Smart Garments for Immersive Home Rehabilitation Using VR

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ABSTRACT

Adherence to a rehabilitation programme is vital to recover from injury, failing to do so can keep a promising athlete off the field permanently. Although the importance to follow their home exercise programme (HEP) is broadly explained to patients by their physicians, few of them actually complete it correctly. In my PhD research, I focus on factors that could help increase engagement in home exercise programmes for patients recovering from knee injuries using VR and wearable sensors. This will be done through the gamification of the rehabilitation process, designing the system with a user-centered design approach to test different interactions that could affect the engagement of the users.

CCS CONCEPTS

• **Human-centered computing → Virtual reality**; **User centered design**.

KEYWORDS

Rehabilitation; Sports injury; Virtual Reality; Wearable sensors

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1 CONTEXT AND PURPOSE

In physically demanding sports, such as rugby, Gaelic football, and hurling, injuries are always a risk for athletes that participate in them, especially in amateur players. In Ireland, Anterior Cruciate Ligament (ACL) injuries are the main reason for absence of a player, and overall, lower extremity injuries represent almost 70% of all injuries [33, 37]. When we consider ACL injuries, the normal course of treatment is the reconstruction of the ligament through a surgical procedure, followed by physical therapy and a rehabilitation programme [34].

Completing the rehabilitation programme in a clinical setting is just the first step to regain mobility, the challenge for patients comes when they have to complete their exercises at home with no supervision. Studies show that between 50-70% of patients never complete their HEP [1]. Engagement to a HEP can be difficult to achieve due to the lack of supervision of the patient. This causes a drop in adherence in comparison to clinic-based programs. This drop could happen because of two main reasons: There are barriers that prevent the person from doing their exercises, or there is a lack of motivation [13].

Among these barriers we can find: Weakness due to the health status of the patient, no interest, and low expectations in the outcomes of the programme. Other barriers have to do with the personal situation of the patient, such as social support, self-confidence, the gravity of the injury, age of the patient, among others. Some of these barriers are physical, depending on general health and the injury, but most of them are psychological factors that can be reducing the patient's adherence to the programme [13, 14, 18].

We want to tackle these issues by using smart garments to monitor and save the progress of the patient during their HEP. Wearable sensors offer a more natural way of sensing movement wherever they are placed, allowing the person to move more freely without disturbances caused by uncomfortable devices. Being able to monitor the movements can also give the patient more confidence regarding their performance and hence, increase engagement [12, 22]. Improved home monitoring through textile sensors is only part of the solution, given that a psychological factor is involved in these therapies, we need to avoid barriers and improve motivation by increasing user engagement through VR. Previous works have concluded that gamification can help motivate users into following and completing their training. The aim of this work is to explore factors that could improve adherence to these programmes when using a Virtual Reality (VR) system and wearable sensors.

2 RELATED WORK

Extended reality (XR) has the capabilities to offer new ways of interaction with an application, opening possibilities into the gamification of more tasks. One of these tasks is physical rehabilitation, an activity necessary for the recovery of movement after an injury, but it still gets low engagement rates from the patients.

Previous works related to the use of VR in rehabilitation, focus on patients that have suffered a stroke or another neurological injury. Some studies focus in regaining motor control by using virtual reality, they conclude that VR has the potential to improve motor skills, balance, and pain level on patients with pathologies and conditions such as stroke [23, 27], brain damage [30], spinal cord injury [8], Parkinson's disease [11, 28], and others. Although there is improvement in regard to the physical state, there are still

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questions of how effective the long term use would be, if the patients would keep using it without supervision, and which type or virtual experience would suit each condition for better results.

In the case of rehabilitiation of knee injuries, some studies have focused on the perceptual impairments after a lower extremity ligament injury, using VR to do balance training, or by providing a scenario where the patients move away from consciuos motor control [2, 15]. In addition, VR and wearables are also being used to identify the injury risk of athletes, or evaluating if the athlete is ready to go back to sports, but not as a way to regain range of motion as their HEP after the injury [9, 21].

In the work of Chen et. al. [4], they describe the psychological benefits of Virtual Reality during rehabilitation therapy on patients with spinal cord injuries. This study showed that a VR system can ease patients' tension and induce calm during the therapy.

In terms of technology used to include lower limb motion in the VR environment, some studies have included RGB-D camera-based motion capture systems [7, 24], infrared complementary metal-oxide semiconductor (CMOS) image sensors along with depth sensors [35], Kinect [6, 16, 19, 32]. Also, when it comes to tracking lower limbs in a gamification for rehabilitation setting, the use of Inertial Measurement Unit (IMU) sensors has been used [25, 36]. However, these studies have used these sensors to track and display the lower limb movements on a phone or tablet, but not on an immersive environment. Therefore, there is an opportunity to explore their effectiveness when using virtual reality.

The previously mentioned works focus on different parts of the rehabilitation process, such as the correct performance of tasks, evaluation of sport readiness, and injury risk prevention. But there is no study focusing on how to improve patients' engagement in an unsupervised environment in order to complete their rehabilitation programme. Furthermore, previous studies using VR technology need external cameras and equipment in order to track lower limb movements. This makes the home rehabilitation setting more complicated to set up for the user. This project aims to use wearable IMU sensors to track the lower limb movements of the patient while doing their exercise programme in a virtual reality environment, and determine design features that could improve motivation of patients following a HEP.

3 STAKEHOLDERS

In this project, according to the Context and Purpose Section, we identified three main stakeholders: Patients, Physicians, and Researchers.

3.1 Patients

As the first identified stakeholder we have the patients themselves, that will be directly affected by the outputs of this project, given that they will be the end users of the system and get benefits from it. In this context, patients with knee injuries are the aim of this project.

3.2 Physicians

Physicians are the ones in charge of designing the rehabilitation programme for the recovery of a patient's injury, more specifically, physiotherapists. This kind of health professionals have the necessary knowledge about the human body and the exercises that are needed to recover range of motion in patients. Unfortunately, given the volume of patients, and the available time, physiotherapists are not able to offer a clinical setting for these exercises for longer than what it is established, given that there are 6-8 physiotherapists available per 10.000 people in Ireland [10]. This is why after some sessions with the supervision of the physician, patients have a HEP that they must follow to continue the treatment they need. As previously said, adherence to these HEP is low, causing patients to take longer to recover or to not recover their full range of motion at all.

From the perspective of this stakeholder, it would be useful to create a tool that is accurate that would allow physiotherapists to study the effect of VR environments on rehabilitation. Also, with a system like this, data could be gathered so that the physician can evaluate if any change on the HEP should be made, or simply to make sure that their patients comply with it.

3.3 Researchers

Researchers working on human performance, sports rehabilitation, user interaction, and virtual reality can find the system useful for their own research. And of course give important inputs into the project due to the interdisciplinary nature of it.

3.4 Research focus

Taking into consideration the context of the stakeholders, and the background reading, the research questions that are to be answered are:

Does Virtual Reality have the potential to enhance engagement on people recovering from knee injuries?

Can we determine a list of guidelines of design practices specific for knee injury rehabilitation applications in VR?

4 RESEARCH PLANNING AND DESIGN

In this section, the different activities to perform in this project will be described, as well as the outputs. This activities will be presented as Work Packets (WP).

4.1 WP1: Literature review

The literature review was made using mainly the following keywords: VR in rehabilitation, AR in rehabilitation, technologies for rehabilitation, exercise adherence, VR in sports rehabilitation.

The goal of this review is to refine the topic of the project and find a gap that we could fill. Part of this literature review can be found on Section 2. Key findings include: the lack of use of IMU sensors along with VR for rehabilitation programmes; the need to explore how to improve patients' engagement during their rehabilitation process rather than the prevention and evaluation of recovery.

4.2 WP2: Selection of components

4.2.1 VR headset and platform. For this part of the work, the Meta Oculus Quest 2 was chosen as the headset to be used in this application. When comparing to other brands such as the HTC Live, and SteamVR, we found that the Quest 2 had some advantages over the others:

Studies suggest that the positional accuracy of the HTC Vive headset is not good enough for rehabilitation purposes, given that the headset uses a reference plane that is tilted away, affecting the measurements, the studies also show position accuracy of 1.9mm [5, 29].

Other studies that compared the Oculus Quest 2 with the SteamVR tracking system, showed that the Oculus Quest 2 had higher accuracy, and makes it suitable for research and industry [17, 31]. These studies show an accuracy of ≈ 0.5mm [3].

Besides the characteristics of the headsets, we also compared prices, in which the Oculus Quest 2 was also the most affordable. Another advantage of this system is that the app can run wirelessly, giving the person more freedom of movement while immersed in the virtual environment. All these points determined our choice of headset.

As for the platform, Unity was the software chosen given the wide documentation available, making the development easier.

4.2.2 Wearable sensors. For the selection of wearable sensors we have to take into account a couple of characteristics:

- Able to stay in place
- Accuracy of position
- Able to connect to Unity

Based on the system requirements, which include accuracy, wireless connection, form factor, and price range, we have selected the Shimmer IMU sensors for this work. These sensors have a weight of approximately 23g per sensor, and dimensions of 51x34x14 mm; making it comparable to the size of a smart watch. In the case of this project, these sensors will be located on the lower limbs. One sensor in each thigh, and one sensor in each shin, all of them attached with straps. With these sensors we are able to access raw data and communicate through Bluetooth to the application.

4.2.3 Evaluate selection of elements. The Oculus Quest 2 has a weight of 503g, so we have to consider that maybe the added weight will affect the person's natural movement. Plus, the way that the headset is attached could also change the way people move.

For the Shimmer sensors, orientation can affect calibration and therefore the readings. The straps would make it easy to place were needed, but we need to evaluate the best way to indicate the user how to wear them correctly. Also, if the straps are too tight or placed overlapping some clothes, it could cause discomfort, impeding natural movements. For this part we will explore and evaluate these factors and any other that could affect the normal way of moving. After this, we can either introduce changes in the system, or try to reduce those factors as much as possible.

4.3 System Integration

The proposed system should integrate the aforemention hardware and software like it is shown in Fig. 1. The main activity for the user will happen in the immersive environment. The sensors readings will be linked to the application through Bluetooth, and gathering data for physicians will happen on the Consensys Software.

4.4 WP3: System Design Methodology

4.4.1 Ethical approval. For this step we met with the stakeholders needed to define the amount of subjects for the experiments, and the characteristics that each participant should fulfil. Ethical approval was obtained from the Dublin City University Research Ethics Committee to carry out experiments on human participants using the system.

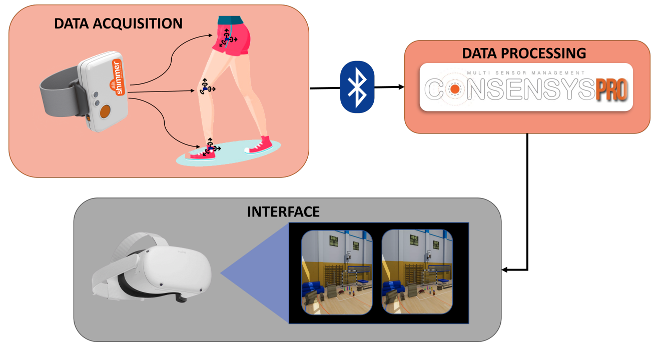

Figure 1: System integration that includes The VR headset and virtual environment, the wearable sensors, and the bluetooth connection.

4.4.2 Basic virtual environment. A basic virtual environment will be tested, which will consist on a gym scenario (VR Scenario 1), and a see-through scene (VR Scenario 2), and some movements will be performed by the user.

After the use of the basic scenario, the user can give some feedback so we can incorporate it in the system. For this, we have prepared questionnaires specific to the application, and also we will use a couple of existing ones, such as the Simulator Sickness Questionnaire (SSQ-X) [20], and the Virtual Reality Neuroscience Questionnaire [26]. These questionnaires will act as a baseline to evaluate the user experience of the application.

4.4.3 Collaborative design process. Each iteration of the system will be tested with 20 participants that are 18 years old or older, 10 of them will be healthy participants, and the other 10 will be participants who have recovered from a knee injury. This is done so we can differentiate the needs of the users.

Participants will be recruited through social media and contacts in the School of Health and Human Performance at Dublin City University.

The participants will have short training sessions (2 sets of 15 minutes each, one using each VR scenario) to test out the system when following the instructions given. The exercises to perform are heel raises (10 times, holding for 5-10 seconds), half squats (10 times, holding for 10 seconds), and leg standing (10 times, holding for 10 seconds).

After the session, participants will complete a form where they will be asked for specific points of the application. Also, each participant will have the opportunity to give feedback about the system, this will be done as guided interviews aided by the aforementioned questionnaires, in order to identify any point of the system that needs improvement, especially when it comes to human interaction. Figure 2 shows an overview of the procedure that will take place with each participant during the experiment.

With the collected data, we will iterate in the design of the system, improving it and then testing out once more. This will

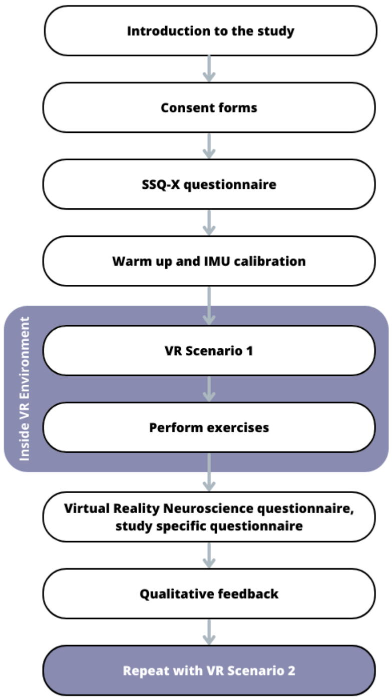

Figure 2: Overview of the user study procedure. The exercises performed, and the VR scenarios are described in more detail in Section 4.4.2 and 4.4.3.

continue until we reach a desired level of user satisfaction and we can identify the decisive elements of the design.

5 CONCLUSION

In this paper, we show the progress of the PhD project, that includes the review of different approaches of applications directed to physical rehabilitation. From there, a methodology on how to test each iteration of the system was established, and ethical approval has beeen attained to proceed with the study. The next step is to evaluate the first iteration of the system with the participants. Once we have the first results, we can start analising the common factors between participants that can affect the long term use of the system.

The expected contribution from this work is to determine a set of design guidelines based on the users' experience, specifically targeted towards the rehabilitation of knee injuries. With a clear view on how users feel during their rehabilitation process, interaction designers will be able to reduce the number of iterations needed to come up with a usable application. This project focuses on patients with knee injuries, but the use can be extended to other types of injuries, or even to healthy users that have trouble engaging with an exercise routine.

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