Locomotiver, that supports exercise for locomotion rehabilitation based on the needs and expectations of their physiotherapist's partners. It was concluded that physiotherapists would like to implement this application in their rehabilitation process to their patients.

Another example of the usage of full body tracking for rehabilitation is this one [5], where a Kinect was used in order to track the user in the virtual environment. It were developed several exercises that the therapist could customize. The study has pointed out remarkable results in terms of motivation, usability, and customization.

Although the use of virtual reality in the contest of rehabilitation as been growing over the years, there isn't much research about the full immersive that virtual reality, using full body tracking in order to simulate user entire body in the environment. Taking this in consideration, in this thesis, we try to experiment if the full body tracking in a virtual environment could lead to a better and faster rehabilitation from the athletes.

2.1.2 Application of Virtual Reality Technology in Sport Rehabilitation

The principal problem for athletes in terms of physical effort is that during the sport participation the athletes have a high rate to musculoskeletal injuries leading sometimes to major injuries. To recover from these injuries the athlete performs rehabilitation in order to recover to a level prior to his injury, returning to a normal professional life in a more effective way [14] [28]. When an athlete suffers an injury and considering that each injury has its differences, a rehabilitation plan occurs fundamentally in several phases. These phases demand a multidisciplinary team, from the time of the diagnosis until the direct rehabilitation, involving multiple areas of medicine and beyond, where this athlete performs exercises that should result in the athlete gradually returning to his pre-injury condition. To perform this task of rehabilitation, the athlete must correctly perform the prescribed exercises from the medical staff [14]. The athletes learn to execute these exercises when accompanied with someone from the medical team that guides them to the steps they must execute. This member of the medical team helps and teaches the athlete to perform the exercises in the most appropriate way, so that the exercise helps in their rehabilitation, instead of having the opposite effect [14] [13]. Nevertheless, athletes do not always have a close contact, control or guidance with the medical staff when they are realizing the rehabilitation exercises from their plan. This makes it impossible to check if they are doing the exercise with the best technique and get instant feedback about that [14]. Consequently, this support and supervision that is usually realized by the medical staff can be done using Virtual Reality since it is possible to show in the immersive world instant feedback to the athlete where they are, regarding the correct technique needed for each exercise, and without the need for an extra person supervising the athlete [14] [11]. Naturally, immediate, informative feedback and knowledge of their performance is needed in order to improve the accuracy and speed of performance on cognitive, perceptual and motor tasks [1] [33].

According to Qin et al. [28], one of the principal advantages of using VR in rehabilitation is the possibility of displaying instantaneous feedback of two types, rehab and performance, and in the case of rehab providing realtime information on their technique in each exercise executed by the athlete. It is also mentioned that this multiple feedback can motivate athletes to accomplish the exercises and their repetition [28].

Since rehabilitation in athletes uses repetitive muscle exercises in a strict manner, VR systems allow to overcome the monotony performing these exercises with scenarios interesting to the user [33]. Another advantage is that VR systems have the option to be customized, therefore users and medical staff can customize according to their personal preferences and taking in account the current situation of the injury they are in [28].

Gokeler et al. [20] evaluated the influence of immersion in a virtual reality environment on knee biomechanics in patients after ACL (Anterior Cruciate Ligament) reconstruction (ACLR). It was hypothesized that virtual reality techniques aimed to change attentional focus would influence altered knee flexion angle, knee extension moment and peak vertical ground reaction force (vGRF) in patients following ACLR. Similarly, Fitzgerald et al. [14] describe a system that allows an automatic audit of this activity. They developed a computer game for instructing an athlete through a series of prescribed rehabilitation exercises. To prevent or treat musculoskeletal type injuries along with trying to improve physical performance, athletes are prescribed exercise programs by appropriately trained specialists. The system utilizes ten inertial motion tracking sensors incorporated in a wearable body suit which allows a Bluetooth connection from a root hub to a laptop/computer.

However, despite the focus in VR systems for athletes, there is currently limited scientific evidence of rehabilitation for injured athletes in professional sport using VR systems and the scenarios applied to it.

Previous studies [24] [37] divided their participants into two groups: one group would conventionally perform the rehabilitation and another group would add the virtual experiment, the application developed in their experiments, to the conventional way. Both studies used the Fugl-Meyer Assessment [17] to measure the improvements gained in both rehabilitation sessions. In the study [37], the participants were chosen to take into consideration a motor arm subscore between one and three on the Italian version of the National Institutes of Health Stroke Scale and without severe neuropsychological impairments interfering with recovery. Also, small groups were created inside the two main groups where participants were split considering the level of impairments: severe, moderate, and mild. Not only that, subjects were separated into small groups according to the time the rehabilitation was done after the stroke: less than three months, between three and twelve months, and more than twelve months. In the study [24], it was also used alongside the Fugl-Meyer Assessment, the Manual Function Test to measure the improvement of the rehabilitation. In yet another study [21], a virtual reality application was developed using full-body tracking to help in the rehabilitation of the locomotion function. The authors collaborated with nine participants, all of them in the physiotherapy area. It was used this type of subjects instead of the conventional persons who need the rehabilitation because the purpose of the study was to see if physiotherapists would want to include this application in the patient's rehabilitation. The study was conducted in three parts: in the first part, the participants would test the application as the patients doing the rehabilitation where they performed the exercises developed; the second part, the subjects used the application as the physiotherapist and how they manage to use the application to help future patients and understand the application overall; the final part was a questionnaire and a talk with the physiotherapists to receive the most information possible about the experiment where they tried to find if the participants would want to include this application in their patient's rehabilitation. Although the study was conducted with a small group of testers, the authors find out that the physiotherapists would want to include the application in their rehabilitation program.

2.2 BEYOND STATE OF THE ART

Virtual reality has been applied in several aspects and areas of our society. The great technological evolution that occurs every year allows its development to be improved and applied in the area of rehabilitation, as it is already applied in medicine, military, video games and also mainly because it is highly customizable [6] [28] [11]. With the improvement of 3D graphics that allow the creation of environments with quality very close to what we see or interact, that allow a better and more realistic immersive experience.

In this thesis, we propose the use of Virtual Reality systems to motivate athletes not only physically but also cognitively, with the goal of a faster recovery from the injuries they have obtained. The use of VR for rehabilitation is mainly due to his principal advantage of giving the possibility of displaying instantaneous feedback, of two types, rehab and performance, and in the case of rehab providing real-time information on their technique in each exercise executed by the athlete, according to Qin et at. [28]. Besides that, this multiple feedback can motivate athletes to accomplish the exercises and their respective repetitions [25]. The VR system with his several scenarios helps athletes overcome the monotony when performing rehabilitations exercises which are based on the repetition of muscle exercises in a strict manner [11]. Our approach to avoid this monotony is giving to the athlete the possibility of choosing the scenario he/she wants for the exercise. Taking this in count we hypothesize that the use of this solution will lead to a quick recovery of the injured athletes, increasing their motivation and performance.

In conclusion, there is significant, recent potential in virtual reality combined with HCI for improving athletes' performance returning to their normal professional life in a more effective way, recovering from their injuries, as it stems from literature review, and the approach we propose will leverage the current state of the art to better support physical and mental health of this growing target population.

3 DEVELOPMENT METHODOLOGY

This chapter will explain which and why each equipment was decided to be used and as well all the implementation process that took us to get our final prototype. It was a complex project, so the help of several persons including a team to develop the system and professionals from the sports area was necessary. The team changed over the development of the system, having initially another engineer that left halfway through the project, entering in his place a designer that helped update the environments that were designed at the time.

3.1 PRE-DEVELOPMENT

Before starting to develop the VR system it was necessary to firstly meet with our partner in the project – Club Sport Marítimo. These meetings were done with administration and medical staff with the purpose of discussing where all the equipment would be placed as well which exercises would be implemented respectively.

3.1.1 Club Sport Marítimo

Club Sport Marítimo is a multi-sports club on the island of Madeira. Its main sport is football having a consolidated position in national competitions and always fighting for a place in the classification that gives access to a European competition.

The club founded on 1910 counts with a vast heritage, including a college where through sport it was possible to work on the intellectual skills and emotional partners of its students. This was an innovative project both regionally and nationally. With this concern to bring innovative projects to the club aimed at enriching the sport, it was easy to interpolate the project being worked on in this thesis.

3.1.2 VR Room

To develop this kind of project, it was necessary to create a room where all the materials, computers, and virtual reality equipment, were assembled. Since the project involved a lot of movement of the user in the virtual environment, was required that the room was big enough with a play area at least of 3.5mx4m. Due to this constraint, several places were considering trying to find the best space.

Firstly, it was thought to separate a gymnasium in two making one part for the virtual reality space. Before starting with the division we designed how the room would be mounted. The following figures, Figure 1 and Figure 2, show the design of the virtual reality room.

Figure 1: Room Design - Example 1

Figure 2: Room Design - Example 2

Due to some complications of the possible location of the room, it was determined it was better to construct the room from scratch. Although the result was different from the previously designed, the new space was bigger and was more isolated from sound since it was located next to a gymnasium.

The construction of the room was done by Marítimo alongside our help to accomplish a room where it was possible to develop the application and have a well-sized play area to be able to perform all the rehabilitation exercises.

Figure 3: Development of the Room

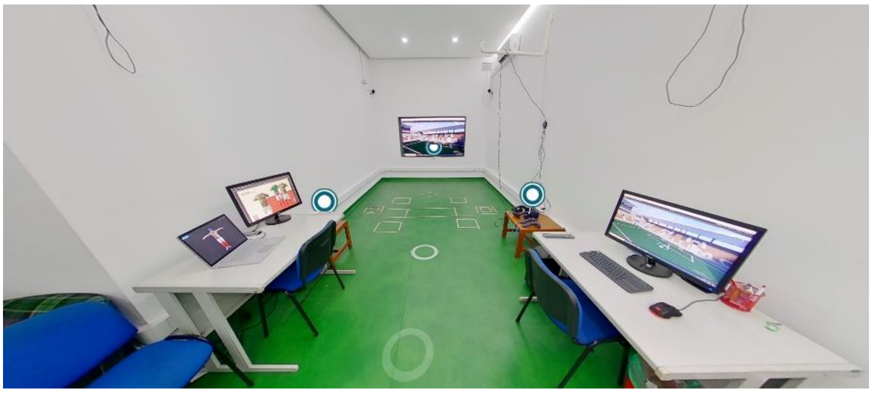


Figure 4: Result of the room

3.1.3 Selection of the Exercises

As said previously, to select the exercises of rehabilitation, was conducted several reunions with specialized medical staff that exemplified the exercises, as showed in the next figure, and videos showing the exact movement from each exercise. These exercises were selected taking into consideration exercises performed by the medical staff during a usual rehabilitation session.

Figure 5: Weight Transfer exercise

Figure 6: Balance exercise

3.1.4 Session - Exercises

Since the exercises provided by the medical staff were too many it was decided to select only a few ones, more specifically five exercises, that would be enough to perform a session of rehabilitation. The exercises selected were done by a specialist in the sports area included in our group that choose exercises that would work balance, resistance, and strength of lower limbs that considered the exercises selected were sufficient for a first session of 30 minutes. These exercises were chosen during the second phase of the development as will be explained later.

The exercises selected were:

1. Weight transfer – Balance
2. Walking along a straight line – Balance
3. Military march – Balance/Resistance
4. Side Squat – Strength of lower limbs
5. Progressive March – Resistance/Strength of lower limbs

1. Explanation of Exercises Chosen

After the selection of the exercises that would be included in the session was necessary to watch the videos provided by the medical staff together as a group and check each movement of the exercises to determine what is necessary to implement in our system.

Our group watched the videos and wrote down each movement. At the same time some sketches were done that showed each movement of the exercises to help us afterward when programming each exercise:

1.1.Weight transfer

One leg forward and one leg behind. The purpose of the exercise was to transfer the weight forward and back by raising the toe of the leg that was in front transferring the weight of the user backward, low the toe, and raise the heel of the foot of the leg that was behind and then low the heel.

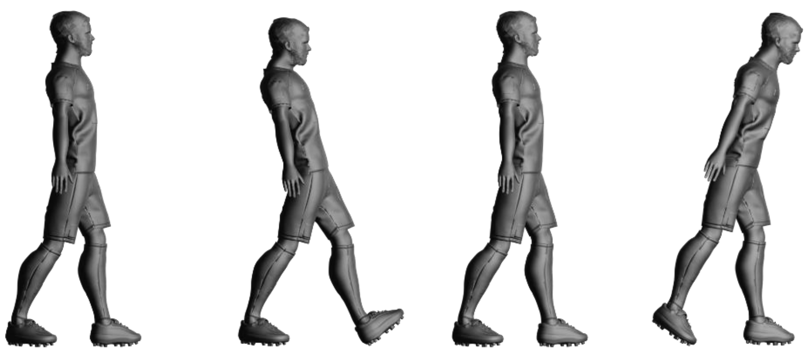


Figure 7: Sketch of Weight Transfer exercise

2.1.Walking along a straight line

Like a tightrope exercise. Follow a straight line with the left foot on the floor and the heel of the right foot touching (on the floor) the left toes, then move the left foot forward of the right foot with the heel of the left foot touching the right toes, repeat until the end of the line.

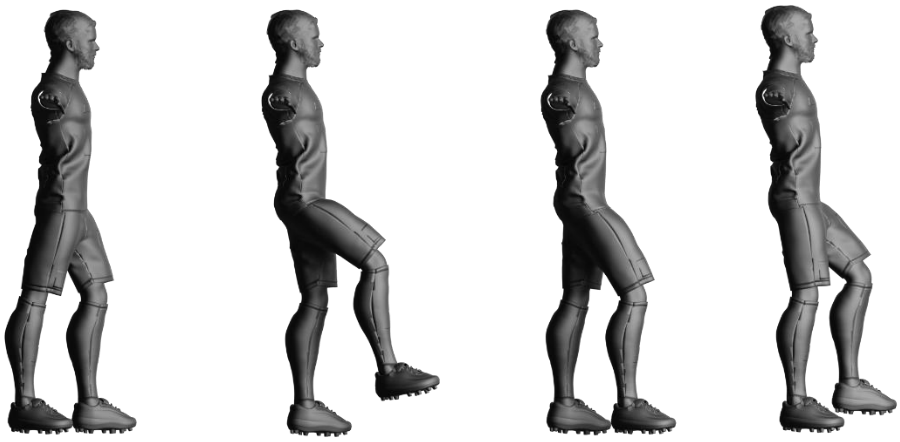


Figure 8: Sketch of walking along a straight-line exercise

3.1.Military march

Raise the left knee until it forms a 90-degree angle with the belly and at the same time stretch the right arm. Then repeat for the opposing members.

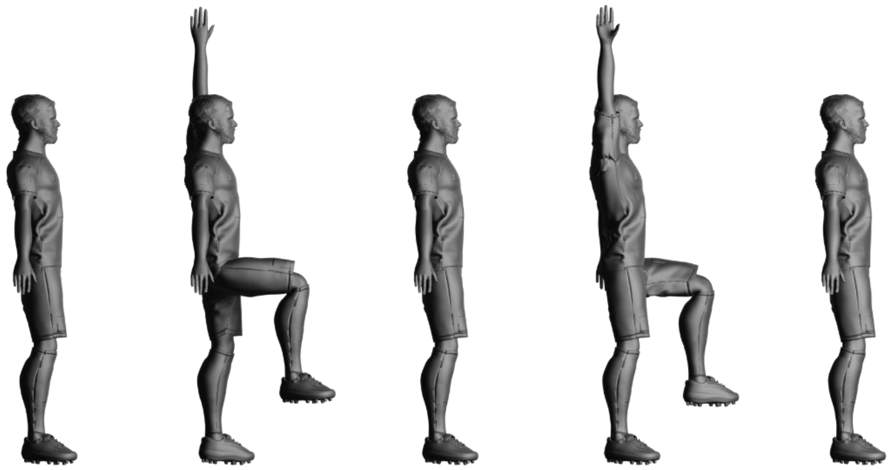


Figure 9: Sketch of military march exercise

4.1.Side squat

Step sideways while pushing the hips back and bring the torso toward the floor. Stand on the other side and prepare to repeat the back-and-forth movement.

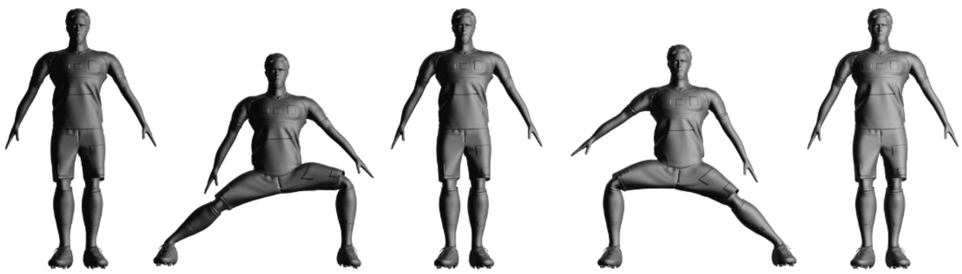


Figure 10: Sketch of Side Squat exercise

5.1.Progressive march

Similar to the military march but only needed to raise the knee until it forms a 90-degree angle with the belly.

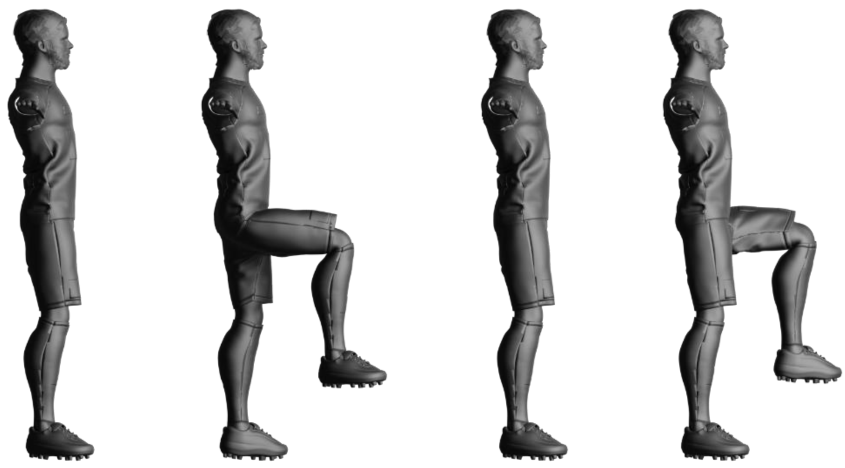


Figure 11: Sketch of Progressive march exercise

3.1.5 Composition of the Session

After the selection of the exercises, were determined how these exercises would work with each other to make a session of rehabilitation.

The SPA determined that to make a better rehabilitation it would start with the least effort exercise as warming, proceeding to more complex ones, and finishing with an exercise that would cool of the effort used in the session. This session focused in the rehabilitation of the lower limbs of the athlete. Alongside the order of the exercises, the numbers of repetitions and series for each exercise were delivered by the SPA.

The session would be composed by:

Nr	Exercise	Series	Repetitions
1	Weight Transfer	4*	8
2	Military March	2	8**
3	Side Squad	2	8**
4	Progressive March	2	-
5	Walking along a straight line	1	3

Table 1: Session

* 2 series for each leg in front.

**8 repetitions for each leg.

The progressive march was concluded that did not have to have many repetitions, but the game created would control the number of repetitions done.

To summarize, the session would be constituted with five exercises starting with a balance exercise to warm up for the session. The next three exercises would require more effort from the user, so the last exercise is used to cool off the athlete so that the session does not finish at a high peak of effort.

3.2 SYSTEM DEVELOPMENT

In this chapter, we will provide a succinct description of the development process for this project. We explain what hardware was used, include a brief description of all the software utilized and why, and finally how the exercises and their gamification were done.

The development of the project went through two major phases: in the first phase we developed all the exercises provided by the medical staff from Marítimo where all the mechanics of each exercise were developed. The second phase happened when the session was selected and the exercises in that session were gamified to make the exercises less boring when doing each repetition and motivate players.

The system can be divided into two main parts, hardware, and software. The hardware part consists of the physical equipment that the system requires, and the software which is responsible for making the connection between the hardware and the application.

It will be shown how the virtual reality equipment gave us the possibility of creating full-body experiences and which plugins were used to help us make the system more accurate by integrating the avatar with all sensors and Unity making the tracking more accurate, smooth, and rapid.

The project itself had another variant, we wanted to capture the body of the user using a camera and pass it to a television. This method would provide us another way to realize rehabilitation exercises since some exercises could not be suitable for virtual reality.

Since this project was inserted in a research project, the system developed involved several researchers (with several changes in the team) but all the parts that I did not contribute will be mentioned.

3.2.1 Hardware

Before going into detail about the VR system developed, it is necessary to explain what was necessary for terms of technology.

Taking into consideration that the system would require a good computer to run the application it was searched a desktop to be able to develop. The desktop selected was equipped with an i7-8700k 3.7ghz processor, gaming RX Vega 64 graphics card and 16GB (2x8GB) DDR4 3200MHZ memory kit.

1. *HTC VIVE*

To develop virtual reality applications, we could consider several headsets from Oculus, Sony, and Valve for example, but in this project, we wanted to implement a full-body tracking experience and for that, the best option was a headset from HTV Vive. We wanted to develop the VR system with full-body tracking since it helps to reduce cognitive overhead when performing tasks that involved cognitive processing [32].

Until today, HTC Vive is the only one possible to experience a full tracking experience using trackers alongside the controllers and the headset. For that reason, the HTC Vive chosen was the HTC Vive Pro Set, including an HMD, two controllers, four SteamVR base stations 2.0, and three trackers. The HTC Vive Pro HMD is connected by a Link Box that connects two cables, one USB 3.0 and a Mini-DisplayPort to DisplayPort that is connected to one of the graphics card DisplayPort outputs. The base stations send signals to the HMD and these base stations perform the tracking of the controllers and trackers.

6.1.Trackers

Virtual reality systems normally do not use trackers in their systems because they do not need to detect anything other than the head and the hands of the user. Like previously mentioned we've chosen HTC Vive because it was the best option in terms of getting full-body tracking. It's possible to track the full body of use by using some hardware that is possible to acquire from HTC VIVE and it's called trackers. These trackers bring any real-world object into the virtual world [42]. In our case we needed the trackers to obtain data from the user's feet and body, to know their position to translate it into the virtual environment. The next figure shows the trackers used.

Figure 12: Trackers used

2. Intel RealSense D435

As was mentioned before, this project had two methods to capture the movement of the user during the execution of the rehabilitation exercises. The second method was the usage of a camera to detect the body of the user and show it on a tv where it would be possible to see his body and the instructions to perform the exercise.

The camera selected was the Intel RealSense D435. The D435 is a depth camera containing a pair of depth sensors, an RGB sensor, an infrared projector. It presents precise depth perception when an object is moving, or the device is in motion.

Although the Kinect was a more reliable camera than the Real Sense [26], the fact that it was discontinued was the major factor to decide to use the D435 camera [18].

3.2.2 Application Technologies

After having all the hardware necessary to develop the project, we conducted some research to understand the software required to develop a VR system of this magnitude.

1. Game Engines

The first was to investigate which game engine would be used. A game engine is a software framework designed for the development of video games. Although there are several game engines, they share core functionalities like rendering engines for 2D and 3D graphics, physics engines, sound, artificial intelligence, networking, and scripting [43].

Since the focus of this project was virtual reality. It was taken into consideration the two best known in this category: Unity3D and Unreal Engine [19]. Even though both engines have their pros and cons the decision would fall to which game engine the group had knowledge and which was easier to use.

Unity3D: a multi-platform game engine (smart-phone, Mac, PC, video game consoles, and web) developed by Unity Technologies. It is offered under a free license and another professional paid one. It offers rapid prototyping and a possibility to deploy developed applications on different VR devices. It allows easy generation of VR applications. By being the most famous engine, has a bigger community allowing to developers discuss their questions faster. Not only that, have the bigger asset store in the market. The language used in the scripting is C# [19].

Unreal Engine: developed by Epic Games. It is free containing programming guides (best programming practices), demos, and video tutorials. Unreal has two ways of scripting: with C++ or with a Blueprint visual scripting system, allowing the developer to use both if wanted [19] [44].

Taking into consideration these two game engines, our team decided to use the Unity3D duo to the experience we had using the engine and because Unity has a larger community that could help when coding the virtual reality system.

1.1. Unity Concepts

To a better understand the development process, we first explain some concepts from unity.

- GameObjects: fundamental objects in Unity that represent characters, props and scenery. They act as containers for Components, which implement the real functionality. For example, a ligh object is created by attaching the light component to a GameObject [45].

- Prefabs: a system that allows to create, configure, and store a GameObject complete with all its components, property values, and child GameObjects. The Prefab acts as a template from which you can create new Prefab instances in the Scene [35].

- NavMeshAgent: allow the character to navigate the Scene using the NavMesh [46].

- NavMeshSurface: component that represent the walkable area for a specific NavMesh Agent type [36].

2. SteamVR

After we decided which game engine to use, was searched how would be the integration of the HTC VIVE on the game engine. At the time of the research, Unity had launched a tool for the development of VR in their engine but since I had previous experience with another tool our group decided to use the tool I was skilled to reduce the time needed to learn the basics of a virtual reality system development. The tool chosen was the SteamVR.

SteamVR is a free tool to experience VR content supporting HTC Vive, Oculus Rift, Valve Index, and others.

Unity store it's possible to download this plugin, and to integrate afterward on the project. This plugin helps developers in three main things: loading 3D models for VR controllers, handling input from those controllers, and estimating what the hand looks like using those controllers [47].

When opening the SteamVR [48] it’s possible to visualize each component of the HTC VIVE hardware automatically and afterward add the wanted trackers. In Figure 13 is possible to see the SteamVR on with four base stations switched on. In this project four base stations instead of the usual two base stations were used because it provided more a accurate detection of all sensors considering this system needed a good constant detection to do the full-body tracking.

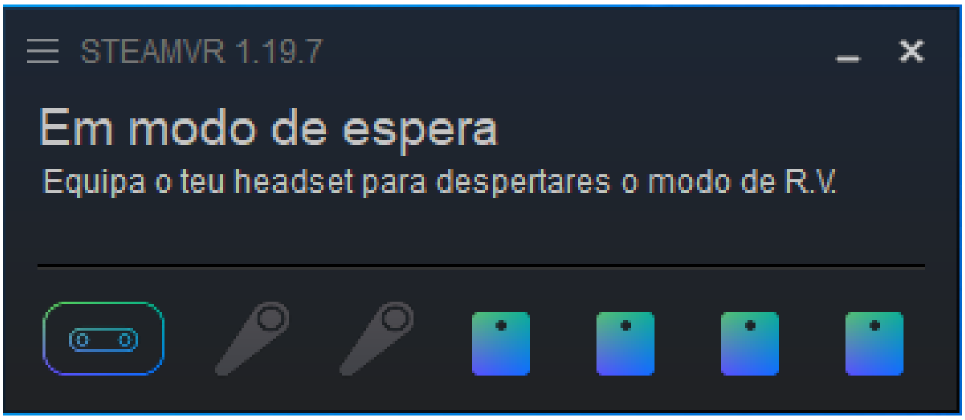


Figure 13: SteamVR application

3. *FinalIK*

With the previous tool, it was possible to create a virtual reality system but not with full-body tracking. With that in mind, was researched what was the best solution to accomplish that. The solution reached was FinalIK, an inverse kinematics library for Unity containing over 15 different types of IK solvers and solutions.

Inverse kinematics (IK) is a way to automatically calculate the joint angles of e.g., a leg or arm based on where the end effector (typically the foot or hand) should be. This allows avatars to synthetically reproduce human motions, even with a limited number of sensor points [29]. The IK work alongside the trackers XYZ values to calculate the joint angles. It was chosen the FinalIK library because one of the types of IK solvers was dedicated to virtual reality supporting up to six tracked points for head, hands, feet, and body [49], and was the most used by the unity community. The next figure shows how the HTC VIVE hardware must be placed so the FinalIK library is able to mimic the user movement to the avatar.

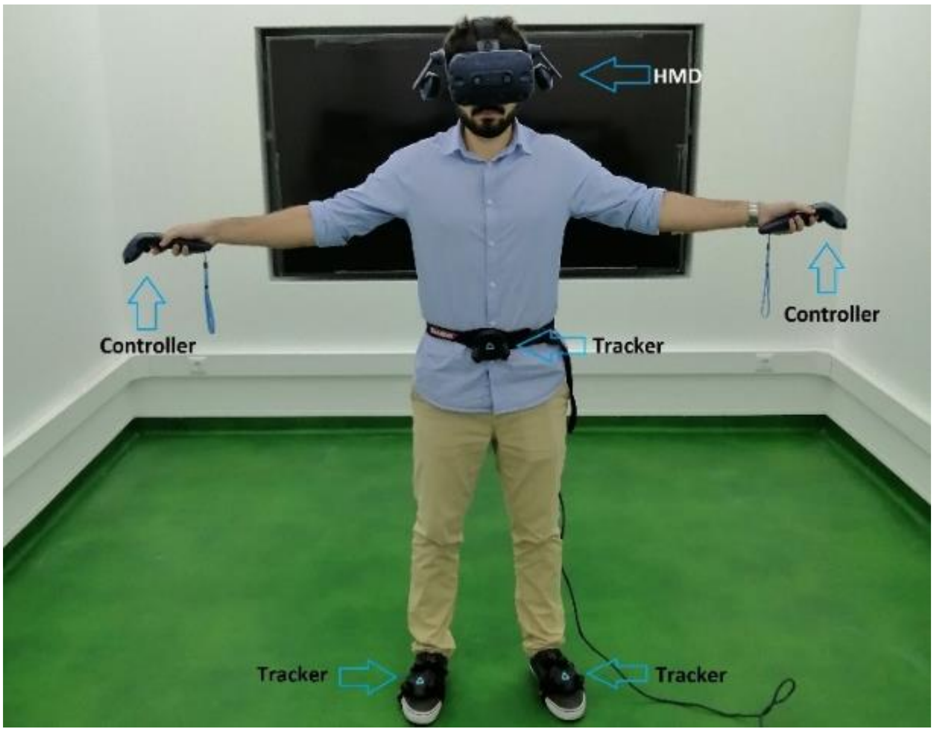


Figure 14: System setup to have the full body experience

4. 3D and Textures

In the development of the virtual application, the environments are very important since the better the environment more immersive the experience can be. Taking into account that one of the main reasons we are developing this application is to the patient do not feel bored when doing his rehabilitation, making it more immersive will contribute to the engagement and excitement for the patient [33].

Although entered in our group a designer to help us in the graphics part at the time of when the project started, we were lacking in that sector, so I had to focus some time developing 3D assets as well the first avatar to the project. Considering the time, we had to put into creating these assets was not as much as developing the mechanics, we used software that we had previously work it.

The software used to create the avatar was MakeHuman [50], a software that generates photorealistic humanoids. I used this software because it has an easy integration to Unity3D while also making it possible to export the avatar rigged, something which was necessary to implement the full-body tracking. It will be explained afterward what the rig of an avatar is and why was needed.

To create the 3D assets necessary to the virtual environments we used Blender. This software permits the creation of the entire 3D pipeline: modeling, rigging, animation, simulation, rendering, compositing and motion tracking, even video editing and game creation [15]. It was chosen due the previous knowledge and because it's open-source software. It was used for creating the environments, the 3D assets and to texture all the assets created.

5. Nuitrack SDK

It was necessary to have an SDK to connect the camera from Intel and Unity. The selection was between the Nuitrack SDK [51] and Skeleton Tracking SDK [52].

The Nuitrack SDK was developed by 3DiVi Inc. and is a 3D tracking middleware, that main purpose is to set up an API to transmit with 3D sensors. The key features are full-body tracking with 19 joints, gesture recognition, and have Unity and Unreal Engine plugins with tutorials for easy integration.

The Skeleton Tracking SDK was developed by cubemos and is designed to offer, to applications, deep learning-based 2D/3D full-body tracking. It has 18 joints for tracking the human pose and also has a plugin for Unity.

Although both SDKs were similar, we choose the Nuitrack SDK because had a bigger community and more support than the other SDK. These tutorials helped in faster learning of how the plugin worked.

3.2.3 Summary

To summarize this chapter, it was necessary to choose the hardware and the software that we were going to use to be able to develop a virtual reality system of this dimension and the exercises developed in the second method.

It was chosen HTC Vive as the headset for this project considering it enabled our team to acquire trackers needed to track the full body of the user. Using full-body tracking was an important aspect of our project because we wanted for the user to be immersed in the environment the most as possible. For the second method was selected the camera Intel RealSense D435.

After having all the hardware necessary, we chose which software we were going to use, and the plugins needed to obtain the desired system. It was with this material that was developed the virtual reality system and the exercises from the camera.

3.3 IMPLEMENTATION OF THE SYSTEM

In this section, we will explain in more detail every process necessary to develop the system including the code implemented and the 3D design.

Since our team was lacking in terms of design skills, I had to start first creating the environments and the 3D necessary to the project. Although it ended not being used in our final prototype it helped to bring some visual appeal when the code part was started.

When the initial environments and 3D were finished, we started coding the exercises developing the exercises that would end in the session.

Our final prototype achieved a full session of rehabilitation carefully selected by the SPA that provides feedback if the user is doing the exercise correctly or not.

3.3.1 3D

As said previously I started this project by designing the initial avatar, environments, and other 3D needed. The development of the 3D firstly helped when coding was done since we had some visual references to work with.

1. *Avatar*

As said previously, to design the avatar that would be the body that the user would incorporate was used MakeHuman. In the app was created a humanoid avatar, as follows in the next figure:

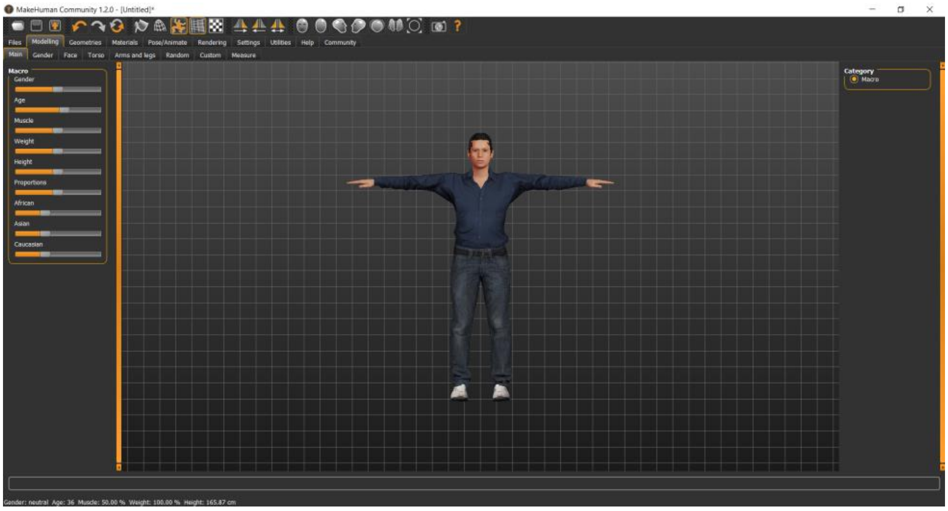


Figure 15: Customization of avatar

As was possible to see in the previous figure, MakeHuman allowed to construct the avatar based on several human characteristics like gender, age, high, type of skin, etc. Not only that but had several accessories that were possible to incorporate.

After the final customization of the avatar, we needed to choose the type of rigging. The following figure shows all the rigging that was possible to choose and what was selected. The selection of the best rig to use in this project was done with some research because it was necessary to know how the calibration of the avatar with the user would be done. Despite the calibration process will be explained afterward, was used the CMU MB for the reason that had the least bones having at the same time all the bones necessary to the calibration.

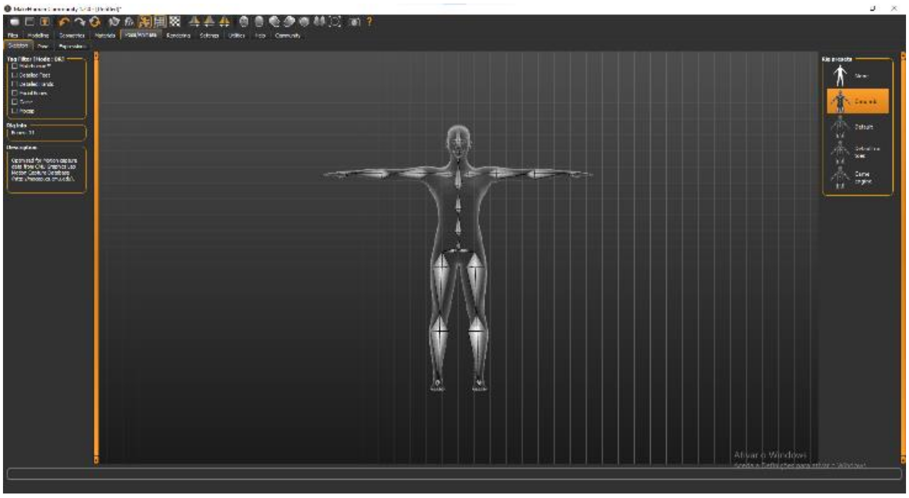


Figure 16: Rigging of the avatar

When the avatar was finished it was exported in the .fbx format, a format that works well with Unity3D, making it easier when was time to implement.

As said in the past, the 3D done by me was temporary since our team was lacking in design experts. The avatar that I designed was used until enter a design in our group that created a new avatar more appropriate to the context of the project: football athletes. He designed an avatar with the club’s kit.

Figure 17: Final avatar done by our designer

2. *Environments*

Initially it was thought that would be good to compare the use of multiple environments on each exercise to see in which environment the athletes would be more motivated, as the physiotherapist suggested that athletes with a long injury would like an environment related to football/club while in a minor injury athletes would prefer another scenario not associated to football. Taking that into consideration the environments chosen originally for the application had two possible environments: inside the football field of Marítimo, and another not related to football. The ones not related to football were chosen after meetings with the physiotherapists that the project had collaborated concluding that the environments of a beach and nature were going to be more appealing to the athletes.

Since at the beginning of the project we had no designer to do all the 3D processes, we divided the environments among the team meaning I was responsible for developing the stadium one. To design this stadium we used Blender3D [16] and to make it most realistic as possible making the environment more immersive [33], the model was designed considering photos and videos of the stadium that can be seen in the following figures:

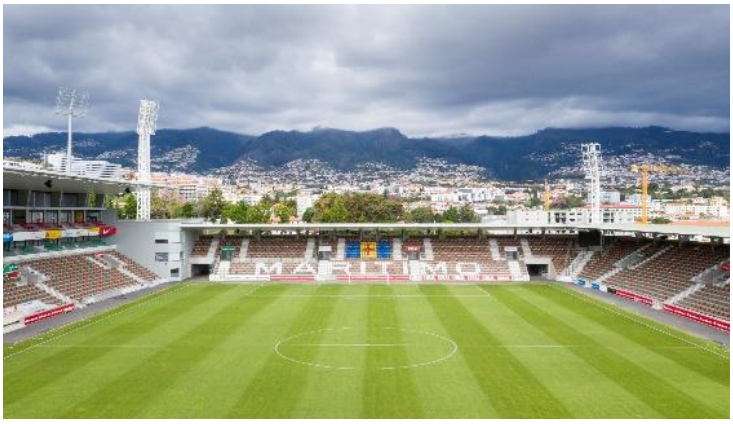


Figure 18: Photo of the stadium

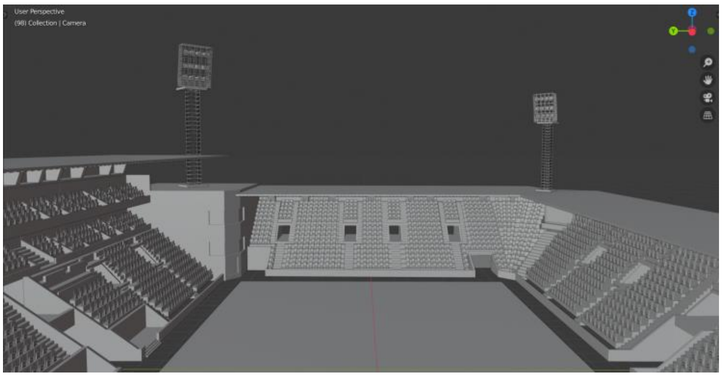


Figure 19: 3D Model of Stadium

Figure 20: 3D Model of Stadium with Textures

When the designer entered the team, it was decided that although was interesting to test if having two different environments for each exercise would differentiate the motivation to do the exercise, we had no time to do the two environments. Because of that, it was necessary to focus only on one scenario making the other environments saved for future work. Since our project was focused on football athletes and the medical staff gave their opinion, was decided to concentrate on the stadium. With that in mind, our designer started designing the stadium reaching the following:

Figure 21: Final stadium by our designer

3.3.2 Implementation on Unity3D

In this subsection it will be described how everything was implemented, starting with the implementation of the virtual reality on Unity3D, then how the calibration of the avatar, how the exercises work, and finally the session.

It was from this part we started using the game engine Unity3D and use the SteamVR to implement virtual reality on the scene and the FinalIK to apply the calibration of the avatar.

3. *Virtual reality on Unity*

The execution of the virtual reality on the scene of the Unity3D was made by dragging prefabs from the SteamVR tool that automatically permitted to test the system on the headset. The next figure is showed the prefab needed to be on the scene.

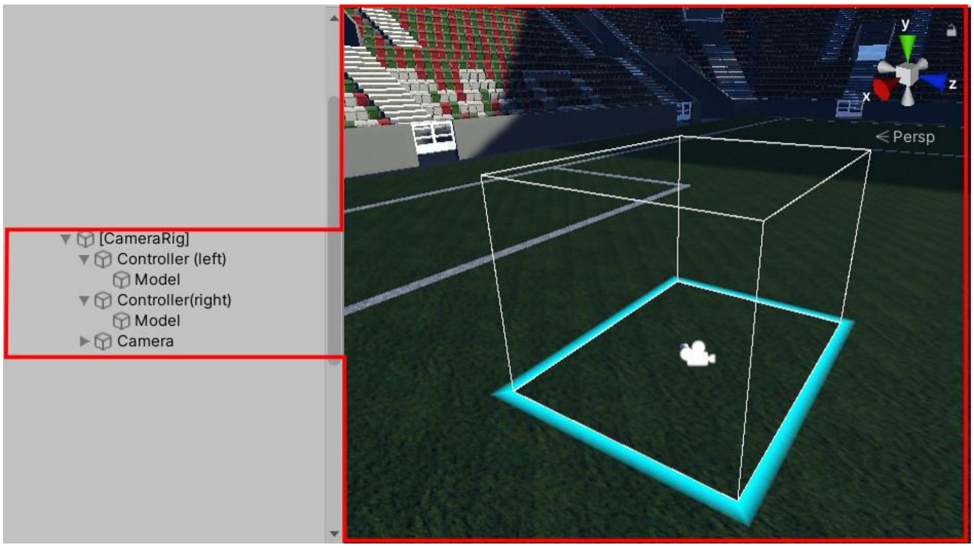


Figure 22: Implementation of VR on Unity3D

As its possible to see in the previous figure, the prefab [CameraRig] came with the SteamVR tool and is responsible to interconnect the Vive headset with Unity3D. It had two objects for each controller each one having script that get the input provided by the controller and his 3D model. Also, a camera was responsible for what will be seen from the headset.

4. *Calibration*

The calibration of the avatar into the user was an important part of the project and it was necessary to be perfectly integrated because if the avatar was not well calibrated or with lack of detail in the rendering, the avatar might not adequately accurately represent the user's movements and appearance. This may perhaps then lead to the user finding it problematic to interact with the world or to the user experiencing a break-in presence when they notice the discrepancies [32] [31].

First, it was created targets for each sensor that was going to be used: head, hands, feet, and hip. The following Figure 24 will be showing how the targets of the feet and hip were made. It was composed of a hierarchy where on the top was an object called Targets that existed to organize the remaining hierarchy. Followed with three objects (Left Foot, Right Foot, Hip) each one had one script from SteamVR that stated which tracker we selected. With this was necessary to turn on the controllers and trackers in a specific way or else the sensors would swap the order as possible to see in Figure 23 the correct way where first was the headset, followed by the two controllers, next four base stations, and ultimately the three trackers, left foot, right foot, and hip respectively. Finally, was added three objects (lf target, rf target, and hip target) that would be the actual position of the tracker in the virtual environment. During the development of the system, these last objects had a 3D object of a sphere to help visualize the tracker's position when using the headset.

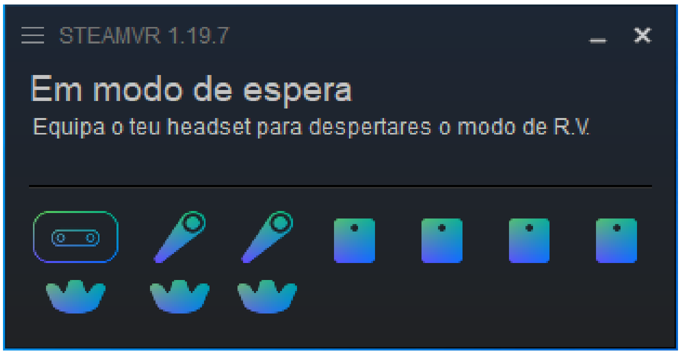


Figure 23: SteamVR application with controllers and trackers turn on

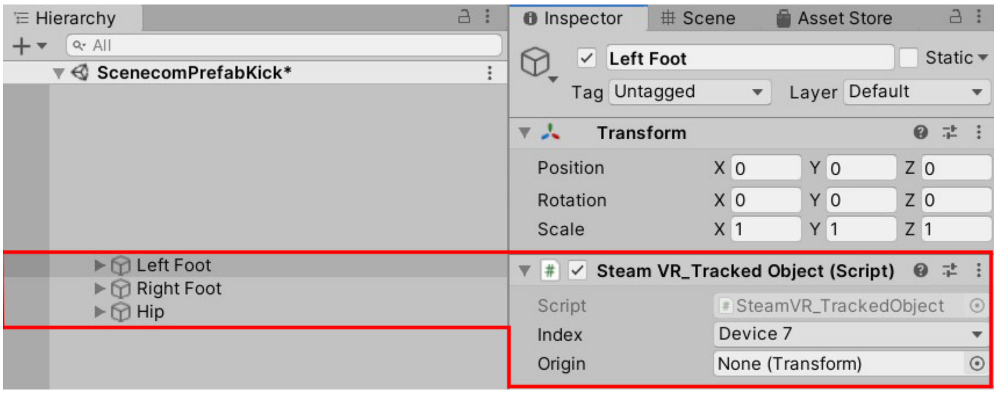


Figure 24: Tracking of targets

To implement the full body was vital to use the FinalIK plugin as it was said before. Since this plugin had an IK solver focusing the virtual reality, it has scripts that automatically calculate all the sensor's data and calibrate the avatar to the user body.

The usage of FinalIK plugin was essential for using two main scripts. The first one was inserted into the avatar wherewith that script automatically selected all the bones from the rig in the correct position as showed in Figure 25. Also, the script provided some options that we could change for calibrating better each body member as possible to see in Figure 26.

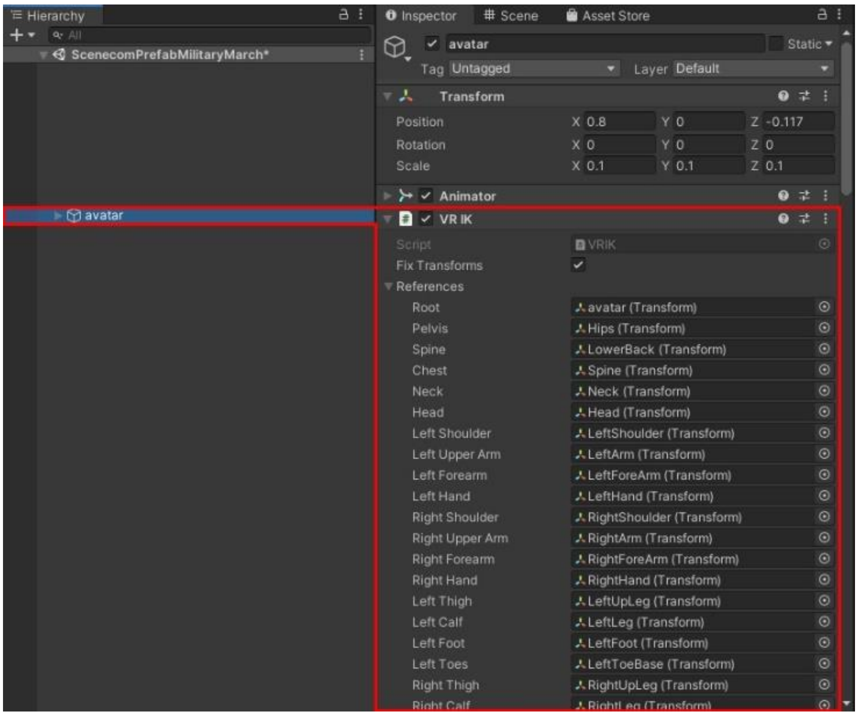


Figure 25: FinalIK Rig script that detect the rig from the avatar

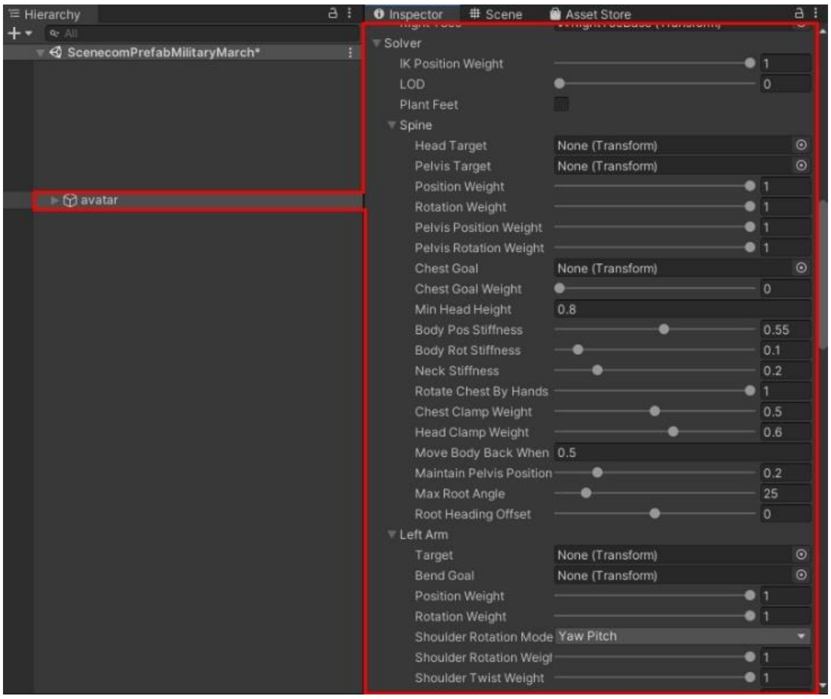


Figure 26: Continuation of the figure before showing the rest of the component where is possible to change some aspects of the body components

The second script was inserted into a Gameobject called calibration and that script was responsible to calibrate the avatar with the trackers the user was using. The way the script worked was by getting the inverse kinematics from the avatar from the previous script and the position of each tracker (head, body, hands, and feet) and when the function to calibrate the avatar was called it calibrates the avatar and saves the data necessary as in Figure 27.

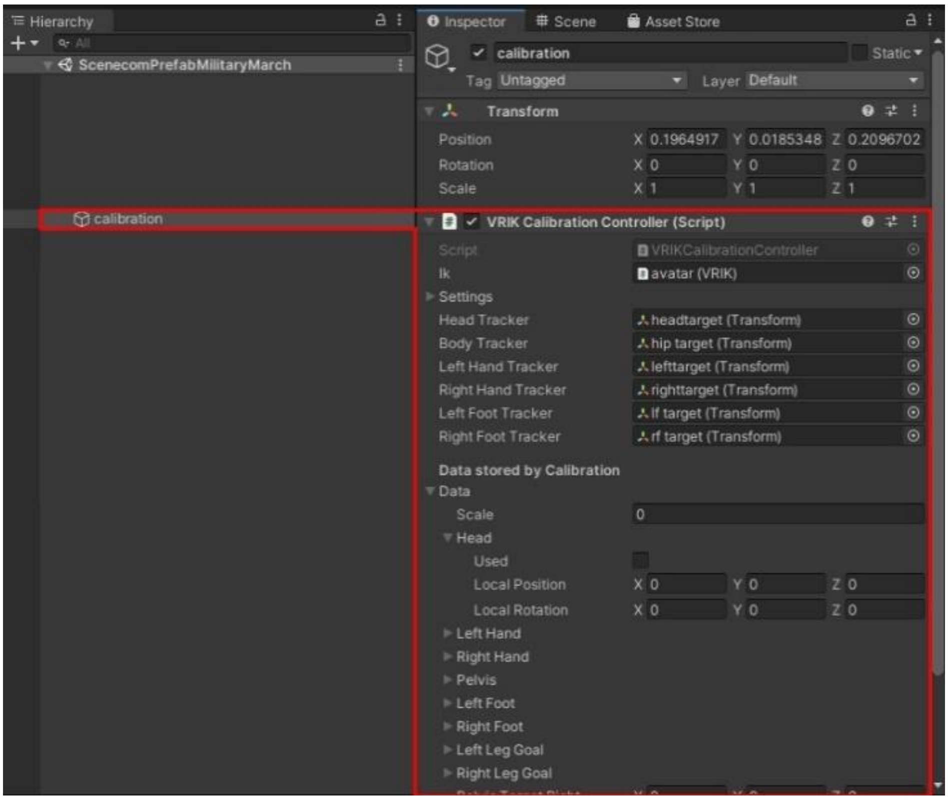


Figure 27: Calibration script

Although these two scripts permitted to calibrate the avatar more and less well-calibrated if we left the calibration like that the user could have problems interacting with the world or to the user experiencing a break-in presence when they notice the discrepancies [32] [31], so was necessary to straightening each sensor in the environment for a good calibration, meaning that if the calibration was not done correctly the user might lose immersion when noticing the discrepancies. The way it was done was by while executing the program change the position of the target for each tracker in the environment to a way it feels the closest as possible in the real world.

To a better calibration, it was required to the user position in a T-pose as possible to see in the next figure not only because it helped in the calibration process but also was important to get some measurements of the user necessary to implement in the exercise.

Figure 28: T-Pose to a better calibration

After all this process it was possible to see the avatar calibrating each body part exactly as the user body and performing accurately what the user was doing in the real world inside the virtual environment.

5. Scripting the exercises

The development of the exercises made was divided into two phases, as was said previously, the first phase was for coding the actual mechanics for every exercise provided by the medical staff from the club and the second phase was to do the gamification to the exercises that were chosen for the session. Although the development of the prototypes was divided into two phases, some exercises were done between the conclusion of the first phase and the beginning of the second phase, meaning that some exercises only existed in the second phase. Still, the explanation of the exercises will be done in the first phase for an easier understanding of the development.

The first phase would originate our prototype with the mechanics from all the exercises provided to us implemented using the initial stadium and avatar developed.

The second phase originated our final prototype, where it was presented a full session of five rehabilitation exercises being all gamified.

1.1.First Phase

To start the development of the exercises, we started by looking at those videos we got from the physiotherapist and the sketches our team previously did. We agreed that our exercises should have similarities to a finite state machine [39], the exercises were implemented using the same concept to control the flow of states in each exercise, since it was easier to provide instant feedback depending of in which state the user was. Exercises have their state machine, which consists of a set of states that change at the same time the athlete is executing the chosen exercise. Each state from an exercise has a sequential logic condition that is checked each time that state is executed, if these conditions are met, the actual state is changed to another and again another set of conditions are verified. Using state machines gave us more control in each exercise since we knew in which state the user was when performing the exercise and providing the possibility of developing additional feedback to make a more immersive and responsive experience. The next figure shows how a state worked in our finite state machine. The state was divided into three parts, the first one was a function called OnStateEnter() that, as the name indicates, played once the function when entering that state. The second part was the function called Tick() that worked like the function Update(), in other words, the function was called every frame being able to control every frame the movement of the user. The last part was a function called OnStateExit() that was played before changing the state. With these three functions was possible to know where the user entered the state, what he did when on the state, and when left the state.

```
public class LeftRightFootGroundTimerState : State
{
    public HeelExercise character;
    public LeftRightFootGroundTimerState(HeelExercise character)
    {
        this.character = character;
    }

    public override void Tick()
    {

    }

    public override void OnStateEnter()
    {

    }

    public override void OnStateExit()
    {

    }
}
```

Figure 29: Example of a state

Our team decided to do a timer before the user started performing each exercise, so the first stage of the script was to check if the feet were in position, in other words, if each foot was inside the cubes as was showed in Figure 32. When that condition was met it started the timer and started checking two conditions if the user change their feet, and if the timer was finished. If the timer is finished without the user move one foot, it changes to the first state of the exercise properly. The next figure shows the flowchart of the timer:

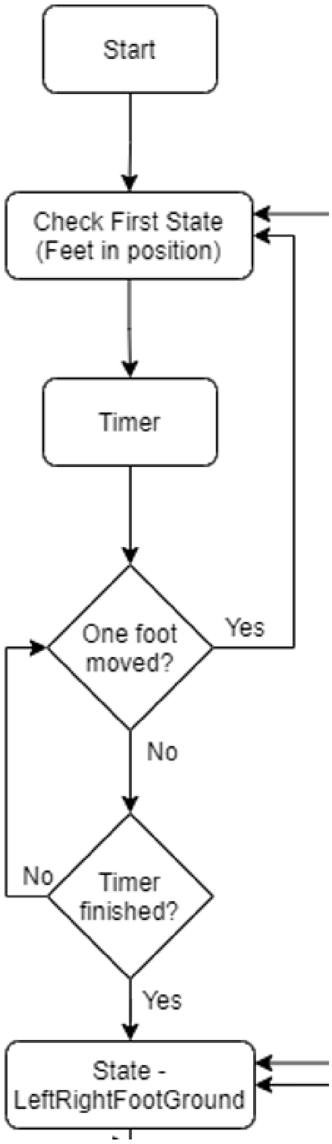


Figure 30: Flowchart of the Timer

Depending on the exercise, it was developed the repetitions and series system. These systems allowed to verify how many repetitions and series were done. In the first phase was also developed a scoring system because it was as though it would increase the motivation of the users when comparing the score of each other. The next figure shows the flowchart of how was checked the repetitions and series as well as the scoring system.

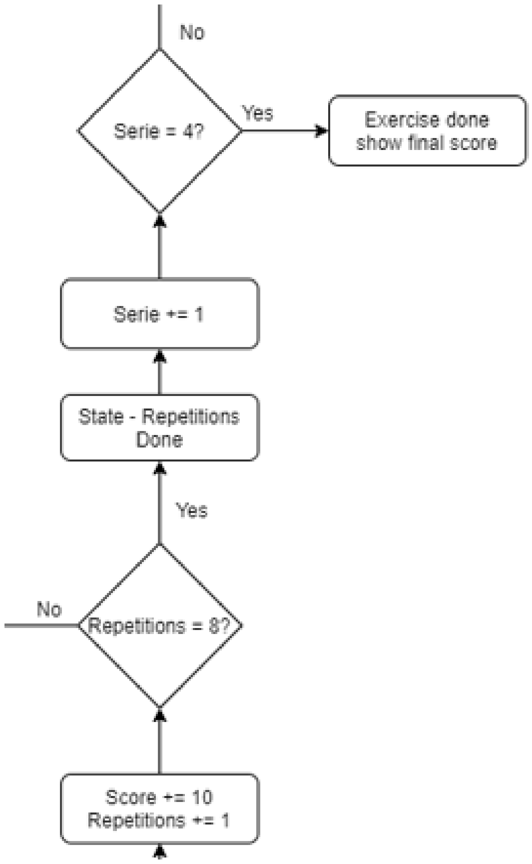


Figure 31: Flowchart of how was checked the repetitions and series as well as the scoring system

In the following points, there's a description of how each exercise mechanics was implemented.

1. Weight Transfer

The weight transfer exercise, in 1.1, was the first one that our team developed. Since it was the first one and the one trickier to do it took us more time to develop as it requires a precise movement of each foot. Anyway, the exercise was chosen because our team thought that after developing the hardest exercise the following ones would be developed more easier, since it would be possible to copy part of the code developed in the first exercise.

This exercise obligated the user to put one foot in front of the other with some space in between. Since the space needed for each user would differentiate depending on the high of their legs was necessary to create the space between the feet dynamically. The way this process was achieved was by placing two cubes in the virtual environment to show where the user had to put their feet. The space between the cubes was obtained when the user calibrated the avatar. Since the avatar matches the user when is calibrated, the height of the user's legs was measured and afterwards the cubes were adjusted considering the size of the leg.

As previously said, in First Phase, the mechanics for this exercise was done by developing a finite state machine, and our team decided that implementing all the finite state machine in the only script would make it easier when we needed to get the information in which state the user was. To change states in the finite state machine the avatar had attached to his feet colliders in both heels and toes. These colliders allowed us to know the position of each foot allowing them to change the state according to the right movement of the foot. The next figure shows the space between the cubes and one state of the movement with the toe of the leg that was forward raised.

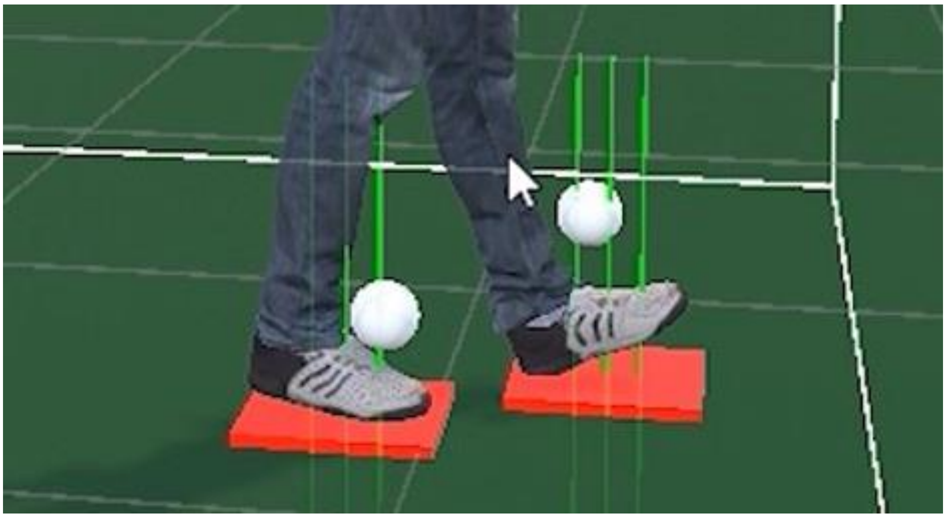


Figure 32: Example of a state in the virtual environment

To code, the script of the finite state machine was necessary to watch the videos to check the movement of each foot at the same time we write it down on paper some conditions each state had to have to help us when writing the script. Attachment one shows the complete flowchart of the exercise including the states necessary to have and the conditions of each state that the user had to meet to change the state. The verification of the mechanics of the exercise was done in four main states, the ones that certificate if the movement of the user was done correctly. To perform the exercise properly was required the user to raise the toe of the foot it was in front, then lower it, afterward raise the heel of the foot it was at back, and finally lower the heel. With those four main states was possible to check if those keys movements were done correctly. The next figure shows an example of the transition from one of the main states to another.

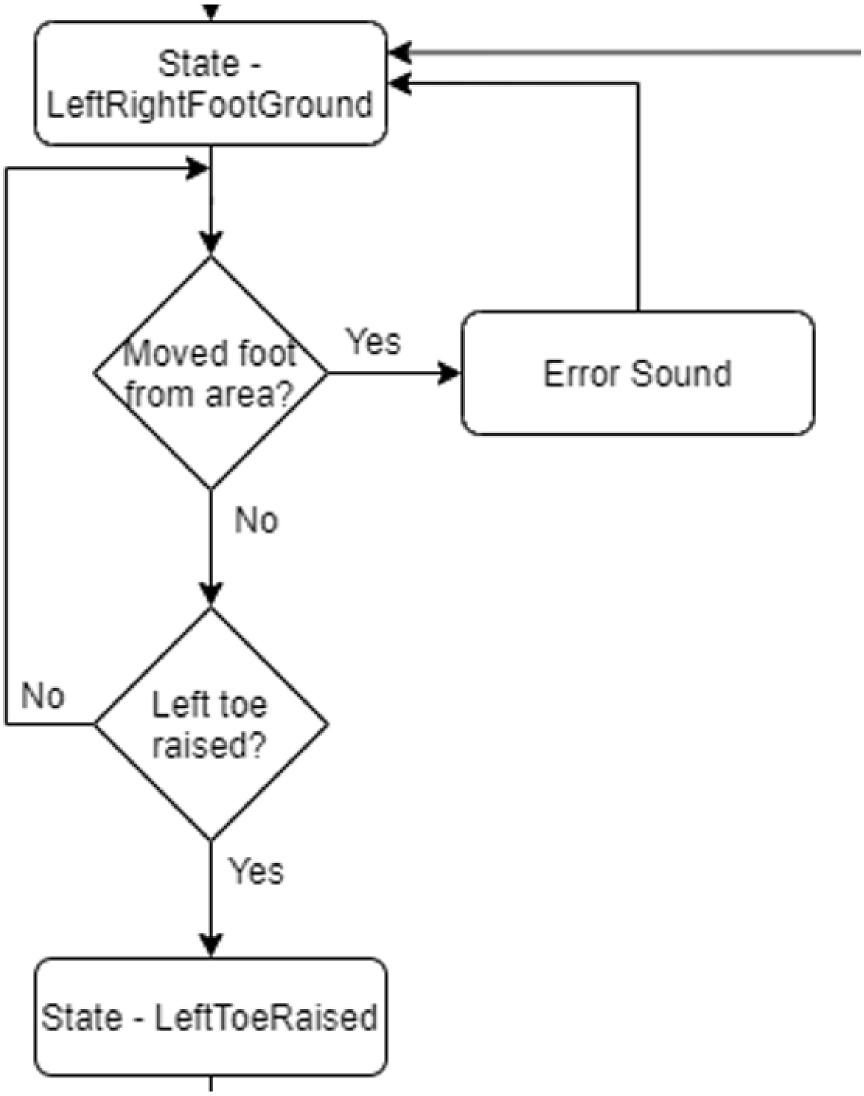


Figure 33: State that check if the toe was raised

2. Walking along a Straight Line

The development of this exercise required more effort than our team previously thought. In this exercise, explained in 2.1, we wanted to work out the balance of the user and since the objective of this exercise was to walk along a straight line so it was decided to put a red rectangle in the virtual environment, as shown in Figure 34, that obligated the user to perform the exercise on top of the rectangle. Since this is a virtual environment and the rectangle would be higher than the rest of the environment would create the illusion of falling. To check if the user placed his feet always on top of the rectangle one collider was created on each foot and three other colliders, one on the rectangle and the other two on the side of the rectangle. With those colliders it was possible to determine if the user put his foot on the rectangle or the side.

Figure 34: Walking along a straight line exercise

The main purpose of the exercise was when the user walked in a straight line his heel always touched the toe of the foot it was behind, as was possible to see in the previous figure. Because of that was needed to create a method to prevent the user not touching one foot on another. The method chosen was creating colliders for both his heels and toes. With that method was possible to check in the finite state machine if the user was putting their feet together or not. This exercise required a larger number of states because the exercise was not only walking forward but also walking backward. To a better understating of the full state machine, attachment five shows the complete flowchart of the states of this exercise. For the explanation of how the states worked, was chosen two figures that represent important parts of the exercise.

The following figure, Figure 35 ,exemplified how it was done the part of walking forward. To a better control of the exercise was developed more states to know exactly where the feet of the user was. To make one movement the user had to put the foot he had behind on front of the other foot touching the toe. The way it was programmed was by creating three states, the first one the user had the right foot behind and the objective was to lift it. When the user lifted the right foot it changed to the second state, where the user had the right foot in the air intending to put the right foot on the rectangle in front of the left leg. After the user performed that movement, it changed to the third state, where the first step was done. With all this process, the user had moved the right foot from the back to in front.

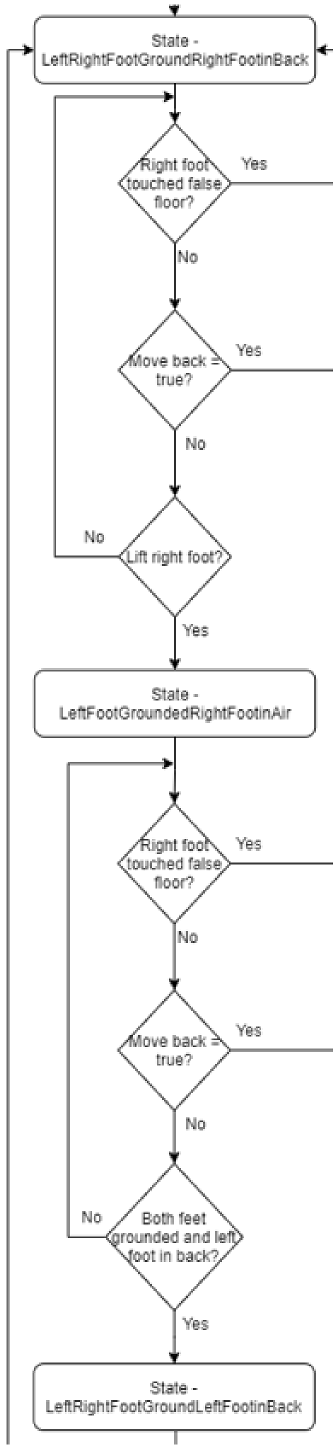


Figure 35: Flowchart of walk along a straight line exercise - first and second state

In Figure 36 we can see the initial states of the exercise when walking backward. Although the way of the movement of the feet coding-wise was similar to walking forward needing only to exchange some parts were needed to create a state

(MoveBackFirstState) that determined which foot was at back at the time was started the walking backward movement. This state was necessary because even the position of the rectangle to start moving backward was always the same, depending on the size of the foot of the user could differentiate which foot was at back at that time.

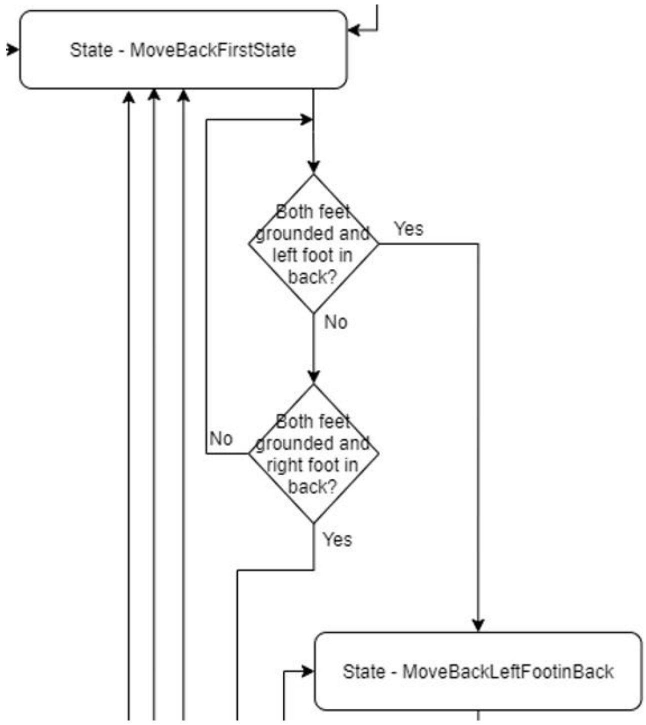


Figure 36: Flowchart of walk along a straight line exercise - backwards

3. Side Squat

This exercise, explained in 4.1, was one of the exercises that were developed between the first phase and the second phase. Taking into consideration that the implementation of the mechanics of this exercise was done already knowing the gamification for this exercise. With that, the development was adjusted so that it would be easier for the gamification afterward.

The development of this exercise was divided into two parts: the first part was necessary to create something that obligated the user to move to the left and right sides. For that reason, was implemented one ball that went to the left and right sides as it is possible to see in the next figure, the flowchart of how the ball was sent to the left side. After the ball was sent, the state machine changed to a WaitNextBall State that was a timer to wait to send the ball to the next side. With the creation of this state was possible to implement feedback if necessary:

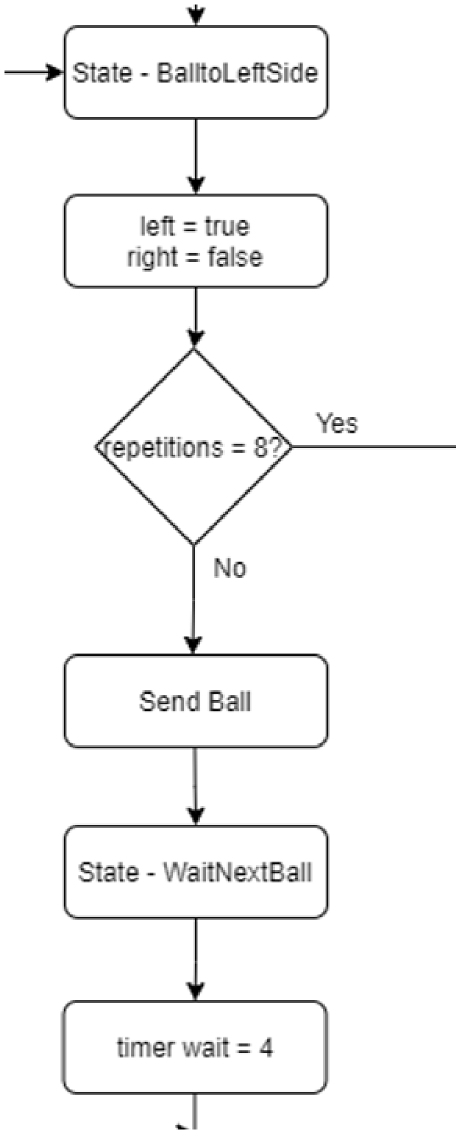


Figure 37: Flowchart of side squat exercise - Left Side Squat

The second part was to implement something that obligated the user to crouch down as was necessary for the exercise. It was chosen to put inside the virtual environment an object that would indicate if the user did not crouch down when changing sides. The height of the object was determined after the calibration of the avatar and with some calculations of how much the object needs to be lower than the high of the user to make the crouch down correctly. The Figure 38 shows the flowchart of what happens in the state machine when the user did not crouch down enough. If the user touches with his head in the object inside the virtual environment he loses the opportunity to catch the ball and automatically passes to the next state:

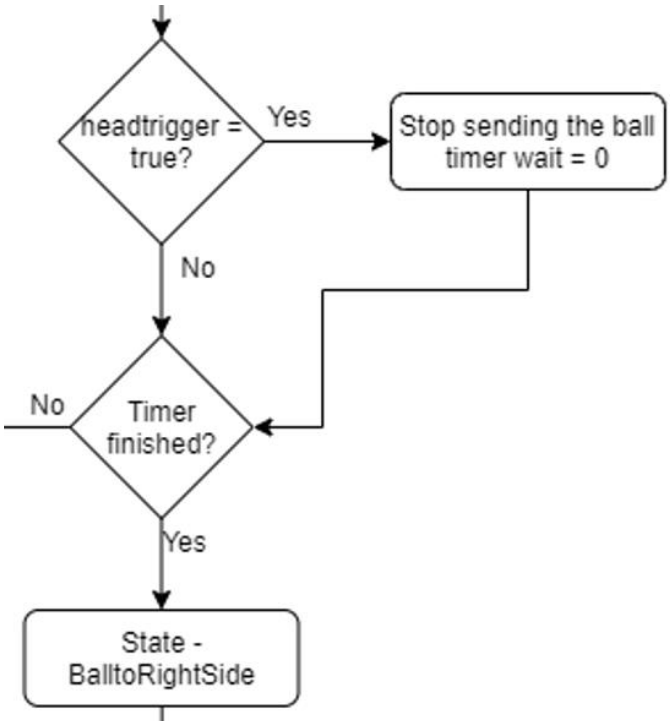


Figure 38: Flowchart of side squat exercise - Losing one repetition

4. Military March

The development of the military march exercise, 3.1, required attention to two parts, how high the knees and arms were raised and check if the arm raised was the opposite of the knee. The recognition of how much the arm was raised was done by when the user calibrated the size of the user, we got the size of the user plus the size of his arm. After receiving these two important data, both were added giving the final high the user needed to lift their arms to do that part correctly. To raise the knee was used the information we got of the high of the user when the avatar was calibrated and then do some calculations of how much percentage of the user high the user needed to raise his knee. After getting all this information was developed the finite state machine where we would take care of the second part, know if the knee raised was the opposite of the arm lifted. To develop this part was created two states that had each one condition that determinate if the right knee was raised the left arm also needed to be lifted to meet the condition or if the left knee was raised the right arm needed to be lifted. Attachment four shows the flowchart of the finite state machine.

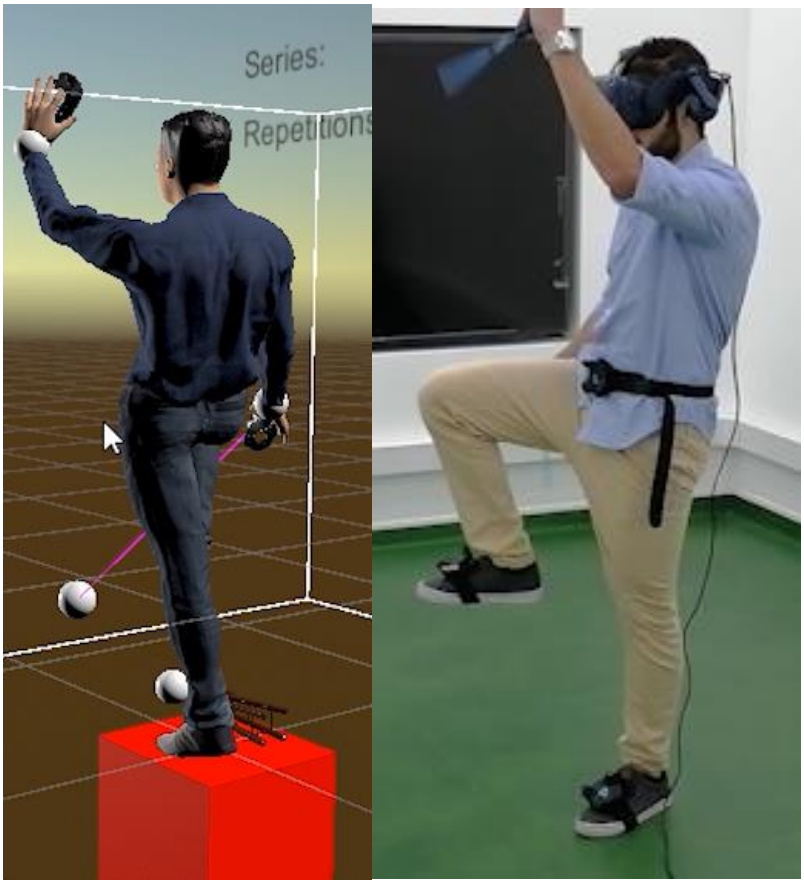


Figure 39: Military march exercise with right knee and left arm raised

5. Progressive March

The last exercise developed that was included in the session was the progressive march. As previously said, this exercise was similar to the last exercise, the military march, explained in 5.1, since the difference between the last exercise with this one was that the previous exercise was necessary to lift the hand opposite off the knee raised while this exercise was only necessary to raise the knee. Ever since we had already developed the military march, the implementation of this exercise was easier, because it was only necessary to remove the verification of the hand lifted. Considering that, we achieved the following finite state machine:

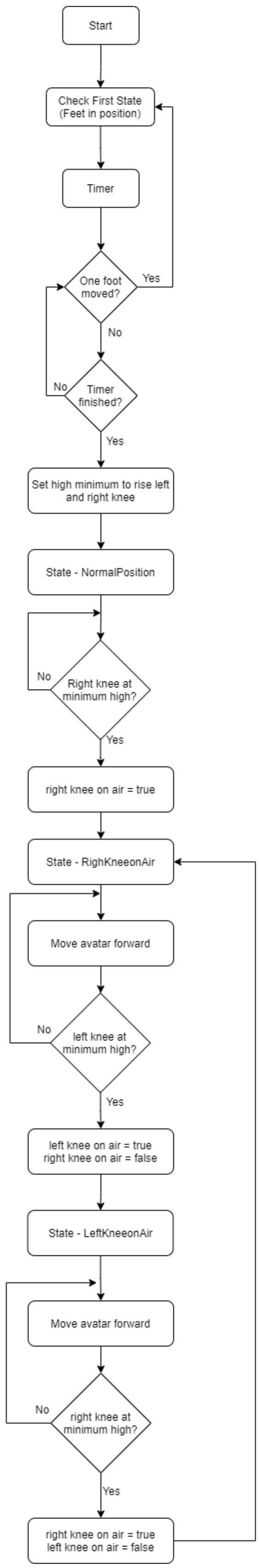


Figure 40: Flowchart of progressive march

As it is possible to see in Figure 40, the exercise has two main states, RighKneeonAir and LeftKneeonAir responsible for when the right knee and left knee were raised, as the name indicated. This particular exercise did not have a limit of repetitions so when the user performed one repetition by raising his right knee and afterward his left knee, the state machine went back to the previous state to continue the repetitions. As said previously this exercise was one of the exercises that were developed already in the second phase so the plan of the gamification for this exercise was already decided so the mechanics were adapted to what the exercise would become.

6. The remaining exercises

Despite the exercises chosen for the session, other exercises were developed that did not enter the session. These exercises helped to develop the first prototype and testing the possibilities of this system. In the future, these exercises could enter in other sessions of rehabilitation. In total were developed another three exercises.

1. Walk-in Toes/Heels

One of the exercises that were not chosen for the session was the walk-in toes/heels, as it is possible to see in Figure 41. The purpose of this exercise was to the user walk forward using only his toes or his heels.

To develop this exercise was necessary to know the size of the user's leg to know the space between the cubes necessary since each user had a different leg size. To accomplish that, similarly with other exercises, was collected the information of the user leg size when calibrating the avatar and then done the calculations of how much percentage of the leg was used to separate the rectangles.

Figure 41 shows one cube bigger than the others. This cube was the one that started the countdown to start the exercise, like previous exercises, this one had a timer at the beginning of the exercise that started after the user was on top of the bigger cube. The rest of the cubes were created considering the space calculated before. The number of cubes that the user was going to walk with the toes/heels was done dynamically, meaning that was possible to choose how many cubes were going to be created, allowing the user to walk depending on the need.

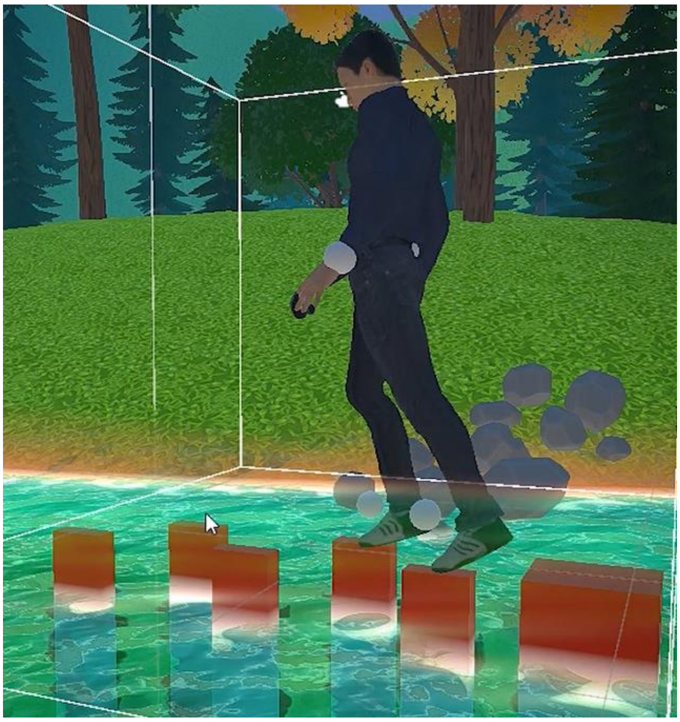


Figure 41: Walk in toes exercise

2. Sidewalk

The development of this exercise was what originated the idea for the side squat exercise. Similarly with the side squat, was needed to obligate the user to walk to the left and right side. The big difference between these two exercises was that the side squat needed to crouch down and only did one step for each side while the sidewalk was several steps for each side not crouching down and always looking forward. To make the user to move each side was used a ball that was sent left and right with the purpose of the user catches the ball. Since we wanted the user to walk for each side as much as possible the ball was sent to the maximum for each side, as it is possible to see in Figure 42.

The objective of the exercise was that when moving for each side the user's feet always looking forward making the user to walk sideways. To force the user to accomplish this a script was developed that was possible to check where the feet were facing considering the world space inside the virtual environment. The script also allowed to provide user when his feet were correctly or not.

Figure 42: Sidewalk Exercise

3. Standing Leg Lifts

Before starting to explain how the exercise was developed, it is important to describe how the exercise was done. The Figure 43 shows an example of the execution of the exercise. The objective of the exercise was to lift one leg upfront and backward without touching the leg on the ground.

The development process for this exercise was divided into two parts, the first one to know much the user had to lift his leg and the other part to create the state machine where all the exercise mechanics would be controlled. The first part was obtained by getting the leg size of the user when the avatar was calibrated. With this information was possible to calculate the percentage the user needed to raise his leg upfront and backward. To help the user performing the exercise two balls were placed inside the virtual environment in the right position the user had to lift the leg. In the second part, the state machine was developed two main states of when the user touched that ball inside the virtual environment upfront and backward. It was also created conditions to check if the user touched the ground. Touching with the ball upfront and afterward the ball backward would materialize one repetition and when the user completed the number of repetitions proposed was possible to exchange the leg to raise. The movement is shown in the next figure:

Figure 43: Stading Leg Lifts Exercise [10]

2.1.Second Phase

When the exercises had their state machine the gamification of each one was developed, with of SPA to make sure the gamification wouldn't make the users do movements that would worsen the athlete instead of helping. To support deciding if this gamification would be good for the users, we had the assistance of the medical staff from our partner and other students from the sports area that provided us constructive feedback on each exercise. The gamification was chosen over several meetings because we intended to gamify the exercises but not lose our main purpose that was to make the user do the rehabilitation exercises. Taking that into consideration each exercise required a lot of planning not to make the user realize movement that was not what we wanted in the exercise.

With the gamification of the exercise and since we wanted to develop a full session that did not require any restart while the user was doing the session was decided to create a tutorial for each exercise that would play before starting the exercise when the user looked to the left side. These tutorials not only explain how to do the exercise but also how to perform the game.

During the development of the second phase one designer entered our team and updated the virtual environment, making it more appealing, including the avatar.

To create the virtual environment the more immersive as possible, we added sound effects and text alerts in all exercises. This also provided instant feedback to the user not only visually but also via audio.

1. Weight Transfer Gamification

The gamification of the weight transfer exercise was tricky to decide the game part since we could not lose the focus on the movement of the exercise.

After several meetings, we came up with an idea that the user had to “shoot” to circles of different colours that were moving randomly in a goal while performing the exercise. Before explaining in more detail, the development of the gamification it will explain how the gamification works. To start the exercise the user must place his feet on the squares indicated in the environment and wait for the countdown to finish before starting the exercise. The exercise starts by lifting the left toe, which selects the color for the user to “shoot” signalled in the goal. After selection, the user must rest the toes of the foot and finally lift the right heel. By lifting the right heel, it activates the laser (for the user to aim) and the timer (time the user must select one of the circles). When the user selects the right circle by pressing the trigger from the command, he/she gets a score of 10 points, and if selected the wrong one/do not select in the supposed time lose 10 points. To finish the first repetition, the user must rest his right heel. The next figures represent an example of part of the repetition:

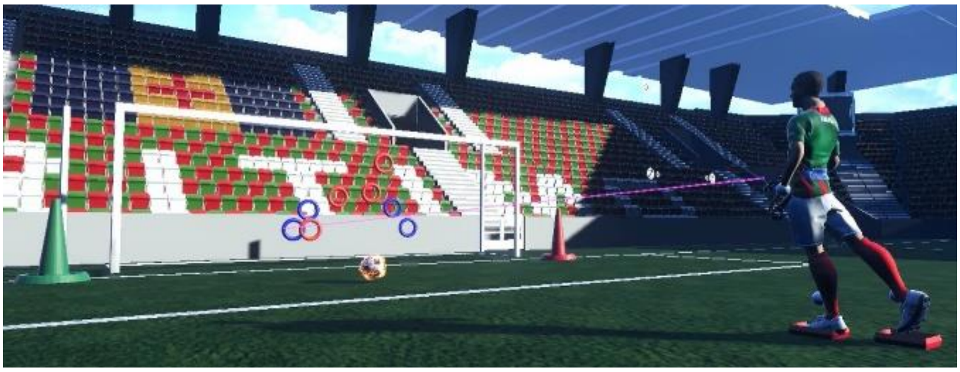


Figure 44: Weight Transfer Exercise Gamified

To make the circles walk randomly inside the goal was done two steps. The first one was creating a cube the size of the goal and put one component called NavMeshSurface that would be responsible to allow the circles to move around. The render component was removed of the cube to make it invisible and not influencing the environment. The second step was making each circle a navmesh agent to allow them to navigate in the environment and implemented one script to make them walk randomly as it is possible to see in Figure 45, the circle founded a random position and if that position was valid he moved to the position determined.

```
IEnumerator DoSomething()
{
    inCoroutine = true;
    yield return new WaitForSeconds(timerForNewPath);
    GetNewPath();
    validPath = navMeshAgent.CalculatePath(target, path);
    //if (!validPath) Debug.Log("Found an invalid Path");

    while (!validPath)
    {
        yield return new WaitForSeconds(0.01f);
        GetNewPath();
        validPath = navMeshAgent.CalculatePath(target, path);
    }
    inCoroutine = false;
}
void GetNewPath()
{
    target = getNewRandomPosition();
    navMeshAgent.SetDestination(target);
}

Vector3 getNewRandomPosition()
{
    float x = Random.Range(-3, 4);
    float y = Random.Range(0, 2);

    Vector3 pos = new Vector3(x, y, -0.2f);
    return pos;
}
```

Figure 45: Circles walk randomly

The game itself of this exercise was done with two scripts: one was responsible to have all the functions of the game that were going being called from the state machine and the second script controlled the laser. Figure 46 shows an example of a function used in the first script. The example provided represents the function responsible to select the colour of the circle the user would going to “shoot”. The function searched a list that contained all the circles and then randomly choose one colour of a circle. After that created a new list containing all the circles with that colour to make it easier afterward when was needed to see if the circle selected was the correct one. The second script being used for the laser was necessary to have a Raycast (a ray that gets sent out from a position in 3D or 2D space and moves in a specific direction) to the user know where was pointing. The Figure

47 displays an example of how the selection of a correct circle works. When the previous function from the Figure 46 was called it activated the Raycast from the laser and waited to see if the circle the user-selected meet the condition of selecting a circle from the list that was created before.

```
public void EscolherCorDoBalao()
{
    baloes.Clear();
    baloesComMesmaCor.Clear();
    Mats2.Clear();

    GameObject.Find("SoundManager2").GetComponent<SoundManagerHeelExercise>().DesignarSons(0); //Som selecionar cor

    foreach (GameObject balaoObj in GameObject.FindGameObjectsWithTag("Balao"))
    {
        baloes.Add(balaoObj);

        if (Mats2.Contains(balaoObj.GetComponent<Renderer>().sharedMaterial))
        {
            //Debug.Log("ja tem textura");
        }
        else
        {
            Mats2.Add(balaoObj.GetComponent<Renderer>().sharedMaterial);
        }
    }

    index = Random.Range(0, Mats2.Count);

    foreach (GameObject balaomesmacor in baloes)
    {
        if (Mats2[index].name == balaomesmacor.GetComponent<Renderer>().sharedMaterial.name)
        {
            baloesComMesmaCor.Add(balaomesmacor);
        }
    }

    corDestruir.text = "Cor a destruir: " + Mats2[index].name;

    baliza.GetComponent<MeshRenderer>().material = Mats2[index];

    naoSelecionouBalaoeCorParaCone = Mats2[index];
}
```

Figure 46: Example of code - Choose goal colour

```
if (GameObject.Find("Baloes").GetComponent<JogoDosBaloes>().activarRebentarBaloes == true)
{

    if (m_ClickAction.GetStateDown(m_TargetSource))
        carregarbotao = true;

    LR.SetPosition(0, transform.position);
    RaycastHit hit;
    // Does the ray intersect any objects
    if (Physics.Raycast(transform.position, transform.TransformDirection(Vector3.forward), out hit, Mathf.Infinity))
    {
        LR.SetPosition(1, hit.point);
        LR.endColor = Color.red;
        if (hit.transform.gameObject.tag == "Balao" && carregarbotao && jogoDosBaloesScript.baloesComMesmaCor.Contains(hit.transform.gameObject) && escolherBalao)
        {
            GameObject.Find("soccerball").GetComponent<BolaTocarNoBalao>().soUmaVezTrigger = true;
            hit.transform.parent.gameObject.GetComponent<UnityEngine.AI.NavMeshAgent>().enabled = false;
            Destroy(hit.transform.parent.gameObject.GetComponent<BallsRandomMovement>());
            posicaoBalaoCarregado = hit.transform.GetComponent<Renderer>().bounds.center;
            escolherBalao = false;
            selecionouBalao = true;
            GameObject.Find("Baloes").GetComponent<JogoDosBaloes>().RematarParaOBalao();
            GameObject.Find("Baloes").GetComponent<JogoDosBaloes>().TimerAcabou();
            BalaoTocado = hit.transform.gameObject;
            GameObject.Find("SoundManager").GetComponent<SoundManagerHeelExercise>().DesignarSons(1); //Som selecionar

        }
```

Figure 47: Example of code - Laser

With this we are exercising not only the physical part but also in cognitive terms like the memorization through the memorization of the colour and the speed of decision, forcing the user to correctly select the circle in a short period.

2. Walking along a Straight Line

The gamification of this exercise needed to consider the fact that it required a lot of balance by the user and because of that we wanted to create a game that did not lose focus on our main purpose, the realization of the exercise. Initially, was thought of putting one ball moving towards the user and make him head the ball in direction of a goal but since the user had one foot in front of another could make him lose his balance. So, it was decided to, similarly to the previous exercise, the user will have to "shoot" to the circles with the color shown in the flag while walking in a straight line in the virtual environment on top of a pole. The following figure shows the movement necessary to perform the exercise and how it’s in the virtual environment:

Figure 48: Walking along a straight line exercise gamified

To perform the gamification, the user needs to place the left foot in front of the right foot touching the heel of the same on the tip of the right foot. After placing the feet in the right position starts a count that triggers at the same time the colours of the flags are chosen randomly respectively the number as possible to see in the previous figure. Afterward, the user will have to walk in a straight line until the flags number one and then shoot to the right circle. After that, the user must walk backward until flags number two and three always shooting to the goal when arriving at the flags.

Considering the fact, the gamification of this exercise consisted almost of the previous exercise, it was reused the code for the random movement of the circle as well as the selection of the colour of the circle to shoot. The difference between those two exercises was that in the previous exercise to select the colour was by lifting the toe while this exercise was by putting the foot on top of the flag. Since the colours of the flags were always chosen randomly at the start, the exercise would be different no manner the number of repetitions done.

3. Side Squat

In the side squat exercise, the gamification was already a part of the development of the mechanics, as said in the first phase. At this point was only necessary to put the exercise more appealing to the user. That part was done by the designer in our team that created the object that the user should avoid touch with his head, creating the avatar that would be an NPC (non-player character) that would send the ball and at last the squares the user would try to hit. In this phase, the requirements I had were to develop a way that the ball sent by the NPC followed his hand while performing the animation and then stop following the hand and making the squares appear randomly inside the goal. The next figures represent the implementation:

Figure 49: Side Squat Exercise Gamified

To make the ball follow the hand it was necessary to parent the ball as a child of the hand while performing the animation, as it is possible to see in Figure 50. The way it was done was by creating a function that was called in the state machine that parent the ball to the hand and started the animation of the goalkeeper sending a ball. When the animation was at a certain time, the ball was unparented from the hand and was sent to the left or right side depending on the state machine.

```
    if (verificarAnimacaoisPlaying && anim.GetCurrentAnimatorStateInfo(0).normalizedTime > 0.6f)
    {
        print("mandar bola is not playing");
        anim.SetTrigger("backtoIdle");
        verificarAnimacaoisPlaying = false;
        bola.transform.parent = null;
        mandarbolabool = true;

    }

    if (mandarbolabool)
    {
        GameObject.Find("BallTarget").GetComponent<ChooseBallTargetAgachamentoLateral>().EasyMode();

        GameObject.Find("BallLauncher").GetComponent<BallMovementAgachamentoLateral>().Launch();

        mandarbolabool = false;
    }
    Debug.Log("verificar " + verificarAnimacaoisPlaying);
}

public void MandarBola()
{
        //anim.SetBool("backtoIdle", false);
        bola.transform.parent = segurarbola.transform;
        Debug.Log("MANDAR BOLA");
        anim.Play("mandar bola");
        verificarAnimacaoisPlaying = true;
        Debug.Log("verificar dentro mandar bola " + verificarAnimacaoisPlaying);
}
```

Figure 50: Example of code - ball follows the animation of the NPC

To make the squares appear randomly on the goal, the goal was divided into two, and then the position of the square was calculated randomly with restrictions of the size of the goal. The goal was divided into two since the objective of the exercise was to squat for left and right side. It would be easier to head the ball to the left side when the square was on the left side of the goal and head to the right side when the square was on the right side of the goal.

4. Military March

The gamification of this exercise would require integration in the virtual environment of something that obligated the user to raise his knee and his hand at the same time. Considering that aspect was though on creating a dartboard that the user had to point with his knee and only shoot when the hand was lifted. To implement this idea two balloons in the air were put in the environment that were responsible for knowing if the user raised the requested hand. To know how high the balloons had to be, we added the height of the user with the size of his arm when calibrating the avatar. To make the user to raise his knee was integrated the laser that was developed in the previous exercises on the knee, but only appeared when the user lifted his knee to the height wanted. With that, the user had to raise the right knee and hand to appear the laser and since the state machine already controlled that, was easy to implement that. When the user accomplished these two movements the user could aim at the dartboard and press the controller of the hand it was lifted and get points. The dartboard had three possibilities of getting points, twenty, thirty, or fifty because had more competition alongside the users that could compare scores and try to do better next time. To punish the user when failed to balance the knee raised, the user loses ten points and provides sound feedback. The following figure represents an example of a repetition:

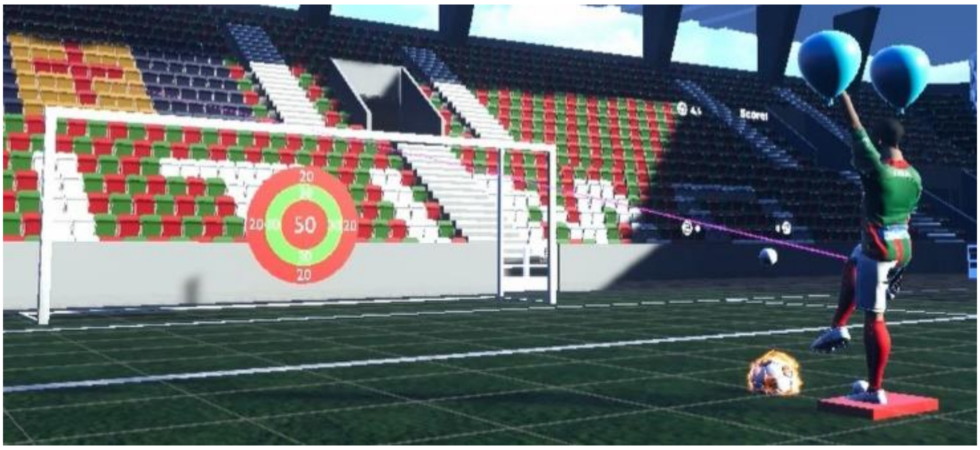


Figure 51: Military March Exercise Gamified

5. Progressive March

Despite the development of this exercise’s mechanics was similar to the military march exercise, its gamification did not have any resemblance.

The idea that our team considered for this exercise was that the user would start in the middle of the field and when he raised his leg to a certain percentage of his height his avatar was “pushed” forward having a virtual movement of the avatar whenever the user raised his leg. When approaching the goal, enemies would appear (opponents of another team that will trip the user), and the user could "shoot" at them by pressing the command button. For each “killed” enemy the user gained points and for each enemy that manages to trip the user loses points. When getting close to the goal, the user was given the possibility to shoot against the goal for extra points.

To implement this idea, it was necessary to develop a way to detect the distance between the avatar and the goal to make the enemies appear according to the distance to the goal. One script was created that detected the distance of the avatar to the goal and while the avatar was getting closer the script spawned the enemies. These enemies had also one script that make them follow the user. To “kill” the enemies and to shoot the ball was used the script developed earlier in the weight transfer exercise but with some changes. These changes allowed the user to kill and shoot while using the same script by using tags on the objects. With the usage of tags it was easy to detect which object the Raycast from the laser was pointing and calling the function accordingly. The following figure shows the exercise:

Figure 52: Progressive March Exercise Gamified

3.1.Implementation of the session

When was concluded the gamification of all the exercises chosen for the session was developed a system that automatically change the exercise when the previous one was finished. To do this system was needed to consider the fact that each exercise had their tutorial so was required that when the new exercise was open the tutorial changed.
The idea for this system was to have a scene with all the exercises and only activate the one it was supposed to. Initially activated the first exercise, then when the exercise finished, reload the scene and activate the next exercise and so on until had activated all the exercises. Every time the scene was reloaded it detects which exercise was and changed the tutorial for the corresponding exercise. Our approach was by creating two scripts, one that controlled the exercises and the other that controlled the tutorials. The one that controlled the exercises had every exercise labeled with an integer like the first exercise was the zero, the second exercise was the one, etc. The script that controlled the tutorials had one list containing all the videos and when the scene was reloaded the script activated the video corresponding to the exercise.

6. Exercises developed for the Intel RealSense camera

The exercises chosen to use with the RealSense camera were exercises that were not possible to do in the virtual reality application because it was the necessary movement that could lead to nausea, or the exercises needed an extra object that the user had to hold.

To develop these exercises, our group had help from students during summer scholarships from Universidade da Madeira that supported us in implementing some exercises and their gamification. The students that worked with us came in two groups. Both groups were oriented by me.

Before the first group integrated the project, I did some research and implemented the first exercise with the basic code that the students that would integrate the project would use.

The exercise is done, in Figure 54, was a front lunge where was necessary to check if the user was moving the leg to the front and then if did the lunge well done. To check if the leg was in front or in back was integrate into the script a way that detected the orientation of the movement of the leg, Figure 53, and to determine if the lunge was done correctly was calculate the high of the knee to see if the movement was done well, Figure 54.

Although it was possible to check the movement of the user, duo to only use one camera the calibration of the user to the avatar wasn't reliable, since if some part of the user body was in front of another it loses the coordinates of some joints of the avatar bugging it.

Figure 53: Front Lunge - leg in front

Figure 54: Front Lunge – lunge well done

When the first group of students came, it was decided to help us developing some more exercises without using the avatar since it wasn’t consistent as explained before. The exercise the students help implementing was the squat. To realize the squat exercise the user had to lower his hips from a standing position and then stand back up. The way to obtain this exercise on the RealSense was to get the joint of the user's hip and then calculated how much the user had to lower considering his height.

As the second group of students arrived, we decided that they could help us developing exercises to a more advanced state of rehabilitation. These exercises didn’t have to be so restrictive as the ones developed previously since the athletes would be close to the end of the rehabilitation process. Considering that, the exercises selected were reaction games, games to improve the user’s reaction.

In the first exercise, the user had four markers, in which one of them was highlighted on the television above, then the subject had to place one foot over the corresponding mark. To realize this exercise was necessary to obtain the joints of the feet of the user like was used in the previous exercises when was necessary to acquire data from a joint. Then four squares were created in the edge of what the RealSense can detect and then randomly highlight the one supposed to the user put one foot one. Since we had data from his feet was possible to check if the user arrived at the square in time or not.

The second exercise was inspired by Subway Surfers [53], which developed a game where the user had to move right or left to escape, jump, or crouch down to avoid obstacles. To detect the movement of the user, the system used the joint of his hip, as the previous exercises, utilized for detecting what was the movement the user did. As was concluded previously, wasn’t possible to use an avatar calibrated to the user, so we used an avatar that performed animations corresponding to the user movement. The next figure shows the exercise.

Although the result of the exercises developed with the RealSense camera was interesting, it wasn’t done tests with athletes from the club as the exercises were finished in a time the athletes were on vacation. Because of that and since we wanted to test out if the exercises had bugs and to see the reaction it provided was done some demos with students from several schools of Madeira and in Macaronight 2021 [40]. The feedback gathered was that the exercises were exciting and competitive.

Figure 55: Students testing

Figure 56: Macaronight 2021

In Macaronight 2021 was also explained the concept of the project and what was being developed obtaining enthusiastic feedback on the usage of new technologies to help the rehabilitation process of injured athletes.

3.3.3 Summary

This chapter was explained in detail all the processes necessary to lead us to the current state of the project. It was first explained how the 3D (avatar and environment) was designed followed by all the implementation process to include on the game engine Unity3D. This included implementing the virtual reality, the calibration process that was necessary, and how was developed all the exercises proposed. We also explained the process of creation of exercises on the RealSense camera, but with a less detailed since was a secondary method to use on this project with only exercises that were not possible to do in virtual reality and because our team did not accomplish tests with athletes from the club.

4 PROTOTYPES

As it was presented before our development process was divided into two phases originating three prototypes. These three prototypes were important to the development process since it enabled to test our prototypes with the medical staff and athletes from Club Sport Marítimo habilitating the improvement of the system.

4.1 PROTOTYPE ONE

In the first prototype, we created an application of two environments that the user could walk around with a keyboard inside a football stadium or a beach. This application was developed during the Covid pandemic and since we could not go to the workplace it was impossible to develop the virtual reality system. Considering that, was built then the first prototype to test if using two environments was a good trajectory to take like the medical staff said in the meetings we had, and to check which environment would be more appealing to the user. The next section will explain the results of these tests. This prototype was built with the two environments done initially and with a simple script that controls the movement of the user with the keyboard and the rotation of the mouse.

4.2 PROTOTYPE TWO

In second prototype we created was possible to choose the exercise we wanted to test as well as choose the number of repetitions and series the exercise would have. Figure 57 shows the menu that was created, on the left side the virtual environment the user was in having the possibility to choose one of two environments: stadium and nature, and on the right side a menu that was possible to see on the screen of the computer where we could select the exercise, number of repetitions and series. One menu was developed for selecting the exercise because we could only execute one exercise at a time.

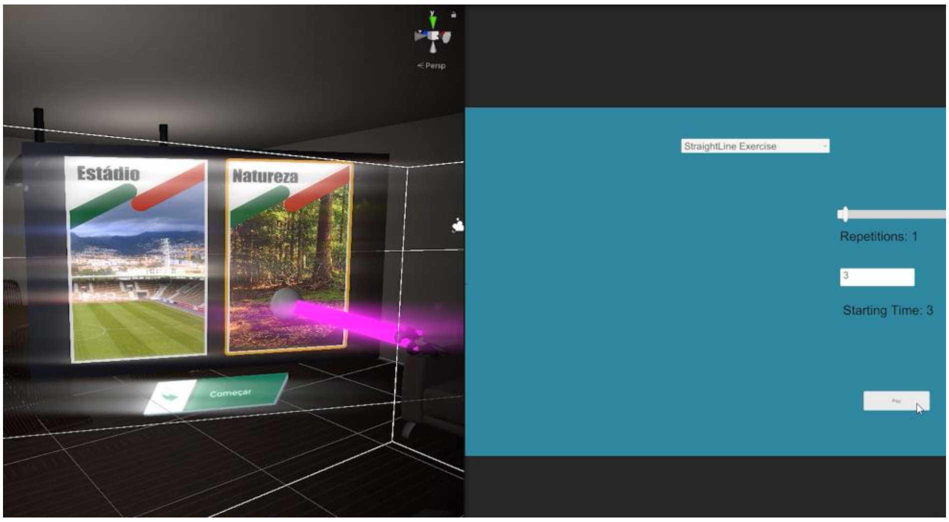


Figure 57: Start Menu

This prototype provided us the possibility to write some initial papers for some conferences. Although the papers were denied it provides feedback on what we needed to improve and develop for the next prototype for one of the conferences it was necessary to send a video of the prototype so we had to create a video showing how the prototype worked. The created video can be founded at the next link:

https://www.youtube.com/watch?v=1IDVWH9gZc8&ab_channel=CristianoFran%C3%A7a

4.3 FINAL PROTOTYPE

After all the feedback provided by the medical staff, experts on the sports area, and users that tested the prototype, we have conducted the implementation of improvements into the last prototype as well added what was thought would help the system.

The final prototype concluded with a full session of rehabilitation made of five exercises that focused on balance, resistance, and strength. The session was fully independent meaning that after the execution of the session the user could perform all the sessions without any help from the research team. All exercises had their tutorial that the user could see if needed help to execute the exercise, or just if it was his first time on our system. Not only that but it was also implemented audio and text feedback that made easier to comprehend what the user was doing as well making the environment more immersive.

This prototype was tested by all members of our team, some persons that helped correct some bugs, the medical staff, and athletes from the club. Being the last ones used for the final study of this thesis. The next link is a video created by the Club Sport Marítimo to promote the project:

https://youtu.be/RULpjg8leB4

5 EVALUATION METHODOLOGY

The development of several prototypes gave us the possibility to conduct several studies that helped us improve the system until doing the final study.

We gather several users before to test the implementation of the code to check if the system had some bugs and to correct aspects that could not be detected when was developed exercises. During this chapter will be used the M that refers the average and SD that represents standard deviation.

5.1 PRELIMINARY STUDY

In a preliminary state of our investigation, we conducted a small experiment to analyze which scenarios overcome the monotony in athletes when performing the rehabilitation exercises. The scenarios chosen and the exercises took into account an interview with a physiotherapist of the Premier League club, which provided us important information about how the rehabilitation works and the frustration caused by the injury of the athlete. From the interview we received the information: 1) the process of rehabilitation of a football player and what kind of exercises are easier to develop in an early stage; 2) demonstration of basic rehabilitation exercises by the physiotherapist - to create an ideal scenario for the athlete to perform the exercise previous proposed by the physiotherapist, strengthening the work done before. After the interview with the physiotherapist of athletes, this study was carried out in two phases:

First phase: the scenarios created with the rehabilitation exercises were presented and the athletes were asked to fill out a questionnaire on a Likert Scale (1-5 values) if they considered the present scenario appealing to the rehabilitation exercises. For each exercise, it was determined two scenarios: a football stadium and an environment not related to sports. With this, the athletes would be able to choose which scenario they prefer to perform the exercise, since according to the physiotherapist, "the athlete in longer rehabilitation may want to choose a football stadium scenario to not feel that he has been away from it for so long, unlike an athlete in short-term rehabilitation who may want to choose a normal scenario to do the exercise in a different environment, other than the football stadium".

Second phase: we asked athletes to try two scenarios - a Beach scenario and a Football Stadium scenario using the Unity3D executable to understand if these scenarios would motivate them in their rehabilitation process having a more immersive experience comparing to the previous phase of the study. After testing the scenarios, we interviewed the participants to obtain qualitative data.

As a prerequisite, participants had to be an athlete or former athletes and they had to have injuries and went through a process of physiotherapy and rehabilitation. It was also mandatory that they had gone through a rehabilitation process that had repeated the same exercise several times and we're bored and tried to do the exercise in the same place. Due to the covid-19 pandemic [50] and to all the circumstances that it implied there was great difficulty in finding participants.

Participants: This study involved 15 athletes (9 athletes and 6 former athletes) recruited through the physiotherapist. They were professional soccer, handball, and trail running athletes, aged between 19 and 48 years old (*M=26.28; SD=8.12*). Considering the pandemic situation, it has become difficult to obtain more participants and because of that, it was necessary to interview not only football athletes, since the study was made in March when the entire country was in lockdown.

5.1.1 Results

In this study, we highlight the value of the athlete to be able to choose which scenario they want to perform the exercise. According to the physiotherapist, the athlete in a long and exhaustive rehabilitation process may want to choose a football stadium scenario, so they don't feel like they are out of work for a long time, unlike an athlete in a short-term rehabilitation who may want to choose a different scenario to perform the exercise in a completely new environment. After analysing the two questionnaires made by the participants, we concluded that athletes considered that an inspirational scenario in a different environment - rather than a football stadium - could lead them to a better mood to perform some of the rehabilitation exercises, as possible to see in the next figure:

		Score (Likert Scale)				
	SCENARIOS	1	2	3	4	5
	Beach	14,30%	7,10%	14,30%	14,30%	50,00%
Exercise 1	Stadium	21,40%	14,30%	21,40%	7,10%	35,70%
	Mountain	21,40%	14,30%	7,10%	14,30%	42,90%
Exercise 2	Stadium	14,30%	14,30%	21,40%	7,10%	42,90%
	Mountain climbi	21,40%	14,30%	7,10%	28,60%	28,60%
Exercise 3	Stadium	21,40%	21,40%	42,90%		14,30%
	Stairs in Nature	21,40%	14,30%	21,40%		42,90%
Exercise 4	Stadium	21,40%	14,30%	14,30%	35,70%	14,30%
	Walk in a lake	28,60%		14,30%	28,60%	28,60%
Exercise 5	Stadium	21,40%	21,40%	28,60%	14,30%	14,30%
	Walk in a lake	21,40%		28,60%	21,40%	28,60%
Exercise 6	Stadium	21,40%	21,40%	21,40%	21,40%	14,30%
	Ninja fight	28,60%	14,30%	7,10%	7,1	42,90%
Exercise 7	Stadium	14,30%	7,10%	21,40%	21,40%	35,70%
	Ninja fight	28,60%	14,30%	7,10%	7,10%	42,90%
Exercise 8	Stadium	21,40%	14,30%	21,40%	14,30%	28,60%
	Tree branch	14,30%	7,10%	14,30%	21,40%	42,90%
Exercise 9	Stadium	21,40%	7,10%	21,40%	28,60%	21,40%
	Lake	14,30%	7,10%	7,10%	28,60%	42,90%
Exercise 10	Stadium	28,60%	21,40%	14,30%	21,40%	14,30%

Figure 58: Preliminary Study - Results

5.1.2 Design Implications

It is important to increase the research efforts on designing new virtual reality environments to support the psychological part of an athlete that can be affected by any type of injury to reach the peak again quickly and efficiently. The problem that involved all the world, the COVID-19 pandemic, prevented us to be in touch with the physiotherapist/athletes the number of times necessary to obtain more detailed information so that we could cover and portray in our virtual environments and readjust when necessary, after the tests realized with athletes.

5.2 FINAL STUDY

To evaluate our final prototype was conducted a final study that evaluated the usage of this system with the professional athletes. Although it was the final study for this thesis it was only a pilot study for the project. This study was mainly to understand what professional athletes felt when using the virtual reality system as well gather some physical data that could be interesting for the future work of the project. Before realizing the study with the user tests it was necessary to describe what were the evaluation methodologies we were going to use as well as the process involved in this study.

5.2.1 Experimental Protocol of the Study

In the experimental protocol we scripted what we wanted to achieve with the user tests. We determined that we wanted to test the session of rehabilitation exercises made in the virtual reality system that was focused on the improvement of the physical and volitional abilities. In this document, we could see also what methods were chosen to evaluate this study. It was also possible to see all the processes involved to understand what the user and the tester had to do.

1. *Methods*

The methods used in the pilot study were divided in three points: investigate the internal load, external load, and the motivation of the end-user.

1) To investigate the internal load we used three methods: an E4 Wristband [54] and a polar h10 [55] enabling the extraction of physiological parameters, and the Rated Perceived Exertion (RPE) Scale [56] to determine the personal effort from each user.
2) To investigate the external load produced by each exercise were used the accelerometer sensor from E4 Wristband as well the polar h10.
3) To investigate the motivation of the end-user two questionnaires containing several metrics that could provide us important information about how the user felt and about the system were created

Two questionnaires were filled up, one before realizing the test and other after. The first questionnaire was mainly to get the basic information of the user, to characterize him and to know how they were feeling at the time. The other questionnaire had two important metrics, the Intrinsic Motivation [27] and System Usability Scale (SUS) [2] and other questions that could help improve the system afterwards. Both questionnaires were made in Portuguese since almost every user test was Portuguese or at least spoke the Portuguese language. Before we described the experimental protocol, an explanation of all the metrics and equipment's used will help to understand what we wanted to be achieved:

4) E4 WRISTBAND

The E4 wristband [54] is an empathic band that provides real-time physiological data through a variety of sensors. These data come in a way that allows investigators to easily analyse them. The sensors that will be used in this experiment will be the PPG for measuring the variation of the blood volume pulse (BVP) and the accelerometer in which we will analyse activity based on movement. With these sensors, it will be possible to quantify the effort that the user has.

5) Rated Perceived Exertion (RPE) Scale

The perceived exertion scale [56] is a scale that is a way of measuring the level of intensity of physical activity. Perceived exertion is how hard the user feels as if their body is working. It is based on the physical sensations a person experiences during physical activity. In this experiment, we will use a scale from 0 to 10 where 10 is the most intense. With this measurement, we will be able to know which exercises users think to have a higher level of physical activity.

6) Intrinsic Motivation

Intrinsic motivation [27] [57] refers to behaviour driven by internal rewards. In other words, the motivation to engage in a behavior arises from within the individual because it is naturally satisfying to the behaviour. It was used the IMI scale that was divided in subscales:

7) Interest/Enjoyment (EN): considered the self-report measure of intrinsic motivation;
8) Perceived Competence (CO): theorized to be positive predictors of both self-report and behavioural measures of intrinsic motivation;
9) Effort (EF): a separate variable that is relevant to some motivation questions;
10) Pressure/Tension (TE): theorized to be a negative predictor of intrinsic motivation;
11) Perceived Choice (CH): similar to perceived competence;
12) Relatedness (RE): used in studies having to do with interpersonal interactions, friendship formation;
13) Value/Usefulness (US): used in internalization studies.

14) System Usability Scale (SUS)

SUS [2], as the name implies, is a scale that allows you to check the usability level of a system. The SUS criteria help to assess the effectiveness, efficiency and satisfaction of the product. The scale contains 10 questions rated from 1 to 5, with 1 being Completely Disagree and 5 Completely Agree.

1) The basic questions are:
   a) I think I would like to use this system often.
   b) I find the system unnecessarily complex.
   c) I found the system easy to use.
   d) I think I would need help from a person with technical knowledge to use the system.
   e) I think the various functions of the system are very well integrated.
   f) I think the system has a lot of inconsistency.
   g) I imagine people will learn how to use this system quickly.

h) I found the system awkward to use.
i) I felt confident using the system.
j) I needed to learn a lot of new things before I was able to use the system.

This questionnaire will let you know if the product (the exercises) is on track or if you need to go back and rethink the exercises.

15) End User Initial Questionnaire (PRE)

Pre-study form to be completed, where they entered their demographic data (age, gender, nationality, and education level), previous experience with similar technology and assess their emotional state through SAM (The Self-Assessment Manikin) [7].
The initial questionnaire is possible to check in the Pre-Questionnaire – Questionnaire to athletes before realizing the test.

16) End User Satisfaction Questionnaire and Suggestions (POST)

In the post-study phase, the SAM were collected again to obtain comparisons before and after the experience, to understand if there was any significant impact on the emotional bond caused during the interaction.
In addition, the System Usability Scale (SUS) was used to assess possible flaws in the application. Later, to measure the overall user experience, the Intrinsic Motivation Inventory (IMI) was used to understand how immersive the experimental apparatus was. The questionnaire used the Likert Scale [23].
The satisfaction questionnaire is possible to check in the Post-Questionnaire – Questionnaire to athletes after realizing the test.

To make sure the tests ran without any problem was written down every step that both user and tester had to do to the experience occurred well. The steps are possible to see in the Appendix C – Steps to realize during the pilot study.

5.2.2 Participants

This study was important to check the viability of this virtual reality system so was necessary to select the best users. All the users selected were athletes from the Club Sport Marítimo and had to meet the inclusion and exclusion criteria.

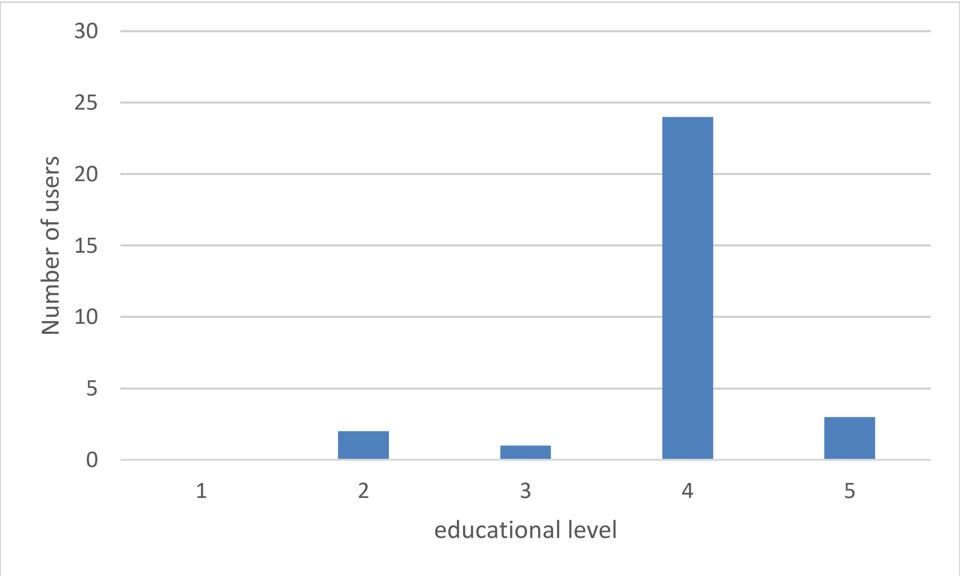
The inclusion criteria were:

1) Little or no previous experience with Virtual Reality situations.
2) Soccer player for over 5 years.
3) over 18 years of age.

The exclusion criteria were:

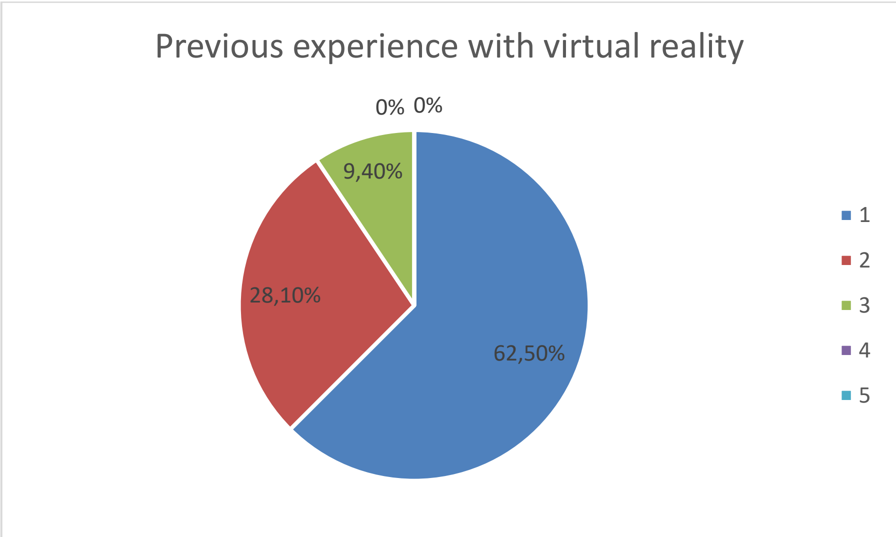
- Having an injury or being in the process of recovering from an injury.
- Present any contraindication from the medical department to not exercise.

Taking into consideration these criteria 30 athletes were selected from the Club Sport Marítimo being 15 male and 15 female aged between 18 and 29 years old (*M*=21.13; *SD*=3.32). All these athletes were selected by staff from the club and gave the authorization to collect their data and information for this study. It was asked their education level and the results are as shown in Graphic 1.



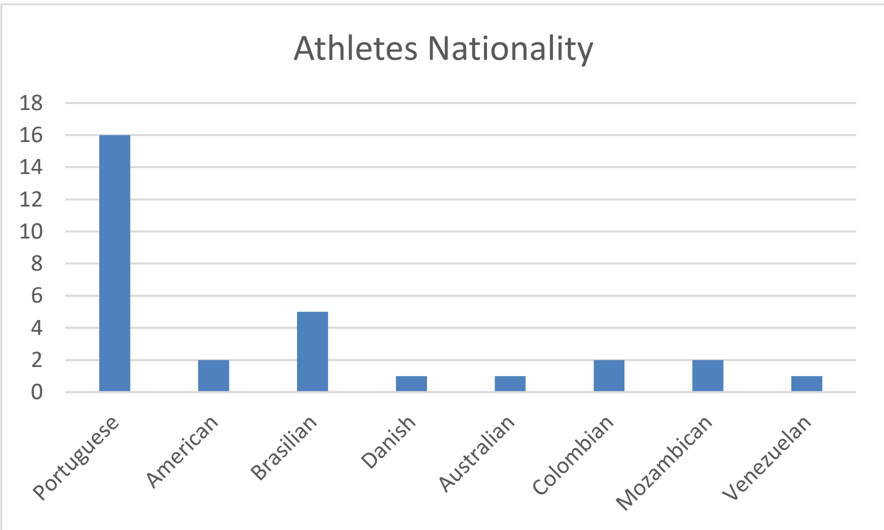
Graphic 1: Educational level of the user. 1 - First cycle of basic education; 2 - Second cycle of basic education; 3 - Third cycle of basic education; 4 -High school; University education

One of the inclusion criteria was if the athlete had little or low previous experience when using virtual reality and because of that was necessary to question that. It was detected that almost every user had no experience with virtual reality as it is possible to see in the next figure:



Graphic 2: Previous experience with virtual reality. 1 - never used virtual reality; 2 – used once; 3 – used sometimes; 4 – used on a regular basis; and 5 - developed virtual applications.

One of the main transfer policies of the club was buying athletes from South America and Africa and because of that our participants had several nationalities meaning that we had to adapt our explanation of the study:



Graphic 3: User's nationality

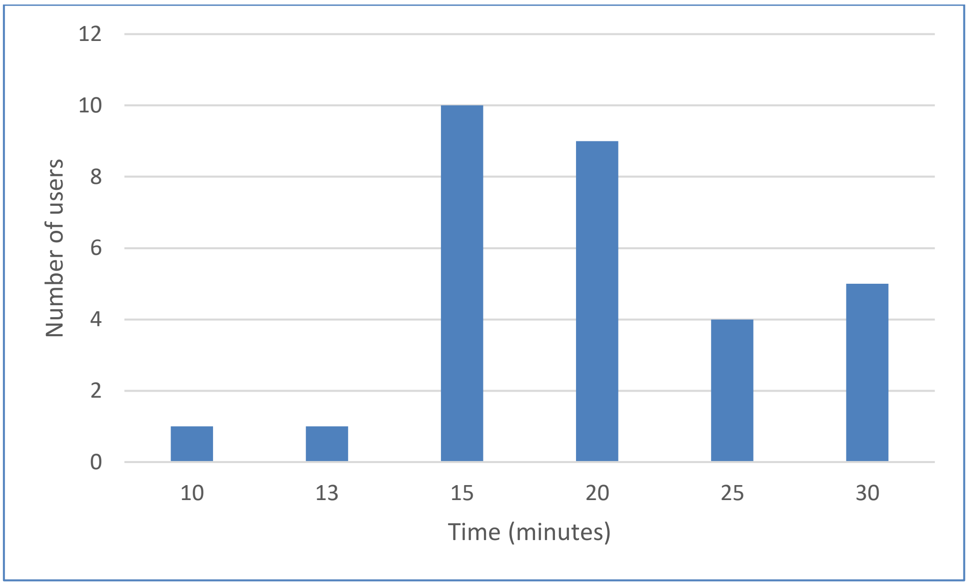
5.2.3 Results

To better understanding of the questionnaires, the questions will be analysed in English. As explained before it was realized two questionnaires being one used before the experience and the other after the user did the experience. The Pre-Questionnaire was only used to gather some basic information about the user and their emotional state through SAM. The information about the user was already showed in Participants and the emotional state will be shown at the same time with the emotional state after the experience in Figure 59: , Figure 60: , and Figure 61: . The Post-Questionnaire involved the usage of the scales of System Usability Scale (SUS), Intrinsic Motivation Inventory (IMI) and SAM. Finally, was given the opportunity to the user write some observations to gather some qualitative results.

1. *Post-Questionnaire*

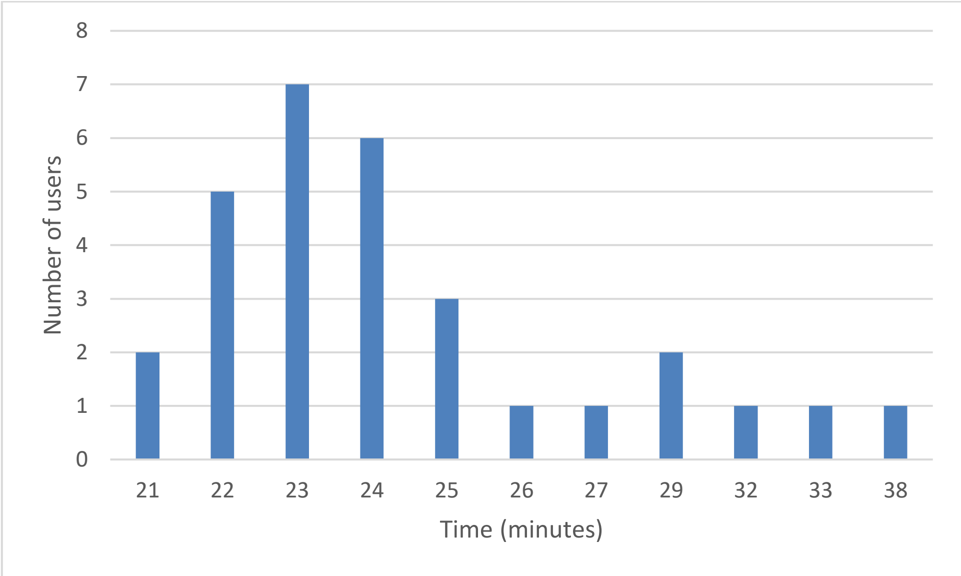
In the beginning of the Post-Questionnaire a question was asked to determinate how much thee user felt the experience took. This information could be important to compare how much the users felt immersive during the experience losing track the time passed.

1) How much time you think the experience took?



Graphic 4: The time users felt the experience took

The time that actually took to the users realize the experience was:



Graphic 5: The time users took to realize the experience. The time was rounded to minutes.

The next tables, Table 2, and Table 3, represents the results obtained in the Post-Questionnaire regarding the IMI, and SUS, respectively. The Figure 59, Figure 60, and Figure 61 represents the results of the SAM.

2) Intrinsic Motivation Inventory (IMI)

IMI		
Subscale	M	SD
EN	4,50	0,78
CO	3,27	1,05
EF	2,10	1,21
TE	3,30	1,39
CH	4,53	1,01
RE	4,30	1,02
US	4,57	0,77

Table 2: IMI Results

3) System Usability Scale (SUS)

	Results				
Questions	1	2	3	4	5
I think that I would like to use this system frequently.	3,33%	0%	10%	16,66 %	70%
I found the system unnecessarily complex.	46,66 %	23,33 %	20%	6,60%	3,33%
I thought the system was easy to use.	3,33%	6,60%	40%	30%	20%
I think that I would need the support of a technical person to be able to use this system.	10%	13,33 %	40%	13,33 %	23,33 %
I found the various functions in this system were well integrated.	0%	0%	10%	46,66 %	43,33 %
I thought there was too much inconsistency in this system.	50%	33,33 %	16,66 %	0%	0%
I would imagine that most people would learn to use this system very quickly.	0%	6,60%	26,66 %	30%	36,66 %
I found the system very cumbersome to use.	40%	26,66 %	20%	13,33 %	0%
I felt very confident using the system.	6,60%	0%	20%	40%	33,33 %
I needed to learn a lot of things before I could get going with this system.	30%	40%	13,33 %	13,33 %	3,33%

Table 3: SUS Results

4) Emotional State (SAM)

5) SAM 1 (Rate your emotional state between happy and unhappy).

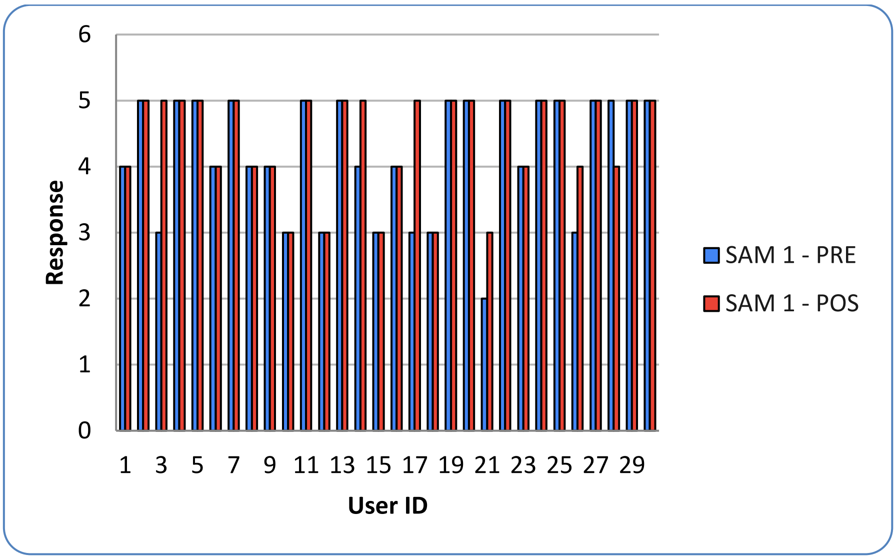


Figure 59: Results of the users from unhappy to happy. The response was between 1-5 being 1 unhappy and 5 happy. SAM 1 – PRE represents the response of the Pre-Questionnaire and SAM 1 – POS represents the response of the Post-Questionnaire.

6) SAM 2 (Rate your emotional state between calm and excited).

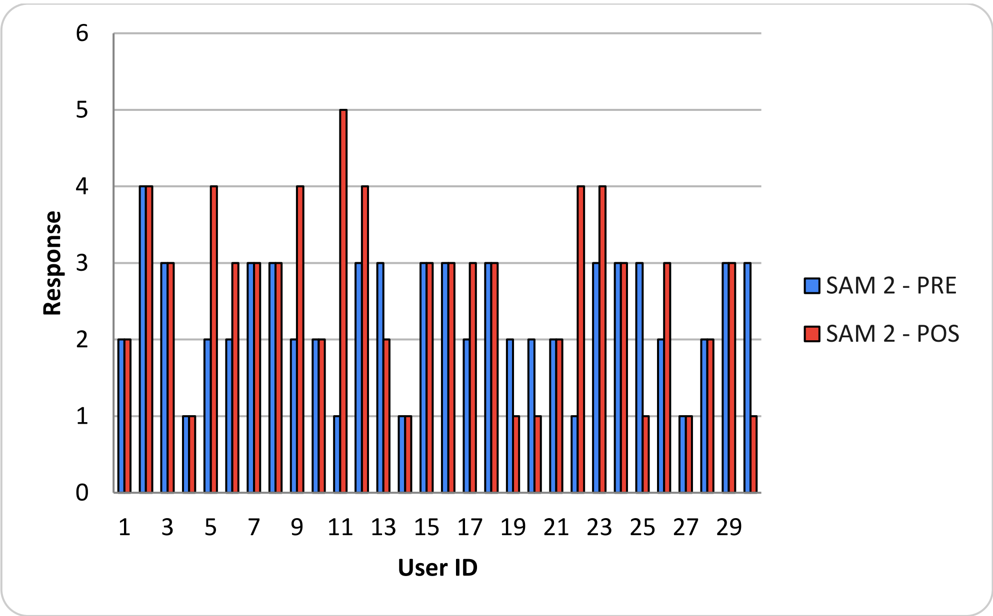


Figure 60: Results of the users from calm to excited. The response was between 1-5 being 1 calm and 5 excited. SAM 2 – PRE represents the response of the Pre-Questionnaire and SAM 2 – POS represents the response of the Post-Questionnaire

7) SAM 3 (Rate your emotional state between controlled and under control).

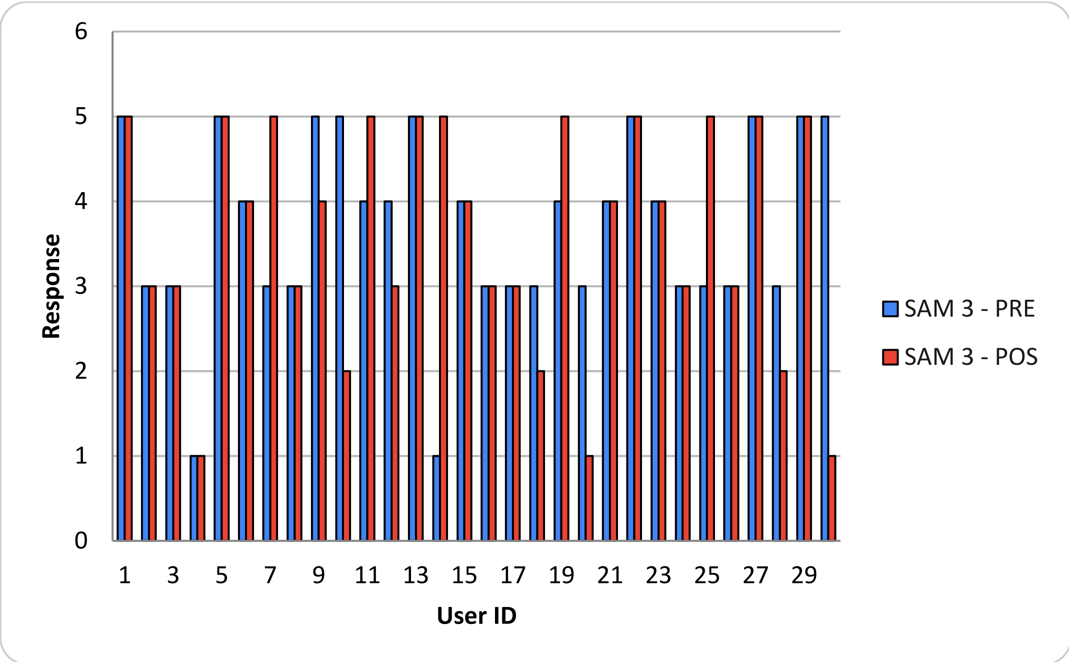


Figure 61: Results of the users from under control to controlled. The response was between 1-5 being 1 under control and 5 controlled. SAM 3 – PRE represents the response of the Pre-Questionnaire and SAM 3 – POS represents the response of the Post-Questionnaire

The results that were gathered of the Rated Perceived Exertion Scale was the follows:

	RPE Scale	
	M	SD
Exercise 1	1	1,18
Exercise 2	3	1,55
Exercise 3	4	1,60
Exercise 4	3	1,53
Exercise 5	3	1,53

Table 4: RPE Scale for each exercise; M – average; SD - standard deviation; Exercise 1 – Weight transfer; Exercise 2 – Military March; Exercise 3 – Side Squat; Exercise 4 – Progressive March; Exercise 5 – Walk alongside a straight line

The next table shows the data obtained from the polar h10:

	H10 Data			
	M HR	SD HR	M VMag	SD Vmag
Exercise 1	79	11,13	2814,5	2044,26
Exercise 2	88	9,43	1412,5	602,67
Exercise 3	98,5	15,15	12142	3505,59
Exercise 4	90	12,26	2091,5	815,987
Exercise 5	87	12,79	1853	1051,76

Table 5: Data obtained from polar h10; M HR– average of heart rate (beats per minute); SD HR - standard deviation of heart rate; M Vmag – average accelerometer ; SD Vmag – standard deviation of accelerometer.

In the end of the Post-Questionnaire was left a space to users write some observations of the experience. This data made possible to have some qualitative results. The next table shows the observations provided by some users:

User	Answers
1	The system is very good, I think it is a very good step for the coming future.
4	The system was very well equipped. The games inside the system were very identical to real life making it easy to use.
7	Productive. I can exercise and still help with motor coordination
14	The System is good for gaining confidence.
17	I found it a very important opportunity for evaluating the athletes and personal growth.
30	I really enjoyed the experience

Table 6: Observations provided by the users at the end of the experience

5.2.4 Discussion

In this subsection the results showed before will be analysed. First will be examined the user experience followed by the physical data extracted from the users during the experience. Finally, some participant feedback will be discussed.

1) User Experience

It was questioned to the participants the time they felt the experience took resulting in the data showed at Graphic 1,with an average of 20.1 (*SD* = 5.86). When comparing with the actual time that the experience took, with an average of 24.86 (*SD* = 3.84), we can conclude that although the experience didn't take much time, users felt that the experience took less time of what actually took, meaning that it is a good indicator that users might been immersed in the virtual experience losing the track of the time. This was important to us because we wanted to fight the monotony the rehabilitation of injured athletes have [8].

Taking into consideration the results obtained in the IMI scale, where both CH and RE subscales had good rankings, we can conclude that was a good indicator for the overall value of the experience and user's motivation. The values obtained from the subscale EF and TE indicates that the system was well implement in a way that did not require much effort for the user's engagement, but in average they felt some pressure.

2) Usability

Considering the results of the SUS showed before was possible to calculate the final score obtaining a score of 3.91 (*SD* = 1.10). The system ranked medium to high meaning the users succeeded to effectively interact with the system and accomplished a meaningful experience.

3) Emotional State

To evaluate the emotional state of the users was used the SAM scale. For an easier analysis of the data obtained, the SAM scale was divided in three subscales: SAM 1, SAM 2, and SAM 3. Since we located data of this scale before and after the experience, these three subscales had two results, one PRE and one POS. The PRE results were: SAM 1 – 4.20 (*SD* = 0.92), SAM 2 – 2.33 (*SD* = 0.80), SAM 3 – 3.65 (*SD* = 1.11). The POS results were SAM 1 – 4.40 (*SD* = 0.77), SAM 2 – 2.63 (*SD* = 1.16), SAM 3 – 3.60 (*SD* = 1.35). This yields a total variation of +0.2 to SAM 1, +0.3 to SAM 2, and -0.05 SAM 3. With this data is possible to conclude that the system provided excitement to the user as well increased the happiness of the user. It is possible to conclude that the user a little bit less in control after realizing the experience.

4) Intensity of physical activity

Table 4 shows the results obtained of how hard the user feels as if their body is working. It was expected that the exercise two, three and forth would have a RPE higher than the other two exercises since demand more effort from the user. The results showed that even though the first exercise had a RPE lower as expected, the last exercise had the same average RPE as the three exercises that demanded more effort. This result may have occurred because we had some errors when performing the exercise with some users making them to have a bigger effort than the expected. The main error that we found in the last exercise was that the exercise provided the experience of look as it was falling, and some users felt fear of falling making their internal physical activity and RPE higher than expected. Not only that, the first exercise took more time to conduct and even thought the exercise is simple, but the gamification of the exercise also made the accelerometer results higher than expected. The expectation of the physical activity of the results was done by the SPA.

5) Physical Data

As mentioned before, was used the E4 Wristband and polar h10 to collect physical data from the users, their hearth rate and the accelerometer. It was detected a problem of the data gathered from the E4 Wristand and because of that all the information was not counted. Like the RPE Scale was expected that the first and last exercise would have data that showed a lower effort from the user. When comparing the average of heart rate from each exercise it's possible to detected that the results are similar to the RPE Scale, the first had a lower heart rate than the three exercises expected to have higher heart rate, but the last exercise had similar results with the exercises that demanded more. This result may happen because of the problem encounter in the last exercise. In terms of the accelerometer data collected, the Table 5 showed that the third exercise was the one that originated more movement from the user.

6) Participant Feedback

It was not only collected feedback showed in Table 6, but more feedback was also given while they performed the experience. Almost every user tester asked when they could repeat the experience again meaning that they enjoyed realizing the rehabilitation exercises with the virtual reality system and wanted to try again since every exercise had their own score and they wanted to improve the score they achieved. The users also provided us the feedback that they didn’t felt with nausea while performing the experience which was a very important feedback considering we were using virtual reality and it can causa nausea if it was not well implemented.

5.2.5 Limitations of the study

This study was part of an innovative project that used new technologies as a form of rehabilitation for professional athletes and considering that this study presented its strengths and weaknesses.

In terms of limitations of the study, we emphasize the following:

1) The Covid pandemic that occurred in the last years had a major effect on this thesis not only that was necessary to wait for instructions from the government to know where was possible to go back to the office to work as well made difficult the interaction with the medical staff and athletes from the club.
2) The medical staff from the club never used virtual reality before the start of the project and was a bit reticent towards this new technology.
3) With the Covid pandemic, the development of the project was slower than expected making it impossible to test the system with injured athletes.
4) The study done had some problems with the data received from the E4 Wristband, becoming not possible to use the data collected from that device.

6 CONCLUSION

In this dissertation, we presented a proposal of a virtual reality application that will help athletes recovering from their injuries during the rehabilitation process. Due to some constraints such as the Covid19 pandemic and reduced number of injured athletes from the club, it was not possible to test the system developed with injured athletes. Despite that limitation, a preliminary study and a pilot study were conducted to test if the system was well-implemented and gather the information that could be possible to use when the future final study would be realized.

The preliminary study presented the users with different virtual reality training scenarios to address the subjective preferences of athletes when injury recovery, especially to investigate which scenarios overcome the monotony in athletes when performing the rehabilitation exercises. Reflecting upon the state of the research, we saw there are many aspects of this study that remain open for future investigation, such as improving the sample size. In normal situations, we know that it is sometimes difficult to recruit users in the most varied studies; with a pandemic situation such as COVID19, it has become even more difficult to recruit more participants. Virtual reality has been applied in several aspects and areas of our society. Waterworth et al. [38], suggest that virtual and mixed reality environments can produce vivid experiences and generate powerful emotions. The great technological evolution that occurs every year allows its development to be improved and applied in the area of rehabilitation, as it is already applied in medicine, military, video games and also mainly because it is highly customizable [6] [28] [11]. With the improvement of 3D graphics that allow the creation of environments with quality very close to what we see or interact, that allows a better and more realistic immersive experience. Finally, in this preliminary study, we highlight the value of virtual reality interaction as a powerful mean to encourage the rehabilitation of athletes.

The final study in this thesis - a pilot study in the overall context of the R&D project - presented the users with the current state of the system developed. It led users to realize the full session implemented and test the gamified exercises in their final environments. The data gathered from the questionnaires and polar h10 in the pilot study permitted to conclude that will be possible to realize a final study of rehabilitation of injured athletes with the system that was implemented in this thesis.

7 FUTURE WORK

For future work, we would like to continue the development of the system by gamifying the exercises that already have their mechanics done and creating other sessions with them. Furthermore, we are looking to test the exercises made with the RealSense camera like the virtual reality system was tested.

For investigation purposes we would like to investigate the performance of injured athletes, enhancing them to feel much more motivated when doing their rehabilitation exercises, and their physical and mental health, we would use a control group of football players to perform rehabilitation exercises during a period, using the traditional way - using the physical therapy they have had until now, and an experimental group would perform the same rehabilitation exercises during a period using the VR system. With this study would be possible to check if the usage of this VR system would decreased faster the injury of the athlete.

8REFERENCES

[1]Jack A. Adams and A. T. Welford. 1970. Fundamentals of Skill. *The American Journal of Psychology* 83, 2 (June 1970), 299. DOI:https://doi.org/10.2307/1421343

[2]Assistant Secretary for Public Affairs. 2013. System Usability Scale (SUS). Retrieved September 26, 2021 from https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html

[3]Anna Akbaş, Wojciech Marszałek, Anna Kamieniarz, Jacek Polechoński, Kajetan J. Słomka, and Grzegorz Juras. 2019. Application of Virtual Reality in Competitive Athletes – A Review. *Journal of Human Kinetics* 69, 1 (October 2019), 5–16. DOI:https://doi.org/10.2478/hukin-2019-0023

[4]Christoph Anthes, Ruben Jesus Garcia-Hernandez, Markus Wiedemann, and Dieter Kranzlmuller. 2016. State of the art of virtual reality technology. In *2016 IEEE Aerospace Conference*, IEEE, Big Sky, MT, USA, 1–19. DOI:https://doi.org/10.1109/AERO.2016.7500674

[5]Danilo Avola, Luigi Cinque, Gian Luca Foresti, and Marco Raoul Marini. 2019. An interactive and low-cost full body rehabilitation framework based on 3D immersive serious games. *Journal of Biomedical Informatics* 89, (January 2019), 81–100. DOI:https://doi.org/10.1016/j.jbi.2018.11.012

[6]Štefan Balkó, Josef Heidler, and Tomáš Edl. 2018. Virtual reality within the areas of sport and health. *TSS* 25, 4 (December 2018), 175–180. DOI:https://doi.org/10.23829/TSS.2018.25.4-1

[7]Margaret M. Bradley and Peter J. Lang. 1994. Measuring emotion: The self-assessment manikin and the semantic differential. *Journal of Behavior Therapy and Experimental Psychiatry* 25, 1 (March 1994), 49–59. DOI:https://doi.org/10.1016/0005-7916(94)90063-9

[8]Grigore Burdea. Key Note Address: Virtual Rehabilitation- Benefits and Challenges. 11.

[9]Polona Caserman, Augusto Garcia-Agundez, Robert Konrad, Stefan Göbel, and Ralf Steinmetz. 2019. Real-time body tracking in virtual reality using a Vive tracker. *Virtual Reality* 23, 2 (June 2019), 155–168. DOI:https://doi.org/10.1007/s10055-018-0374-z

[10]Debbie. 2018. Benefits of Standing Leg Lifts. *DebbieSchultzHealthCoach*. Retrieved September 29, 2021 from https://www.debbieschultzhealthcoach.com/2018/09/benefits-standing-leg-lifts/

[11]Peter Düking, Hans-Christer Holmberg, and Billy Sperlich. 2018. The Potential Usefulness of Virtual Reality Systems for Athletes: A Short SWOT Analysis. *Front. Physiol.* 9, (March 2018), 128. DOI:https://doi.org/10.3389/fphys.2018.00128

[12]Charles Faure, Annabelle Limballe, Benoit Bideau, and Richard Kulpa. 2020. Virtual reality to assess and train team ball sports performance: A scoping review. *Journal of Sports Sciences* 38, 2 (January 2020), 192–205. DOI:https://doi.org/10.1080/02640414.2019.1689807

[13]Jane M. Fedorczyk. 2020. Therapy Considerations for Getting Athletes to Return to Play. *Clinics in Sports Medicine* 39, 2 (April 2020), 481–502. DOI:https://doi.org/10.1016/j.csm.2019.12.009

[14]Diarmaid Fitzgerald, John Foody, Dan Kelly, Tomas Ward, Charles Markham, John McDonald, and Brian Caulfield. 2007. Development of a wearable motion capture suit and virtual reality biofeedback system for the instruction and analysis of sports rehabilitation exercises. In *2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, IEEE, Lyon, France, 4870–4874. DOI:https://doi.org/10.1109/IEMBS.2007.4353431

[15]Blender Foundation. About. *blender.org*. Retrieved September 27, 2021 from https://www.blender.org/about/

[16]Blender Foundation. blender.org - Home of the Blender project - Free and Open 3D Creation Software. *blender.org*. Retrieved May 27, 2021 from https://www.blender.org/

[17]A. R. Fugl-Meyer, L. Jääskö, I. Leyman, S. Olsson, and S. Steglind. 1975. The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance. *Scand J Rehabil Med* 7, 1 (1975), 13–31.

[18]Chaim Gartenberg. 2018. Microsoft has discontinued the Kinect Adapter for newer Xbox One consoles. *The Verge*. Retrieved September 26, 2021 from https://www.theverge.com/circuitbreaker/2018/1/2/16842738/microsoft-kinect-adapter-xbox-one-x-s-discontinued

[19]Naoures Ghrairi, Segla Kpodjedo, Amine Barrak, Fabio Petrillo, and Foutse Khomh. 2018. The State of Practice on Virtual Reality (VR) Applications: An Exploratory Study on Github and Stack Overflow. In *2018 IEEE International Conference on Software Quality, Reliability and Security (QRS)*, IEEE, Lisbon, 356–366. DOI:https://doi.org/10.1109/QRS.2018.00048

[20]Alli Gokeler, Marsha Bisschop, Gregory D. Myer, Anne Benjaminse, Pieter U. Dijkstra, Helco G. van Keeken, Jos J. A. M. van Raay, Johannes G. M. Burgerhof, and Egbert Otten. 2016. Immersive virtual reality improves movement

patterns in patients after ACL reconstruction: implications for enhanced criteria-based return-to-sport rehabilitation. *Knee Surg Sports Traumatol Arthrosc* 24, 7 (July 2016), 2280–2286. DOI:https://doi.org/10.1007/s00167-014-3374-x

[21]Alexandre Gordo. Virtual Reality for Locomotion Rehabilitation. 10.

[22]Matt C. Howard. 2017. A meta-analysis and systematic literature review of virtual reality rehabilitation programs. *Computers in Human Behavior* 70, (May 2017), 317–327. DOI:https://doi.org/10.1016/j.chb.2017.01.013

[23]Ankur Joshi, Saket Kale, Satish Chandel, and D. K. Pal. 2015. Likert Scale: Explored and Explained. *Current Journal of Applied Science and Technology* (February 2015), 396–403. DOI:https://doi.org/10.9734/BJAST/2015/14975

[24]Jae-Sung Kwon, Mi-Jung Park, In-Jin Yoon, and Soo-Hyun Park. 2012. Effects of virtual reality on upper extremity function and activities of daily living performance in acute stroke: A double-blind randomized clinical trial. *NRE* 31, 4 (November 2012), 379–385. DOI:https://doi.org/10.3233/NRE-2012-00807

[25]Mounia Lalmas, Heather O'Brien, and Elad Yom-Tov. 2014. Measuring User Engagement. *Synthesis Lectures on Information Concepts, Retrieval, and Services* 6, 4 (November 2014), 1–132. DOI:https://doi.org/10.2200/S00605ED1V01Y201410ICR038

[26]Jeison David Mejia-Trujillo, Yor Jaggy Castano-Pino, Andres Navarro, Juan David Arango-Paredes, Domiciano Rincon, Jaime Valderrama, Beatriz Munoz, and Jorge Luis Orozco. 2019. Kinect™ and Intel RealSense™ D435 comparison: a preliminary study for motion analysis. In *2019 IEEE International Conference on E-health Networking, Application & Services (HealthCom)*, IEEE, Bogota, Colombia, 1–4. DOI:https://doi.org/10.1109/HealthCom46333.2019.9009433

[27]Pierre-Yves Oudeyer and Frederic Kaplan. 2009. What is intrinsic motivation? A typology of computational approaches. *Frontiers in Neurorobotics* 1, (2009), 6. DOI:https://doi.org/10.3389/neuro.12.006.2007

[28]Rongzhou Qin. 2017. Research on Application of Virtual Reality Technology in Sports Rehabilitation. In *Proceedings of the 2017 International Conference on Humanities Science, Management and Education Technology (HSMET 2017)*, Atlantis Press, Taiyuan, China. DOI:https://doi.org/10.2991/hsmet-17.2017.108

[29]Daniel Roth, Jean-Luc Lugrin, Julia Buser, Gary Bente, Arnulph Fuhrmann, and Marc Erich Latoschik. 2016. A simplified inverse kinematic approach for embodied VR applications. In *2016 IEEE Virtual Reality (VR)*, IEEE, Greenville, SC, USA, 275–276. DOI:https://doi.org/10.1109/VR.2016.7504760

[30]Ilaria Saroglia and Giulia Pompili. 2018. Rehabilitation in the Athletes. In *Hand and Wrist Injuries In Combat Sports*, Riccardo Luchetti, Loris Pegoli and Gregory I. Bain (eds.). Springer International Publishing, Cham, 249–284. DOI:https://doi.org/10.1007/978-3-319-52902-8_16

[31]Mel Slater and Anthony Steed. 2000. A Virtual Presence Counter. *Presence* 9, (October 2000), 413–434. DOI:https://doi.org/10.1162/105474600566925

[32]Anthony Steed, Ye Pan, Fiona Zisch, and William Steptoe. 2016. The impact of a self-avatar on cognitive load in immersive virtual reality. In *2016 IEEE Virtual Reality (VR)*, IEEE, Greenville, SC, USA, 67–76. DOI:https://doi.org/10.1109/VR.2016.7504689

[33]Joseph Anthony Stone, Ben William Strafford, Jamie Stephen North, Ciaran Toner, and Keith Davids. 2018. Effectiveness and efficiency of virtual reality designs to enhance athlete development: an ecological dynamics perspective. *Mov Sport Sci/Sci Mot* 102 (2018), 51–60. DOI:https://doi.org/10.1051/sm/2018031

[34]Sandeep K. Subramanian, Christiane B. Lourenço, Gevorg Chilingaryan, Heidi Sveistrup, and Mindy F. Levin. 2013. Arm Motor Recovery Using a Virtual Reality Intervention in Chronic Stroke: Randomized Control Trial. *Neurorehabil Neural Repair* 27, 1 (January 2013), 13–23. DOI:https://doi.org/10.1177/1545968312449695

[35]Unity Technologies. Unity - Manual: Prefabs. Retrieved September 26, 2021 from https://docs.unity3d.com/Manual/Prefabs.html

[36]Unity Technologies. Unity - Manual: NavMesh Surface. Retrieved September 26, 2021 from https://docs.unity3d.com/Manual/class-NavMeshSurface.html

[37]Andrea Turolla, Mauro Dam, Laura Ventura, Paolo Tonin, Michela Agostini, Carla Zucconi, Pawel Kiper, Annachiara Cagnin, and Lamberto Piron. 2013. Virtual reality for the rehabilitation of the upper limb motor function after stroke: a prospective controlled trial. *J NeuroEngineering Rehabil* 10, 1 (2013), 85. DOI:https://doi.org/10.1186/1743-0003-10-85

[38]Eva L Waterworth and John A Waterworth. 2003. 15 The Illusion of Being Creative. (2003), 14. DOI:https://doi.org/10.1.1.4.3453

[39]2018. Understanding State Machines. *freeCodeCamp.org*. Retrieved January 10, 2021 from https://www.freecodecamp.org/news/state-machines-basics-of-computer-science-d42855debc66/

[40]PAGINA INICIAL. *Macaronight2021*. Retrieved September 26, 2021 from https://itecformadores.wixsite.com/macaronight2021

[41]StrokeBack project. Retrieved April 21, 2020 from https://www.strokeback.eu/

[42]VIVE Tracker | VIVE European Union. Retrieved September 26, 2021 from https://www.vive.com/eu/accessory/vive-tracker/www.vive.com/eu/accessory/vive-tracker/

[43]Game Engines: How do they work? *Giant Bomb*. Retrieved September 26, 2021 from https://www.giantbomb.com/profile/michaelenger/blog/game-engines-how-do-they-work/101529/

[44]Mixing Blueprints & C++ | Unreal Engine Community Wiki. Retrieved September 26, 2021 from https://unrealcommunity.wiki/mixing-blueprints-and-cpp-8keheovh

[45]Unity - Manual: GameObject. Retrieved September 26, 2021 from https://docs.unity3d.com/560/Documentation/Manual/class-GameObject.html

[46]Unity - Scripting API: NavMeshAgent. Retrieved September 26, 2021 from https://docs.unity3d.com/ScriptReference/AI.NavMeshAgent.html

[47]SteamVR Plugin | Integration | Unity Asset Store. Retrieved September 26, 2021 from https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647

[48]SteamVR no Steam. Retrieved September 26, 2021 from https://store.steampowered.com/app/250820/SteamVR/

[49]Final IK | Animation Tools | Unity Asset Store. Retrieved September 26, 2021 from https://assetstore.unity.com/packages/tools/animation/final-ik-14290?gclid=Cj0KCQjwtMCKBhDAARIsAG-2Eu9jfw7A_QHpFZR_D48YAtfipe0PmTI9zUmniqMh30Ai-vWTZjvdcUsaAhDiEALw_wcB

[50]www.makehumancommunity.org. Retrieved September 26, 2021 from http://www.makehumancommunity.org/

[51]Nuitrack Full Body Skeletal Tracking Software. Retrieved September 26, 2021 from https://nuitrack.com/

[52]Skeleton Tracking SDK by cubemos™ - Intel RealSense Technologies. Retrieved September 26, 2021 from https://www.intelrealsense.com/skeleton-tracking/

[53]Subway Surfers – Apps no Google Play. Retrieved September 26, 2021 from https://play.google.com/store/apps/details?id=com.kiloo.subwaysurf&hl=pt_PT&gl=US

[54]E4 wristband | Real-time physiological signals | Wearable PPG, EDA, Temperature, Motion sensors. *Empatica*. Retrieved January 29, 2021 from https://www.empatica.com/research/e4

[55]Polar H10 | Heart rate monitor chest strap. *Polar Global*. Retrieved September 26, 2021 from https://www.polar.com/en/products/accessories/H10_heart_rate_sensor

[56]Rated Perceived Exertion (RPE) Scale. *Cleveland Clinic*. Retrieved September 26, 2021 from https://my.clevelandclinic.org/health/articles/17450-rated-perceived-exertion-rpe-scale

[57]The Academic Motivation Scale: A Measure of Intrinsic, Extrinsic, and Amotivation in Education - Robert J. Vallerand, Luc G. Pelletier, Marc R. Blais, Nathalie M. Briere, Caroline Senecal, Evelyne F. Vallieres, 1992. Retrieved September 29, 2021 from https://journals.sagepub.com/doi/10.1177/0013164492052004025

9APPENDIX

9.1 APPENDIX A – DEVELOPMENT

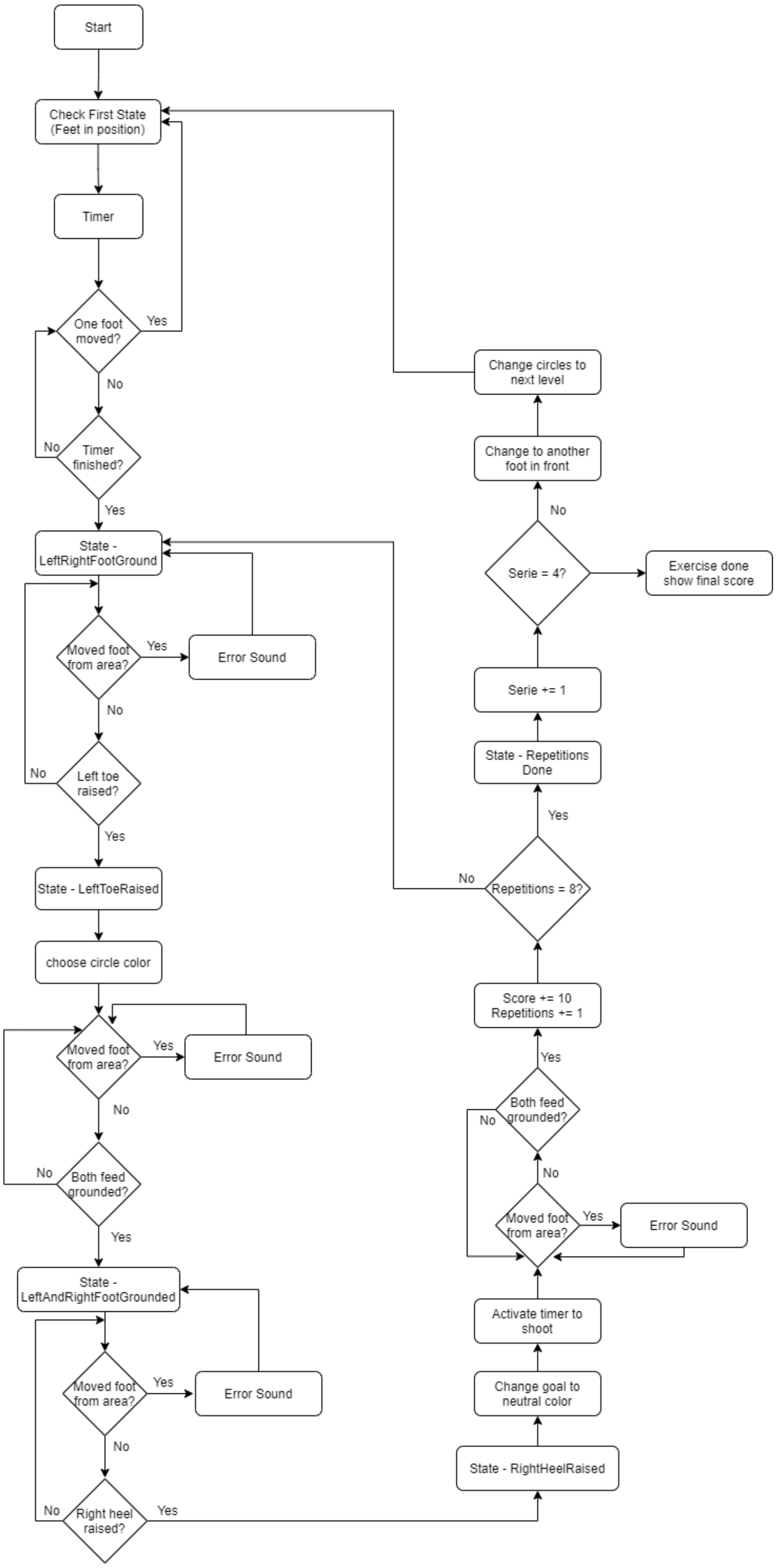


Figure 62: Flowchart of the Weight Transfer Exercise

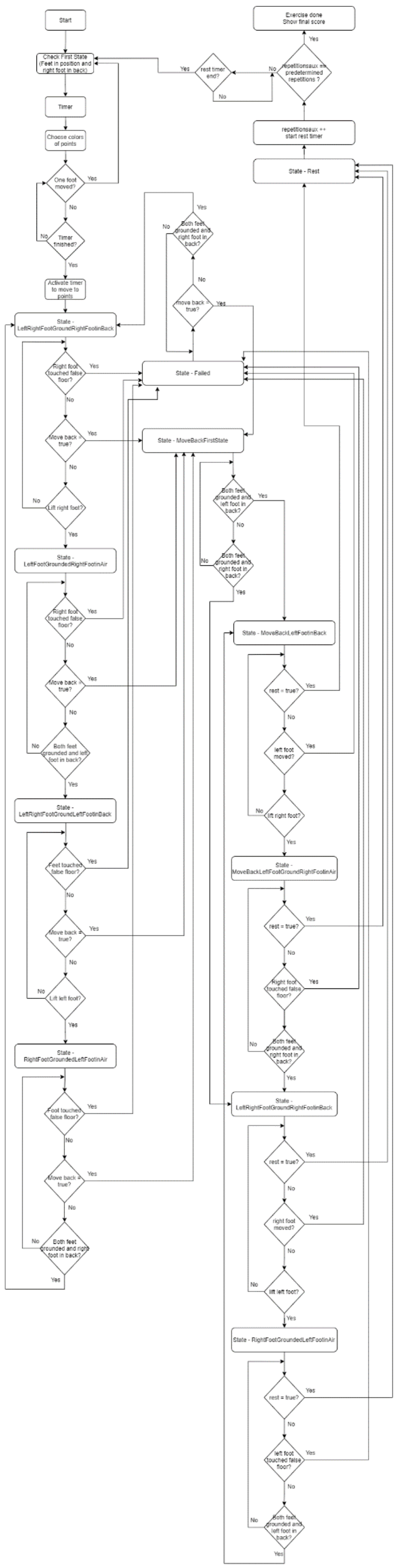


Figure 63: Flowchart of Walking along a Straight Line Exercise

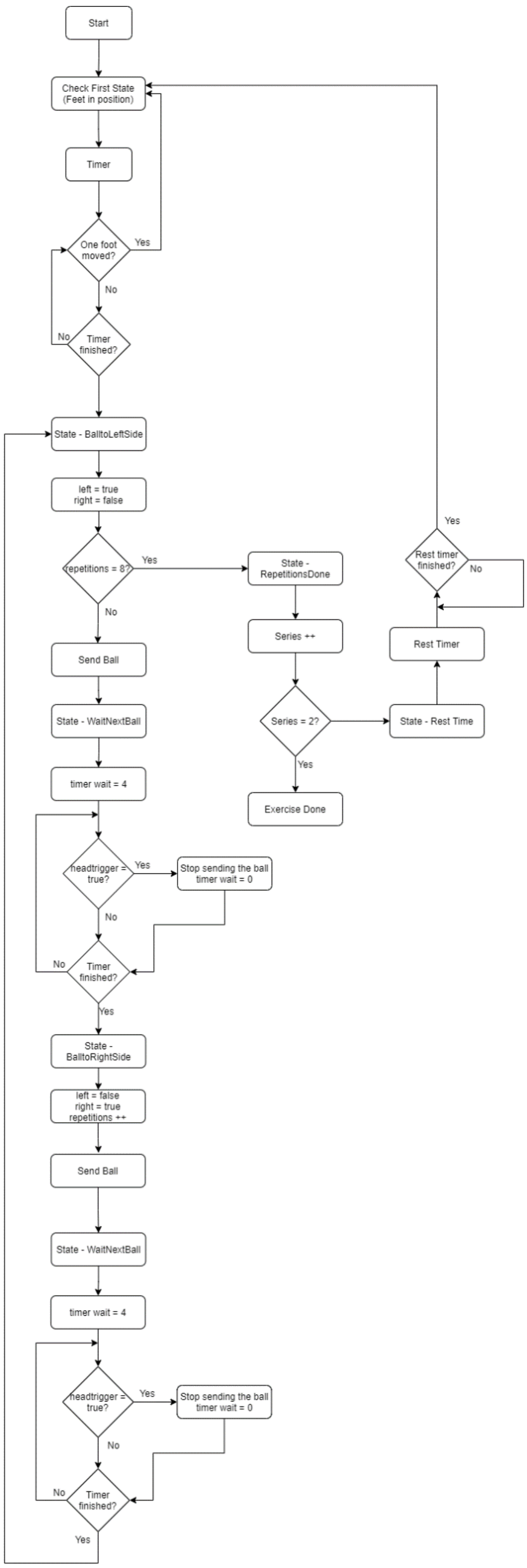


Figure 64: Flowchart of Side Squat Exercise

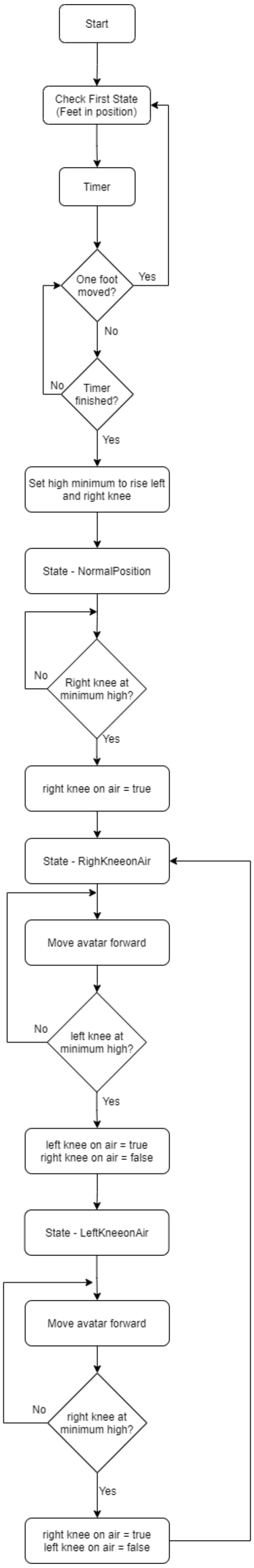


Figure 65: Flowchart of Progressive March

9.2 APPENDIX B – QUESTIONNAIRES

9.2.1 Pre-Questionnaire – Questionnaire to athletes before realizing the test

MTL - VR (Pre User Test)

Os utilizadores terão que dar autorização para a sua recolha de informações e imagem.

Objetivos:
- Genericamente: testar uma sessão de exercícios realizados em VR focados na melhoria das capacidades físicas e volitivas.
Especificamente:
Investigar a carga interna produzida por cada um dos 5 exercícios realizados em VR;
Avaliar os parâmetros fisiológicos através do E4 WRISTBAND e o Rated Perceived Exertion (RPE) Scale durante a experiência.

- Investigar a carga externa produzida por cada um dos exercícios realizados em VR;
Avaliar a atividade produzida através do acelerómetro do E4 WRISTBAND.
- Investigar a motivação do enduser para a utilização deste tipo de sistema na melhoria das capacidades físicas e volitivas
Avaliar a presença do usuário no contexto virtual, a motivação intrínseca e a usuabilidade do sistema com recurso aos seguintes instrumentos: Witmer-Singer Presence Questionnaire (WSPQ); Intrinsic Motivation; System Usability Scale (SUS)

*Obrigatório

1. User ID *

____

Demografia

Para esta primeira subseção, você precisa preencher suas informações demográficas.

2. Qual é o seu gênero? *

Marcar apenas uma oval.

- ( ) Masculino
- ( ) Feminino
- ( ) Prefiro não dizer
- ( ) Outra: ______________________

3. Quantos anos você tem? *

____

4. Qual é a sua nacionalidade? *

Marcar apenas uma oval.

- Americano
- Inglês
- Francês
- Alemão
- Italiano
- Português
- Sérvio
- Espanhol
- Venezuelano
- Outra: ____________________

5. Grau de Escolaridade

Marcar apenas uma oval.

- 1º Ciclo do Ensino Básico
- 2º Ciclo do Ensino Básico
- 3º Ciclo do Ensino Básico
- Ensino Secundário
- Ensino Superior

Experiência anterior

O objetivo desta subseção é determinar sua experiência anterior com outros aplicativos de realidade virtual, bem como seu conhecimento tecnológico geral.

6. Como você classifica seu conhecimento de tecnologia? *

Marcar apenas uma oval.

	1	2	3	4	5	
Inexistente						Excelente

7. Como você classifica seu background anterior com experiências de VR com HMD's (jogos 3D, simulações, vídeo 360º, etc)? *

Marcar apenas uma oval.

- Eu nunca usei
- Eu usei uma vez
- Eu tenho usado algumas vezes
- Eu uso regularmente
- Eu desenvolvi aplicações de VR

8. Antes dos 12 anos, com que frequência você se sentia enjoado ou com náuseas? *

Marcar apenas uma oval por linha.

	Não sei / nunca usei	Nunca	Raramente	Algumas vezes	Frequentemente
Carro					
Autocarro					
Comboio					
Avião					
Barco					

9. Nos últimos 10 anos, com que frequência você se sentiu enjoado ou enjoado? *

Marcar apenas uma oval por linha.

	Não sei / nunca usei	Nunca	Raramente	Algumas vezes	Frequentemente
Carro	◯	◯	◯	◯	◯
Autocarro	◯	◯	◯	◯	◯
Comboio	◯	◯	◯	◯	◯
Avião	◯	◯	◯	◯	◯
Barco	◯	◯	◯	◯	◯

Estado emocional

O objetivo desta subseção é determinar seu estado emocional atual.

10. Classifique seu estado emocional entre feliz e infeliz. *

Marcar apenas uma oval.

	1	2	3	4	5	
Infeliz	◯	◯	◯	◯	◯	Feliz

11. Classifique seu estado emocional entre calmo e excitado. *

Marcar apenas uma oval.

	1	2	3	4	5	
Calmo	◯	◯	◯	◯	◯	Excitado

12. Classifique seu estado emocional entre controlado e sob controle. *

Marcar apenas uma oval.

	1	2	3	4	5	
Sob Controlado	◯	◯	◯	◯	◯	Controlado

Este conteúdo não foi criado nem aprovado pela Google.

Google Formulários

9.2.2 Post-Questionnaire – Questionnaire to athletes after realizing the test

MTL - VR (Post User Test)

Os utilizadores terão que dar autorização para a sua recolha de informações e imagem.

Objetivos:
- Genericamente: testar uma sessão de exercícios realizados em VR focados na melhoria das capacidades físicas e volitivas.

Especificamente:
Investigar a carga interna produzida por cada um dos 5 exercícios realizados em VR;
Avaliar os parâmetros fisiológicos através do E4 WRISTBAND e o Rated Perceived Exertion (RPE) Scale durante a experiência.

- Investigar a carga externa produzida por cada um dos exercícios realizados em VR;
Avaliar a atividade produzida através do acelerómetro do E4 WRISTBAND.
- Investigar a motivação do enduser para a utilização deste tipo de sistema na melhoria das capacidades físicas e volitivas
Avaliar a presença do usuário no contexto virtual, a motivação intrínseca e a usuabilidade do sistema com recurso aos seguintes instrumentos: Witmer-Singer Presence Questionnaire (WSPQ); Intrinsic Motivation; System Usability Scale (SUS)

*Obrigatório

1. User ID *

2. Quanto tempo você acha que a experiência durou (minutos)? *

Experiência do utilizador

O objetivo desta subseção é avaliar a experiência / sistema geral.

3. Achei que usar este sistema era agradável. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

4. Acho que sou muito bom em usar este sistema. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

5. Não me esforcei muito para usar este sistema bem. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

6. Não me senti nem um pouco nervoso ao usar este sistema. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

7. Fiz essa atividade porque quis. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

8. Acredito que fazer essa atividade foi benéfico para mim. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

9. Eu gostaria de ter a oportunidade de interagir com este sistema com mais frequência. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

Usabilidade

O objetivo desta subseção é avaliar a usabilidade e a complexidade da experiência.

10. Eu gostaria de usar este sistema com freqüência. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

11. Achei o sistema desnecessariamente complexo. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

12. Achei o sistema fácil de usar. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

13. Acho que precisaria do apoio de um técnico para poder usar este sistema. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

14. Achei que as várias funções deste sistema estavam bem integradas. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

15. Achei que havia muita inconsistência neste sistema. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	⬭	⬭	⬭	⬭	⬭	Concordo plenamente

16. Eu imagino que a maioria das pessoas aprenderia a usar esse sistema muito rapidamente. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

17. Achei o sistema muito complicado de usar. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

18. Eu me senti muito confiante ao usar o sistema. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

19. Eu precisava aprender muitas coisas antes de começar a usar este sistema. *

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo fortemente	◯	◯	◯	◯	◯	Concordo plenamente

Estado emocional

O objetivo desta subseção é determinar seu estado emocional atual.

20. Classifique seu estado emocional entre feliz e infeliz. *

Marcar apenas uma oval.

	1	2	3	4	5	
Infeliz	⬭	⬭	⬭	⬭	⬭	Feliz

21. Classifique seu estado emocional entre calmo e excitado. *

Marcar apenas uma oval.

	1	2	3	4	5	
Calmo	⬭	⬭	⬭	⬭	⬭	Excitado

22. Classifique seu estado emocional entre controlado e sob controle. *

Marcar apenas uma oval.

	1	2	3	4	5	
Sob Controlado	⬭	⬭	⬭	⬭	⬭	Controlado

Obrigado por participar !

Obrigado por nos ajudar com este estudo. Você pode fornecer algum feedback geral na seção abaixo, ou pode terminar o estudo agora, se desejar.

23. Feedback geral

9.3 APPENDIX C – STEPS TO REALIZE DURING THE PILOT STUDY

1. O utilizador irá chegar à sala no marítimo. Após uma breve apresentação de ambas as partes e do projeto em si irá ser dado ao utilizador um questionário (**Questionário inicial do end user (PRE)**) bem como um documento em que permite a sua recolha de dados.
2. Desinfetar os equipamentos antes de começar a experiência.
3. O utilizador irá colocar os sensores (HTC e E4) com a nossa ajuda, para termos a certeza que fica bem colocado. Fazemos uma breve introdução ao hardware que o utilizador tem colocado bem como dos botões do comando necessários para esta experiência.
4. Ligamos todos os sensores e damos play no Unity no primeiro exercício.
5. Filmamos com o telemóvel o utilizador a realizar o exercício.
6. Quando o utilizador terminar o exercício paramos de filmar e perguntamos ao utilizador qual a taxa de esforço para o exercício apontando no caderno (RPE Scale). Apontar também o score obtido.
7. O utilizador realiza o segundo exercício
8. Filmamos com o telemóvel o utilizador a realizar o exercício.
9. Quando o utilizador terminar o exercício paramos de filmar e perguntamos ao utilizador qual a taxa de esforço para o exercício apontando no caderno (RPE Scale). Apontar o score obtido.
10. O utilizador realiza o terceiro exercício
11. Filmamos com o telemóvel o utilizador a realizar o exercício.
12. Quando o utilizador terminar o exercício paramos de filmar e perguntamos ao utilizador qual a taxa de esforço para o exercício apontando no caderno. (RPE Scale). Apontar o score obtido.
13. O utilizador realiza o quarto exercício
14. Filmamos com o telemóvel o utilizador a realizar o exercício.
15. Quando o utilizador terminar o exercício paramos de filmar e perguntamos ao utilizador qual a taxa de esforço para o exercício apontando no caderno ((RPE Scale). Apontar o score obtido.
16. O utilizador realiza o quinto exercício
17. Filmamos com o telemóvel o utilizador a realizar o exercício.
18. Quando o utilizador terminar o exercício paramos de filmar e perguntamos ao utilizador qual a taxa de esforço para o exercício apontando no caderno ((RPE Scale). Apontar o score obtido.

19. Dizemos ao utilizador que já acabou os exercícios e paramos o sensor E4 para deixar de medir.
20. Ajudamos o utilizador a retirar os sensores e fornecemos o questionário (**Questionário de satisfação do end user e sugestões (POS)** final.
21. Agradecemos ao utilizador por ter participado e acompanharmos-lhe à porta.
22. Vamos ao software do E4 alterar o nome da sessão para uma que seja possível identificar o utilizador.
23. Desinfetar os equipamentos depois da experiência.

9.4 APPENDIX D – PUBLICATION

Pilot Implementation in Virtual Reality: Pitfalls, Tensions and Organizational Issues

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Abstract. Pilot implementations are, essentially, field tests of properly engineered yet unfinished systems. Contrasting with usability evaluations, pilot implementations are typically conducted in the field, and involve users performing their real work using the pilot system. There are many open research questions regarding pilot implementations. In this position paper, we briefly reflect on work-in-progress of a virtual reality installation for physical rehabilitation of professional football athletes. Concretely, we debate on the pitfalls, organizational issues, stakeholders' tensions and overall open questions about this particular pilot implementation. Results can be used to drive further work, as well as to foster discussion about pilot implementation challenges and research agenda.

Keywords: Pilot Implementations, Virtual Reality, Human Work Interaction Design, Field Tests, Rehabilitation.

1. Pilot Implementation in Virtual Reality

1.1. A VR system for Rehabilitation of Professional Football Athletes

Throughout their career, professional football athletes suffer many types of physical injuries, and are naturally affected by them. Whenever that happens, a rapid, swift recovery is paramount to maintaining their career level strong. The longer the recovery, the more difficult it is for the athlete to overcome it, and motivation can quickly become a serious issue, even when physical recovery is attained.

Typically, the rehabilitation process of an athlete is coordinated by a trained physiotherapist as well as other medical staff, depending on the football club's dimension. However, this process is always tedious and frustrating to the athlete. Exercises are relatively simple to perform, yet they can become extremely tedious.

On the other hand, Virtual Reality (VR) and its derived technologies have been increasingly popular in a variety of rehabilitation domains, as well as entertainment. Challenging the player or promoting exploration makes the plan of rehabilitation more exciting and more enjoyable than the traditional rehabilitation plan [3].

The rationale of using VR in soccer players is also based on its exceptional features. The possibility of creating different scenarios with an infinite number of repetitions where it is possible to manipulate the visual environment, for example, brightness of objects, their location, different perspective, temporal and spatial distortions of the movement trajectory, and feedback, may influence the performance in a way that is hard to achieve in the real world [3]. Besides that, VR can invoke embodied simulations of the human in the world, used to represent and predict actions, concepts, and emotions [4].

In this pilot implementation, we created, designed and rolled-out five different rehabilitation exercises built in a virtual environment in order to understand if the stimulation of the virtual environment promoted better psychological and social influence on the athletes. These exercises were performed in two different scenarios to give some freedom to the athlete performing the rehabilitation exercise.

Fig. 1. A user testing out the implementation of a series of physical rehabilitation exercises

Figure 1 provides an idea of the environment.

The athletes learn to execute the exercises when accompanied with someone from the medical team that guides them to the steps they must execute. This member of the medical team helps and teaches the athlete to perform the exercises in the most appropriate way, so that the exercise helps in the rehabilitation, instead of having the opposite effect. Nevertheless, athletes do not always have a close contact, control or guidance with the medical staff when they are realizing the rehabilitation exercises from their plan. This makes it impossible to check if they are doing the exercise with the best technique and get instant feedback about that [3]. Consequently, this support and supervision that is usually realized by the medical staff can be done using Virtual Reality since it is possible to give instant feedback to the athlete from the immersive world where they are, regarding the correct technique needed for each exercise, and without the need for an extra person supervising the athlete.

1.2. Implementation Issues

The development of this system was made using the Unity3D game engine in conjunction with a VR headset and body tracking off-the-shelf equipment (VIVE) for the sake of bringing more immersive and realistic experiences to the rehabilitation process. We used VIVE Trackers, which give us the possibility of creating full-body experiences. To create this full body avatar, we track the athlete's skeleton using three different trackers that work synchronously with the headset and two controllers, creating the six points necessary for the effective, smooth tracking of the athlete's body. The three trackers are placed in each foot and in the athlete's waist, the headset in his head and the controllers in their hands. We also used VR inverse kinematics to help make the tracking more accurate, smooth and rapid. When injured athletes try these scenarios with the full body tracking, it is possible to have a more immersive experience since the athlete sees his body inside the scenario performing exactly what he is doing in real life and with very low latency [2].

The development of these exercises for the rehabilitation of injured athletes was implemented using state machines. Each exercise has its own state machine where we have states for each temporal part of the exercise and states for when all the repetitions are made. There is also a game-over state, triggered when the athlete fails to complete a given exercise. Using state machines gives us more control in each exercise, since we know in which state the user is when performing the exercise. It also provides the possibility of developing additional feedback to deliver a more immersive and responsive experience.

2. Pitfalls, Tensions and Organizational Issues

Pilot implementations are, essentially, "field tests of properly engineered yet unfinished systems" [1]. Contrasting with usability evaluations, pilot implementations are typically conducted in the field, and involve users performing their real work using the pilot system. There are many open research questions regarding pilot implementations [1].

It is important to reflect on this work-in-progress of a virtual reality installation for physical rehabilitation of professional football athletes. Concretely, we debate on the pitfalls, organizational issues, stakeholders 'tensions and overall open questions about this particular pilot implementation.

Profiling our project with Hertzum's five activities of pilot implementations [1], we detail the following:

Planning and design. We employed a multidisciplinary approach to this pilot's planning and design activity. The main tension was to accurately depict the actual VR system behavior in a visual way, to achieve a common understanding by all stakeholders, namely the medical staff, athletes, experts in rehabilitation and sport sciences, as well as the engineers.

Technical configuration. The configuration of such systems always faces the extra challenge of calibration due to different users's body sizes, arms' length, etc. In a pilot implementation of a "sole"-digital system this does not occur. The parts of the VR system necessary for the pilot implementation had to be properly configured to fit the pilot site, interfaces to the users 'other systems were developed and tested. Adapting a novel space to such a highly-technological equipment also generates tension, but it helped some users to avoid withholding their opinion about the system or even try to derail pilot implementations by means of counter-implementation strategies.

Organizational adaptation. Introducing a VR cave-like, immersive environment in such a large and diverse organization such as a Premier league football club is far from trivial in terms of organizational adaptation. Many different people, with many different backgrounds intervene in the pilot implementation in one way or another. Additionally there is the continuous, almost realtime pressure of results. We consider that avoiding unrealistic expectations was the main pitfall in this activity.

Use. The actual usage of the pilot implementation was not yet tried by the actual athletes, but current results are showing that users often consider that an inspirational scenario in a different environment rather than a football stadium can lead them to a better mood to perform some of the rehabilitation exercises.

Learning. This last activity is still ongoing. According to the physiotherapist, the athlete in a long and exhaustive rehabilitation process may want to choose a football stadium scenario, so they don't feel like they are out of work for a long time, unlike an athlete in a short-term rehabilitation who may want to choose a different scenario in order to perform the exercise in a completely new environment. But the actual preferences need to be measured in-loco and should be triangulated with physiological metrics of heart rate variability, galvanic skin response or even EEG real time data. Qualitative information plays a useful role as well and we plan on collecting a significant amount until the end of the pilot.

In conclusion, we hope this position paper can be used to drive further work, as well as to foster discussion about pilot implementation challenges and research agenda. We are particularly interested in contributing to an immediate research agenda revolving around the pitfalls and challenges that come up with pilot implementations when a multidisciplinary project is at stake, but the results can probably scale to any other type of VR project for physical rehabilitation.

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References

1. Hertzum, M., Bansler, J.P., Havn, E., Simonsen, J.: Pilot implementation: Learning from field tests in IS development. *Communications of the Association for Information Systems* 30(1), 313-328 (2012).
2. Akbaş, Anna & Marszałek, Wojciech & Kamieniarz, Anna & Polechoński, Jacek & Kajetan, Słomka & Juras, Grzegorz. (2019). Application of Virtual Reality in Competitive Athletes - A Review. *Journal of Human Kinetics*. 69. 5-16. 10.2478/hukin-2019-0023.
3. Mestre, Daniel & Ewald, Marine & Maiano, Christophe. (2011). Virtual reality and exercise: Behavioral and psychological effects of visual feedback. Studies in health technology and informatics. 167. 122-7.
4. Bossard, Cyril & Kermarrec, Gilles & Bénard, Romain & De Loor, Pierre & Tisseau, Jacques. (2009). Virtual Reality for Research and Training in Sport: an Illustration with CoPeFoot.