

Understanding Barriers in Physical Engagement: Prototyping an Exergame for Anterior Cruciate Ligament Rehabilitation

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Abstract—Anterior Cruciate Ligament (ACL) tears are severe and relatively common injuries with potential long-term consequences. Rehabilitation is a vital part of recovery, but patients frequently have trouble adhering to their Home Rehabilitation Programme (HEP) long-term. There are several reasons for this, (e.g. pain, boredom, having no expectations, etc). This paper aims to present a first step towards a Virtual Reality (VR) application that can improve adherence to the HEP. An analysis of themes is undertaken to identify why patients have difficulties in continuing their HEP, and based on this, a storyboard for a VR application is created with the forward lunges exercise as a case study. After the storyboard, a mid-fidelity prototype is designed and tested by one participant to obtain feedback and improve the prototype in a future second iteration. The participant's responses show potential for improvements of the prototype in terms of presenting the game and the environment for a better experience. The use of Meta Horizon Worlds as a prototyping tool allows for faster iteration without the complications of developing a high-fidelity VR application. The importance of discussing barriers with patients, storyboarding and prototyping is highlighted and discussed, showing that they are important steps to create a VR application that will be used to improve a monotonous exercise.

Index Terms—Design, Rehabilitation, Storyboard, Virtual Reality, Prototyping

I. INTRODUCTION

Gaelic Football, hurling, soccer and rugby are some of the most popular sports in Ireland, enjoyed by people from all levels of sport [1]. These sports require the player to land and make sudden changes of direction, which predisposes them

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to Anterior Cruciate Ligament (ACL) injuries [2]. Injuries to this ligament represent the highest injury burden for athletes, with an absence of around 20 and 30 per cent of total training and playing time in male and female athletes, respectively [3]. To recover from such an injury, patients commonly go through an ACL Reconstruction (ACLR) surgery, followed by physical rehabilitation. After an initial and more intense therapy schedule, patients are prescribed with a Home Exercise Programme (HEP) which they will need to commit to long-term if they want to regain strength, explosiveness and Range of Motion (ROM). Doing so can improve the patient's chances of recovery and prevent re-injury [4]. Even though patients are aware of the benefits of completing their HEP, around 50-70% never complete their programme, making them less likely to return to pre-injury levels of performance [5]. Besides the injury itself, patients also face other barriers during rehabilitation, which can be psychological (false expectations, fear of reinjury, lack of motivation, feelings of isolation), physiological (pain level), or situational (access to services) [6] [7] [8]. Finding ways to overcome these barriers is essential to a better recovery of patients, especially for recreational athletes, who may not have the same level of monitoring and personalised care as professional athletes.

Virtual Reality (VR), as a technology that allows the user to be immersed in a virtual world, creating an illusion of being somewhere completely different from the real world, has the potential to enhance the experience of an already painful and tedious process, such as physical rehabilitation. This technology, along with a form of gamification, could be an effective way to tackle some of the barriers that patients have. But it is not enough to get a patient to wear a VR

headset and do the same exercises that they find boring already, it is imperative to design an experience that will increase engagement to the HEP. For this purpose, the needs of patients need to be identified to create a change in how they are handling their rehabilitation process.

Taking the aforementioned context into consideration, the primary aim of this paper is to present the storyboarding and initial prototyping process of a VR application that could help patients to increase adherence to their HEP. The case study and focus of this paper will be the forward lunges exercise because of its extensive use.

The paper is structured as follows: Section II details previous work around rehabilitation using VR. Section III describes a list of themes that ACL patients have in common in terms of barriers for rehabilitation. Section IV explains the process of creating a storyboard in VR. Then, Section V depicts a mid-fidelity prototype based on the storyboard. Lastly, Section VI discusses the results of the design process.

II. RELATED WORK

This section summarises prior research in the Virtual Reality rehabilitation domain, and more specifically, how it has been applied to lower-limb injuries like ACL tears.

Various works are related to the use of VR in the context of physical rehabilitation, but depending on the type of injury, different uses of the technology are needed. For example, for patients who have suffered from a stroke, the main goal is for them to regain motor control. In order for the rehabilitation to be effective, the exercises have to be repetitive and continuous. Some studies have investigated VR as a tool to incorporate into these programmes [9] [10] [11] [12]. While these studies conclude that more research is needed, overall, the results are very positive in terms of improving the rehabilitation process.

Other works have explored the use of VR for the recovery of patients with other neurological pathologies, such as brain damage [13], spinal cord injury [14] [15], and Parkinson's disease [16] [17]. The results of these therapies using VR look promising initially, but the long-term use is still a challenge, as well as defining the type of experience that could give better results for each condition.

For lower limb injuries, particularly, ACL injuries, VR has been used for balance training or as a way to distract the patient from conscious motor control [18] [19]. Other works focus on preventing re-injury by evaluating readiness to go back to sports [20].

A clear challenge of VR in rehabilitation for lower limb injuries lies in the fact that a headset cannot track the position of the lower part of the body by itself, and therefore, tracking the progress of the patient is not possible. Wearable sensors are necessary to get more information about the movements being performed. Some works have focused on using wearable devices or suits to improve the rehabilitation process by registering the information about the movements only, without using VR to increase engagement [21] [22] [23] [24] [25] [26]. The information from the sensors is generally used by

the clinicians to assess the state of the patient's injury, but not to inform the patient directly.

Looking at the previously mentioned works, there is potential in VR to help improve the rehabilitation process for patients. However, as of now, there is no focus on improving engagement in the long term for the patients to benefit fully from the rehabilitation programme. Also, as per our knowledge, there are no guidelines as to how to design an exercise VR application specific to rehabilitation. This paper focuses on the design of such a system, which can take advantage of an immersive environment to bring more motivation into a rehabilitation programme and make the process easier for patients.

III. THEMES ANALYSIS OF PATIENTS WITH ACL INJURIES

Using secondary research, we examined four studies [27] [28] [29] [30] that aimed to understand the barriers that ACL injury patients go through during rehabilitation. These studies are based on surveys and first-hand experience from ACL patients who have gone through surgery and rehabilitation.

We extracted the barriers that patients were facing while doing the rehabilitation, grouping them in similar clusters to be able to define common themes. In total, we identified five common themes:

A. Kinesiophobia and other fears

Many ACL patients suffer from kinesiophobia after the injury [31]; this is a fear of certain movements that they believe will cause another injury. Individuals with a greater fear of reinjury are less likely to return to sport. According to Burland et. al [30], up to 24% of athletes do not return to play because of this. Walker et. al [29] reported that jumping and sudden changes of direction are the hardest for patients to overcome.

Other types of fear experienced by athletes after an ACLR include the fear of loss of income, having to repeat the rehabilitation programme, and sporting incompetence [30].

By immersing patients in a virtual space, with a gamified experience, there could be less of a conscious movement and more a task-related response, decreasing the feelings of fear.

B. No relation with sport

Athletes are very passionate about the sport they play. When confronted with a set of repetitive exercises to facilitate recovery, it can be difficult to see what the advantages are with respect to their specific sport. After being away from the field for at least 6 months, athletes want a more specific training that they can clearly relate to and see that it will help them return-to-play [28] [27] [29].

The great advantage of a VR experience is that the user can be anywhere. In this sense, the application can take the patient to a rugby or soccer field, or just an open space, to minimise the feelings of being stuck at home.

C. Feelings of isolation/Boredom

In various cases, patients feel isolated from people around them, as they don't feel understood by their family and friends [32]. An ACL injury is devastating and career-ending for some athletes, and this will also affect their physical stability later in life, with a higher risk of developing arthritis in their knee [33]. These feelings of isolation can affect the overall engagement to finish their exercise rehabilitation programme.

Boredom is also an additional factor in completing physical rehabilitation. While repetition of a set of exercises is important to build strength and improve range of motion, for patients, repeating the same exercises every day is not appealing, and they are likely to start skipping the sessions.

The gamification of the rehabilitation process has the objective of overcoming this feeling of boredom while still training and exercising. Also, by including social aspects (e.g. connecting with other patients, commenting on their own progress, receiving feedback, etc), the patient could feel less isolated.

D. Expectations and information management

ACL patients can become impatient when the results of their rehabilitation differ from their expectations [27].

Patients can feel overwhelmed by the amount of information they receive in one go. This affects their ability to follow the home exercise programme. Also, patients need constant reminders on why they are doing the exercises, and the benefits they will obtain if they continue to exercise [29].

Virtual Reality is a digital tool where information can be displayed when it is most convenient. Given this, information about the exercises and their benefits, progress, and other metrics, can be easily seen or heard by the patient to manage expectations about the programme.

E. External factors

Access to services can be a challenge for ACL patients, they may have difficulty in locating an appropriate therapist, and the treatment can be expensive. Other factors such as challenges with scheduling, significant travel distances and reliance on others for transport can make the patients feel like the appointments are too time-consuming and onerous [29].

VR headsets in general are still not very accessible, but some headsets like the Meta Quest 2 and 3 are rapidly becoming a low-cost option compared to the other commercially available devices. Once the patient has access to a headset, they can access their rehabilitation whenever they want in the comfort of their own home, without depending on others.

IV. STORYBOARDING

After defining the themes that are the most present as barriers for ACL patients, we can start with the design of the system. For this, we can create gamified scenarios that will allow the user to perform the exercises needed for rehabilitation. Interviews with specialist ACL athletic trainers and physiotherapists highlighted lunges as an exercise that

patients find hard to perform or train, and that is also essential to strengthen their knee and hip extensor muscles [34]. Moreover, this exercise is normally appropriate for any stage of ACL rehabilitation [35]. For this paper, we will explore the gamification of forward lunges.

Storyboards are a common way to convey ideas before turning into the development phase of a product. Essentially, a storyboard is a narrative of the application, made with a sequence of images in order to present a more complete story about how people will interact [36] [37].

Storyboarding in VR applications can be more complicated than a 2D application. Given the nature of VR, we need to take into account all the surroundings and interactions that occur in a 3D space. When there are complex mechanics of interaction involved, it can be difficult to show ideas. At the moment, design teams sketch on a 360° storyboarding template, but this limits the changes that can be made when reviewing that storyboard. Others prefer to use role-playing to express the ideas for the application, but this could also be difficult if there are not enough people [38].

For the creation of the storyboard, the software called "Storyboarder" [39] is used, which is normally used for cinematography storyboarding, but the software has a "shot-generator" feature to allow for a 3D scene, where characters and 3D models can be added.

V. MID-FIDELITY PROTOTYPE

Prototyping is a crucial step when developing VR applications. We need to test if the game dynamics and the user interaction are what we are looking for before diving into a more time-consuming development. For prototyping, we developed a mid-fidelity scenario using Meta Horizon Worlds [40], a VR online game with its own creation system.

Horizon Worlds was chosen to create the mid-fidelity prototype, given the set of tools available to create a 3D scene in an intuitive way. The platform offers interactions like grabbing, movement around the entire scene, customisable UI, etc. Their scripting system also provides a fast way to create more complex features, like an inventory or a scoreboard. It is important to mention that this mid-fidelity prototype does not provide feedback on the execution of the exercise and does not collect any biomechanical information. This first prototype aims to test the interactions in a VR system in the context of executing exercises.

The goal of the finished application is an open-world game in which the player needs to find the exercise points, perform the necessary repetitions, and accumulate materials and resources for later use, as described by Magre [41]. As mentioned previously, this prototype will test the VR interaction of the player to perform the forward lunges exercise. Once the dynamic of this first mini-game is satisfactory, similar techniques can be applied to other exercises to expand the tasks available in the application.

In Fig. 1, we can see the narrative of the tasks as seen from the user's point of view in the Horizon Worlds app next to the

storyboard they are based on. When the player enters the mini-game, instructions on what exercise to perform will be shown in front of them, with marks on the ground that define where the player should be standing to start the exercise (The left foot on the yellow mark, and the right foot on the blue mark). For the forward lunges exercise, the user has to step forward, then lower their hips until both knees are bent approximately 90°. After that, the user pushes off their front heel in order to return to the starting position. The resource to collect in this prototype are logs of wood, so this will be the object that the user will grab while doing forward lunges, at the point of maximum flexion. Then, as the user grabs the log, one point will be counted towards the number of repetitions to do, and the user will have visual feedback of this action. In this way, the player will perform 10 repetitions (the number of repetitions was chosen for testing, and it can be different depending on the patient's need) of the forward lunges, after which they will see a notification informing them that they have collected the total amount of wood.

A first test was done on one participant who had recovered from two ACL injuries (2010 and 2021). The participant is a 31-year-old male who plays sports at least twice a week. His technology literacy is high, although he has only experienced Virtual Reality once or twice. The participant's adherence to rehabilitation was very low for their first injury (2010), and for the second injury (2021) adherence was around 70% of the HEP. Although the participant is not currently in their rehabilitation phase, they have had the experience of going through an ACL surgery twice and its respective HEP.

The participant was asked to go to Dublin City University, where enough space was provided to avoid crashing against surrounding objects. The participant was then introduced to the headset, controllers, and instructed on the exercise to perform. While performing the exercises, videos and photos were taken with the participant's permission, to observe if the exercise was done correctly (Fig. 2).

The total experience lasted about 10 minutes, after which the participant was asked to provide feedback in an unstructured interview. A sample of the participant's comments are the following:

- "I definitely would do this everyday, it is fun to be transported somewhere else without actually leaving the house"
- "I liked doing the exercise, but I felt like I was in a cage, it should be a more open space."
- "It is satisfactory to have the inventory and see everything I have done so far."
- "At first I felt a bit unsure about where my legs were, but after two or three repetitions I was doing fine."

From the initial feedback of the participant, improvements can be applied and a second version with more features can be tested. The complete system will contain multiple exercises for patients to perform in the form of mini games, along with a complete reward system where they will be able to "spend" what they have earned while exercising. Some improvements that will be made include modifying the aesthetic of the virtual

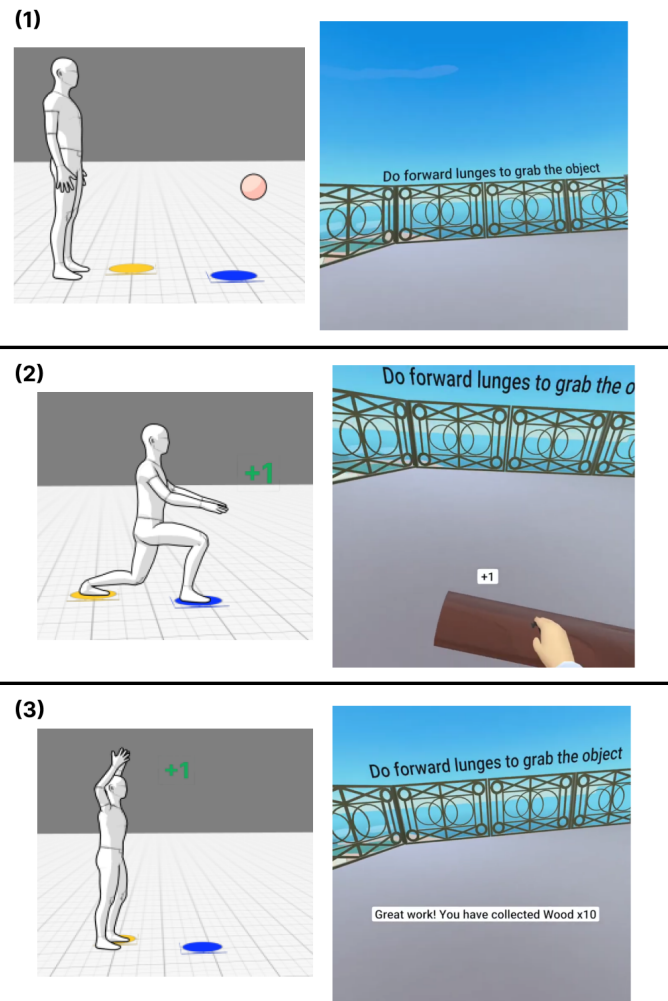


Fig. 1. Storyboard (Left side of each scene) and Mid-fidelity prototype from user's point of view (Right side of each scene) for the game of lunges based on the storyboard. (1) The user is presented with instructions for the task. The marks on the floor indicate the user where to place their feet when executing the repetition. (2) User adds a point when grabbing the object as instructed; this is equivalent to one repetition of the forward lunges exercise. (3) The user stands up again and continues repeating the exercise until 10 repetitions have been done. The users have an inventory with the rewards obtained per exercise.

space, addressing the comment about "being in a cage", and the use of wearable sensors, so the patient knows whether they have the correct form when exercising.

VI. CONCLUSIONS

The goal of this VR experience is to provide an unsupervised and engaging environment for physical rehabilitation of an ACL injury, helping to overcome barriers that patients commonly face. Storyboarding and prototyping have proven to be an excellent tool to visualise and test interactions and gameplay before spending time and resources developing a high-fidelity prototype. This saves time when a change is needed after receiving user feedback.



Fig. 2. Participant testing the prototype by performing forward lunges.

In this work, the needs of ACLR patients were identified with the goal of designing the dynamics and interactions in VR for one type of exercise, forward lunges. This same process can be made for more exercises, taking into account that different interactions may be needed. The first version of the mid-fidelity prototype was tested on one participant, giving us feedback for improvement. A second version of the application will be tested in more participants to identify further improvements and test its effectiveness in rehabilitation after an ACLR.

The next step for this work is to design a reward system to increase engagement in the long-term. Then, the exercises and reward system can be merged into a gamified application developed for patients with ACL injuries or other types of lower-limb injuries. In addition to that, it is necessary to incorporate sensors that would assess and indicate when exercises are being performed correctly/incorrectly.

There are challenges that need to be tackled in this type of application, from physical limitations, such as the available space at the patient's home, to a more intangible limitation, such as making the experience engaging enough for the patients to want to come back to it for longer periods of time. This paper is a first step into exploring ways to create experiences for rehabilitation that could make patients feel more at ease with their injury, knowing that they are a step closer to recovery and return-to-play.

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