Universidade de Aveiro
Ano 2017

Departamento de Electrónica,
Telecomunicações e Informática

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Virtual Reality in post-stroke upper limb rehabilitation: serious games using Hand Tracking

Realidade Virtual para reabilitação do membro superior pós-AVC: jogos sérios usando seguimento de mãos

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Engenharia de Computadores e Telemática, realizada sob a orientação científica do Professor Doutor Paulo Miguel de Jesus Dias, Professor Auxiliar, e da Professora Doutora Maria Beatriz Alves de Sousa Santos, Professora Associada com Agregação do Departamento de Electrónica, Telecomunicações e Informática da Universidade de Aveiro

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palavras-chave Realidade Virtual, reabilitação, AVC, acidente vascular cerebral, Jogos Sérios, telereabilitação.

resumo

Recentemente, tecnologias de Realidade Virtual têm demonstrado grande potencial como ferramentas para a terapia de reabilitação, pois permitem a criação de Ambientes Virtuais que providenciam múltiplos estímulos que podem motivar, atrair ou distrair os pacientes. Além disso, aplicações de RV podem satisfazer os quatro princípios básicos da reabilitação: intensidade, treino orientado a tarefas, biofeedback e motivação, sendo todos estes fatores fundamentais para o sucesso do programa de reabilitação.

Conscientes deste potencial e preocupados com a falta de motivação de pacientes a recuperar de AVC na execução de exercícios repetitivos para treino do membro superior, um grupo de médicos pertencentes a um centro de reabilitação nacional contactaram a universidade com o objetivo de desenvolver jogos de RV focados no aumento de motivação através do uso de contextos mais próximos de atividades da vida real para a execução dos movimentos.

Esta dissertação estabelece a primeira iteração no processo de integração de RV na rotina de terapia ocupacional no centro de reabilitação, incluindo a avaliação de requisitos, estabelecimento da arquitetura geral do sistema, desenvolvimento de protótipos de jogos sérios para reabilitação e integração dos mesmos com uma base de dados remota e uma página web de configuração.

O trabalho foi concluído com um estudo formal de usabilidade e satisfação no uso das aplicações de RV com pacientes residentes no centro de reabilitação.

keywords Virtual Reality, rehabillitation, stroke, serious games, telerehabilitation.

abstract

In recent years, Virtual Reality has been shown to have considerable potential as a rehabilitation tool, as it allows the creation of Virtual Environments providing multiple stimuli that can motivate, engage or distract the patients. Moreover, VR applications may meet the four basic principles of rehabilitation: intensity, task oriented training, biofeedback and motivation, all pivotal factors for the success of rehabilitation programs.

Aware of this potential, and concerned with the lack of motivation of stroke patients while performing repetitive upper limb movements, a group of professionals working at a national rehabilitation center contacted the university to develop VR games aimed at increasing motivation by providing everyday life context to the movements.

This dissertation establishes the initial iteration towards the addition of VR to the occupational therapy routine in the rehabilitation center, including the assessement of requirements for the applications to be developed, establishment of the system architecture, development of rehabilitation game prototypes and integration with a backend database server and a configuration web page.

The work was concluded with a formal usability and satisfaction study with patients residing at the rehabilitation center.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

I: Introduction

1.1 Context

A stroke occurs when the blood flow is cut in a specific section of the brain, resulting in damage caused to the brain cells by the lack of oxygen and nutrients carried in the blood. The consequences of a stroke can be varied, depending on the injured part of the brain. They can range from immobilization of body extremities or even full limbs (a stroke on one side of the brain typically causes paralysis on the opposite side of the body) to the loss of cognitive aptitudes like speech (left brain) or vision (right brain).

A stroke can be caused by an extended range of behaviors (fat or salt excess in one's diet, high consumption of alcohol, inactivity, smoking …). The stroke is often a consequence of the repetition of a dangerous and unhealthy habit.

The mortality rate for diseases associated with the circulatory system, despite diminishing every year, is still the greatest in Portugal (in 2015, 29.7% of the mortality rate was attributed to circulatory system diseases, with malignant tumors being responsible for 24.5% of the deaths and Diabetes in third place with 4.1%).

The number of deaths caused by strokes is decreasing each year (from 2010 to 2015, the mortality rate of circulatory system diseases has decreased from 31.8% to 29.7%). However, surviving a stroke generally implies rehabilitation in order to recover from the loss of brain function, since the inability to perform the tasks related to the debilitated brain area remains after the stroke.

Traditional rehabilitation techniques usually involve the repetition of a specific physical task using the affected limbs or solving problems to recover cognitive functionality.

These treatments are usually performed in formal and controlled environments (clinics or rehabilitation centers) and require the constant presence and help of a doctor or therapist, to help the patient complete the exercise and monitor the results of the treatment.

Recently, with the development of accessible and easy to use Virtual Reality systems, there have been several attempts to use VR in the post-stroke rehabilitation treatment.

The use of Virtual Reality in rehabilitation scenarios presents several benefits: patients feel more comfortable by abstracting from the serious and formal environment of a clinic or rehabilitation center. These techniques can also increase motivation, through the use of competitive games in which the user gets feedback to perform better.

The accessibility of VR equipment also makes it possible for patients to keep practicing the exercises at home, preventing them from giving up on recovery or relying on incorrect postures or gestures after they've been released from the rehabilitation center.

Besides motivation, the use of VR and tracking technologies allows for the quantification of movement, which in turn allows doctors to monitor the patient's recovery remotely (usually through the internet or using a specific desktop or phone application). This process, along with the tools needed for the doctors or therapists to edit the exercise's conditions or goals, is defined as Telerehabilitation.

1.2 Objectives

The benefits of Virtual Reality in post-stroke therapy served as the basis for a collaboration between the 'Centro de Medicina de Reabilitação da Região Centro – Rovisco Pais' rehabilitation center and the University of Aveiro with the objective to develop, evaluate and include Virtual Reality applications in the routine exercises of patients recuperating mobility in the upper limb region after a stroke.

The general objective of this project was the development of Virtual Reality serious games aimed at helping in the recovery of patients residing at the rehabilitation center.

A secondary objective is to develop tools to allow the configuration and monitoring of the exercises remotely as initial work to evaluate the viability of the system in a Telerehabilitation setting.

The development of the system follows a participatory design, involving several meetings with doctors working at the rehabilitation center to ensure the applicability of the exercises, as well as tests with patients to access the usability and acceptance of the applications by the target audience.

1.3 Outline

This document is structured in 5 chapters, as follows:

- Chapter II – Virtual Reality for Rehabilitation Therapy and Pain Management: A presentation of previous work in the use of Virtual Reality applications in rehabilitation scenarios.
- Chapter III – Rehabilitation Applications Development and Integration: Description of the system developed including several mini-games for upper limb rehabilitation as well as a monitoring architecture to evaluate the possibility of remote use of the system. This chapter presents the project requirements, the system architecture, the hardware and software selection and the description of the developed applications and platforms.
- Chapter IV – Patient Tests: Report of the several tests performed with the system, in particular the tests performed at the rehabilitation center. These tests include both informal testing sessions with patients to evaluate and correct technical and usability errors in the developed applications as well as a formal study performed to test the validity of the final prototype as a rehabilitation tool that might be integrated in a patient's therapy routine.
- Chapter V – Conclusion and Future Work: Final remarks and contextualization on the current state of the collaboration between the university and the rehabilitation center. Also, suggestions for possible further developments on the project in order to upgrade it or solve current limitations.

II: Virtual Reality for Rehabilitation Therapy and Pain Management

2.1 Introduction

This section of the document describes previous work and studies using new technologies in a rehabilitation scenario, with an emphasis in Virtual Reality systems.

For this, the systems studied were divided in 3 distinct types: Movement tracking without VR; VR with no tracking and VR with tracking.

2.2 Movement Tracking Without VR

The first applications we present are based mainly on tracking systems. These can be divided in two groups: active system (using robotic exoskeletons) that help the execution of the desired gestures (i.e.: walking or reaching an object with the affected hand) and passive tracking equipment for training and assessment of the correct execution of the desired gesture.

2.2.1 Robotic Exoskeletons

These systems involve attaching mechanic exoskeletons to the patient's affected limb (i.e.: hand, arm or leg).

These exoskeletons tend to work in the following way: When the patient thinks 'I want to move', a signal is transmitted from the brain to the muscles involved in the desired movement. The signal sent from the brain is then detected by sensors attached to the patient's skin. The mechanic exoskeleton interprets the signal received and moves the patient's limb according to it (either through electrical stimulation or motor assistance). With the correct execution of the gesture, the brain confirms that the signal sent causes the desired movement, which translates as positive feedback and helps the brain re-learn how to emit the necessary signals to execute the gesture.

Some examples of exoskeletons used in rehabilitation are the Hand of Hope (HOH) exoskeleton[1] (used in rehabilitation of hand movement) (fig.1), the HAL® (Hybrid Assistive Limb®) exoskeleton[2] and the H2 robotic exoskeleton (Bortole et al., 2015) (both used for lower limb motion recovery) (fig.2).

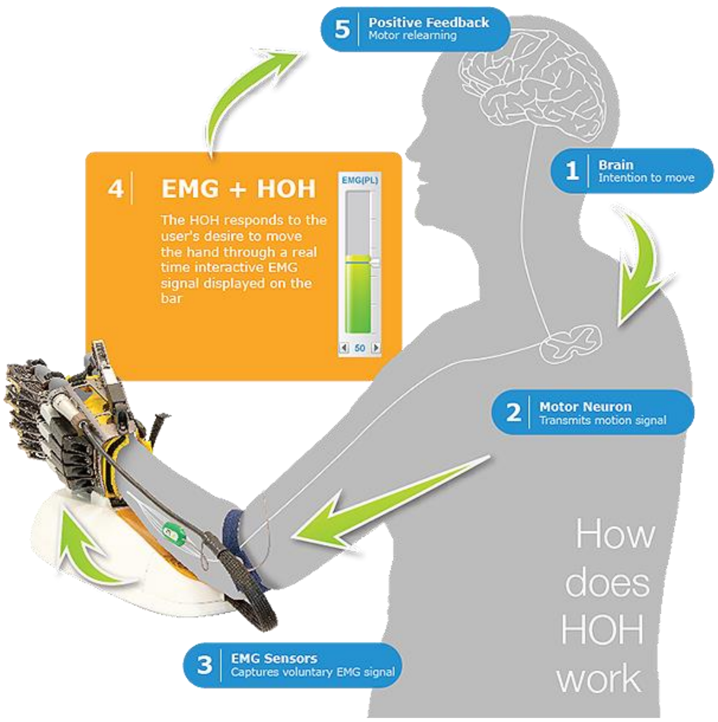

Figure 1: Hand of Hope (HOH)[1].

In their literature review assessing the usability of powered robotic exoskeletons in post-stroke rehabilitation of gait (Louie et al., 2016) concluded that the use of exoskeletal gait training 'can be used safely as a gait training intervention for sub-acute and chronic stroke'. It

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[1] http://www.rehab-robotics.com/hoh/
[2] https://www.cyberdyne.jp/english/products/HAL/

was noticeably beneficial for sub-acute (<7 weeks) stroke patients but no considerable benefit was noted for chronic (>6 months) patients when compared to traditional therapy methods.

So far, the major obstacle to the widespread use of robotic exoskeletons in rehab is the cost of the exoskeletons themselves and their maintenance (e.g.: the HAL exoskeleton is still in testing but ‘qualifying patients can purchase it in Japanese hospitals for $ 20.000’).

Figure 2: Lower limb rehabilitation exoskeletons: Left – H2 robotic exoskeleton; Right – HAL® (Hybrid Assistive Limb®).

2.2.2 Passive Trackers

While robotic exoskeletons actively help the patient execute the desired gesture and can be used in normal life, passive trackers are only used as part of the training routine for specific gestures.

These trackers (can be magnetic, mechanic or camera-based) digitize the patient's movement during the execution of a predefined gesture and quantify its accuracy and fluidity. The results can then be logged and displayed as feedback to ensure the correct execution of the gesture by the patient.

This real-time help can also be paired with a predefined program which includes a sequence of gestures to perform and the number of required repetitions.

Recently, solutions only using passive movement tracking without pairing it with virtual reality are rare, mainly due to the accessibility of virtual reality equipment and software. One of the most recent examples is the 'SWORD Health' solution[3] (fig.3), which uses wireless trackers to monitor the patients' movement and provides a logging and scheduling system that can be used by doctors.

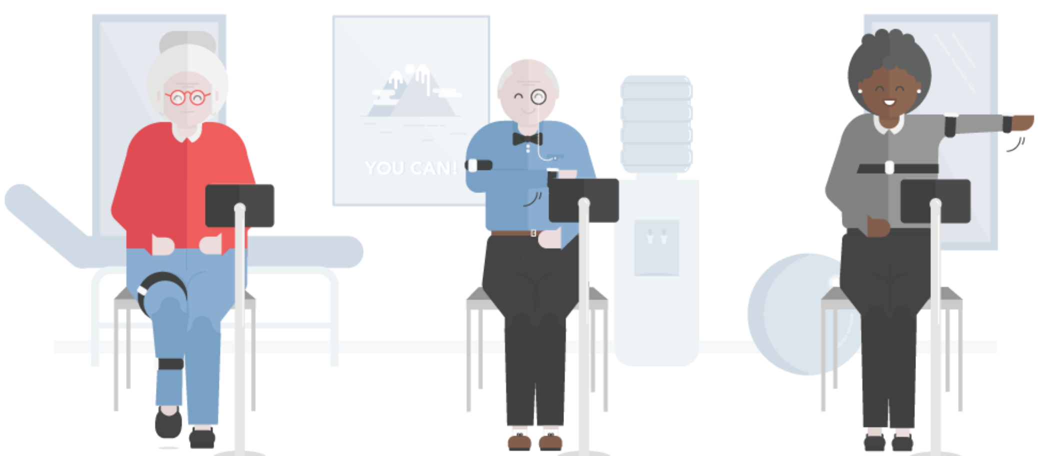

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Figure 3: SWORD Health stroke rehabilitation solution[3].

[3] https://www.swordhealth.com

2.3 VR With No Tracking

These solutions are used mainly to distract the patient during painful and uncomfortable treatment by immersing him/her in a relaxing or fun virtual environment ('Because of its immersive and distractive nature, researchers believe that VR may be safer and more effective than traditional analgesic methods' (Liu et al., 2016)).

VR might be a viable alternative to traditional methods for pain treatment that relies on the use of pharmaceutical drugs, although other options are available (some more common, like physical therapy, some more unusual, like hypnosis or acupuncture). Though these methods work, they also present several limitations: some lead to negative side effects (pharmaceutical drugs can induce dependency or cause new healthy problems), others require very specific circumstances to be properly implemented (therapies like acupuncture and hypnosis can only be performed in certain settings).

The use of Virtual Reality as a pain-relieving method has many convincing arguments in its favor:

- Can be interactive, as the content is displayed in real time.
- The process can be started and stopped at any time, unlike a pharmaceutical drug (of which the effects can last for hours after the treatment).
- Can be tailored for the patient (there are many virtual environments to choose from).
- May motivate the patients to do and even enjoy the treatment, unlike other approaches which only make them easier to endure.

Although the use of Virtual Reality cannot directly help the patient cure his/her disease or physical condition, it can be successfully applied as a pain-relieving method.

In a literature review study performed in 2016 (Liu et al., 2016), over 100 articles studying the use of Virtual Reality for pain management were analyzed in order to find a general consensus on whether or not it is a dependable method.

The review evaluates the efficacy of VR therapy, compares it with traditional methods and also explores 'novel or unusual' approaches as possible paths to invest on in future research (Georgoulis et al., 2010; Konstantatos et al., 2009; Schneider et al., 2011).

When evaluating the efficacy of Virtual Reality therapy, researchers participating in the reviewed studies inspected the subjects' 'pain, anxiety and other relevant sensory and emotional levels' before and after they received the Virtual Reality treatment.

The efficacy of the therapy would be evaluated according to the changes in sensory and emotional levels monitored.

All the articles (Baños et al., 2013; Botella et al., 2013; Sato et al., 2010; Villiger et al., 2013) reviewed revealed positive results 'which meant VR therapies helped the patients to improve their mental status'. The obtained results are not comparable to traditional pain-relieving methods as only VR therapy was tested. Also, no conclusions could be determined regarding the effect of the Virtual Reality therapy in the overall recovery of the patients as the improvement in mental state could be attributed to both VR therapy and the subject's self-recovery.

When comparing Virtual Reality treatment to other analgesic methods (Gold et al., 2006; Gordon et al., 2011; Hoffman et al., 2007, 2008, 2009; Kipping et al., 2012; Loreto-Quijada et al., 2014; Maani et al., 2011; Miller et al., 2011; Nilsson et al., 2013; Patterson et al., 2010; Rutter et al., 2009; Schneider et al., 2007; Windich-Biermeier et al., 2007), the pain-relieving effects of VR were compared to a varied array of different techniques, including 'TV programs, music, books or even lollipops'.

Two different experiment designs were used: a within-subject style, in which the same group of subjects received both treatments, with the assessment inquiries being performed afterwards to conclude which of the methods obtained better results and a between-user style, in which the subjects were divided in separate groups, one group receiving the VR therapy and the other the traditional method.

The overall analysis achieved by (Liu et al., 2016) revealed that 80% of the articles concluded that the VR therapy has great potential regarding pain-relieving treatments, 'not only because it was proven to be effective among sick and healthy subjects but also because it had very little side-effect and was much safer than other aggressive or offensive therapies'.

Several works focused not on comparing the VR therapy with the more commonly used methods but on the changes caused in the treatment by circumstantial and technical differences in the VR system used.

- HMD quality: One article (Hoffman et al., 2006) compared low quality head mounted displays with more recent, high quality ones and concluded that higher quality rendering equipment led to better results.
- Environment presented: Another study (Mühlberger et al., 2007) assessed the efficacy of using cold Virtual Environments for patients suffering from heat related pain and hot Virtual Environments for patients with cold related injuries. It was concluded that this circumstantial adaptation caused no significant benefit.
- View: One study (Dahlquist et al., 2010) compared the use of a first-person view in the Virtual Environment with a third-person view. Although the first-person view was expected to obtain better results (due to being believed to be more immersive), no significant improvement in pain tolerance was noted.
- HMD/Desktop: Three studies (Dahlquist et al., 2010; Gordon et al., 2011; Magora et al., 2009) compared the use of HMDs with a non-immersive version of the Virtual Environment and 'concluded that the value of HMDs was questionable', but this was only a secondary objective of the projects so no finite conclusions could be reached (according to (Dahlquist et al., 2010), 'the VR helmet may help children ignore extraneous stimuli in the clinical environment that might otherwise interfere with focusing their attention on a videogame' but all three studies were performed in settings 'free of unintended distractions', so there was no real need for the user to be fully isolated from his/her environment by using the HMD).
- VR Reality acceptance: In one article (Schneider et al., 2011), 137 patients undergoing chemotherapy participated in 3 experiments with the aim of exploring the variation in effectiveness of VR as a distraction across factors like age, gender, anxiety, tiredness and diagnosis. The virtual scenarios used were PC games, presented with a HMD. This study concluded that it should not be assumed that every patient will accept Virtual Reality as a valid distraction while undergoing treatment. The work also showed that women being treated for breast cancer experienced the strongest altered time perception while lung cancer patients experienced the weakest.

Although most articles reached the conclusion that Virtual Reality therapy was an effective treatment for pain management, one study (Konstantatos et al., 2009) diverged from this trend.

In this study, 86 patients suffering from burn injuries were divided in 2 groups, one of which would receive an intravenous morphine PCA infusion and the other would take the same infusion paired with the VR therapy. These treatments were applied as a pain reliever for awake dressing changes for the burn injuries.

The results revealed that the patients who had both taken the morphine infusion and undergone the VR treatment demonstrated a significant increase in pain intensity during and after the dressing changes.

No global conclusions can be obtained as this study was the odd one out in the total reviewed, but it opened the path for more focused research in the future.

In conclusion, Virtual Reality therapy appears to be an effective and competent method for pain relieving, having the added benefit of being non-invasive treatment and, being part of an always growing branch of technology, can be expected to become more impactful with the passing of time.

2.4 VR With Tracking

This type of solution joins the monitoring of the user's movements (using trackers) with the distraction from the clinical setting through the creation of virtual environments and fun, game-like scenarios.

These solutions, instead of using passive virtual environments which are only meant to distract the patient, tend to incorporate games in which the patient performs a set of tasks that require the use of the affected limbs (for physical therapy) or involve solving problems related to the cognitive aptitudes weakened by the stroke.

When treating loss of limb mobility, movement trackers can be used by the patient to navigate the virtual scenario while ensuring the correctness of the gestures to train.

In a literature review (Laver et al., 2015) focused on determining 'the efficacy of virtual reality compared with an alternative intervention or no intervention on upper limb function and activity', 37 different studies were analyzed, incorporating multiple approaches (scooter driving re-training (Jannink et al., 2008); public transport use re-training (Lam et al., 2006), etc.) and several technologies, from commercial gaming systems like the PlayStation EyeToy (Yavuzer et al., 2008) to more expensive and difficult to obtain equipment like the GestureTek IREX, a camera-based full body tracker (Jo et al., 2012; Kwon et al., 2012).

After analyzing the 37 studies, the authors of the literature review concluded that 'use of virtual reality and interactive video gaming may be beneficial in improving upper limb function and ADL (Activities of Daily Living) function when used as an adjunct to usual care (to increase overall therapy time) or when compared with the same dose of conventional therapy' (Laver et al., 2015). However, due to 'significant heterogeneity between studies… it is unclear which characteristics of the intervention are most important'.

2.5 Alternative Approaches

Unlike Virtual Reality, where the user interacts with a fully virtual environment, Augmented Reality places the user in the real world, while adding virtual elements to it.

The main advantage of this technology in rehabilitation is the ability to allow the patient to still see his/herself while interacting with the virtual elements in the environment (e.g.: in a study conducted in 2016 (Liu et al., 2017), one of the developed applications requested the patient to place a virtual mug in a virtual shelf. While the shelf and mug were virtual, the patient could still see his/her real hand performing the actions.).

Another benefit of using Augmented Reality is the use of tangible interfaces. Natural or artificial markers are real objects that, when captured by the system's camera, are re-rendered as different virtual objects to be used in the application's scenario. Having these markers present in the real world allows easier and quicker changes to a game's settings during its execution (e.g.: if the objective of a task is to place one marker on top of another, if the goal marker is too far for the patient to reach, a doctor or therapist can move it closer to the patient's position).

The use of this technology has, so far, obtained positive results as part of rehabilitation therapy, comprising "obvious advantages in comparison with traditional rehabilitation methods, can be applied to hand rehabilitation training in daily life." (Liu et al., 2017; Trojan et al., 2014; Luo et al., 2005).

Another technology with promising use in post-stroke therapy is Telerehabilitation.

Telerehabilitation represents the use of network communication between the applications used by the patients and control portals used by doctors or therapist, which are used to monitor the patient's progress and update the settings of the end user applications. This standard, if proven to be reliable, could allow the expansion of rehabilitation therapy from clinical environments to the patient's home, as well as let doctors check on patients quicker (by using the internet instead of having to meet in person as often).

In a literature review (Laver et al., 2013) focused on determining 'whether the use of Telerehabilitation leads to improved ability to perform activities of daily living amongst stroke survivors when compared with (1) in-person rehabilitation (when the clinician and the patient are at the same physical location and rehabilitation is provided face-to-face); or (2) no rehabilitation', after several studies were analyzed, the authors concluded that although 'Evidence is currently insufficient to guide practice', 'The potential advantages of Telerehabilitation are clear and have the potential to facilitate access to services (thereby improving equity) and reduce costs associated with providing rehabilitation programs'.

III: Rehabilitation Applications Development and Integration

This chapter describes the developed applications. It starts by presenting the requirements for the system established with the help of doctors working at the rehabilitation center and the architecture implemented.

3.1 Approach

In order to plan the type of applications to develop, several meetings with the doctors of the rehabilitation center were scheduled. At these meetings, existing methods for the assessment of a patient's progress during treatment were discussed. The treatments are evaluated using one of the following tests (a detailed description of each test is presented in 'Annex I – Therapy assessment tests'):

- Box and Block Test
- Fugl-Meyer Assessment
- Action Research Arm Test
- Frenchay Arm Test
- Enjalbert Test

The Enjalbert test is a well-established test used at the center, presenting the following five levels:

- Raising the affected arm and holding the position.
- Bringing the affected hand to the mouth.
- Opening and closing the affected hand (for the closing motion, the grip strength is measured by asking the patient to squeeze the doctor's fingers).
- Touching the index and middle fingers with the thumb (pinch gesture).
- Touching the ring and pinky fingers with the thumb (also pinch but harder to execute).

Due to the simplicity of the test, along with the fact that it does not require any additional equipment (other tests require the use of specific items: the Fugl-Meyer test uses a tennis ball; the Action Research Arm test uses a specially designed table, etc.), it was decided that the initial prototypes to be developed would replicate the gestures of the Enjalbert test.

It was also decided that it would be interesting to monitor the patients' gestures during the game and make this information available in a web page to evaluate the possibility of monitoring the evolution of the patients

3.2 System Architecture

Based on the initial requirements, it was decided to implement a system composed of 3 components (fig.4).

- Game Applications: Virtual Reality applications/games where the patients use relevant hand and arm movements to complete tasks. The completion parameters for each of these games are defined by a doctor through the Configuration Page.
- Backend server: A HTTP server which regulates the access to the database (where the data relating to the patients, games and tests is stored) and to the configuration web page.
- Configuration web page: an interface where the doctors can add/edit patients, games and tests, as well as consult the data relative to the progress of the patients (test completion success, improvements in mobility).
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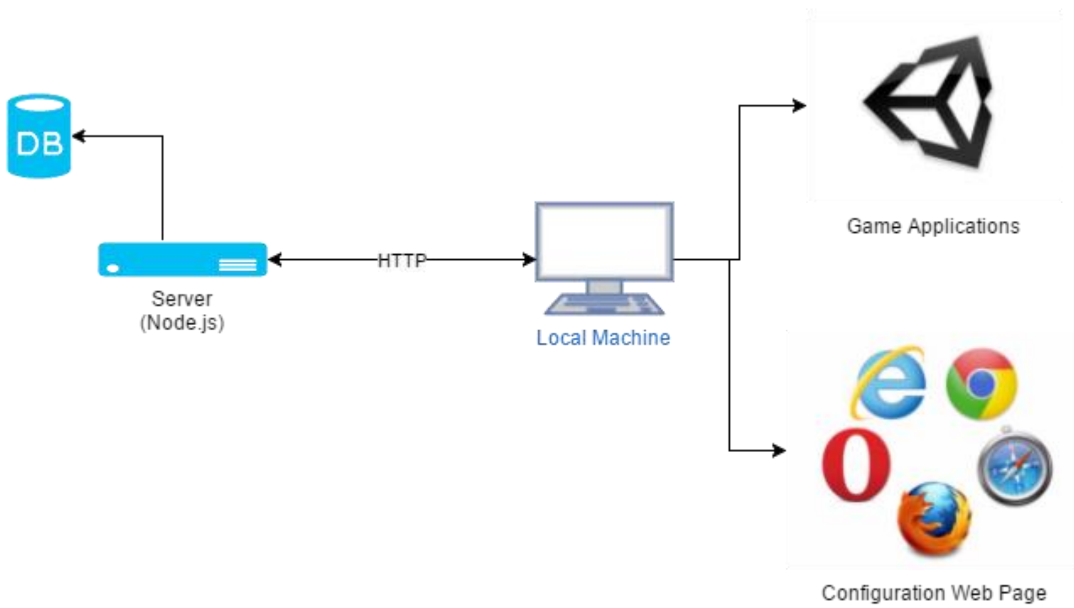

Figure 4: System Architecture.

3.3 Technologies Used

After the system architecture was established, the technologies to be used were selected. This section describes the chosen hardware and software as well as the reason for choosing it.

3.3.1 Hardware

In the context of the project, 2 specific types of hardware were required: a tracker to monitor the user's movements and a stereoscopic display to provide full immersion during the use of the Virtual Reality applications.

Trackers:

From the available equipment, 2 sensors were chosen to track the patients' gestures: The Leap Motion[4] and the Kinect v2[5].

Out of the 2 available trackers, the Leap Motion (fig.5) was chosen, being a low-cost controller (~70€ from the official distributer) which would allow the patients to purchase one for themselves and use the rehabilitation applications at home, as well as the easy integration with the Unity Engine (official plugins and assets are provided and keep up to date) and the 'plug and play' interface on Windows systems.

With this controller, fine hand movements (particularly finger pinches) can be monitored, due to the small interaction area in which it operates.

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[4] https://www.leapmotion.com/
[5] https://developer.microsoft.com/en-us/windows/kinect

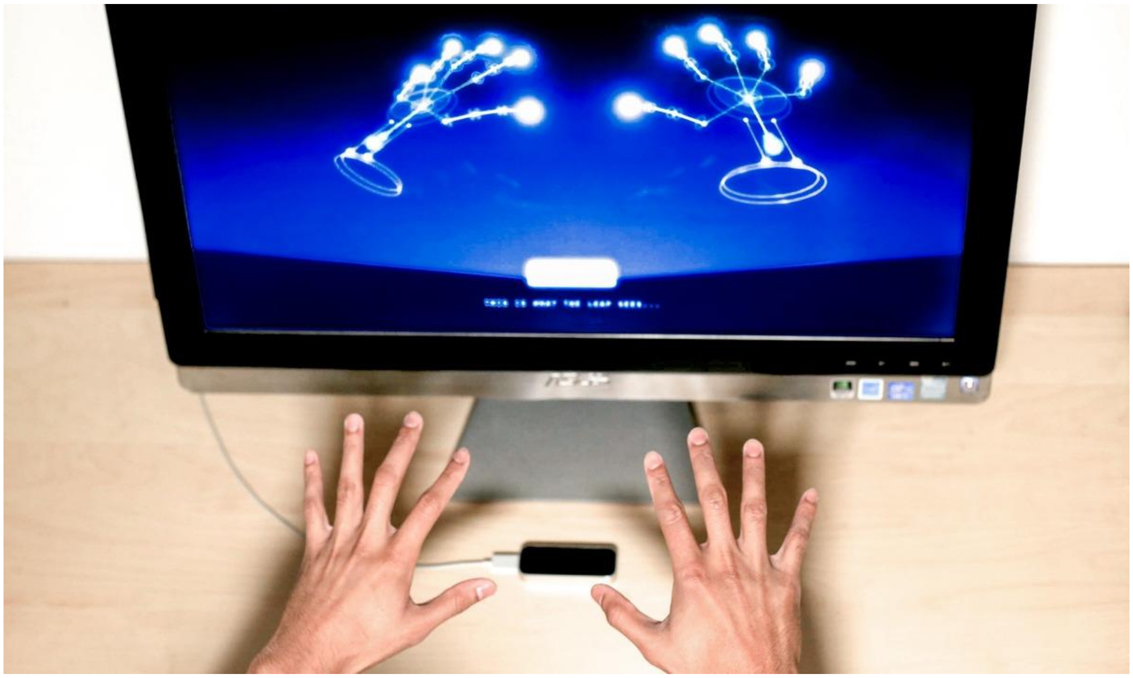

Figure 5: Leap motion tracker[4].

Although the official interaction area defines the limits of distance to the controller at ~61 cm, empirical use of the device revealed that the position of the hand can be accurately tracked up to around 1.5 m away from the controller but, with larger distances, the tracking of fine movements (pinch specifically) becomes less reliable.

The Kinect motion tracker, like the Leap Motion, was used to track the player’s movements but, unlike Leap, the games developed with this controller were focused in rough upper body movements.

The Kinect sensor was only used for preliminary works as none of the developed applications were tested with patients.

Display:

Apart from the non-immersive PC screen used to play the mini-games, the fully immersive Oculus Rift Dk2[6] Head Mounted Display (HMD) (fig.6) was also used.

This device, apart from allowing full immersion in the virtual environment, is also equipped with an accelerometer and a gyroscope to track head movements, allowing the players to look around in the virtual environment. Using this equipment, the benefits of using full immersion during treatment could be analyzed.

Due to the lack of drivers for the integration of the hardware with most laptop computers (the DK2 software requires the HDMI input of the Head Mounted Display to be connected directly to the HDMI port of the graphics card which is not available in laptop PCs with mobile graphics cards), the Oculus was installed in the computer provided by the rehabilitation center, a desktop computer.

This setup was used for the tests executed by the patients at the rehabilitation center as well as the preliminary tests performed at the university.

Figure 6: Oculus Rift Dk2 Head Mounted Display.

[6] https://www.oculus.com/

3.3.2 Software

Regarding software, the relevant technologies chosen were: a game engine (integrated development environment focused on game development) and the runtime used to manage the database access and provide the configuration web page.

Game Engine:

Several game engines are available to develop games (Unity, Unreal, CryEngine, etc.). Unity[7] was the selected engine due to its ease of use, large and active community and previous knowledge of the platform. The Unity engine also provides easy integration with the available equipment since it has native support for fully immersive Oculus Rift HMDs and official packages and example projects for the Leap Motion and Kinect controllers.

Backend Server:

The backend server used to manage the database and provide the configuration web page was developed with the JavaScript runtime 'Node.js'[8]. This is an 'asynchronous event driven runtime, designed to build scalable network applications'.

Using this platform, the database access was controlled through a REST server, while the configuration page was provided by an additional server.

The Node.js runtime was chosen over other alternatives (python, php, Java) because of the familiarity with the technology.

[7] https://unity3d.com/
[8] https://nodejs.org/en/

3.4 Virtual Enjalbert Test

The virtual Enjalbert test was the first application developed. The objective was to develop an application with gestures that are important for upper limb rehabilitation and also evaluate the Leap Motion tracking capabilities in this context.

3.4.1 Application Description

The virtual Enjalbert Test (fig.7) application is divided in 5 levels, each one corresponding to a task performed in the test. For each level, the task to be completed is displayed in text form and, in some cases, visual hints using color were also used (fig.7).

In order to adapt the test to the patient using it, some configurable parameters were used. These parameters can be set using the Configuration web page, which accesses the database server. Both these components are further described in the ‘Backend Server and Configuration Page’ section.

It was established that only the user’s affected hand (hand suffering from the post-stroke lack of mobility sequels) could be used. If the user tried to use the non-affected hand, or both hands, no progress in the execution of the tasks would be allowed.

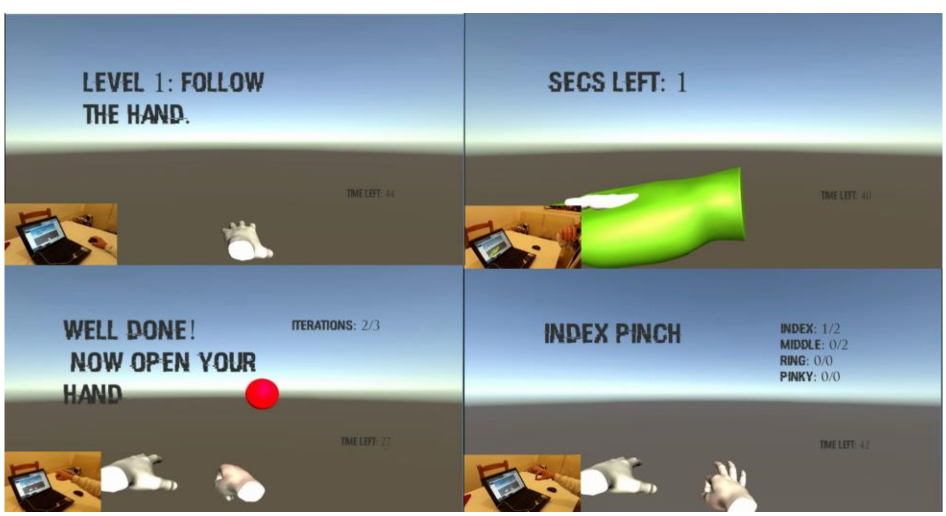

Figure 7: Virtual Enjalbert Test – screenshots.

Table 1 presents the description of each level, along with its configurable parameters:

Table 1: Virtual Enjalbert Test – Level Description.

Enjalbert Level	Virtual Task Description	Configurable Parameters
1 – Lift Arm and Hold	The user's affected hand must follow the path of a virtual hand gameObject, starting in a resting position and rising upwards until it reaches the goal position; after reaching the goal altitude, the player must wait for a time to complete the task and move on to the next level. The number of seconds left to wait at the highest point is displayed in text and, for each second waited, the virtual hand becomes greener.	**Vertical Distance:** distance between rest and goal positions for the affected hand. **Hold Time:** number of seconds to hold in highest position. **Tunnel Space:** horizontal margin inside which the user's hand must remain while lifting the affected hand (used to prevent muscle spasms which would cause the gesture to be erratic).
2 – Bring Hand to Mouth	Similar to the previous task but, instead of having to lift the affected hand only vertically, the user must bring the affected hand towards his/her general mouth area and hold it there for a predefined time.	**Vertical Distance:** establishes the height of the user's 'mouth zone' *1. **Horizontal Distance:** depth distance between the hand's rest position and the user's 'mouth zone' *1. **Hold Time:** number of seconds to hold in goal position. **Tunnel Space:** horizontal margin of error for the user's movement**.**
3 – Open/Close Hand	In this level, the user must open and close his/her hand a pre-established number of times, holding the hand in that state for a specific number of seconds before moving to the next state. When moving from one hand state to another, a sphere present in the virtual environment will change color according to how close the user's hand is to reaching the expected state (from red to green).	**Margin:** allowed error margin for the hand state *2. **Hold Time:** number of seconds to hold in goal hand state. **Iterations:** number of iterations required to complete the level.
4 – Index and Middle Finger pinch	In this level the user must execute a pre-established number of pinches with his/her index and middle fingers. The number of executed pinches for each finger, as well as the number of pinches required to complete the task, is displayed in text form.	**Total Index Finger Counts:** number of index finger pinches required to complete the level. **Total Middle Finger Counts:** number of middle finger pinches required to complete the level.
5 – Ring and Pinky Finger Pinch	Similar task to the previous one, but counting the ring and pinky finger pinches executed by the user.	**Total Ring Finger Counts:** number of ring finger pinches required to complete the level. **Total Pinky Finger Counts:** number of pinky finger pinches required to complete the level.

*1: this method of establishing the position of the user's mouth was later deprecated in favor of a method where the user defines the position of his/her mouth during the execution of the game.

*2: The state of the user's hand in the application ranges between 0 and pi radians (i.e.: a value of 0 corresponds to a fully open hand, 3.14 defines a fully closed hand). This variable applies threshold by which the virtual test accepts the users hand state (e.g.: values lower than 0 plus margin are processed as an open and state).

3.4.2 Feedback and Concluding Remarks

The development of the Enjalbert Unity application showed that the sensor used (Leap Motion) can track the desired movements effectively, apart from some limitations:

- Unfavorable external light conditions can make the sensor lose track of the user's hands.
- Pinch movements with the middle and ring finger may be falsely tracked as index and pinky finger pinches, respectively.

In order to get some feedback, a video demonstrating the use of the application was made and sent to the doctors at 'Rovisco Pais'.

Although the doctor's agreed that the gestures used in the Enjalbert test would be a good basis for the development of the virtual reality application and that the Leap Motion sensor could be used to track the patients' movements, some emphasis was put in the need for the applications to integrate more realistic scenarios and concepts as well as providing a more entertaining experience.

With this knowledge, the project progressed towards the development of a new application, this time with the perspective of creating serious games, while still using the same movements required for the completion of the Enjalbert test.

Since the Virtual Enjalbert Test application was deprecated, neither its appearance or configurability was improved any further.

3.5 Five Rehabilitation Mini-Games

The scenario and concept of the games developed was kept somewhat tame in accordance with the advice given by the rehabilitation doctors, who expressed the need for the games to relate to real-life activities. This way, the patients would be able to establish a stronger connection between the success in the game and the progress towards autonomy and a regular life. With this in mind, 5 serious games (fig.8) were developed mimicking the 5 main gestures evaluated in the Enjalbert test.

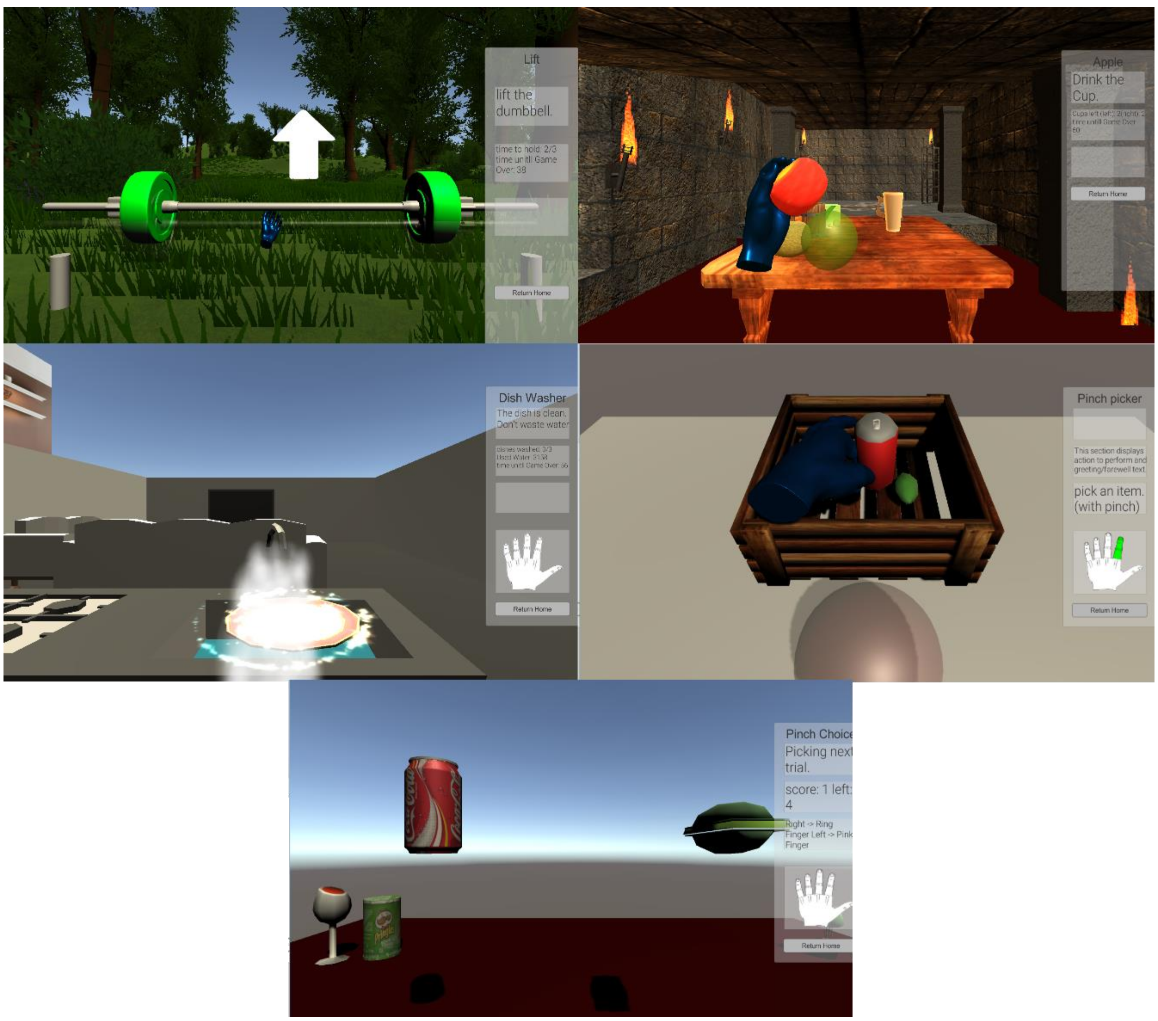

Figure 8: Rehabilitation Mini-Games. (top to bottom): Lift, Apple Eater, Dish Washer, Pinch Picker and Pinch Choice.

3.5.1 Lift

The ‘Lift’ game (fig.9) focuses on the action of raising the affected arm and holding the position.

In this game, the user must lift a virtual dumbbell past the goal position (represented by a translucent version of the dumbbell) and hold it above this position for a pre-established time.

In order to lift the dumbbell, the patient must position the affected hand below it and raise it vertically. As this level was supposed to be available to patient which still could not reliably open and close the affected hand, it was decided that it should not be required for the patient to grab the dumbbell bar to lift it.

After waiting for a pre-defined number of seconds, the patient must bring the dumbbell back down (bringing the affected hand to a resting position) before moving it back up again.

The mini-game would be complete after the patient completed a pre-determined number of iterations of the task.

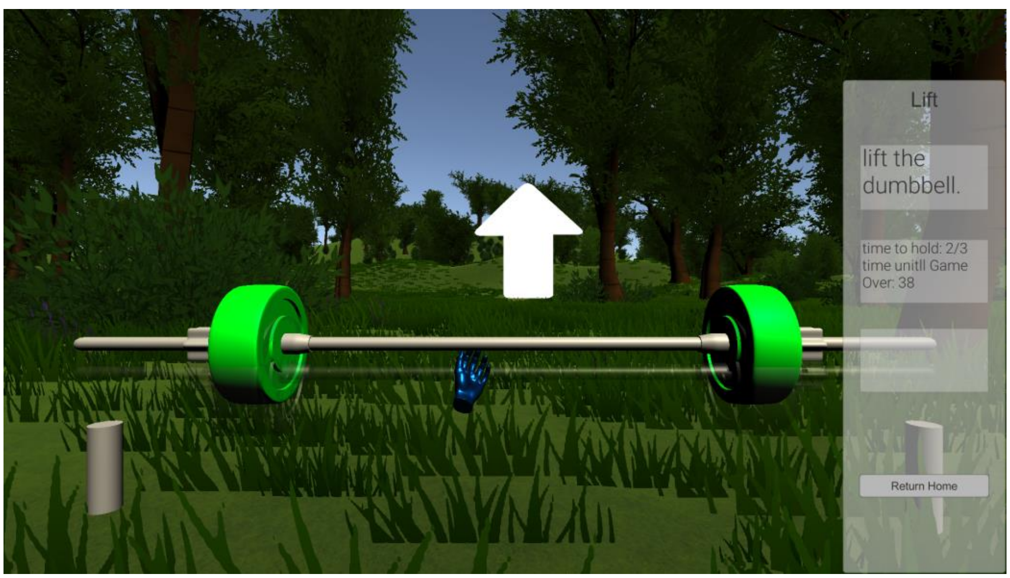

Figure 9: Rehabilitation Mini-Games - Lift.

The parameters used to configure the game are presented in table 2.

Table 2: Lift – Game Parameters.

Variable	**Description**
Language	the language to be used in the game's messages and menu items.
Hand	the patient's affected hand.
Distance (m)	the length the dumbbell must be lifted.
Time to Hold (seconds)	number of seconds the dumbbell must remain above the goal height for an iteration to be completed.
Number of iterations	number of times the exercise must be done for the game to be completed successfully.
Time between iteration (seconds)	resting time between iterations.
Total time (seconds)	total time allowed for the execution of one iteration.

3.5.2 Apple Eater

The ‘Apple Eater’ game (fig.10) focuses on the action of bringing the affected hand to the mouth.

The user is presented with two apples placed on top of a table and must reach for one of them, grabbing it, and subsequently bring it to his/her mouth. This action must be repeated until no more apples are on the table.

The two apples are placed on opposite sides of the table (left and right) and the number of times the user must ‘eat’ each one before it disappears can be pre-configured.

Before the user can reach for the apples, his/her mouth position must be defined. To do this, the user’s hand must be placed on his/her mouth area and the ‘space’ key pressed on the keyboard. This establishes the virtual location of the user’s mouth to be used as goal position of his/her hand for each iteration.

Because this game was intended to be accessible to patients who have not yet regained full control over opening/closing their hands, it is only necessary for the user’s hand palm to reach an acceptable distance from the center of the apple in order for the virtual hand to grab it (regardless of whether the hand is open, closed or neither).

Figure 10: Rehabilitation Mini-Games - Apple Eater.

The parameters used to configure the game are presented in table 3.

Table 3: Apple Eater – Game Parameters.

Variable	**Description**
Language	the language to be used in the game's messages and menu items.
Hand	the patient's affected hand.
Green apple Quantity	number of green (left) apples/iterations.
Red apple Quantity	number of red (right) apples/iterations.
Apple margin (dm)	minimum distance between hand palm and goals (apple/mouth).
Time between iteration (seconds)	resting time between iterations.
Total time (seconds)	total time allowed for the execution of one iteration.

3.5.3 Dish Washer

The ‘Dish Washer’ game (fig.11) focuses on the action of opening and closing the affected hand.

In this game, the goal is to wash a sequence of dishes by turning on the faucet of a virtual sink, while trying to control the amount of water used (by keeping the faucet turned off in the moments when no dish is present to be washed).

For each dirty plate that appears inside the sink, the user must open the affected hand (turning the faucet on) and keep it open until the dish is clean (this event is announced by a sparkle effect on the dish), at which point the user must close his/her hand and wait for another dirty dish to appear.

If at any time the user closes his/her hand before the dish is fully clean (iteration complete), the number of seconds waited is reset and the dish is returned to its original state. After a pre-defined number of dishes is washed the game ends.

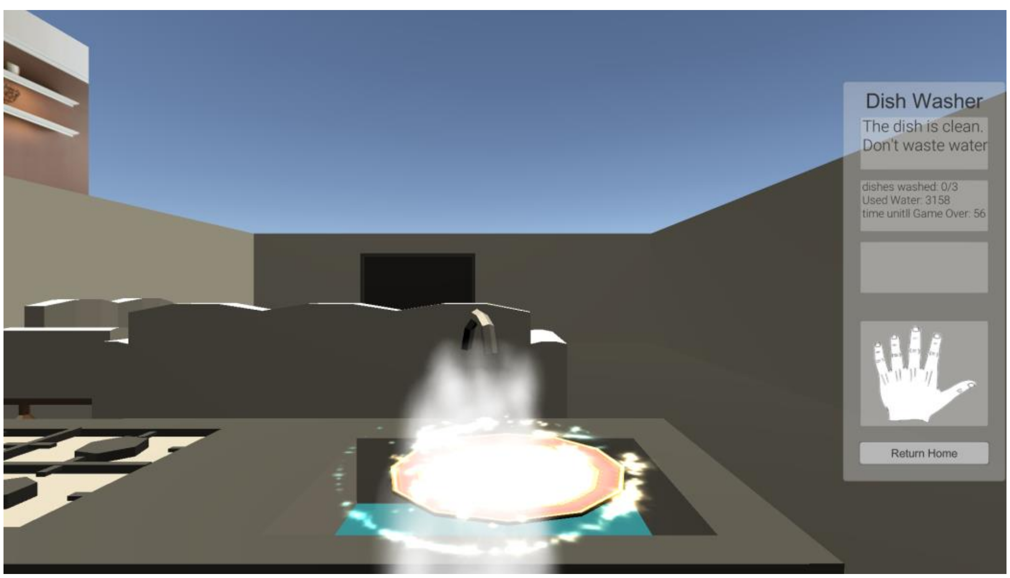

Figure 11: Rehabilitation Mini-Games - Dish Washer.

During the development of the first prototype, in order to turn the faucet on, the user was required to close the affected hand. This was changed in later prototypes so that the required movement to turn on the faucet was fully opening the affected hand.

This change was advised by the doctors at the rehabilitation center, as the stroke recovery patients tend to start with a contracted hand, so the more relevant exercise would be holding the hand in an open state instead of closing it.

For the purpose of providing additional information regarding the detection of changes in the hand state, a 2D representation of a hand was added to the virtual environment, placed in a panel to the right of the user’s point of view.

The 2D hand is presented as closed when the system considers the user’s hand to be closed, otherwise it is open (fig.12).

This panel is only visible to the patient in the non-immersive version of the game. When using the HMD, the panel will only be visible in the PC screen, providing the information to the doctor/therapist accompanying the patient during the execution of the exercise. This information is provided as additional feedback, while the turning on and off of the virtual faucet is used as direct feedback for the patient.

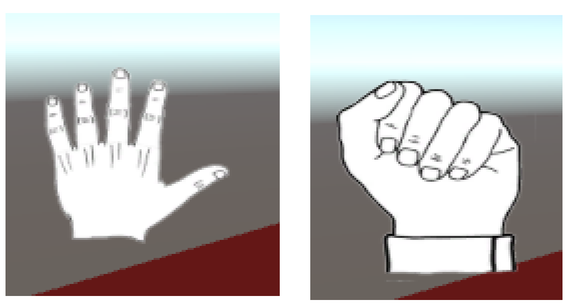

Figure 12: Rehabilitation Mini-Games - Dish Washer – Hand state feedback.

The parameters used to configure the game are presented in table 4.

Table 4: Dish Washer – Game Parameters.

Variable	Description
Language	the language to be used in the game's messages and menu items.
Hand	the patient's affected hand.
Grab Margin (rad)	threshold for hand state changes (if the value is 0, all fingers must be fully extended and perfectly aligned to the hand palm for the hand to be considered open; with higher values the game will recognized the hand as open in less strict circumstances both relating to finger extension and the angle with the hand palm.
Number of Iterations	number of dishes to wash.
Time to Hold (seconds)	number of continuous seconds the affected hand must be open for each iteration.
Time between iteration (seconds)	resting time between iterations.
Total time (seconds)	total time allowed for the execution of one iteration.

3.5.4 Pinch Games

The first pinch game ('Pinch Picker' – fig.13) focuses on the index and middle fingers.

In this game, the player is presented with a wooden box containing two types of items, red soda cans and green limes. The purpose of the game is for the player to pick the items and drop them in a specific zone using pinch gestures.

The item's color defines which kind of pinch must be used to pick them. Red items are picked with an index pinch while green items require a middle pinch.

Figure 13: Rehabilitation Mini-Games - Pinch Picker.

The second pinch game ('Pinch Choice' – fig.14) focuses on the ring and pinky fingers.

In this game, for each iteration, the player is presented with a choice between two different items and he/she must choose one of them by executing a pinch gesture with the finger on the same side as the item (i.e.: if the player is using the left hand, a right finger pinch is used to choose the item on the right while a pinky finger pinch chooses the item on the left).

During the execution of the game, the user's score (number of right answers) is counted to be presented at the end.

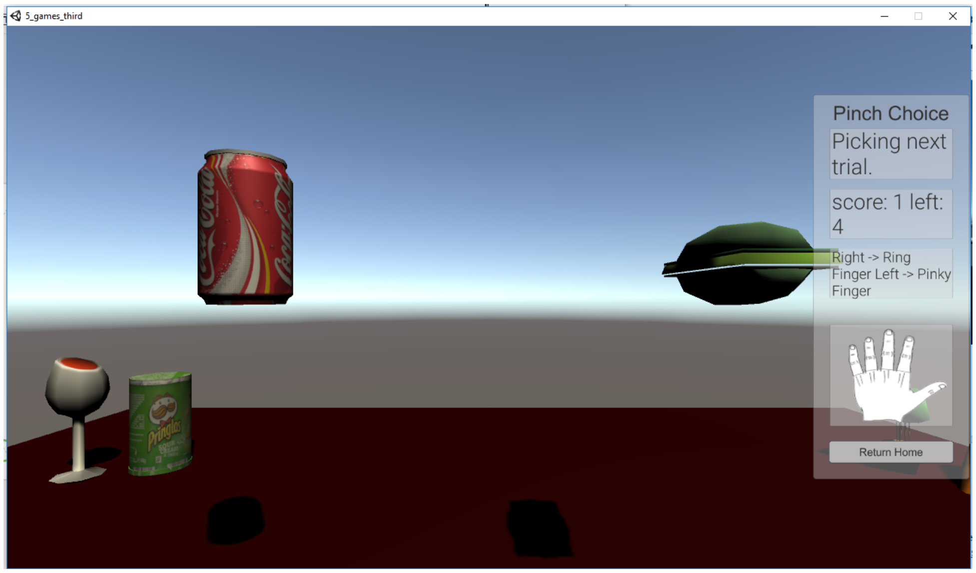

Figure 14: Rehabilitation Mini-Games - Pinch Choice.

These games were not developed further than the first prototype phase because, when testing them with the doctors, it was concluded that detection of a specific pinch was not reliable for users who are not familiar with the Leap Motion sensor, which would be the case with the large majority of the patients.

3.5.5 General Game Definitions

Although each game is specified for a particular movement, some parameters and rules were applicable across all mini-games, such as:

- Only the affected hand must interact with the virtual environment. This way, if the system detects both of the user's hands, no hands or just the non-affected hand, an error message is displayed (different messages appear for 'wrong number of hands' or 'wrong hand detected' scenarios) and the game will not progress until the situation is corrected. This is done to prevent users from cheating the game by using their healthy hand or helping the affected hand's movements with the other hand.
- The language of the games can be set to English (default) or Portuguese. This was done due to the fact that most patients being rehabilitated at 'Rovisco Pais' are not English speakers.
- The object models used to create the virtual environments of the games were taken from free assets published on the Unity store.

Game Instance Parameters:

Each of the 5 developed mini-games is defined by a 'type', which is used when contacting the database server (described in the 'Backend Server and Configuration Page') in order to get the specific game parameters and objectives for a mini-game instance.

When the game application is executed, the program contacts the backend server (making a REST request) and receives the set parameters for the game.

The following JSON block is an example of a REST reply containing the parameters for an instance of a game.

Request url: /getGameById?id=0&type=0

Reply body:

```
{
 "left_hand": true,
 "language": 0,
 "total_time": 60,
 "distance": 0.3,
 "time_to_hold": 3,
 "total_interactions": 3,
 "time_between_interactions": 2,
 "id": 0,
 "custom_name": "Ricardo - Lift",
 "name": "Lift",
 "type": 0
}
```


The parameters for each game instance can be modified through the configuration web page (using a form similar to the example in fig.15).

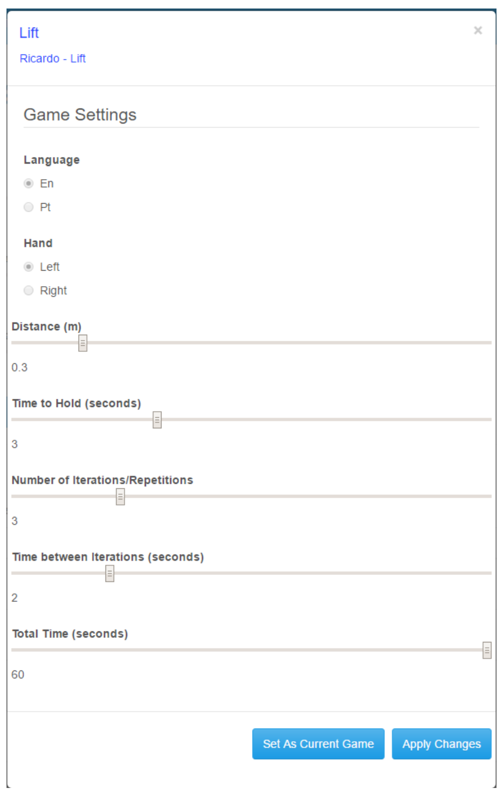

Figure 15: Mini-game Configuration Form.

After the user completes a game or the time to execute an iteration runs out (game over), the application sends the results to the backend server using the POST request with the '/sendGameResults' (the full REST API used to interact with the backend server is present in 'Annex IV - Backend Server API').

3.6 Patient Movement Calibration

An application was developed to allow the configuration of some variables according to each patient. The editable values are the maximum vertical distance the patient can lift the affected hand and the thresholds for fully open or fully closed hand states.

These variables are especially relevant for the games tested with patients (‘Lift’, ‘Apple Eater’ and ‘Dish Washer’).

In this application, after selecting his/her name from the patient list, the patient is presented with a virtual environment containing a virtual hand representation and a 2D panel displaying the current values.

The patient (accompanied by a doctor or therapist) can then update one or more variables and send the new values to the server (fig.16).

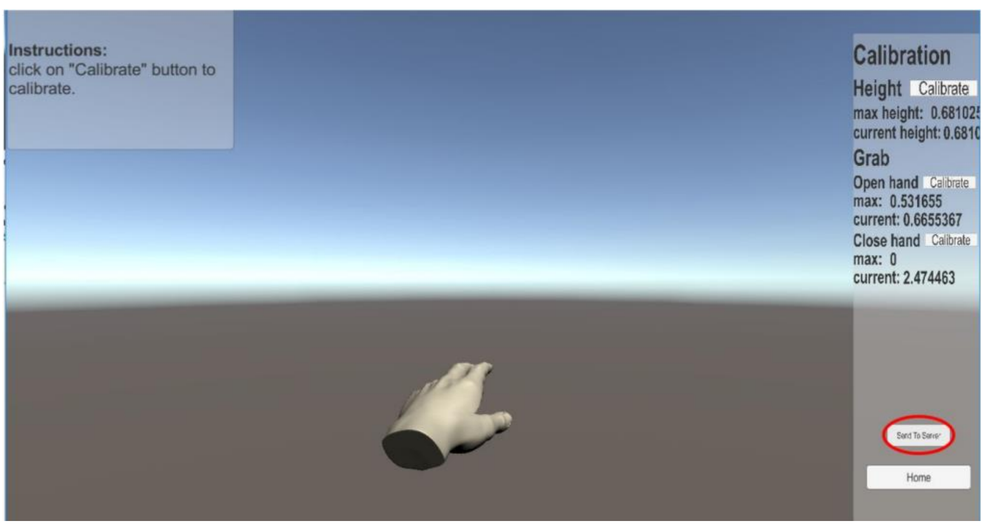

Figure 16: Calibration App.

The Calibration App was developed for situations where a patient wants to update the parameters used for the mini-games without requiring the use of the Web Page by a doctor or therapist. This may apply to patients who want to increase the difficulty of the games already completed or patients using the applications for the first time, who prefer to start with tailored variables instead of default values.

3.7 Backend Server and Configuration Page

3.7.1 Database Server

The database server can be accessed both through the Configuration Web Page (used by the doctors and therapists) and the developed Unity applications (used by the patients).

The database itself consists of 6 JSON files, each holding a specific part of the stored information as presented in Table 5.:

Table 5: Database description.

Name	Description
Patients	data relating to the patients' information (name, process number, affected hand, etc.) and current recovery status (maximum movement distance, hand opening capacity, etc.)
Enjalbert Tests	data relating to stored enjalbert tests (number of iterations, seconds to hold, etc.)
Enjalbert Test Results	saved results of previously performed enjalbert tests (success/failure, time used, etc.)
Games	mini-game parameters, similar to enjalbert test data (number of iterations, distance to cover, time limits, etc.)
Game Results	stored patient performances (success/failure, time used), including punctual values (maximum distance covered, maximum hand opening, etc.)
Local Variables	log of last accesses and created test and game instances, debug values.

The interaction with the database is managed by a REST server using the API provided in the 'Annex IV - Backend Server API'.

3.7.2 Configuration Page

Although all the actions relating to the database can be performed using any REST client application, a configuration web page was developed to ease the process for any user.

The configuration portal is divided into the patient list and the patient page.

On the patient list page (fig.17), the user can manage patients and check general information like name, process number and date of birth as well as information specific to the developed games (range of motion, capability of fully opening/closing the affected hand).

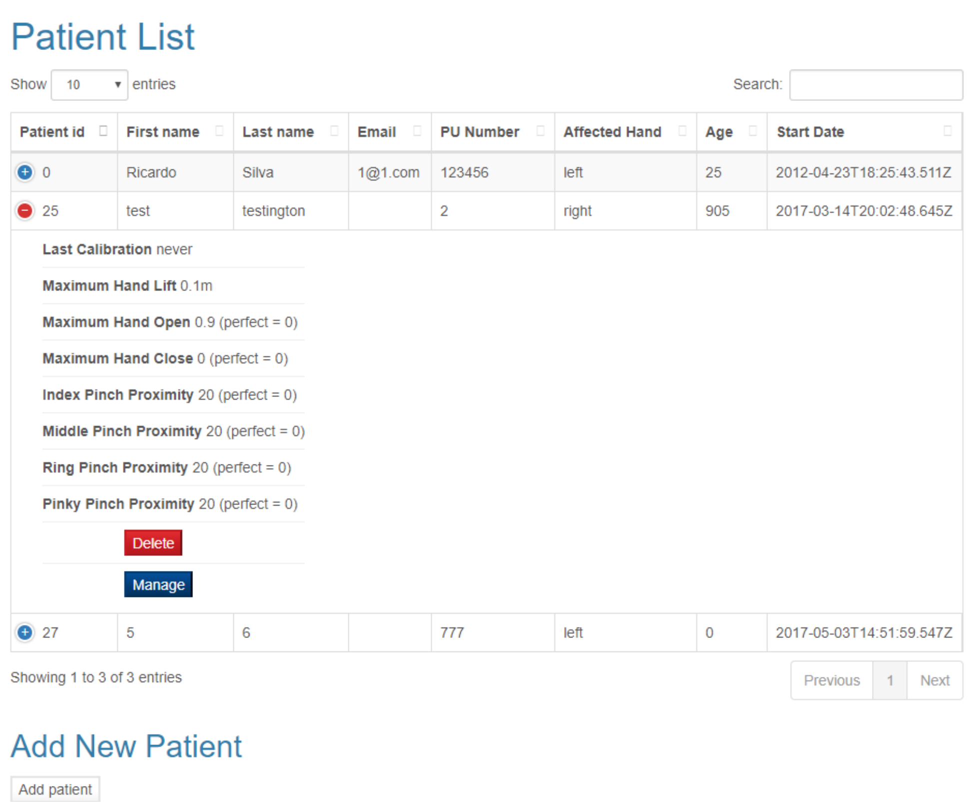

Figure 17: Configuration Portal – Patient List.

When a patient is added, new instances of the mini-games present in the server are associated with the new patient. These mini-game instances are initiated with the default game parameters for each game type.

Patient Page:

In the patient page (figs. 18,19), the user can update the variables to be used when calibrating games to the patient as well as change the parameters for each game and monitor the patient’s results after playing the games.

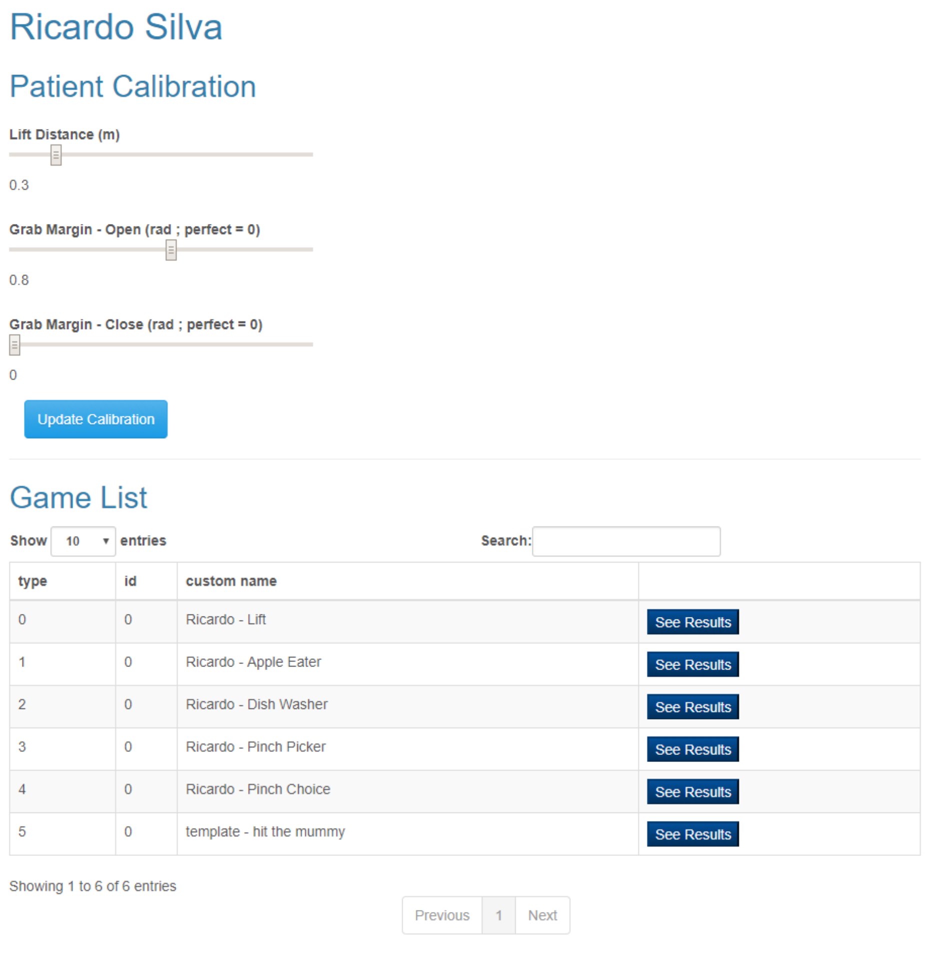

Figure 18: Configuration Portal – Patient Page – Patient Status and Game List.

The editable variables (maximum vertical distance and open/closed hand thresholds) are the same ones that can be updated though the calibration application.

A game’s parameters can be changed by selecting the game in the list and updating the form (fig.14).

For each game, the patient's success rate when playing it can be monitored with two similar charts (fig.19), one for non-immersive attempts, the other for fully immersive (using Head Mounted Display) VR plays.

In the charts, for each day the game was played, three bars are present:

- The total number of attempts (blue).
- The number of successful plays (green).
- The number of failed tries (red).

This information can be used by the doctor/therapist when deciding to change the parameters of a selected game or updating the patient centric variables.

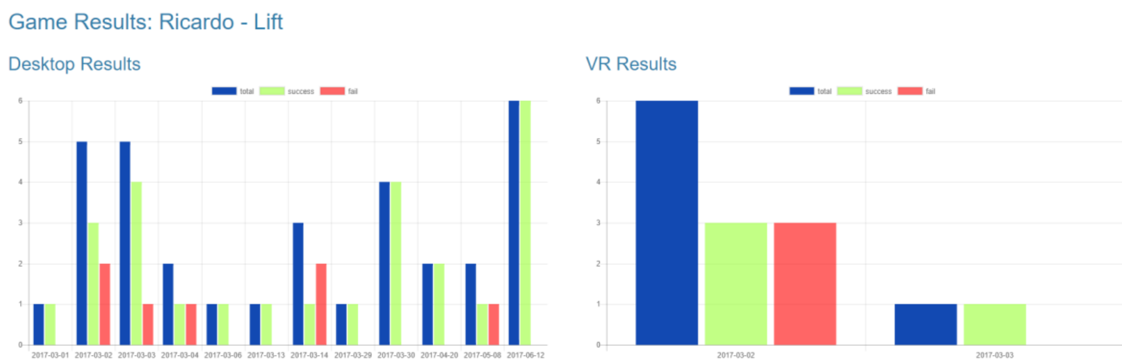

Figure 19: Configuration Portal – Patient Page – Game results (blue – number of times a game is played; green – successful attempts; red – failed attempts).

IV: Patient Tests

After the applications were developed a series of multiple tests, with different purposes, were executed. A preliminary test was performed with the collaboration of 16 students from the U.A., to evaluate the generic usability of the mini-games and correct subsequent usability/technical issues. Secondly, an informal study with 9 patients was conducted at ‘Rovicso Pais’ to observe the adaptation and acceptance of real patients to the technology and the problems that might come from using the system in a clinical environment.

After the initial tests were finished resulting in a more stable version of the mini-games, a formal study involving 12 patients was executed. This study used a transversal approach, involving patients in different states of recovery and suffering from varied post stroke sequels, so the range of the mini-games could be tested.

This transversal study focused on establishing which patients could benefit from the games (both regarding the current state in the treatment and particular post-stroke sequels), as well as accessing the general acceptance of this type of treatment by the resident community at the rehabilitation center.

4.1 Tests with students

As mentioned, a usability test was performed initially with students enrolled in the ‘Realidade Virtual e Aumentada’ (Virtual and Augmented Reality) and ‘Interacção Humano-Computador’ (Human-Computer Interaction) courses offered at the Department of Electronics, Telecommunications and Informatics in the scope of the Computer Engineering MSc Program.

In total, 16 students (ages ranging from 19 to 25) tested 4 developed mini-games (‘Lift’, ‘Apple Eater’, ‘Dish Washer’ and ‘Pinch Picker’).

The Leap Motion sensor was used to track the player’s movements.

During the test, each participant would play the mini-games both in a non-immersive setting (using the PC screen) and with full immersion (using the stereoscopic Oculus Rift Dk2 Head Mounted Display) and, afterwards, answer a questionnaire about possible cybersickness symptoms, difficulties in the completion of the games and general satisfaction with both degrees of immersion (see ‘Annex II - UA student questionnaire’).

As expected, most students found the games easy to complete, with 5 students experiencing mild symptoms of cybersickness. A summary of the results is included in Annex II.

4.2 Preliminary Tests with patients

In a meeting with the doctors at ‘Rovisco Pais’ the five mini-games were demonstrated so that it could be accessed which were ready to be tested with patients currently being rehabilitated at the center.

Due to the fact that the detection of the pinch movements revealed itself to be harder for users with less experience using the Leap Motion equipment, it was concluded that the mini-games to be tested by the patients would be the first three (‘Lift’, ‘Apple Eater’ and ‘Dish Washer’).

After this decision, a preliminary testing session with patients was scheduled. The main objective of this experiment was to find unnoticed usability problems by having users in the application’s target audience try the games.

Three preliminary testing sessions were performed during March 2017 with volunteer patients residing at the rehabilitation center that played the three selected mini-games with the assistance of doctors or therapists in an informal setting.

4.2.1 Testing Sessions Protocol

The criteria used to select these patients was the absence of psychological sequels of the stroke that would prevent the ability to comprehend the test or the game.

A total of 9 volunteer patients (3 per session) participated in the tests. Each patient, after being briefed about the purpose of the test and the context of the project, would play the mini-games in both an immersive and non-immersive set-up (PC screen and Oculus Rift Dk2 HMD).

Any noticeable difficulties or issues in the patient’s use of the application or equipment were discussed with the assisting therapist or doctor at the end of the test.

After the test was finished (successfully or not) the patient would be asked about the experience, both regarding satisfaction in general (‘Did you enjoy the games?’, ‘Did you prefer using the PC screen or the HMD?', etc.) and any usability issues detected during the test.

4.2.2 Results and Usability Corrections

At the end of each testing session, the usability issues and possible improvements noted were discussed with the doctors and therapists and the next testing session would only be scheduled after the planned changes were implemented.

Regarding immersion, 8 of 9 participants preferred the fully immersive display over the non-immersive. The patient who preferred the desktop suffered from a post-stroke sequel which caused the loss of sensitivity in the affected hand (proprioceptive sensitivity). According to the assisting doctor, patients who suffer from this condition sometimes feel the need to look at the affected hand to use it, which could be the reason why the immersive display felt less appealing to the patient.

Regardless of this unusual preference, the patient was able to successfully complete the games using both degrees of immersion.

During these tests some training was given to the occupational therapists, so they could use the Configuration Page (add new patients and manage their attributed games). Being able to use the system by themselves during the last testing session, it was concluded that, after the usability issues encountered were fixed, both the equipment and the applications could be left deployed at the rehabilitation center to be used autonomously by them. Although the therapists did use the system without the presence of the developers, due to time constraints, it was not possible to implement the mini-games as a permanent part of occupational therapy routine.

The 'Calibration App' was also used by one of the patients after it was concluded that he did not have the necessary upper limb dexterity to complete the first game with the default settings. No problems were found in the use of the application and, after his mobility limits were calibrated, the patient was able to complete the mini-games.

Overall, the mini-games were well accepted by the patients and both the volunteers and the assisting doctors/therapists agreed that, after the issues found were resolved, this virtual reality system could bring real benefit as a part of occupational therapy at the rehabilitation center.

Usability Issues and Corrections:

Although, for the most part, the patients were able to complete the mini-games they were assigned, a few problems were encountered and are described in Table 3.

Table 3: Preliminary Tests – Usability Corrections.

Context	**Issue Description and Correction**
Appearance	For all games, it was concluded that the appearance should be improved. In the first game prototypes tested, although the game area was a 3D environment, the background scenario was 2D. The final version of all 3 mini-games uses a fully 3D virtual environment.
'Lift' game	In the 'Lift' game, the position of the Leap Motion sensor in the virtual world was behind the dumbbell. This caused some confusion on the patient's part as they would need to be alerted that they must place their hand past the physical sensor before raising it. This was corrected by placing the LeapHandContoller gameObject directly under the dumbbell in the virtual environment. It was also realized that, for patients that could slightly move their hand but whose arm was still locked against their chest (no shoulder movement) the positioning of the Leap Motion sensor had to be changed (because the patient could not extend their arm

	to the table, the sensor had to be placed in their knee in order for the hand to be tracked and used in the virtual environment). In cases like this, it was hypothesized that a similar game could be developed using the Kinect sensor.
'Apple Eater' game	In the 'Apple Eater' game, the position of the apples was noted to be too distant from the sensor in the virtual world. This caused the patients to place their hand behind the object and wait, supposing they had reached it and expecting some development to happen, only reaching further after behind told they still hadn't touched the apple. This was corrected by reducing the distance between the objects and the Leap Motion sensor in the virtual environment. It was also noted that the replacement of the user's virtual hands by forks (which was part of the initial design of the mini-game) caused a lack of relatability ("nobody eats apples with a fork") and it was decided that the game should use a more realistic representation of the user's hands. In the next version of the 'Apple Eater' game, along with the change in the representation of the user's hands, the apple objects had been replaced by medieval mugs, which seemed to be more in tune with the 3D environment chosen for the game. This made the patients instinctively reach for the mug handle instead of aligning their hand palm with the center of the object. After some discussion with the occupational therapist, it was concluded that apple gameObjects

	should be used again, for simplicity.
Sound	At first, no sound signifying the end of the game was used. This was corrected with the addition of two different sounds, one for a successful attempt (applause) and the other for failure ('Pac-Man' game over sound). It was later advised by the doctors and therapists that the failure sound should be removed as it may be a negative reinforcement and could cause frustration and impede the progress in a patient's rehabilitation. Taking this advice into account, the failure sound was removed from the mini-games.
In-App Navigation	After choosing the patient and game to play in the menu scene, these would always reset when returning to it after playing the games. This caused the wrong patient to be selected inadvertently when the same mini-game was to be executed twice in a row. It was decided that the selected patient should remain to avoid the possible mismatch of patient and game.
Leap Motion sensor position	In some cases, because the patient was not able to reach the Leap Motion sensor on top of the table, the tracker had to be placed on a plastic board positioned on the patient's lap. With this small change, no further problems were found regarding the position of the sensor.

After the tests were performed and the usability problems found were fixed, it was concluded that the application was ready to be formally tested as a rehabilitation tool, with the help of the staff and patients from ‘Rovisco Pais’.

4.3 Formal Study with Patients

A meeting with the doctors was scheduled, so that a formal study could be planned. This study would involve the use of the application by a select group of patients in a recurrent way (once a week) for a period of about a month, so that their progression could be monitored.

The following questions were established for the test to evaluate:

- At what level of recovery could the patients start using the games?
- Which particular stroke sequels cause unusual results in a patient’s capability and enjoyment when playing the games?
- Is this type of treatment well accepted by the patients?
- Is there a preference regarding the level of immersion (non-immersive vs. full immersion)?

Based on these goals, it was decided that, instead of repeating the tests with a small group of patients recurrently, it would be more beneficial to perform a transversal study, in which the applications would be used by a larger and more varied group of patients.

Before the tests could be started, a formal request was sent to the Ethics Committee at the rehabilitation center (this request is presented in ‘Annex V - Formal Study Request to Ethics Committee’).

4.3.1 Study setup

The study was performed at the rehabilitation center in a room containing all the equipment required to execute the tests (this room had been previously used to perform the preliminary tests). The setup is composed by the elements shown in the picture below (fig.20).

Figure 20: VR setup at the rehabilitation center.

The following equipment was used:

1. Desktop computer running the applications and local backend server.
2. A 4k display monitor for the non-immersive experimental condition.
3. An Oculus Rift DK2 HMD for the fully immersive experimental condition.
4. A Leap Motion controller.
5. A speaker positioned in front of the patient to provide audio feedback.

4.3.2 Questionnaire

A questionnaire was developed in collaboration with the clinicians to be answered by both the patients and the doctors/therapists.

The questionnaire (see ‘Annex VI - Rovisco Pais – Transversal Study’). was divided in 7 different sections:

1. Doctor and Therapist Information: name and identification numbers belonging to the doctor assigned to the patient and the therapist assisting at the test.
2. Patient Info: basic demographic information (gender, age) and clinical data (type/location of stroke, cognition, communication changes, etc.).
3. General questions focused on establishing the patient’s familiarity with computers, computer games and virtual reality.
4. Desktop: questions regarding the level of satisfaction the patients experience during the execution of the mini-games when using the non-immersive version such as ‘Did you like the games?’ or ‘Were the games easy to complete?’. Questions about cybersickness were also included in this section, accessing possible discomfort both during the execution of the mini-games as well as after it.
5. Full Immersion: Similar to the previous section but for the HMD version.
6. General Inquiries: This section includes questions regarding the patient’s preference for a specific mini-game or degree of immersion, as well as opinions concerning the use of the system (‘would you use this type of applications at home?’, ‘Would you prefer to play these games in an individual or social setting?’) and suggestions for new mini-games or changes to the existing ones.
7. Occupational Therapy: Opinions of the occupational therapist assisting the test regarding limitations in the use of the application or equipment and possible insight on how these types of projects can improve post-stroke treatment.

4.3.3 Study Protocol

A total of 12 patients (6 males and 6 females, aged between 39 and 71, all residing at the rehabilitation center at the time of the test) in several different states of recovery and suffering from different post-stroke sequels were selected by the therapists to participate in the study.

As in the previous tests, the main factor for participant selection was the absence of cognitive sequels that could cause inability to comprehend the games or questionnaire.

The tests took place over 4 weeks, with one visit to the rehabilitation center per week. In each visit, 3 different patients participated in the study.

No physical mobility minimum was established when selecting the participants, which could possibly result in some patients not being able to complete any of the mini-games. This was done on purpose to evaluate if the current recovery status or post-stroke sequels could be used as exclusion factors for future use of the system.

All the participants would play the mini-games with both degrees of immersion (desktop and HMD), half starting with the non-immersive version, the other half starting with the fully immersive version. This was done to prevent any bias towards one of the immersion degrees.

At all times, the patient playing the game would be assisted by a therapist and a developer.

At the beginning of a testing session, the patient would be instructed about the purpose of the test and the equipment to be used (the Leap Motion sensor and the Oculus Rift Dk2 HMD).

The patient would then play both versions of the mini-games (desktop and fully immersive).

After the execution of the applications (successfully or not), the patient would answer part of the questionnaire regarding the satisfaction and increase in motivation associated with the use of the mini-games, his/her level of familiarity with computers and VR technology and some general questions (including favorite game and opinions regarding the use of the application at home, in group or in an individual setting).

The questions answered by the patients correspond to sections 3 through 6 of the full questionnaire. The other sections were answered by the doctors and therapists.

The following routine was used:

- At the start of the week, the day of the visit would be scheduled with the therapists at the rehabilitation center.
- The therapists would then plan the testing sections for 3 patients who were scheduled to participate in occupational therapy.
- After the final testing section of the day, the partially answered questionnaires were left with the therapists.

At the end of the study the 12 completed experiments and questionnaires were analyzed.

In parallel with the information obtained from the questionnaires, all the participant patients were added to the backend database (through the configuration portal) and the success rate of their playthroughs was logged.

4.4: Formal Study Results and Discussion

The mini-games seemed to be well accepted by the patients. Most of the patients were able to play (only 2 patients were not able to complete all 3 mini-games and only one was not able to complete any of them) and were satisfied with the experience (all patients who played the mini-games claimed to enjoy the experience and expressed interest in including Virtual Reality as part of the rehabilitation therapy).

Only 11 patients answered the questionnaire since one patient was not able to complete the first mini-game and the assisting therapist decided that the testing session should be finished prematurely.

The 2 patients that were not able to complete the games were suffering from muscle tone debilitation which could strongly interfere with the execution of the application (according to the answers in the doctor/therapist section of the questionnaire).

Another relevant event noticed was the fact that a patient who had previously tested the games during the preliminary testing phase played the games again during the study and, although still being able to complete all 3 mini-games, revealed a notorious increase in difficulty the assisting therapist explained that the patient was currently suffering from depression and this change in humor might explain the lack of motivation when trying to perform a difficult task.

With this realization, it was pondered that it would be interesting to have a simple scale at the beginning of the game where the patients could indicate their mood and this information could then lead to a re-scheduling of the session or a temporary decrease in difficulty.

A more detailed review of the collected results is present below.

Familiarity with Technology:

9 of the patients had never before played computer games and 10 were not at all familiar with virtual reality (table 6). This could be a limitation to the use of these technologies for rehabilitation, since a significant percentage of the participants had no gaming experience. Surprisingly, this was not the case: the great majority of the patients described the experience as enjoyable in the questionnaire (table 7) and showed excitement to participate in the study during the testing sessions. This could be caused by the ludic context of the experience, which breaks the serious and repetitive routine of the treatment.

Table 6: Results – Summary – Patient Introduction.

Question	Number of answers				
	0 (never)	2	3	4	5 (every day)
Do you use your computer regularly?	4	3	1	1	3
Do you play computer games?	9	1	0	1	1
Are you familiar with Virtual Reality?	10	0	0	2	0

Non-immersive vs. Immersive:

No conclusions regarding preference could be extracted using this section of the questionnaire since both non-immersive and fully immersive versions of the mini-games (table 7) show similar results relative to discomfort and easiness.

It was, however, noted that both versions of the application received fairly positive reviews (players enjoy the games). During the tests, no patient suffered from cyber sickness in any environment.

Table 7: Results – Summary – non-immersive *vs* immersive.

Question	**Number of answers**									
	DESKTOP					VR				
	0 (no)	2	3	4	5 (yes)	0 (no)	2	3	4	5 (yes)
Did you feel any kind of discomfort during the games?	11	0	0	0	0	11	0	0	0	0
Were the games objects easy to distinguish from the scenario?	1	0	0	10	0	0	0	0	10	1
Were the games easy to complete?	0	0	5	6	0	0	0	4	7	0
Did you like the games?	0	0	0	11	0	0	0	0	11	0
Did you feel any kind of discomfort after playing the games?	11	0	0	0	0	11	0	0	0	0

Despite the fact that there are no significant differences in performance or acceptance between the 2 degrees of immersion, most patients (9 out of 11) said they preferred the VR version of the mini-games (fig.21).

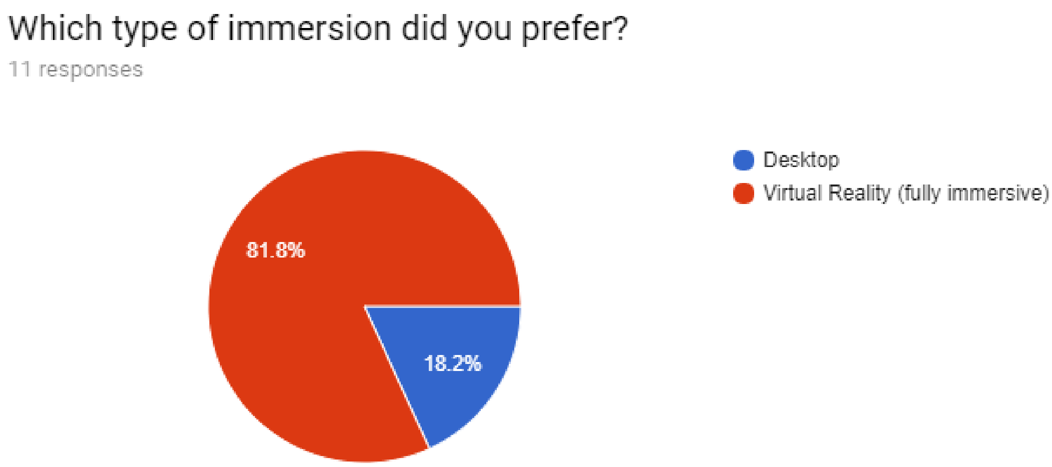

Figure 21: Formal Study Results – Immersion degree preference.

Out of the 2 patients who preferred the non-immersive version, one had never used a computer before and found full immersion to be too invasive. The other patient suffered from proprioceptive sensitivity and, as explained by the doctors, stroke victims with this particular sequel feel the need to look at their hand in order to execute the movements. Not being able to see the real hand when using the HMD may explain the patient's preference, despite being able to successfully play the games in both versions.

This is not a strong conclusion and might require additional research since another patient who also suffered from proprioceptive sensitivity claimed to prefer full immersion when playing the mini-games.

General Inquiries:

When asked which mini-game was their favorite, most patients (6 out of 11) declared ‘Lift’ as the most enjoyable game. This trend, however, can be caused by the fact that ‘Lift’ was the easiest game to complete (less effort needed to be applied before receiving positive feedback) but also the first game played by all patients (fig.22).

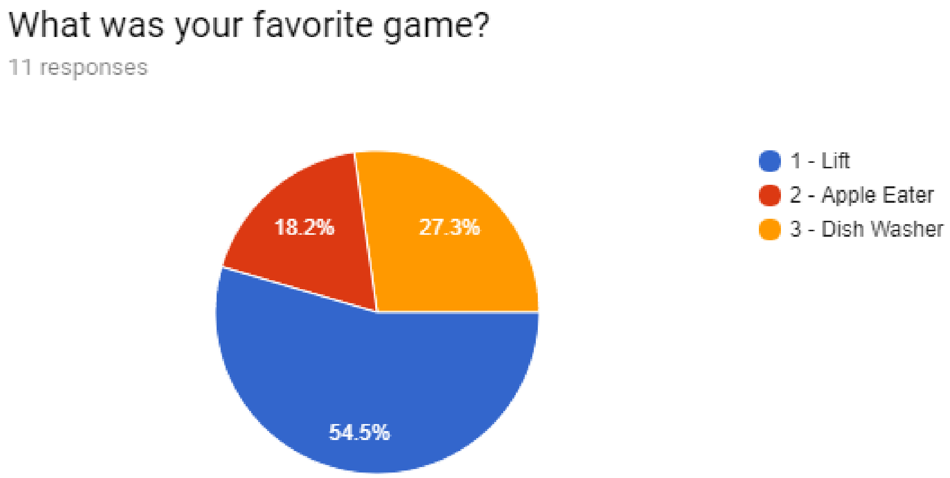

Figure 22: Formal Study Results – favorite game.

All the patients considered this type of treatment (playful/VR) to be useful in the context of rehabilitation therapy and, when asked if they would use the application at home, the majority of patients (10 out of 11) answered positively (fig.23). The only negative answer was from a patient that had never used a computer before.

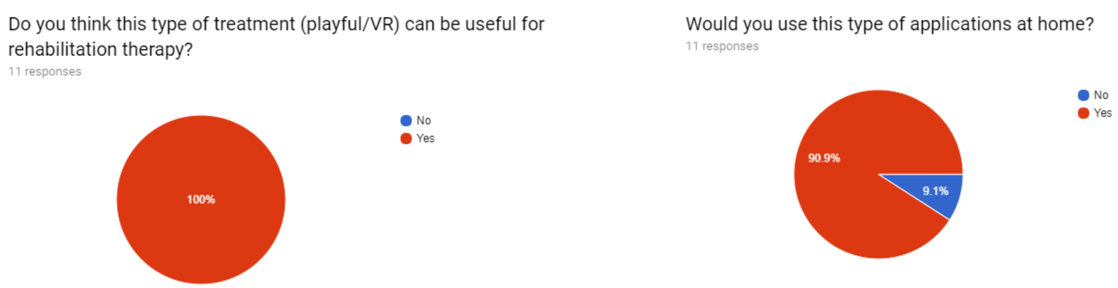

Figure 23: Formal Study Results – openness to serious virtual reality games in therapy.

When asked if they would prefer to play the games in an individual or social setting, opinions were divided with 6 people choosing the option of using the application alone while the other 5 claimed the playing the games in a group setting would be more rewarding (fig.24).

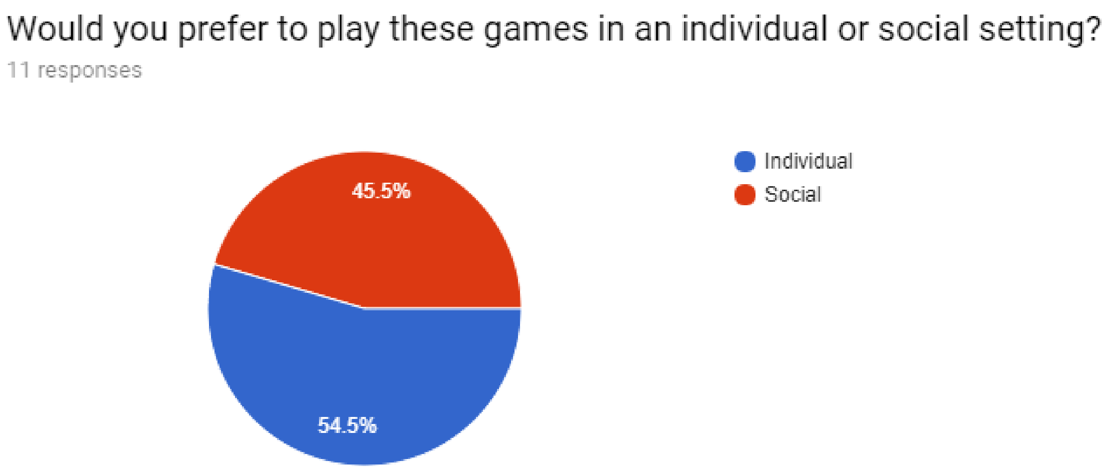

Figure 24: Formal Study Results – preference regarding social or individual use of the application.

Feedback from Occupational Therapists:

Besides the information received from the patients in the questionnaires, notes and suggestions collected from the occupational therapists assisting the testing sessions were also logged and 2 major critiques were found:

- The performance of the Leap Motion sensor was considered to be faulty, causing discrepancies between the user's movement and the gestures performed by the virtual hands inside the games. Although this did not seem to inhibit an enjoyable playthrough of the games (almost all patients were able to successfully complete all 3 games and in the previous section the majority claimed that the 'virtual representation of their movements' was realistic), during the testing sessions, it was possible to notice that the sensor would sometimes lose track of the player's hand or represent it in an incorrect way with no apparent cause, showing that the Leap Motion sensor still has some tracking issues.
- In the 'Apple Eater' game, because the patient's mouth was a fixed point in the virtual environment (defined at the start of the game), any change in the patient's posture would lead to a misalignment between the real position of the mouth and the virtual one. This can both allow patients to cheat (by leaning back and bringing the affected hand to the virtual mouth and not their real mouth) or add unnecessary difficulty to the game (if the patient's posture changes, bringing the affected hand to his/her mouth is not recognized by the system as a successful iteration because the real mouth's position no longer corresponds to the virtual one). When this happened, the patient would then have to be advised by the therapist to regain the initial posture before attempting to bring the hand back to the mouth.

Based on these critiques it appears that, in the mini-games' current state, constant therapist assistance would be required for the patients to take full benefit from them due to the Leap Motion tracking issues (when tracking is lost or faulty, this can often be corrected by obscuring the sensor's field of view and putting it back in place) and to ensure the proper use of the equipment by the patient, reminding him/her to keep a correct posture and avoid relying on incorrect or harmful gestures.

In face of the limitations found in the current state of the application, it was concluded that other tracking devices should be investigated as alternatives to the Leap Motion, for example, the Kinect. Still, the Leap Motion sensor was considered applicable for simple, close-range applications (no issues were found in the ‘Dish Washer’ mini-game, in which the user is only required to open and close the affected hand).

Apart from the issues stated above, the general response regarding the use of virtual reality in occupational therapy in post-stroke rehabilitation was well received, with its major benefit being the increase in a patient’s motivation for recovery through the use of fun and relaxed environments, which successfully distract the patient from the dull clinical setting.

V: Conclusion and Future Work

The main goal of this work was to evaluate the possibility of incorporating virtual reality in post-stroke rehabilitation for upper limb movement.

Several games and tests were performed resulting in a prototype including 3 mini-games using the Leap Motion tracker and a backend system in which patient and game data are stored and accessed through a web page.

After some preliminary testing sessions at the center, used to correct some unforeseen weaknesses in the system, a formal study was performed to evaluate the usability and enjoyment of the applications with patients residing at the rehabilitation center, as well as defining exclusion factors for the application's target audience.

After the study results were analyzed, it was concluded that the new type of treatment was well received by both patients and therapists at the rehabilitation center, with the majority of participant patients being able to successfully play the mini-games.

Regarding the comparison of immersion degrees, although no difference in performance was noted, most patients claimed to prefer using the HMD to play the games.

Although successfully used in simple, close-range games, the Leap Motion presents some tracking limitations namely regarding posture tracking, and other sensors, like the Kinect, should be tested for the development of future applications.

The backend server and configuration web page both are operational and were able to be used by the occupational therapists during the testing sessions. However, these are still in an early stage and should be significantly improved in the future.

At the end of this phase in the overall project of fully integrating virtual reality as part of the rehabilitation schedule of the patients residing at the 'CMRRC – Rovisco Pais' rehabilitation center, both the feedback of the patients participating in the study as well as the doctors and therapists was positive and further research and development was encouraged.

Future Work:

The further development of the system should focus on the following aspects:

- Development of games using the Kinect tracker: the developed games 'Lift' and 'Apple Eater' should be remade substituting the Leap Motion sensor for the Kinect. This would hopefully correct some issues found during the test sessions and also allow for further parameters to be added (using the Kinect sensor, the patient could be required to keep a straight back using the game itself instead of needing the supervision of an assisting therapist). Leap Motion based games can still be developed but should, as advised, be limited to simple, close-range tasks or combined with other tracking devices.
- Expansion to new areas of rehabilitation: although this work was focused on upper limb movement, the doctors at the rehabilitation center have manifested interest in applying virtual reality in other areas of post stroke recovery, namely physiotherapy and neuropsychology.
- Upgrading the backend server and configuration page: although functional, the backend server was developed using one single server that incorporates all the different requests to the database. This makes it very fragile and not scalable. A possible upgrade to this system would be the division of the service into multiple micro services which could be managed by a compositor server. This way, as long as each microservice's API remained the same (only changing in regard to the addition of new features), all the singular servers could be updated independently without causing problems in the overall system. In parallel, the JSON files integrating the database can be re-implemented as JSON objects in a MongoDB database. This was not done because, in order to facilitate testing the system in multiple computers (including the one at the rehabilitation center), it was concluded that the least software installations needed, the better.

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ANNEX

ANNEX I - Therapy assessment tests

This annex lists links to the description of the recovery status assessment tests referred in the 'requirements' section of the main document.

Test list:

- Box and Block: https://www.sralab.org/rehabilitation-measures/box-and-block-test?ID=917
- Fugl-Meyer Assessment: https://www.sralab.org/rehabilitation-measures/fugl-meyer-assessment-motor-recovery-after-stroke?ID=908
- Action Research Arm Test: https://www.sralab.org/rehabilitation-measures/action-research-arm-test?ID=951
- Frenchay Arm Test: http://www.strokengine.ca/indepth/fat_indepth/
- Enjalbert Test (official video description from the 'Rovisco Pais' rehabilitation center): https://www.youtube.com/watch?v=05G37IhWUSs

ANNEX II - UA student Tests

Questionnaire:

IHC - VR demo

This form will be used in the initial analysis of the difference between the desktop version and the fully immersive version of the "5 games" app. The user's movements were tracked with the Leap Motion Hardware in both versions.

* Required

1. **Age** *

____

2. **Are you familiar with Virtual Reality applications?** *

Mark only one oval.

	1	2	3	4	5	
no	◯	◯	◯	◯	◯	yes (very familiar)

DESKTOP

the following questions refer to the Desktop version of the app.

3. **Did you experience dizziness during the game?** *

Mark only one oval.

	1	2	3	4	5	
no	◯	◯	◯	◯	◯	yes (a lot)

4. **Were the in-game objects easily distinguishable from the scenario?** *

Mark only one oval.

	1	2	3	4	5	
no	◯	◯	◯	◯	◯	very easily

5. **Were the games easy to complete?** *

Mark only one oval.

	1	2	3	4	5	
no	◯	◯	◯	◯	◯	yes (very easy)

6. **Did you enjoy the games?** *

Mark only one oval.

	1	2	3	4	5	
no	◯	◯	◯	◯	◯	yes

7. **Did you feel dizziness after playing the games?** *
Mark only one oval.

	1	2	3	4	5	
no	⬭	⬭	⬭	⬭	⬭	yes (a lot)

VIRTUAL REALITY

the following questions refer to the fully immersive version of the app. The hardware used for displaying the virtual environment was the HTC Vive Head Mounted Display.

8. **Did you experience dizziness during the game?** *
Mark only one oval.

	1	2	3	4	5	
no	⬭	⬭	⬭	⬭	⬭	yes (a lot)

9. **Were the in-game objects easily distinguishable from the scenario?** *
Mark only one oval.

	1	2	3	4	5	
no	⬭	⬭	⬭	⬭	⬭	very easily

10. **Were the games easy to complete?** *
Mark only one oval.

	1	2	3	4	5	
no	⬭	⬭	⬭	⬭	⬭	yes (very easy)

11. **Did you enjoy the games?** *
Mark only one oval.

	1	2	3	4	5	
no	⬭	⬭	⬭	⬭	⬭	yes

12. **Did you feel dizziness after playing the games?** *
Mark only one oval.

	1	2	3	4	5	
no	⬭	⬭	⬭	⬭	⬭	yes (a lot)

GENERAL QUESTIONS

13. **Which version of the app did you prefer?** *
Mark only one oval.

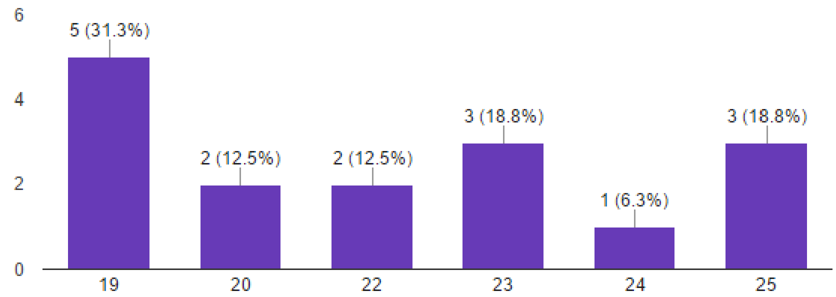
⬭ Desktop
⬭ Virtual Reality (fully immersive)

14. **What did you think of the HTC Vive Hardware as a virtual reality display?**

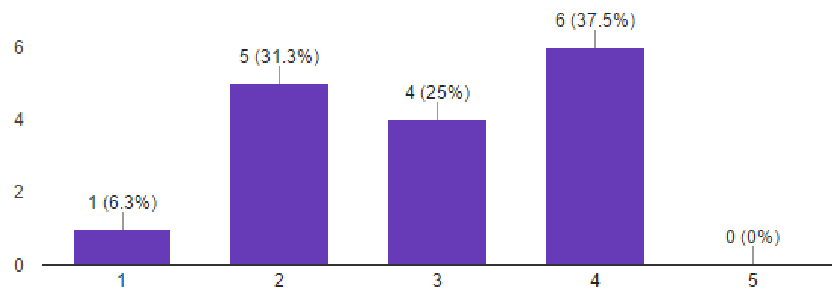
15. **Suggestions:**

Results:

Age (16 responses)

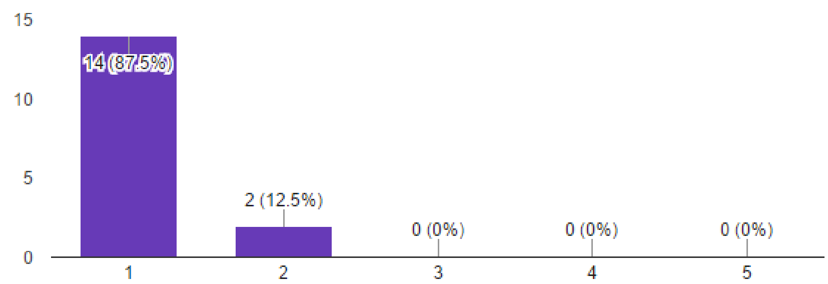


Are you familiar with Virtual Reality applications? (16 responses)

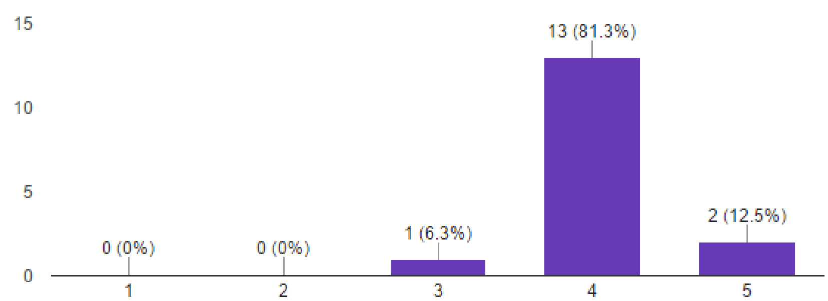


DESKTOP

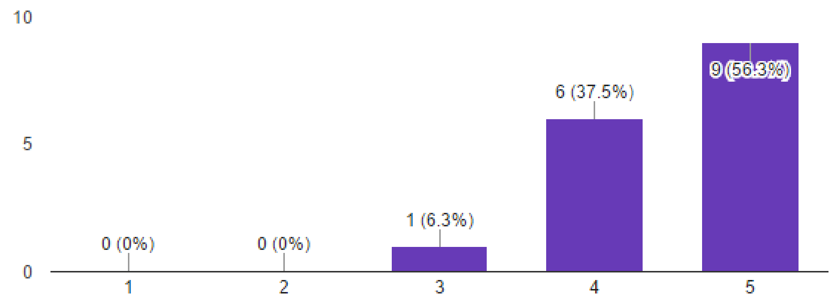
Did you experience dizziness during the game? (16 responses)



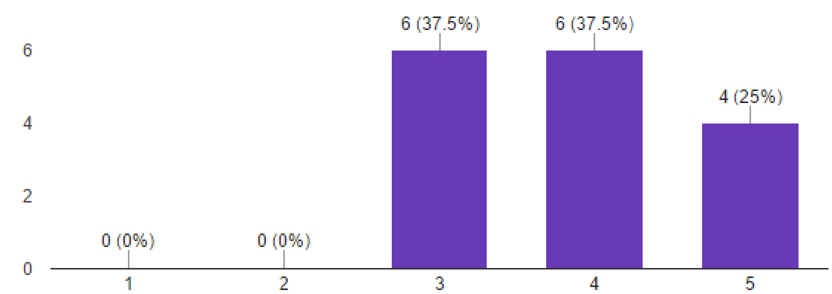
Were the in-game objects easily distinguishable from the scenario? (16 responses)



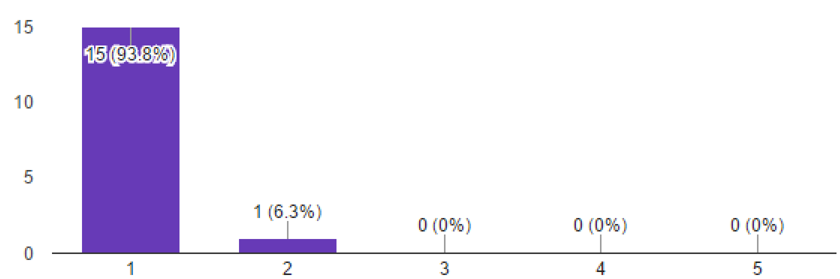
Were the games easy to complete? (16 responses)



Did you enjoy the games? (16 responses)

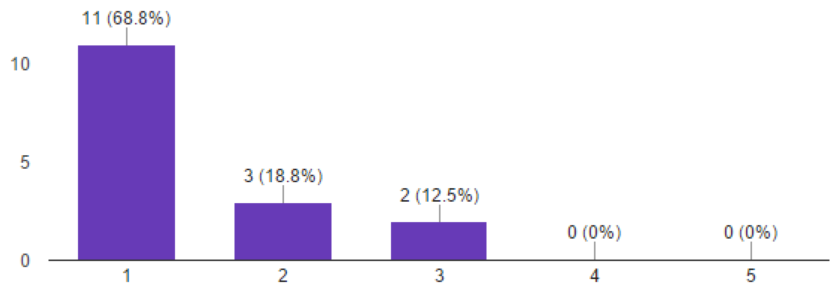


Did you feel dizziness after playing the games? (16 responses)

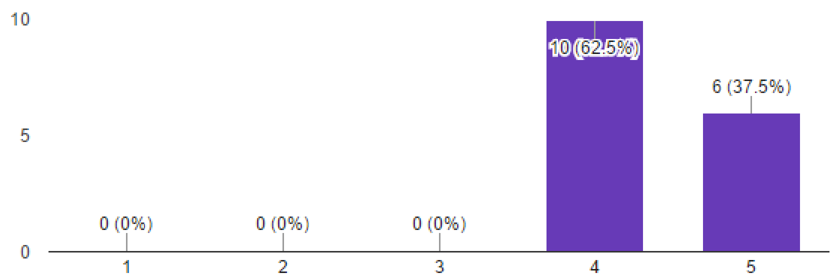


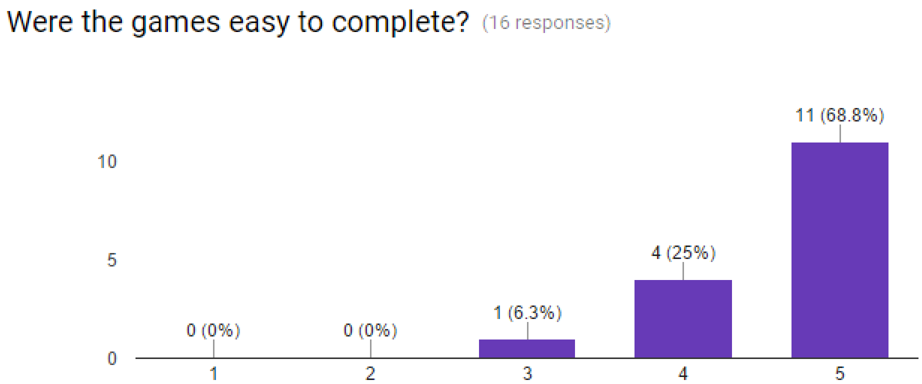
VIRTUAL REALITY

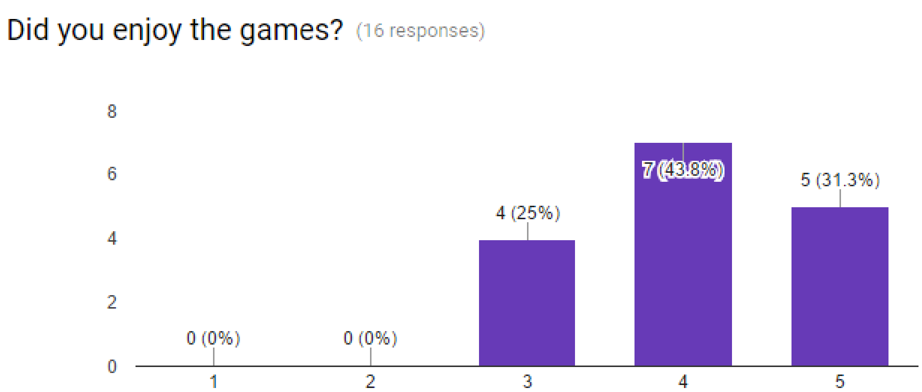
Did you experience dizziness during the game? (16 responses)

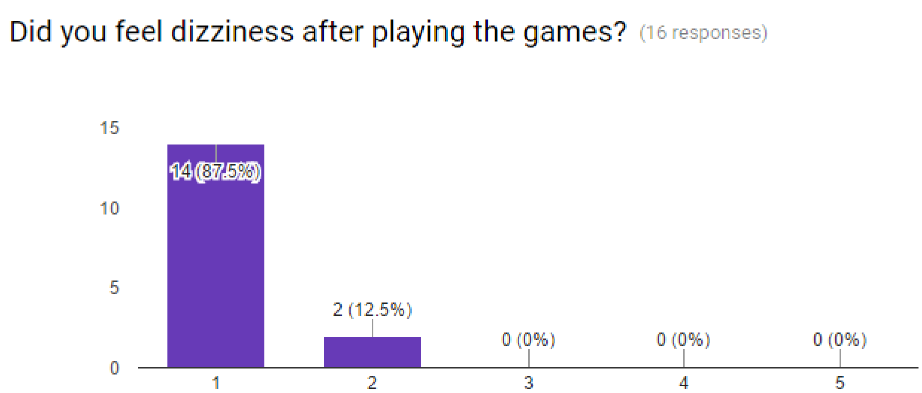


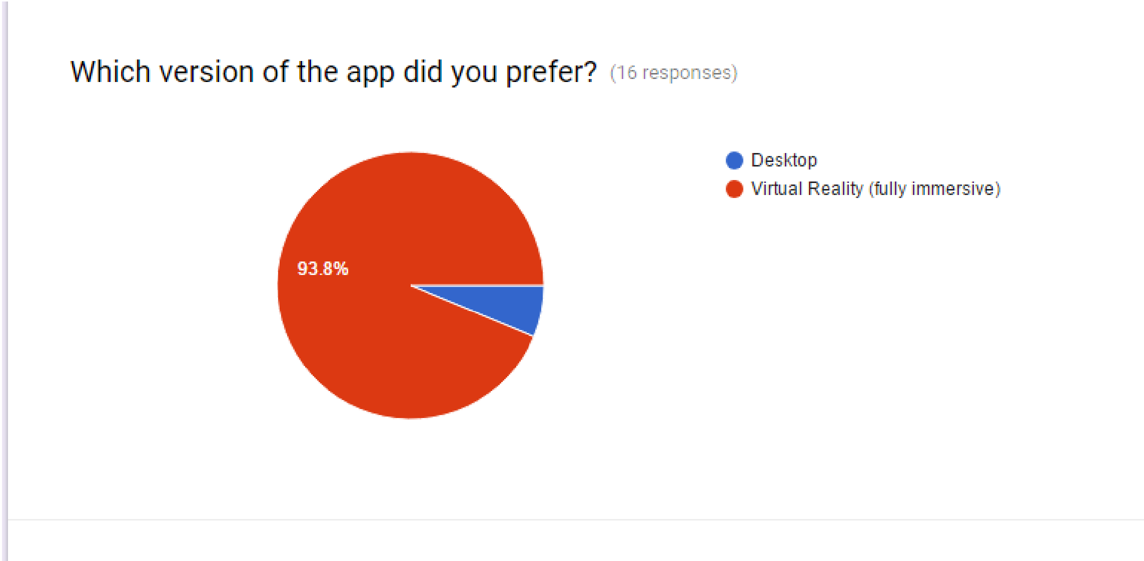
Were the in-game objects easily distinguishable from the scenario?
(16 responses)




Were the games easy to complete? (16 responses)
10
5
0
0 (0%)
0 (0%)
1 (6.3%)
4 (25%)
11 (68.8%)
1
2
3
4
5


Did you enjoy the games? (16 responses)
8
6
4
2
0
0 (0%)
0 (0%)
4 (25%)
7 (43.8%)
5 (31.3%)
1
2
3
4
5


Did you feel dizziness after playing the games? (16 responses)
15
10
5
0
14 (87.5%)
2 (12.5%)
0 (0%)
0 (0%)
0 (0%)
1
2
3
4
5


Which version of the app did you prefer? (16 responses)
Desktop
Virtual Reality (fully immersive)
93.8%

ANNEX III - Adding new games to server

In order to add a new game to the platform the following steps must be executed:

1) Establish the game settings in a JSON format
   a) The parameters used by the game (total time, difficulty, distance to/between objects) must be defined as elements of a JSON object which will be used as the default settings for the game.
   b) Example of a template instance ('hit the turtle' game)

```
"game_template":
{
    "difficulty_level": 1,
    "secondsToHit": 5,
    "time_between_interactions": 2,
    "numberOfLifes": 3,
    "minimumScoreForSuccess": 1
}
```

   c) The template settings must be included in a parent JSON object which also defines the custom name for the new game.

   d) Example of a template instance ('hit the mummy' game)

```
{
        "game_name": "hit the mummy",
        "game_template":
        {
                "difficulty_level": 1,
                 "secondsToHit": 5,
                 "time_between_interactions": 2,
                 "numberOfLifes": 3,
                 "minimumScoreForSuccess": 1
        }
}
```

2) The defined game settings ae used as the body for the ‘addGameType’ REST call to the server
3) After the game is added, it will be available for the template patient (id:0) and for any newly added patient.

ANNEX IV - Backend Server API

Path	HTTP method	Description	Response(GET/POST) and Request(POST) templates

/getPatientsBrief	GET	Get the list of patient names and IDs.	[
			{
			"id": *integer*,
			"name": *string*
			}
			]

/getPatientById	GET	Get the information of a patient identified by a given id.	{
			"id": *integer*,
			"date_of_birth": *string*,
			"bi_num": *integer*,
			"email": *string*,
			"name": *string*,
			"last_name": *string*,
			"register_date": *string*,
			"last_calibration_date": *string*,
			"left_hand": *boolean*,
			"lift_max_height": *float*,
			"grab_open_margin": *float*,
			"grab_close_margin": *integer*,
			"index_pinch_margin": *integer*,
			"middle_pinch_margin": *integer*,
			"ring_pinch_margin": *integer*,
			"pinky_pinch_margin": *integer*,
			"language": *integer*,
			"games": [
			{
			"type": *integer*,
			"id": *integer*,
			"name": *string*
			}
			]
			}

/getPatients	GET	Get array with all the patients.	Array of objects similar to the one above.

/getGameResultsBy Patient	GET	Get array of recorded performances relative to the given patient's ID.
		The results for each game are identified by the game type. The results obtained when playing the games in Desktop mode are stored in a different array from the VR results.
			{
			"results":
			[
			{
			"type": *integer*,
			"results": {
			"id": *integer*,
			"results_desktop": [
			{
			"total_in_game_time": *integer*,
			"max_height_achieved": *float*,
			"success": *boolean*,
			"data_added": *string*
			}
			],
			"results_vr": [ ]
			}
			}
			]
			}

/addPatient	POST	Adds a new patient to the system.	Request body:
			{
			"name": *string*,
			"left_hand": *boolean*,
			"bi_num": *integer*
			}
			
			Response:
			{
			"result": *string*
			}

/removePatient	POST	Removes the patient identified by the given ID.	Request body:
			{
			"id ": *integer*
			}
			
			Response:
			{
			"result": *string*
			}

/updatePatientData	POST	Updates a patient's status	Request body: { "id": *integer*,

			"date_of_birth": *string*,
			"bi_num": *integer*,
			"email": *string*,
			"name": *string*,
			"last_name": *string*,
			"register_date": *string*,
			"last_calibration_date": *string*,
			"left_hand": *boolean*,
			"lift_max_height": *float*,
			"grab_open_margin": *float*,
			"grab_close_margin": *integer*,
			"index_pinch_margin": *integer*,
			"middle_pinch_margin": *integer*,
			"ring_pinch_margin": *integer*,
			"pinky_pinch_margin": *integer*,
			"language": *integer*
			}
			
			Response:
			{
			"result": *string*
			}

/getLastTest	GET	Get last Enjalbert test created.	{
			"custom_name": *string*,
			"time_per_test": *string*,
			"hand": *string*,
			"lvl1": {
			"vertical_distance": *string*,
			"hold_time": *string*,
			"tunnel_space": *string*
			},
			"lvl2": {
			"vertical_distance": *string*,
			"horizontal_distance": *string*,
			"hold_time": *string*,
			"tunnel_space": *string*
			},
			"lvl3": {
			"margin": *string*,

			"hold_time": *string*,
			"iterations": *string*
			},
			"lvl4": {
			"total_index_counts": *string*,
			"total_middle_counts": *string*
			},
			"lvl5": {
			"total_ring_counts": *string*,
			"total_pinky_counts": *string*
			},
			"id": *string*
			}

/getTestsBrief	GET	Get simplified list of Enjalbert tests.	[
			{
			"id": *string*,
			"custom_name": *string*
			}
			]

/getTestToDo	GET	Get Enjalbert test defined as TO-DO. (only for debug)	Response similar to /getLastTest response.
/getTestById	GET	Get the Enjalbert test identified by the given ID.	Response similar to /getLastTest response.

/getTestResultsById	GET	Get array of recorded Enjalbert test performances relative to the given test ID.	[
			{
			"lvl1": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"hold_time": *integer*
			},
			"lvl2": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"hold_time": *integer*
			},
			"lvl3": {
			"success": *integer*,
			"time_taken": *integer*,

			"total_time": *integer*,
			"iterations": *integer*,
			"total_iterations": *integer*,
			"margin": *float*
			},
			"lvl4": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"index_counts": *integer*,
			"total_index_counts": *integer*,
			"middle_counts": *integer*,
			"total_middle_counts": *integer*
			},
			"lvl5": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"ring_counts": *integer*,
			"total_ring_counts": *integer*,
			"pinky_counts": *integer*,
			"total_pinky_counts": *integer*
			},
			"test_id": *string*,
			"timestamp": *string*
			}
			]

/getAllTestResults	GET	Get all recorded Enjabert test performances.	Array of objects similar to the one above.

/addTest	POST	Add new Enjalbert test	Request body:
			{
			"time_per_test": *integer*,
			"hand": *string*,
			"custom_name": *string*,
			"lvl1": {
			"vertical_distance": *integer*,
			"hold_time": *integer*,
			"tunnel_space": *integer*

			},
			 "lvl2": {
			 "vertical_distance": *integer*,
			 "horizontal_distance": *integer*,
			 "hold_time": *integer*,
			 "tunnel_space": *integer*
			 },
			 "lvl3": {
			 "margin": *float*,
			 "hold_time": *integer*,
			 "iterations": *integer*
			 },
			 "lvl4": {
			 "total_index_counts": *integer*,
			 "total_middle_counts": *integer*
			 },
			 "lvl5": {
			 "total_ring_counts": *integer*,
			 "total_pinky_counts": *integer*
			 }
			 }
			
			 Response body:
			 {
			 "result": *string*
			 }

/editTest	POST	Edit the Enjalbert test identified by the given	Request body:
			 {
			 “id”: *integer*,
			 "time_per_test": *integer*,
			 "hand": *string*,
			 "custom_name": *string*,
			 "lvl1": {
			 "vertical_distance": *integer*,
			 "hold_time": *integer*,
			 "tunnel_space": *integer*
			 },
			 "lvl2": {
			 "vertical_distance": *integer*,
			 "horizontal_distance": *integer*,
			 "hold_time": *integer*,
			 "tunnel_space": *integer*
			 },
			 "lvl3": {

			"margin": *float*,
			"hold_time": *integer*,
			"iterations": *integer*
			},
			"lvl4": {
			"total_index_counts": *integer*,
			"total_middle_counts": *integer*
			},
			"lvl5": {
			"total_ring_counts": *integer*,
			"total_pinky_counts": *integer*
			}
			}
			
			Response body:
			{
			"result": *string*
			}

/setTestToDo	POST	Set an Enjalbert test as the “test TO-DO”.
		(only for debug)
			Request body:
			{
			“testId”: *integer*
			}
			
			Response body:
			{
			"result": *string*
			}

/sendTestResults	POST	Send a recorded Enjalbert test performance to the server.	Request body:
			{
			"lvl1": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"hold_time": *integer*
			},
			"lvl2": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"hold_time": *integer*
			},
			"lvl3": {
			"success": *integer*,
			"time_taken": *integer*,

			"total_time": *integer*,
			"iterations": *integer*,
			"total_iterations": *integer*,
			"margin": *float*,
			"hold_time": *integer*
			},
			"lvl4": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"index_counts": *integer*,
			"total_index_counts": *integer*,
			"middle_counts": *integer*,
			"total_middle_counts": *integer*
			},
			"lvl5": {
			"success": *integer*,
			"time_taken": *integer*,
			"total_time": *integer*,
			"ring_counts": *integer*,
			"total_ring_counts": *integer*,
			"pinky_counts": *integer*,
			"total_pinky_counts": *integer*
			},
			"test_id": *string*
			}
			
			Response body:
			{
			"result": *string*
			}

/getLastGame	GET	Get last created mini-game.	{ "left_hand": true, "language": *integer*, "total_time": *integer*, "distance": *float*, "time_to_hold": *integer*, "total_interactions": *integer*, "time_between_interactions": *integer*, "id": *integer*, "custom_name": *string*, "name": *string*

			}

/ getAllGamesBrief	GET	Get a simplified list of game instances in the server (all patients).	[
			{
			"id": *integer*,
			"custom_name": *string*,
			"type": *integer*,
			"name": *string*
			}
			]

/getGamesBriefByPatient	GET	Get a simplified list of game instances in the server associated with the patient identified by the given ID.	Object similar to the one above.

/getGameToDo	GET	Get mini-game defined as TO-DO. (only for debug)	{
			"left_hand": true,
			"language": *integer*,
			"total_time": *integer*,
			"distance": *float*,
			"time_to_hold": *integer*,
			"total_interactions": *integer*,
			"time_between_interactions": *integer*,
			"id": *integer*,
			"custom_name": *string*,
			"name": *string*
			}

/getGameById	GET	Get mini-game identified by the given ID.	{
			"left_hand": true,
			"language": *integer*,
			"total_time": *integer*,
			"distance": *float*,
			"time_to_hold": *integer*,
			"total_interactions": *integer*,
			"time_between_interactions": *integer*,
			"id": *integer*,
			"custom_name": *string*,
			"name": *string*
			}

/setGameToDo	POST	Set a mini-game as the "game TO-DO".	Request body: { "id": *integer*,

		(only for debug)	"type": *integer*
			}
			
			Response body:
			{
			"result": *string*
			}

/editGame	POST	Edit a mini-game instance.	Request body:
			{
			"id": *integer*,
			"type": *integer*,
			"game": {
			"left_hand": *boolean*,
			"total_time": *integer*,
			"distance": *integer*,
			"time_to_hold": *integer*,
			"total_interactions": *integer*,
			"time_between_interactions": *integer*,
			"language": *integer*
			}
			}
			
			Response body:
			{
			"result": *string*
			}

/addGame	POST	Add a new mini-game instance.	Request body:
			{
			"type": *integer*,
			"custom_name": *string*,
			"patientId": *integer*,
			"game": {
			"left_hand": *boolean*,
			"total_time": *integer*,
			"distance": *integer*,
			"time_to_hold": *integer*,
			"total_interactions": *integer*,
			"time_between_interactions": *integer*,
			"language": *integer*
			}
			}

			Response body:
			{
			"result": *string*
			}

/sendGameResults	POST	Send a recorded mini-game performance to the server.	Request body:
			{
			"type": *integer*,
			"id": *integer*,
			"VR": *boolean*,
			"results": {
			"total_in_game_time": *integer*,
			"max_height_achieved": *float*,
			"success": *boolean*
			}
			}
			
			Response body:
			{
			"result": *string*
			}

/addGameType	POST	Add a new game type to the server. (in development)	Request body:
			{
			"game_name": *string*,
			"game_template": {
			"difficulty_level": *integer*,
			"secondsToHit": *integer*,
			"time_between_interactions": *integer*,
			"numberOfLifes": *integer*,
			"minimumScoreForSuccess": *integer*
			}
			}
			
			Response body:
			{
			"result": *string*
			}

ANNEX V - Formal Study Request to Ethics Committee

1. IDENTIFICAÇÃO DO PROJECTO

a) Nome do Investigador principal ____________

b) Título do Projeto Realidade Virtual para Reabilitação

c) Serviço hospitalar / Instituto ou Laboratório onde o projeto será executado ____

d) Existem outros centros, nacionais ou não, onde a mesma investigação será feita?

Sim [ ] Não [X]

Em caso afirmativo indique-os:

e) Descreva sucintamente os objectivos da investigação:

Estudo transversal de aplicações de realidade virtual para a reabilitação do membro superior. Tem como objetivo avaliar a usabilidade da Realidade Virtual no processo de reabilitação do membro superior em pacientes após AVC, no contexto de sessões de terapia ocupacional.

f) A Investigação proposta envolve:

a) Exames complementares – indique o tipo, frequência a natureza da amostra.

Especifique se estes exames são feitos especialmente para esta investigação ou se serão executados no âmbito dos cuidados médicos habituais a prestar aos doentes:

Sessões de teste nos a decorrer no mês de Maio de 2017. Nestas sessões os pacientes envolvidos utilizam as aplicações e, seguidamente, respondem a um questionário. Estes testes, para além da obtenção de resultados, têm como objetivo testar o uso destas aplicações como parte da rotina dos pacientes.
Paralelamente, será preenchido um questionário pelos médicos fisiatras e terapeutas ocupacionais para avaliar de que forma o quadro clínico/funicional dos pacientes interfere com a realização dos jogos, de que forma os jogos no programa de reabilitação, os eventuais efeitos secudários e as limitações observadas pelos profissionais de saúde responsáveis pelos pacientes.

g) Questionários

- A quem são feitos? Pacientes, terapeutas ocupacionais, médicos fisiatras
- Como será mantida a confidencialidade? Identificação do paciente por número e não por nome

(Nota: Junte 1 exemplar do questionário que será utilizado)

2. ENSAIOS CLÍNICOS DE NOVOS FÁRMACOS

a) Tipo de Ensaio:

Fase III ☐ Fase IV ☐ Marketing ☐

b) Tipo de Fármaco:

- Nome(s) Genérico(s)

____

- Grupo farmacológico ou terapêutico

2

- Aprovação noutros países

- Aprovação pelo INFARMED
  - Fármaco: Aprovado ☐ Não Aprovado ☐
  -
  - Forma Medicamentosa: Aprovada ☐ Não Aprovada ☐

  - Indicação terapêutica contemplada na investigação:

    Aprovada ☐ Não Aprovada ☐

  - Posologia contemplada na investigação:

    Aprovada ☐ Não Aprovada ☐

  - Via de administração contemplada na investigação:

    Aprovada ☐ Não Aprovada ☐

- Tipo de Ensaio
  - Comparação com placebo ☐
  - Comparação com fármaco padrão ☐
  - Ensaio com dupla ocultação randomizado ☐
  - Ensaio aberto ☐

- Outro tipo (especifique) ______________________________

____

(Nota: 1 – No caso de medicamentos já aprovados oficialmente junte a bula oficial do produto comercializado.

2 - No caso de medicamentos ainda não aprovados, junte documento do fabricante, certificando a segurança do produto no qual conste a posologia e vias de administração recomendadas, bem como as indicações terapêuticas.)

3. **JUSTIFICAÇÃO CIENTÍFICA DA INVESTIGAÇÃO** - descreva sucintamente os fundamentos científicos da investigação. Indique, em particular, se a investigação já foi feita anteriormente com seres humanos, se o problema foi devidamente estudado a nível experimental de modo a optimizar os aspectos analíticos e técnicos e a avaliar os possíveis efeitos adversos.

   Este estudo transversal tem como objetivo testar a usabilidade da aplicação de Realidade Virtual para um conjunto de pacientes com diferentes sequelas de AVC. O desenvolvimento dos programas foi acompanhado por médicos do Centro de Reabilitação e foram previamente feitos testes do sistema com alunos voluntários da Universidade.

   Os produtos testados (aplicações de realidade virtual e plataforma web de configuração e monitorização das mesmas) serão fornecidos gratuitamente ao Centro de Reabilitação de forma a serem usados como parte da rotina de reabilitação dos pacientes, caso se verifiquem benificios na sua inclusão em sessões de terapia ocupacional.

4. **DOENTES ABRANGIDOS NA INVESTIGAÇÃO**

   . Número 10 a 15

   . As mulheres grávidas são excluídas? Sim [x] Não [ ]

   . Indique como se processará o recrutamento dos doentes

Critérios de inclusão: ser pacientes com sequelas de AVC do Centro de Reabilitação.

Critérios de exclusão: ter alterações cognitivas ou comportamentais que impeçam a compreensão dos jogos e nenhum movimento ativo em todos os segmentos do membro superior.

Este ensaio em parte servirá para que, no futuro, sejam definidos critérios de inclusão e exclusão mais específicos.

5. CONTROLES

. Número ____________

. Indique como serão escolhidos ____________

6. DESCRIÇÃO RESUMIDA DO PLANO DA INVESTIGAÇÃO

Em cada sessão de teste, um grupo de pacientes testará as aplicações e, depois do teste, cada paciente responderá a um questionário relativo à satisfação no uso dos programas e à opinião sobre a inclusão dos mesmos na rotina de reabilitação. Os médicos e terapeutas responsáveis pelo paciente preencherão também um questionário relativo à condição atual do paciente e às circunstâncias do teste em si.

7. ENUMERAÇÃO DOS PROCEDIMENTOS, EXAMES OU SUBSTÂNCIAS QUE IRÃO SER ADMINISTRADAS AOS DOENTES (dietas especiais, medicamentos, radioisótopos, etc.)

8. RISCO/BENEFÍCIO

a) Que riscos ou incómodos podem ser causados aos doentes pelo estudo?

Possibilidade de desconforto causado por imersão completa em realidade virtual (cybersickness): estes efeitos poderam incluir sensações de desiquilíbrio, dor de cabeça ou nauseas e estão relacionados com a exposição a movimento virtual (dentro da aplicação) que não coincide com movimento do utilizador (que normalmente está numa posição de repouso). Este tipo de desconforto não é esperado pois as aplicações a testar não envolvem movimento virtual do paciente que não corresponda ao movimento real. No entanto, caso se verifique desconforto por parte do paciente, a sessão será interrompida.

b) Que benefícios imediatos poderão advir para os doentes pela sua anuência em participar no estudo?

Aumento de motivação para a execução dos movimentos de membro superior.

c) Considera que os meios utilizados no estudo podem violar a privacidade do doente?

Sim ☐ Não ☒

Em caso afirmativo, indique que medidas serão tomadas para assegurar a confidencialidade.

d) Os doentes que não aceitarem participar no estudo ficarão, por esse facto, prejudicados em termos de assistência médica, relativamente aos participantes?

Sim ☐ Não ☒

9. CONSENTIMENTO

a) A expressão do consentimento informado terá forma escrita, conforme a Lei.
Junta-se cópia do seu texto, a ser assinado pelo doente ou pelo seu representante legal.

b) Descreva resumidamente o conteúdo da informação a transmitir.

ô

É usado o formulário de consentimento informado segundo as regras da DGS (DIREÇÃO-GERAL DA SAÚDE)

c) A investigação ou estudo envolve:

. Menores de 14 anos Sim ☐ Não ☒

. Inimputáveis Sim ☐ Não ☒

Em caso afirmativo que medidas estão previstas para respeitar os seus direitos e obter o seu consentimento esclarecido ou dos seus representantes legais?

10. RELATIVAMENTE AO ESTUDO

a) Data prevista do inicio 08/05/17

Data prevista da conclusão 01/06/17

b) Pagamento aos doentes:

. Pelas deslocações Sim ☐ Não ☒

. Pelas faltas ao Serviço Sim ☐ Não ☒

. Por danos resultantes da sua participação no estudo Sim ☐ Não ☒

Em caso afirmativo especifique a identidade que assume a responsabilidade das indemnizações:

Outros pagamentos (especifique):

c) Do estudo que espécie de benefícios, financeiros ou outros resultarão para o investigador e/ou instituição? Especifique em caso afirmativo.

Os resultados obtidos irão contribuir para a avaliação da utilização de realidade virtual no âmbito de reabilitação, podendo sugerir a sua adoção como tratamento complementar na reabilitação, tanto durante o internamento como no domicilio.

d) Os dados obtidos constituirão propriedade exclusiva da companhia farmacêutica ou outra entidade?

Sim ☐ Não ☒ Que entidade? ____________________

11. TERMO DE RESPONSABILIDADE

Data do pedido de aprovação ___/___/___

Eu abaixo assinado, ____

Na qualidade de investigador principal, declaro por minha honra que as informações prestadas neste questionário são verdadeiras. Mais declaro que, durante o estudo, serão respeitadas as recomendações constantes da Declaração de Helsínquia II e da Organização Mundial de Saúde, no que se refere à experimentação que envolva seres humanos.

Declaro ainda que, será entregue no prazo de 30 dias o estudo final, de preferência em suporte digital na vossa Instituição.

____

(O investigador)

12. (Reservado à C.E.S.)

PARECER EMITIDO NA REUNIÃO DE

___/___/2016

____

____

____

____

____

____

____

ANNEX VI – Rovisco Pais Transversal Study

Questionnaire:

Doctor and Therapist Information

* Required

1. **Doctor (name and NMEC)**

2. **Therapist (name and NMEC)**

Patient Info

This section is reserved for doctors/therapists and contains the current status of the patient's recovery.
Doctor: Patient identification, Type and Location of Stroke and Clinical Evaluation.
Therapist: Likert Scales, Limitations and secondary Effects.

3. **Id**

4. **Gender**
   Mark only one oval.
   - F
   - M

5. **Age**

6. **Type of stroke**
   Mark only one oval.
   - Ischemic
   - Hemorrhagic

7. **Stroke Location**
   Mark only one oval.
   - Right
   - Left
   - Bilateral
   - Upper Body

Humor

8. **Is the patient depressed?**
Mark only one oval.

- No
- Yes

9. **Does the patient's current state regarding humor interfere with the execution of the VR application?**
Mark only one oval.

	1	2	3	4	
Not at all					Yes, a lot (makes it impossible)

COGNITION (Mini mental scale – MMS)

Note: patients presenting cognition difficulties which make them incapable of understanding or playing the games were excluded from this study.

10. **Does the patient suffer from cognition changes?**
Mark only one oval.

- No
- Yes

11. **Does the patient's current state regarding cognition interfere with the execution of the VR application?**
Mark only one oval.

	1	2	3	4	
Not at all					Yes, a lot (makes it impossible)

COMMUNICATION

12. **Does the patient suffer from communication changes?**
Mark only one oval.

- No
- Yes

13. **Does the patient's current state regarding communication interfere with the execution of the VR application?** *
Mark only one oval.

	1	2	3	4	
Not at all					Yes, a lot (makes it impossible)

VISION

14. **Does the patient suffer from vision changes?**
Mark only one oval.

- No
- Yes

15. **Does the patient's current state regarding vision interfere with the execution of the VR application?**
Mark only one oval.

	1	2	3	4	
Not at all	◯	◯	◯	◯	Yes, a lot (makes it impossible)

UPPER LIMB FUNCTIONALITY

16. **Enjalbert**

17. **Frenchay arm test**

UPPER LIMB STRENGTH (Medical Research Council scale)

Shoulder

18. **Shoulder - Previous Elevators**

19. **Shoulder - Lateral Elevators**

Elbow

20. **Elbow - Flexors**

21. **Elbow - Extensors**

Fist

22. **Fist - Flexors**

23. **Fist - Extensors**

Fingers

24. **Fingers - Flexors**

25. **Fingers - Extensors**

26. **Does the patient's current state regarding upper limb functionality interfere with the execution of the VR application?**

Mark only one oval.

	1	2	3	4	
Not at all	◯	◯	◯	◯	Yes, a lot (makes it impossible)

UPPER LIMB SENSITIVITY

27. **Does the patient suffer from superficial sensitivity changes?**

Mark only one oval.

◯ No
◯ Yes

28. **Does the patient's current state regarding superficial sensitivity interfere with the execution of the VR application?**

Mark only one oval.

	1	2	3	4	
Not at all	◯	◯	◯	◯	Yes, a lot (makes it impossible)

29. **Does the patient suffer from proprioceptive sensitivity changes?**

Mark only one oval.

◯ No
◯ Yes

30. **Does the patient's current state regarding proprioceptive sensitivity interfere with the execution of the VR application?**

Mark only one oval.

	1	2	3	4	
Not at all	◯	◯	◯	◯	Yes, a lot (makes it impossible)

HEMINEGLIGENCE

31. **Does the patient suffer from heminegligence?**
Mark only one oval.

- ⬭ No
- ⬭ Yes

32. **Does the patient's current state regarding heminegligence interfere with the execution of the VR application?**
Mark only one oval.

	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	Yes, a lot (makes it impossible)

CHANGES IN GESTURE HARMONY – DISKINESIA (EX: TREMORS, DISTONIA, MYOCLONIA, ATAXIA, ...)

33. **Does the patient suffer from diskinesia?**
Mark only one oval.

- ⬭ No
- ⬭ Yes

34. **Does the patient's current state regarding diskinesia interfere with the execution of the VR application?**
Mark only one oval.

	1	2	3	4	
Not at all	⬭	⬭	⬭	⬭	Yes, a lot (makes it impossible)

MUSCLE TONE (ASHWORD scale modified)

Shoulder

35. **Shoulder - Adductors**

____

36. **Shoulder - Abductors**

____

37. **Shoulder - Flexors**

____

Elbow

38. **Elbow - Flexors**

____

39. **Elbow - Extensors**

____

Fist

40. **Fist - Flexors**

____

41. **Fist - Extensors**

____

42. **Fist - Pronators**

____

43. **Fist - Supinators**

____

Fingers

44. **Fingers - Flexors**

____

45. **Fingers - Extensors**

____

46. **Does the patient's current state regarding muscle tone interfere with the execution of the VR application?**
Mark only one oval.

	1	2	3	4	
Not at all	◯	◯	◯	◯	Yes, a lot (makes it impossible)

Introduction

Thank you for participating in this study.
First, we would like to access your familiarity with computers and Virtual Reality.

47. **Do you use your computer regularly?**
Mark only one oval.

	1	2	3	4	5	
never	◯	◯	◯	◯	◯	every day

48. **Do you play computer games?**
Mark only one oval.

	1	2	3	4	5	
never	◯	◯	◯	◯	◯	every day

49. **Are you familiar with Virtual Reality?**
Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	yes (very familiar)

DESKTOP - Computer screen

50. **Did you feel any kind of discomfort during the games?**
Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	yes (a lot)

51. **If so, what kind of discomfort?**

____
____
____
____
____

52. **Were the games objects easy to distinguish from the scenario?**
Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes (very easy)

53. **Were the games easy to complete?**
Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes (very easy)

54. **Did you like the games?**
Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes

55. **Did you feel any kind of discomfort after playing the games?**

Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes (a lot)

56. **If so, what kind of discomfort?**

____
____
____
____
____

FULL IMMERSION - Head Mounted Display

Note: the used HMD was the Oculus Rift Dk2.

57. **Did you feel any kind of discomfort during the games?**

Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes (a lot)

58. **If so, what kind of discomfort?**

____
____
____
____
____

59. **Were the games objects easy to distinguish from the scenario?**

Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes (very easy)

60. **Were the games easy to complete?**

Mark only one oval.

	1	2	3	4	5	
No	◯	◯	◯	◯	◯	Yes (very easy)

61. **Did you like the games?**
Mark only one oval.

	1	2	3	4	5	
No	⬭	⬭	⬭	⬭	⬭	Yes

62. **Did you feel any kind of discomfort after playing the games?**
Mark only one oval.

	1	2	3	4	5	
No	⬭	⬭	⬭	⬭	⬭	Yes (a lot)

63. **If so, what kind of discomfort?**

____
____
____
____
____

GENERAL INQUIRIES

64. **Which type of immersion did you use first?**
Mark only one oval.

- ⬭ Desktop
- ⬭ Virtual Reality (fully immersive)

65. **Which mini-games did you play?**
Check all that apply.

- ☐ 1 - Lift
- ☐ 2 - Apple Eater
- ☐ 3 - Dish Washer

66. **Desktop - Which mini-games were you able to complete?**
Check all that apply.

- ☐ 1 - Lift
- ☐ 2 - Apple Eater
- ☐ 3 - Dish Washer

67. **VR - Which mini-games were you able to complete?**
Check all that apply.

- ☐ 1 - Lift
- ☐ 2 - Apple Eater
- ☐ 3 - Dish Washer

68. **What was your favorite game?**
Mark only one oval.

- ◯ 1 - Lift
- ◯ 2 - Apple Eater
- ◯ 3 - Dish Washer

69. **Which type of immersion did you prefer?**
Mark only one oval.

- ◯ Desktop
- ◯ Virtual Reality (fully immersive)

70. **Why?**

____
____
____
____
____

71. **Was the virtual representation of your movements realistic?**
Mark only one oval.

	1	2	3	4	5	
Not at all	◯	◯	◯	◯	◯	yes (very realistic)

72. **Do you think this type of treatment (playful/VR) can be useful for rehabilitation therapy?**
Mark only one oval.

- ◯ No
- ◯ Yes

73. **Would you use this type of applications at home?**
Mark only one oval.

- ◯ No
- ◯ Yes

74. **Would you prefer to play these games in an individual or social setting?**
Mark only one oval.

- ◯ Individual
- ◯ Social

75. **Suggestions:**

Occupational therapy

76. **What limitations did you encounter in using the equipment or the application?**

77. **What possible side effects do you think this application might have?**

78. **How do you think these VR games benefit the rehabilitation program of this patient?**

79. **Suggestions or relevant information:**

ANNEX VII – PARTICIPATION IN "TeleSaúde no AVC | Do Evento ao Domicilio"

During the testing session performed in the 23rd of March 2017, video of the patients' execution of the tests was recorded to be part of a promotional video to be presented at the "TeleSaúde no AVC | Do Evento ao Domicilio" event (http://spms.min-saude.pt/2017/03/centro-rovisco-pais-recebe-telesaude-no-avc-do-evento-ao-domicilio/).

During the event, a demonstration of the developed applications also took place.