A Customizable Upper Limb Stroke Rehabilitation Tool

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Abstract

With the increasing emergence of interactive rehabilitation systems, some technologies target specific rehabilitation fields. Stroke rehabilitation is one of those fields and a rather important one, considering stroke has affected 1.1 million people each year in Europe alone at the beginning of the 21st century. The biggest obstacle in stroke rehabilitation systems is that stroke patients' symptoms include hemiparesis, causing motor and cognitive impairments that differ from patient to patient. With this in mind, we developed an intuitively interactable system with the ability to record and review any movement desired by a patient. The system also features the capability for a therapist to set the compensatory movement thresholds considered ideal for any actuating body segment in said movement, according to patient need, the means for the patient to practice said movement, with the help of dynamic feedback, and review it alongside the clinician, with access to data metrics, captured during motion execution. Additionally, we conducted a user study where physical therapists interacted with our system, where results suggest that the adaptability to both patient's needs and therapist intervention methodology diversity are imperative for the validity of any neurological therapy interactive tool. Moreover, we concluded that, due to the predominance of stroke victims of an older age group, stroke rehabilitation tools should focus on the simplicity of interface and equipment used and that an exercise review feature, including performance and error metrics, can improve the quality of exercise analysis and consequently treatment quality.

Keywords

Rehabilitation, Stroke, Upper Body, Compensatory Movements, User Interface, HTC Vive

Resumo

Com o surgimento de sistemas interativos de reabilitação, algumas tecnologias focam-se em campos específicos de reabilitação. A reabilitação de AVC é um dos campos mais importante, considerando que AVCs afectaram 1,1 milhões de pessoas a cada ano, na Europa, o início do século XXI. O maior obstáculo nos sistemas de reabilitação de AVC é o facto dos sintomas de um paciente com AVC incluem hemiparesia, causando deficiências motoras diferentes. Com isto em mente, desenvolvemos um sistema de interação intuitiva, com a capacidade de registrar e rever qualquer movimento desejado por um paciente, a capacidade de um terapeuta definir os limites de movimentos compensatório considerados ideais para qualquer segmento corporal que atue no referido movimento, de acordo com a necessidade do paciente, os meios para o paciente praticar o referido movimento, com a ajuda de feedback dinâmico, e revê-lo juntamente com o terapeuta. Para além disso, realizámos um estudo de utilizador, onde fisioterapeutas interagiram com nosso sistema, de onde os resultados sugerem que a adaptabilidade às necessidades do paciente e à diversidade da metodologia de intervenção dos terapeutas são imperativas para a validade de qualquer ferramenta interativa de terapia neurológica. Além disso, concluímos que, devido à predominância de vítimas de AVC numa faixa etária mais avançada, uma ferramenta de reabilitação de AVC deve-se focar na simplicidade da interface e dos equipamentos utilizados, e que um recurso de revisão de exercícios, incluindo métricas de desempenho e erros, pode melhorar a qualidade da análise do exercício e consequentemente a qualidade do tratamento.

Palavras Chave

Reabilitação, AVC, Membros Superiores, Movimentos Compensatórios, HTC Vive

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Acronyms

MBS Marker-Based Stereophotogrammetry

VR Virtual Reality

HMD Head Mounted Display

BS Base Station

IK Inverse Kinematics

UI User Interface

1

Introduction

Contents

A stroke is a common form of brain injury, generally caused by cerebral infarction (ischemic stroke), a nontraumatic intracerebral haemorrhage or an intraventricular haemorrhage [2]. Stroke is a leading cause of disability, affecting approximately 1.1 million people in Europe each year at the beginning of the 21st century [3].

Rehabilitation is a crucial part of muscular dysfunction or motor disability recovery, and it usually implicates muscular stimulation and reinforcement through exercise. However, since the most common and widely recognized impairment caused by stroke is motor impairment, which can be regarded as a loss or limitation of function in muscle control or movement or a restriction in mobility, much of the focus of stroke rehabilitation. In particular, the work of physiotherapists and occupational therapists is on the recovery of impaired movement and the associated functions [4].

This specific approach of rehabilitation, due to its subjective nature, requires the analysis of compensatory movements (movements used to achieve functional motor motions when a normal movement pattern is not practicable), as these are frequent when someone is re-learning limb function-associated motions. While these compensatory movements help patients to achieve their tasks, they can also obstruct recovery progress and induce new orthopaedic problems. In light of this, detecting and preventing compensatory movements warrants particular consideration [5].

On another note, one of the most disabling motor conditions following stroke-related brain damage is the loss of arm function. Following a stroke, up to 85% of patients have a sensorimotor deficit in the arm [6]. Whilst hemiparesis (a common symptom of stroke-related brain damage consistent with the weakness of one side of the body) is evident in both the lower and upper body, initial rehabilitation is generally focused on the lower body rather than the upper limbs. Only 17% of stroke survivors discharged from hospitals felt that they received good arm and hand therapy and approximately 80% of stroke survivors never recover fully from motor impairments in their upper limbs [7]. This said upper-body rehabilitation of stroke-related motor impairments is an area that currently requires particular focus.

With the advancement of technology, several interactive rehabilitation systems have been emerging, some even specific for stroke rehabilitation, improving patient experience, facilitating data logging for therapists and exploring the psychological aspects of rehabilitation, such as motivation, efficacy and emotional reactions.

1.1 Problem

The exponential emergence of interactive solutions has a very positive impact on the field of rehabilitation, and a lot of these solutions are becoming specialized, targeting specific conditions/disabilities, one of them being stroke-related dysfunctions. However, **the current solutions do not allow for enough personalization to cover the specifications of stroke rehabilitation**, not taking into account the diversity of impairments caused by a stroke and, consequently, the subjectivity of the rehabilitation process that each patient should go through. Instead, the existing solutions rely on pre-set exercises/motions/games that limit the possible stroke patients' movements. Moreover, most systems do not consider compensatory movements - an important aspect to monitor when re-learning motor function - and are user-focused - not considering the necessity of therapists to properly take advantage of interactive and feedback technologies to improve treatment.

An additional aspect of opting to have limited motions to preform is the low motion tracking requirements, which lead to the most common choice of technology being depth cameras - which are not accurate enough to detect some compensatory movements and cannot properly detect motions such as limb rotations - considering most marker-based technologies are too expensive to be viable for implementation.

1.2 Approach

The main objective of this thesis is to **develop a user-centered user interface that allows for enough exercise personalization to allow the proper monitorization and execution of any pre-recorded exercise/motion**, taking into account compensatory movements, using an affordable movement tracking technology that is accurate enough to capture these, as well as any motion required.

To do this, we sought to use the combined information collected from studying the current state of the art, leveraging the work and findings of a former IST student project, the ARCADE [1], and some expertise from experienced professionals on our team, to design a prototype concept. We would then present that concept to practising physical therapists that would give us enough feedback and general direction to build a tangible system that would achieve our aforementioned goals while simultaneously meeting clinicians' technical needs to improve the quality and efficiency of their daily work.

1.3 Project Contributions

In this work, we expect to achieve a human-computer interaction system that can objectively contribute to stroke patients' rehabilitation, as well as ease the therapists' function, giving them a platform to extract data from therapy sessions and use it to improve patient recovery. With this in mind, the following contributions are expected:

- Create a system that can detect and measure compensatory movements with different set thresholds of compliance;
- Create an interface that allows stroke patients to record and practice their subjective upper-body motor impairments;

- To make the HTC Vive viable as an accurate and affordable movement tracking system to use interactive rehabilitation systems;
- Validation of the usability and utility of the developed interface.

1.4 Document Structure

This document continues with chapter 2 setting the background of the thesis, explaining what a stroke is, the types of damages stroke survivors can have and what rehabilitation can do to help them recover from them, reinforcing the differences between regular and stroke rehabilitation. In addition, it explains how compensatory movements are being tracked in current development systems, explores the current state of the art related to interactive rehabilitation systems and studies the different user-centred focus in these projects, as well as some of the motion tracking technologies used and development obstacles encountered. This chapter ends with a discussion of all the information presented.

Chapter 3 introduces the ARCADE project, explaining its system and the information leveraged from it, and the design guidelines we formulated. Moreover, we present our first prototype and the findings of the interviews in which we used it. Similarly to the previous chapter, this one concludes with a discussion of the feedback and state of the concept we designed.

Chapter 4 demonstrates how we developed our final prototype, describing, in detail, each feature and the challenges encountered in their creation. It also depicts our goal with each characteristic of the interfaces constructed while explaining our choices along the way.

Chapter 5 reports on the final user study conducted and its results.

This document closes on chapter 6 with a conclusion on all the work developed, alongside the project limitations and possible future work following this one.

2

Related Work

Contents

This chapter starts by setting the background of the thesis, explaining what stroke is, the types of damages stroke survivors can have, and what rehabilitation can do to help them recover, reinforcing the differences stroke rehabilitation can have from general rehabilitation. It also explores relevant work around compensatory movements and their tracking methods, interactive rehabilitation, and the difference between patient-focused designed systems and briefly touches on some obstacles related to physical recovery.

2.1 Background

Stroke is the most common form of acquired brain injury and is one of the leading causes of death and disability worldwide [8]. A stroke is defined as a clinical syndrome of vascular origin, typified by rapidly developing signs of focal or global disturbance of cerebral functions lasting more than 24 hours or leading to death [9]. This occurs when blood flow is interrupted to a particular portion of the brain. This could be due to a blockage of a blood vessel (ischemia) or a rupture of the blood vessel (haemorrhage). Ischemic strokes may be caused by a clot that formed elsewhere, known as an embolism, or due to the formation of a thrombus, which is a build-up of plaque in the artery [10].

The symptoms of a stroke reflect the location because the symptoms are determined by the regions of the brain that are damaged. The majority of stroke incidents affect the premotor and motor cortexes, Broca's area, Wernicke's area, and the parietal lobe. This leads to the commonly seen stroke symptoms such as hemiparesis [10], which is probably the single most disabling factor, certainly in terms of limiting mobility [9].

Hemiparesis leads to problems across multiple systems, including loss of strength (force-generating capacity), dexterity, poor motor control, and multiple cognitive disorders [11]. Upper-extremity and lower-extremity pareses, frequently combined with significantly reduced overground walking speed and walking distance, constitute severe impediments to the ability to perform activities of daily living, and participate in normal social life. In addition to persistent motor deficits, associated poor endurance and increased fatigue can constitute a psychological burden to stroke survivors, as well as their significant others [8].

These impairments, which affect an individual's ability to complete everyday activities and affect participation in everyday life situations, warrant different rehabilitation approaches. Motor recovery is achieved through task-oriented training and repetition intensity [12]. Stroke rehabilitation has an additional requirement: since a patient has lost the ability to perform motions needed in everyday activities, recovery of said motions is the priority. To recover from an arm concussion, the best practice schedule should be focused on rebuilding the muscle around that arm's joints that degrade with initial muscle recovery, but in the training of a paretic arm, in patients with stroke, the best practice schedule should be designed in accordance with the individual's particular movement deficits [6]. This is the main reason stroke rehabilitation is subjective to each patient and relies on personalized exercises according to patient needs [13] [14].

Furthermore, when confronted with motor impairment, movements such as arm reaching, which are not naturally accomplishable due to the impairment, can be achievable through practice and recovery, as was previously established. Some movement patterns may be regained because of true motor recovery. However, because of the redundancy in the number of degrees of freedom of the body, actions can be accomplished by substituting other degrees of freedom for movements of impaired joints. In patients with hemiparesis, the unrestricted and unguided repetition of a motor task may reinforce these alternative movements or motor compensations [15], and long-term can result in pain and inhibition of motor recovery [16].

2.2 Compensatory Movements

Traditionally, the choice between rehabilitation strategies has been based on the phase of stroke recovery. Thus, in acute stages, therapy focuses on preventing maladaptive compensatory strategies while promoting the healing of normal function. In chronic phases, the emphasis is placed on maximizing function, often through the teaching of compensatory strategies. Today, observations suggest that such a clear division between function vs criteria treatment approaches may not be justified [17].

Michaelsen et al. [17], investigated the effects of the suppression of shoulder and trunk compensatory movements on reaching ability in hemiparetic individuals and concluded that compensatory movement restraint allowed patients with hemiparetic stroke to make use of arm joint ranges that are present but not normally recruited during unrestrained arm-reaching tasks. They also found that during reaching, unrestrained movement in hemiparetic individuals may limit the potential recovery of normal arm movement, considering that these patients did not use their possible joint range for free arm movements.

Michaelsen et al. [15], later studied the effects of single-day training with compensatory movement restriction and found that the effects of restricting trunk compensatory movement in arm reaching motions, for even a day's worth of training, lead to greater elbow extension, a greater decrease in trunk compensatory involvement, improved temporal inter-joint coordination and encourages maximal use of degrees of freedom and arm motor recovery.

Wang et al. [5], developed a wearable garment to monitor posture and upper-body movement. Focusing mainly on shoulder impairment rehabilitation, their smart garment system tracks specific compensatory movements providing feedback on task performance involving scapular motor control training whenever posture deviations beyond a preset threshold. This kinematic feedback, in the form of visual and auditory information, resulted in immediate posture correction and allowed patients to achieve movements without dependency on complementary motions comfortably.

Even with evidence defending the restriction of compensatory movements in stroke recovery, some studies still find that task-specific and purely outcome-oriented training are both viable, depending on the severity of the motor impairments displayed by the patients.

Cirstea et al. [6], studied the dependency of improvements with short-term practice on the severity of motor deficits in stroke victims. They found that it is conceivable that task-oriented training improves both movement outcome and performance in patients with mild-to-moderate hemiparesis. In contrast, motor performance might have to be explicitly addressed for patients with more severe impairments so that basic motor function is achievable.

This split view between the importance of compensatory movement restriction is, to this day, visible in doctors' and therapists' criteria.

2.3 Interactive Rehabilitation

With the incremental appearance of new technology-based rehabilitation systems, a couple of areas in the rehabilitation process were immediately improved. These areas include data capture and storage, previously existing only in the form of therapist/doctor notes, exercise feedback and visual movement guidance. As more data is collected, more information can be accessed, different information can be learned, and better results can be achieved.

Interactive rehabilitation systems are revolutionizing the way physical and psychological recovery can be achieved using new technology to capture and display data in different ways.

Feedback in physical recovery is imperative to sustainable rehabilitation. It ensures the patient can recover physical functioning and avoid re-aggravating their injury. In addition, the feedback can contribute to the patient's motivation [18].

Even though interactive guidance has been a reality for decades now, in the form of informative videos, the dynamic potential of new feedback visualization approaches can have big benefits in patient recovery.

Anderson et al. [19] developed a full-body movement training system composed of a whole-body, interactive, augmented reality mirror. Movement guidance and trial feedback management were analyzed, reaching the conclusion that changes in the amount of feedback given while practicing rehabilitation prescribed movements enabled patients to have continuously high performances when comparing to receiving said feedback through video instructions, where patients plateaued when patients learned all of the usable information.

As we mentioned previously, Faria et al. [1] developed a tool to evaluate if a context-aware system can be helpful in a rehabilitation environment called ARCADE. This tool captures exercises performed by a patient, giving immediate feedback to both patient and therapist in the form of skeletal models of the patient demonstrating the success rate of the performed exercises and other valuable metrics.

In terms of context awareness, a Kinect system detects the proximity the physician is to the patient. Depending on it, the system identifies different contexts, providing different levels of feedback to the therapist.

When the therapist is in what they call a ”social” context (more than 1.5 meters away), the display only shows the success rate and exercise duration. As the therapists get closer to the patient, more metrics are displayed, ending with a display of several essential metrics with their absolute values when the therapist is less than half a meter away or even touching the patient.

Still, visualization challenges can arise with the amount of data that can be captured when performing physical therapy exercises.

Tang et al. [18], developed a system that demonstrates the viability of visual feedback for the guidance of physical therapy exercises in a home environment, called Physio@Home. Their software included an on-screen guide called the Wedge with multi-camera views to guide movements and display immediate feedback on patient performance. They found that the main challenge of interactive feedback and motor guidance systems in physical therapy was balancing visual complexity with sufficient guidance, as in their study, patients would sometimes be overwhelmed by the amount of information displayed.

Some projects successfully found a balance in feedback format that improved rehabilitation.

After the development of Exercise Check in 2017, a remote monitoring and evaluation platform for individuals involved in home-based physical therapy, Saraee et al. [20] evaluated the progress made toward a more comprehensive analysis of the performance of patients in therapy sessions and the feedback given to both patients and physical therapists, in order to validate the feasibility and effectiveness of their system. Their results suggest that the quantitative feedback after each trial and the playback of a reference exercise while performing a practice exercise benefit motor recovery.

2.4 User-Centered Focus in Interactive Rehabilitation

Interactive rehabilitation tools have a challenging reality: Therapists will gladly work with new technologies when they provide means to automate processes and/or access to objective data that will help in their work. Patients, on the other hand, either get excited and thus motivated using new tools in their physical therapy sessions or get apprehensive when confronted with new, possibly complex, technologies, especially older people, who constitute a large portion of physical therapy patients.

With this in mind, most tool developers have adopted a user-centred approach since the result is usually more usable and acceptable applications [21]. The problem with this approach is that some of these applications usually disregard the role of the therapist in the rehabilitation process, considering the patient only as the user, even though it has been shown that accurate assessment, evaluation and comparison of the patients' motion patterns over time can improve their motor recovery, when therapists can make more informed decisions [12].

Ayoade et al. [21] developed an interactive home-based rehabilitation visualization system for unsupervised use in patient recovery. Because they planned on carrying out a study where patients tested the systems in their own homes, they employed a user-centred design to accommodate patient needs.

Later they concluded that one of their system's most important features was the ability for patients to conduct video conferences with therapists since it is through the collected data that therapists could make judgment calls that improved rehabilitation performance.

Another example of patient-centred rehabilitation technologies that are not suitable for stroke patients is Exergames (games that are also a form of exercise).

Alankus et al. [22] developed a set of home-based games to improve stroke rehabilitation performance by helping with motivation in the practice of recovery exercises. Although they were successful in motivating patients, they realized that games do not suit the broad range of motions a stroke patient could need to work on, as impaired movements vary so much from patient to patient.

On another perspective, Nicolau et al. [12] presented a computer-assisted virtual rehabilitation platform developed with a focus on therapist priorities, mainly concerning themselves with the platform's usefulness to therapists. The platform developed had requirements in mind - such as motion capture, accuracy, data persistence, movement reproduction and comparison, automatic information extraction and easy set-up - that were conceived to improve contemporaneous therapist rehabilitation methods. This led to results indicating that therapists found their platform a valuable addition to current rehabilitation procedures.

2.5 Movement Tracking Technologies

Motion tracking technologies come in three primary forms: magnetic motion capture, mechanical motion capture and, arguably most used nowadays, optical motion capture. Most modern interactive rehabilitation systems usually use one of two visual motion capture methods: depth cameras or marker-based tracking.

2.5.1 Microsoft Kinect.

The Microsoft Kinect depth camera is the most widely used motion tracking technology in interactive rehabilitation systems because of its very affordable price, good performance and all-around easy to set up and use.

However, the Kinect has shown limitations in precision, especially in skeletal tracking, where the system has difficulty tracking movements that cause large amounts of occlusions [19].

Velloso et al. [23], in the development of MotionMA, a system to encode and communicate movement information and enabling real-time feedback between spatially separated users, where they achieved a capable interface with personalizable goals and immediate and accurate feedback, encountered a lot of obstacles to reach their conclusions due to the limitation of the Kinect.

Although it proved to be very accurate in tracking coarse movements when limbs were pointed directly at the camera, or occluded by the body, the overall tracking was severely penalized. The tracking of extremities was not accurate enough to identify mistakes made by participants. Another limitation identified was the lack of support for detecting rotations such as pronation and supination of the wrist. Due to these limitations, the Kinect cannot track a wide variety of movements.

Tang et al. [18], in their development of Physio@Home (as mentioned in a previous section), recognized that the Kinect had difficulties tracking patients with walkers or wheelchairs. Another difficulty involved the limited area in which the Kinect could accurately track the patient's body motions. These are requirements introduce sources of error that must also be considered when used for rehabilitation.

Tao et al.'s [24] study evaluated the kinematic validity of using the Kinect camera's skeletal tracking for use with an upper limb virtual reality rehabilitation system.

Errors for elbow and hand-reaching movements were identified, likely due to the modelling limitation of the Kinect. They discovered that errors associated with the Kinect camera's motion capture were also space-related.

They found that although the Kinect was a viable option, to minimize errors, the camera had to be within a 30x30cm square at a distance of between 1.45 and 1.75 m from the user, and target locations should be calibrated according to predetermined hand, elbow and trunk positions to account for bias errors.

2.5.2 Nintendo Wii

The Nintendo Wii game console has garnered considerable attention, particularly due to its controller, the Wii Remote, and its motion tracking capabilities. This remote is considered a versatile way to collect abundant, high-quality data since it communicates with the console over a standard wireless Bluetooth interface, making it quite simple to use. Its price is typically a fraction of dedicated, commercial data acquisition tools [25].

Saposnik et al. [26] conducted a clinical trial with two parallel groups involving stroke patients within two months. This study compared the feasibility, safety, and efficacy of virtual reality using the Nintendo Wii gaming system versus recreational therapy (playing cards, bingo, or ”Jenga”) among those receiving standard rehabilitation to evaluate arm motor improvement. They found that this gaming technology represents a safe, feasible, and potentially effective alternative to facilitate rehabilitation therapy and promote motor recovery after stroke.

Karasu et al. [27] carried out a study period to investigate the efficacy of Nintendo Wii-based balance rehabilitation as an adjunctive therapy to conventional rehabilitation in stroke patients. In this project, they evaluated 70 stroke patients completing a series of exercise trials. They concluded that this type of rehabilitation could represent a helpful accessory therapy to traditional treatment to improve static and dynamic balance, functional motor ability, and independence in stroke patients.

However, due to the nature of this system and remote dependency, full limb tracking capabilities are limited, as this remains a single measurement point on ample space of motion possibilities [28].

2.5.3 Marker-Based Motion Tracking.

Marker-based motion tracking is another optical motion-capturing method that uses cameras and a set of markers mounted on joints and other predetermined spots on a person's body to computationally render a simulation of that person's body in specific software. Methods of motion capture of this nature, usually designated by Marker-Based Stereophotogrammetry (MBS) systems, are arguably the most accurate optical motion capture method available [29], being de-facto standard for high-precision applications, including biomechanics research and clinical gait analysis [30].

The issue with these technologies is, compared to a Microsoft Kinect, they are much more expensive, and their set-up is more time-consuming [31] [32], making their deployment in most physical therapy clinics unlivable.

Henderson et al. [33] presented a research prototype that tracks multiple independent physical domain objects and the user's head relative to the world. They use this information to provide an AR user interface that offers dynamic, prescriptive feedback and instructions that guide the user to accomplish an interesting procedural task.

They later concluded that their use of marker-based motion capture, using unaffordable OptiTrack infrared cameras and markers, made it hard to consider this approach for mass use.

2.5.4 HTC Vive.

A newer form of motion tracking hardware is HMD (Head-Mounted Display) Virtual Reality devices, such as Oculus Rift, PlayStation VR and HTC Vive. These devices, amongst other features, are capable of positional and rotational tracking. While Oculus Rift and HTC Vive HMDs offer exceptional tracking through an embedded infrared system, the feature that distinguishes HTC Vive from the others is the Vive Tracker, which allows people to bring any real-world object into the virtual environment, by simply attaching the Tracker to it. The position and orientation of this device are then tracked by two base stations based on infrared signals.

Caserman et al. [34] studied a body tracking approach for VR-based applications using Vive Trackers with the HTC Vive HMD system. In their solution, by strapping only a small number of Vive Trackers to a person, they could track both joint rotation and position with reasonable accuracy with a very low end-to-latency.

Borges et al. [35] studied the validity of the Vive system being able to obtain the ground truth data for robotics. While utilizing Vive Trackers, they found the localization ability of the system to be highly accurate and to have sub-millimetric precision (up to metric in a dynamic state).

2.6 Rehabilitation Efficacy Obstacles

From this state of art study, a couple of themes were apparent to be associated with the efficacy of rehabilitation, in general, and stroke patient-specific, which clearly needed to be defined and considered when developing a rehabilitation tool, just as we are proposing. The main themes we identified were the role of motivation and patient state of mind in the efficiency of the rehabilitation process and the focus of current stroke physical recovery methods due to the limitations resulting from different limb impairments.

2.6.1 The Role of Motivation in Rehabilitation

One of the biggest, but sometimes overlooked, obstacles in rehabilitation is the patient's state of mind. The human mind can quickly go to a state of lack of motivation and disbelief in recovery when faced with a challenge like motor impairment.

Motivation is a subject of great importance in the world of physical therapy, even considered by some *the most important, yet the most difficult part of the work of the therapeutic professions* [36].

Maclean et al. [37] conducted a couple of studies where he concluded that the personality trait model of motivation, prevalent in much of clinical literature, can negatively affect engagement with rehabilitation, as there is an intuitive temptation to place sole responsibility for being motivated on to the individual patient. In the face of this natural impulse, external factors, including therapist professionals' behaviour (such as the provision or not of more extensive and more efficiently communicated information aiming to improve patient rehabilitation understanding), can positively and negatively affect motivation. This said clinical awareness of all the factors impinging on motivation for rehabilitation could only have positive effects on patient care [38].

The study by Shaughnessy et al. [39] indicates that exercise may ameliorate some of these declines in functionally impaired stroke survivors. However, several negative factors negatively affect physical activity, such as lack of motivation, social issues, and environmental and cultural expectations, amongst other factors that influence perceptions and beliefs affecting exercise behaviour, including self-efficacy and outcome expectations. To fight this, one solution is to design interventions to educate stroke survivors regarding outcome expectations and to strengthen self-efficacy, which may improve exercise behaviour and consequent performance.

Galindo et al. [40] explore peer environment to boost performance by developing a workshop that enacts patient fantasies to promote range movement exercises in a community group setting. Their study validates the sense of community as reassuring and stimulating to patient performance.

2.6.2 Physical focus of stroke rehabilitation

Presently, in stroke rehabilitation, focus on lower-limb recovery is predominant, as mobility issues are usually considered more restrictive. In spite of this convention, currently, only 20% of stroke survivors fully regain their ability to use their impaired upper limb [7]. This reality remains, primarily due to upper-limb exercise neglection, since studies have determined that early intensive practice of active functional tasks can lead to more positive outcomes for upper limb rehabilitation [41].

Kytö et al. [7] developed ActivSticks, a dedicated bimanual rehabilitation device resulting from a user-centred design process involving stroke survivors and rehabilitation professionals. They focused on emphasizing the importance of body awareness and grip in training in order to support activities of daily living and customizing the outcome beyond games designed by researchers.

Their study provided insight into the importance of upper-limb interactive rehabilitation technologies to increase stroke survivors' independence in their daily lives.

McNeill et al. [41] developed an immersive VR system focused on upper-limb recovery. This system has a set number of tasks that support reach, touch and grasp actions to reinforce upper-body impaired motions.

They provide a very flexible system where operators can change the order in which tasks are performed and change the position of virtual objects in order to meet an individual patient's needs.

2.7 Discussion

From the research done on the works mentioned in the previous sections, we made some conclusions that helped shape the details of our proposed interface.

2.7.1 Personalized Compensatory Movement Tracking.

Even though more and newer studies tend to prove that compensatory movement restriction in stroke-related motor impairments is better for fully recovering afflicted motions, the medical community still seems split in whether, in chronic cases, compensatory movement restriction is a better approach than focusing on function recovery (even if the body's degrees of freedom are not fully restored), at the cost of recovery time.

This said, to be easily adaptable and viable to clinic use, a system where compensatory movements can be measured and detected (with compensation movements as an input [22]), with variable compensation thresholds would give them the freedom to accommodate any rehabilitation practice, according to each practitioner's compensation restriction criteria.

2.7.2 Record and Repeat System.

When focusing on upper-arm rehabilitation, stroke rehabilitation is very subjective. Tasks and exercises are directed according to the patient's specific motion impairment.

With this in mind, a stroke rehabilitation interface cannot be developed with set tasks or exercises. A means to personalize these tasks or exercises should be possible. A good way of doing this would be to allow patients to record a reference exercise, monitored by the therapist, so he can try to reproduce several times by repeating the same motion, trying to comply with the compensatory movement thresholds.

By recording the motion and giving the patient the goal of reproducing it correctly, along with intuitive feedback, therapists can manage expectations appropriately and strengthen patients' self-efficacy, improving exercise behaviour.

2.7.3 User-Centered Design.

Observing the different systems being either patient-focused of therapist-focused in development phases, we realized that, even though the balance of the two should be made, in the case of stroke rehabilitation, there seems to be a lack of interfaces that meet therapists' requirements and, as we have seen, better information made available to practitioners leads to more informed decision and ultimately better recovery performance. With this said, we believe that considering we predict both patient and therapist interaction with our interface, we can consider both to be end users of the application and thus create a system that caters to clinician technical needs around language, visualization and data collection, while trying to keep the patient side of the interface as usable and intuitive as possible.

2.7.4 Precise and Affordable Technology.

Undeniably, the Kinect is the most used motion capture technology in rehabilitation systems. This is due to its affordable price, a requirement when thinking of viability for therapy clinic adoption. The biggest problem with the Kinect in stroke rehabilitation is that impaired motions and compensatory movement detection, because of it's subjectivity, requires rotation detection at all angles and may cause occlusions when using a depth camera.

The HTC Vive system, using the Vive trackers, is an optimal solution since it allows for position and rotation tracking and is available at an affordable price when considering clinic adoption viability.

2.7.4.A Technology cost comparison

As a rehabilitation system, the equipment cost is a significant element in determining its viability in a rehabilitation clinic environment. This is evident because the impact of the acquisition of a new system on a clinic's budget must reflect the system's impact on upgrading the efficiency and efficacy of the rehabilitation process it aims to upgrade. With this in mind, and to gain some perspective on the differences in acquisition prices regarding the systems previously studied, we made a small comparison table showing average prices in popular retail stores (except MBS, which are not usually available in regular stores).

	System			
	Microsoft Kinect	Nintendo Wii	MBS	Vive Trackers
Price	230€	470€	25000€ - 500000€	425€

Table 2.1: Motion Tracking System's average prices

Considering the difference from a MBS to any of the *off-the-shelf* systems, we can observe why it is not financially viable for a regular rehabilitation clinic to implement a system like this.

3

Building an Interactive Stroke Rehabilitation Concept Design

Contents

To understand the practical side of the concepts that stand as a foundation of the development of our system, Stroke Rehabilitation and Interactive Rehabilitation, and to consider the contributions we aimed to achieve, we concluded that no other work had enough similarities to our personalization requirements. Bearing this in mind, feedback from active professional physiotherapists was a priority, especially considering the need to have a user-centred approach to developing our system due to the nature and profession of our end users.

In order to prepare ourselves to present our idea and to get the best and most appropriate information, we decided to make a Low-Functionality prototype, representing our main ideas and design guidelines. To build this first iteration of a prototype we used, as a baseline, information gathered from the professional expertise of our supervisor, Prof. Marlene Rosa, as an experienced physical therapist, and followed the previous work of a former IST student, Afonso Faria, utilizing important information and feedback from therapists, gathered during the development of his proposed upper-limb biofeedback physical therapy system called ARCADE [1].

3.1 ARCADE

ARCADE is a proximity-based context-aware biofeedback system, that aims to improve clinicians' situational awareness and facilitate communication with the patients, aiming to improve the therapists work quality.

3.1.1 The prototype

The ARCADE system, similarly to what we have done, started its work following another colleague's work. In this case, they used a proposed system, called BROTHERS-IN-ARMS [42], as a baseline for their project development. As a result, they used an off-the-shelf tracking camera, the Microsoft Kinectv2, which is a depth camera capable of tracking human body positions, the movements of the body, and articulations, use their orientations to create a virtual skeleton and keeping track of multiple body frames at the same time. In addition, this technology is of an inexpensive nature and is easy to setup and use, making it, as we have seen while studying state of the art, a prevalent and widely used hardware. Another choice motivated by the use of this foundation project was the use of Unity3D as a development environment, as they wanted to improve on the BROTHERS-IN-ARMS system's main features, and tool compatibility was important.

The main goal for this project was to build a system that could handle different patients and exercises, facilitating therapy clinicians' daily life and, most importantly, assisting therapists in the evaluation of several patients at the same time. To do so, developing set visualizations that are easy to interpret and simplify exercise evaluation that change according to context-based criteria was a primary objective to attempt to improve the overall efficiency and quality of the work performed in rehabilitation centres.

The project's development followed a modular architecture design, focusing on building physical therapy workstation systems, comprised of the Kinect camera as a data tracking tool, a computer running the system's application on Unity3D and a display with touchscreen capabilities. The main idea was to scale the workstation design to a point where multiple patients could perform exercises in multiple individual workstations in a single physical therapy facility.

In the final implementation, the visualization of information focused on giving enough feedback on the status of a patient's exercise to the therapist, no matter his distance from the patient performing it. This distance became the main parameter used to make the context-based changes in the visualization, needed to transmit the information required, in the most straightforward way possible, while remaining efficient. To solve this complex context awareness issue, they resorted to the study of proxemics (the study of human communication through space), using the following metrics, proposed by Hall et al. [43], that is commonly accepted as the standard for the division of interpersonal space:

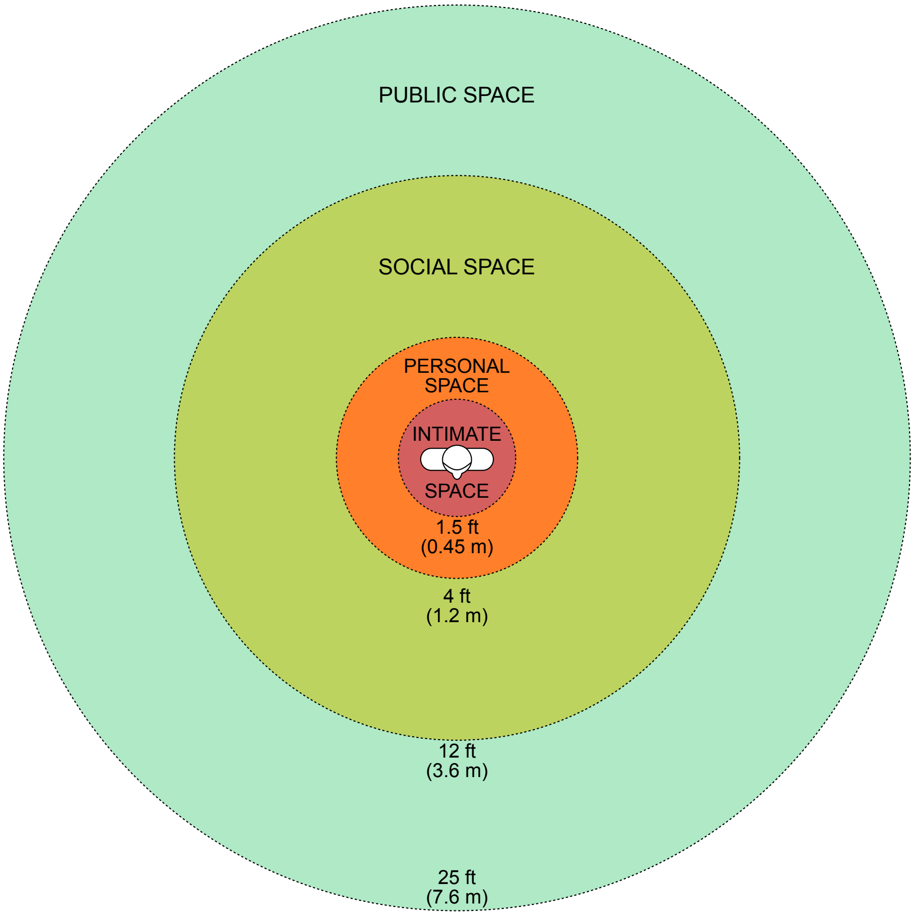


Figure 3.1: Edward T. Hall's interpersonal distances of man [1]

Intimate space: The closest someone can get to a person, normally ranging in between 15 and 45 centimetres from the individual;

Personal space: A close space, usually occupied by interactions with close people, ranging from 45 to 120 centimetres;

Social space: A space normally occupied with acquaintance's interactions. This space ranges from 120 to 350 centimetres;

Public space: Normally used when someone is talking for an audience or is giving any public speech;

With these spatial concepts defined and correctly distinguishing the patient performing the exercise and the clinician, the system changes its visualization whenever a therapist crosses those distance thresholds. For this project, the interpersonal spaces considered and used were the social space, the personal space and the intimate space. While a baseline application in the bottom center of the interface served as the patient screen, displaying the same features as the BROTHERS-IN-ARMS application (a skeletal representation of the patient's body, guiding him through motor rehabilitation and muscle recovery exercises), around that display were represented all the different information in the form of different metrics, with different detail levels, depending on the current interpersonal space occupied by the clinician, in relation to the patient and the workstation he is working at. The used metrics were gathered in a conjuncture of state of art study and user study made with professional physical therapists, alongside other useful information (as we will explore more in depth, in the following chapter).

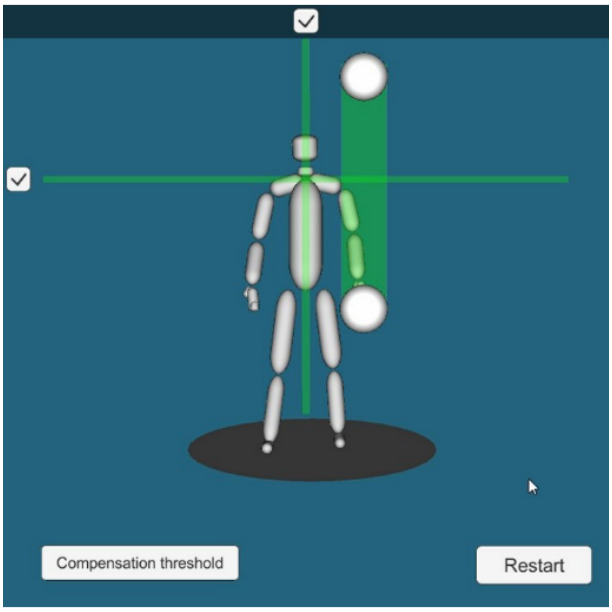


Figure 3.2: ARCADE's *patient screen*

When in the social space, due to the possibility of a more considerable distance from the clinician to the workstation, the information available is a simple display of two metrics (session time and a success metric), in a minimalist way, focusing on telling the therapist if the patient is carrying out the exercise with the desired performance.

In the personal space, the professional is closer to the individual, so it can be inferred that he is even more interested in the particular patient's condition. In addition to adding some more detail about the metrics previously displayed, reducing the size of it, the interface adds two new sectors of visualization, on each side of the *patient screen*. One of these sectors displays the amplitudes of the arm joints in real-time and a "time per repetition" metric, while the other displays compensatory movement information.

The progression to the intimate space, brings the professional, precise details about the two side screens, like the number corresponding to the joint amplitude display, the amplitude limits the patient has gone to, during the session, the exact number of compensations made, and other useful information that would be hard to read and would overload the display at a greater distance.

Figure 3.3: Interpersonal space changes on ARCADE's interface visualization

Finally, for the system to provide a more complete feedback, a session review screen was added so that the data tracked from the exercise repetition could be analyzed and amplitude and compensation patterns could be examined for following sessions' improvement. This visualization took the display forms of an agglomerate of skeletons that corresponded to patient body positions where compensatory movements were made and a *heat map* showing the movement of each individual arm joint during an exercise.

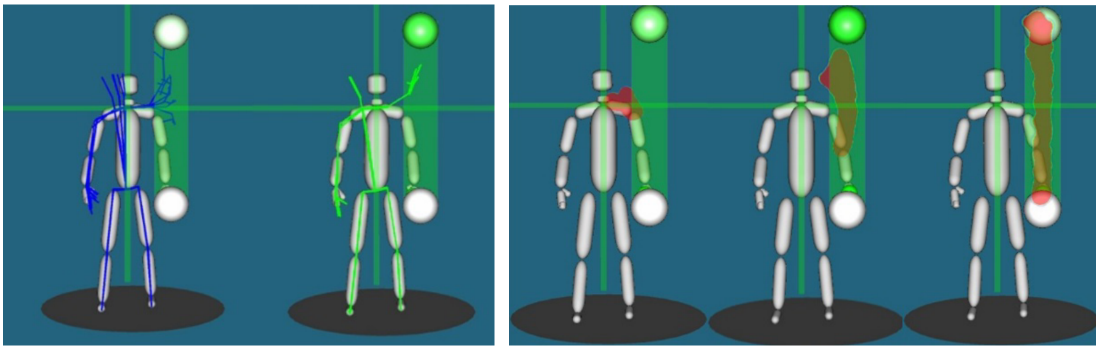


Figure 3.4: ARCADE's Skeleton compensation pattern view and *heat map* view

3.1.2 Design Influences

Even though mainly through the theme of Interactive Rehabilitation, the ARCADE project is very relatable with the purpose of our work, its interface features, mainly due to the limitations of the Kinectv2 as a depth camera and lack of exercise personalization, was not fully compatible. Because of our desired personalization, we turned to a 3D interface display and consequently, ARCADE's system could not be leveraged on a software level in any way. In the face of this limitation, the feedback given by professional physiotherapists in all phases of the development and their visualization metrics study was of great importance for the foundation of our work and to improve the features we conceived.

During the early stages of the development of ARCADE, user research was planned in the form of observation of routine physical therapy procedures and some interviews with professional clinicians. In the observation phase, one more prominent thing noticeable was that physical therapists avoid complicated equipment and preferred more straightforward methods to achieve similar results. Considering we are using trackers that need to be strapped to a patient and are counting on some required setup from physical therapists to better track compensatory movements, this was something we would need to take very seriously and consider taking dedicated time out of development to simplify every single step that seemed more complicated and overall makes sure that our interface was very user friendly and provided as smooth of an experience as we could make it to be.

In the interviews, there was a consensus that not every patient can be left alone exercising since different patient conditions require different needs because of different limitations. Taking into consideration the fact that we are focusing on stroke patient rehabilitation and considering the variety of symptoms hemiparesis can cause, this reality, alongside some later confirmation made by professionals we interacted with (interactions we will go over in a later chapter), made clear that we should stray away from the possibility of our program letting therapists treat multiple patients at once, even if our interface could provide live biofeedback while exercising.

From their later concluded design guidelines, even with the established differences in goals for our platforms, we could relate to some of them, such as *developing a system that could handle different types of patients and exercises*, as this is one of our focus points with the personalization in mind; *developing an easy to set up and use system*, since this, while intended, was going to be one of our main challenges; *developing a set of visualizations that are easy to interpret and promote faster exercise execution*, even if not as focal as a point as it was in their project; *developing a system that understands professionals' needs and delivers important information at all times*, which reflected one of our main motivations for tackling such a specific problem in rehabilitation, and *developing a system that could facilitate daily life for professionals by improving overall efficiency and quality of the work preformed*.

The study of information and metrics in the development stages of the ARCADE system provided some of the most valuable insights we could leverage. Since the information was one of the pillars of their work, it was essential to understand the information needs of physical therapists and adapt them to their workstation structure. To comprehend this, they designed a workshop activity with several professional therapists. At the end of some exercises, having discussed multiple metrics, adding some and discarding others, they reached a list of metrics, ordered by the importance given by experienced clinicians, from which they based their visual development. They considered the list, represented in the following table, to be *an optimal baseline for someone trying to develop a tool that can assess the performance of an individual while doing upper-body exercises*, which is exactly what we intend to use it for.

Importance Level					
1	2	3	4	5	6
• Movement quality • Muscular tonus • Motor objective and efficiency of the gesture • Movement trajectory • Compensatory movements • Head and torso movement in relation to the superior limb • Multigesture and head synchronization / Movement coordination • Scapular movement relation with the shoulder	• Functional movements	• Exercise velocity • Angular amplitudes and translation for the articulations • High speed movements	• Cerebral function • Rotation movements • Muscular activation	• Physiotherapist's hand pressure	• Number of performed sessions • Weight / Load • Complete repetitions • Number of repetitions inside the path • Structure resistance during the movement • Session time • Pain during the movement

Table 3.1: List of optimal metrics for upper-body exercise performance assessment, in order from most important (1) to least important (6)

3.2 Design Guidelines

Creating a technological system where the end user is specialized in a much different field than software development will always be accompanied by knowledge barriers and different conventions that can be crucial for the end result of a system.

In this case, and by studying state of the art, it was abundantly apparent that physical therapists have routines in current physical therapy that translate into specific needs that software that they would need to interact with daily would have to meet.

Therefore, it was evident that experienced professionals should accompany our system's development to design useful and usable features for the intended end users, whose work has a very technical foundation and, therefore, very technical requirements. This process also ensures time is well-spent on unwanted features we might not, at first glance, predict.

With this in mind, and with the orientation and experience in our team, we formulated a set of guidelines from which we based the first iteration of a prototype of our application:

- Design a system that could handle different patients and therapists;
- Design a system that understands the needs of professional clinicians;
- Design a system that allows enough exercise personalization to let patients practice any upper-body exercise they need;
- Design a system that allows enough setup personalization so that therapists can track any compensatory movement made and controlled those compensations limitations;
- Design an easy-to-use interface with easy-to-set-up equipment;
- Design a system that allows for a patient, while assisted, to record any exercise needed in order to repeat it and receive appropriate feedback;
- Design a system that lets therapists define which compensatory movements to focus on and set physical limits for each compensation, depending on what their movement restriction preferences;
- Design a technical but easy-to-understand visualization for setting compensatory movement thresholds;
- Design a biofeedback visualization to help patients when performing rehabilitation exercises;
- Design an exercise review visualization to facilitate therapist and patient exercise reflection and analysis;
- Design a system that could promote better efficacy, quality and efficiency in stroke victims' rehabilitation.

3.3 First Prototype: Low-Functionality Prototype

In order to make sure we developed a system that met the guidelines previously established and did not spend time and resources aimlessly developing an application and features from scratch, we decided to make a low-functionality prototype, representing our vision to embody the design concept. This first prototype iteration aimed to present this vision to professional physical therapists and get feedback and direction to better plan each feature devised.

For a better visual result and to gain some interaction and modular capabilities, making the representation closer to what a final prototype would look like, instead of the traditional method of hand-drawing multiple visualizations and creating a user flow, we used an interactive interface design tool, in this case, Figma. With this tool, we could portray all the features we considered at the start of this development process.

The interface we intended to develop followed the following user flow:

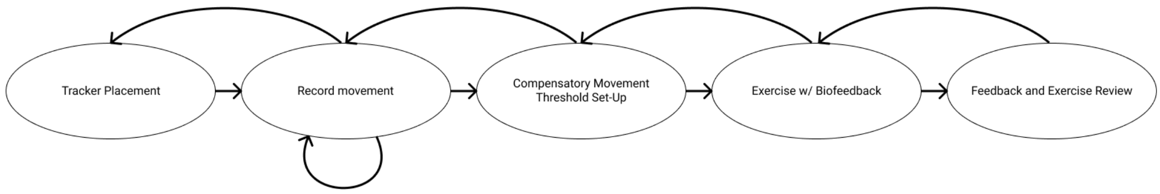


Figure 3.5: User Flow of our system

In a clinical environment, in stroke rehabilitation, as we have studied before, exercises are usually based on recovering a patient's particular movement deficits instead of the usual physical therapy approach of rebuilding muscle around affected joints. This said, it is customary for there to be a decision on what movement to practice in a session. When this movement is defined, and the therapist calculates what limb joints will participate in said movement, the therapist will use the first interface visualization to choose the ideal placement of the trackers. This placement should be done in the most active joints participating in the movement or even from which it is more probable to originate associated compensatory movements. In order to simplify this step, a fixed set of body segments, commonly known to participate in upper-body motions or compensatory movements to those motions, were established: the wrist, the elbow, the shoulder, the chest and the head.

In this visualization, the therapist selects a group of segments, telling the system where the trackers were placed.

Following the tracker placement, the patient records the ideal movement he would like to achieve in that session. With the required assistance from the clinician, the ideal move would be a goal for the patient to attain that he probably could not execute effortlessly. After using a straightforward interface with a *record/stop recording* button, the users are presented with a preview window, where they and the professional can review the recording. This display is where they decide whether it represents their target movement or whether they want to repeat the recording process. We opted for an interactive play

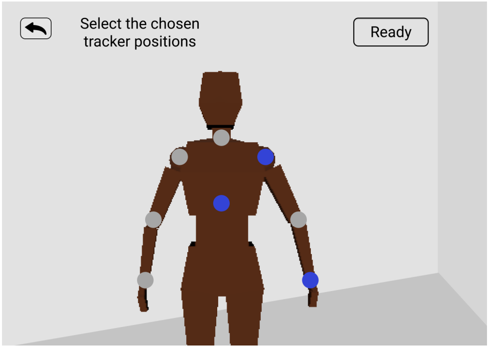


Figure 3.6: Low-Functionality Prototype: Tracker Selection Interface

with the option to play or pause the reproduction of the recording or skip to a moment in time by clicking an interactive progress bar.

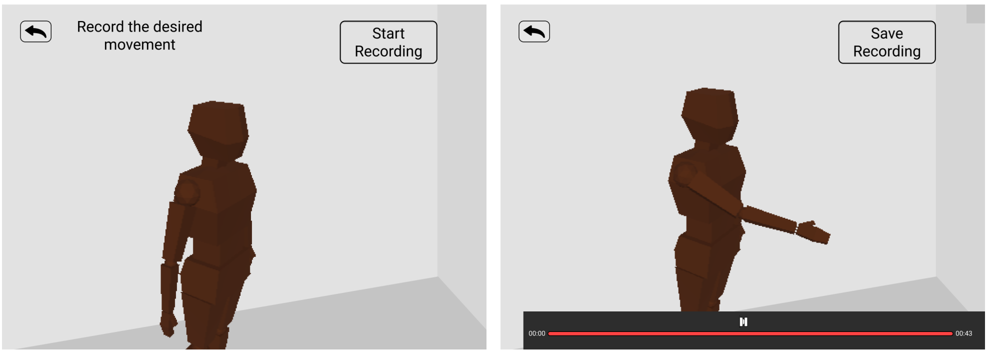


Figure 3.7: Low-Functionality Prototype: Movement Record and Preview Interfaces

At this point, and before the patient can start the exercise by attempting to repeat the movement, the therapist can choose the thresholds he would like to implement on the possible compensatory movements, depending on the patient and the particular motion execution. This visualization was challenging to achieve because of the technical language used daily in rehabilitation environments by professionals. When it comes to compensatory movements, making, so it meets clinicians' definitions, and interpretations was a challenge. To achieve an optimal design, this display had several versions, going from limiting patients movement in the 3D space around him by creating limits on the segments' x, y and z axis, including also rotation on each of those axis 3.8(a), which would prove to be difficult to interpret for even experienced therapists, to our final version, for this prototype, where compensatory movements were limited according to the possible movement ranges of each segment.

In this visualization, the therapist selects a fixed segment and is presented with a window where he can alter the movement limitations of that segment by changing several sliders' positions. The visualization of these limit changes also evolved, from planes representing the spacial limits of each body segment to dummy and transparent segments, showing the positions corresponding to those limits. In

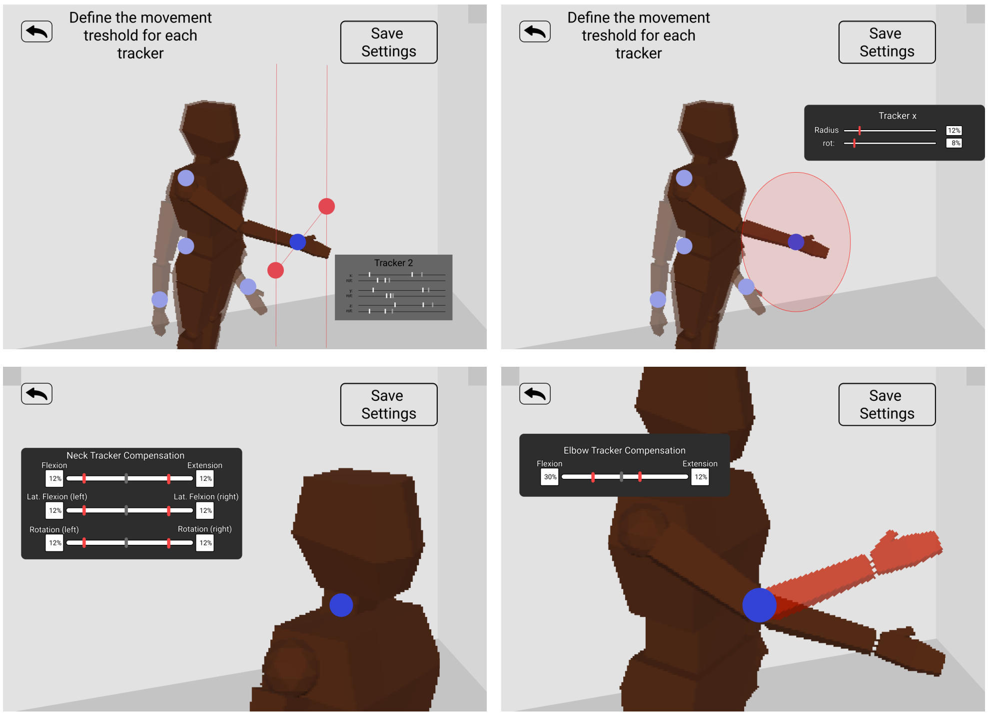


Figure 3.8: Low-Functionality Prototype: Evolution of the Compensatory Movement Thresholds Interface

addition, a percentage value for each compensation was added to aid in value to limit association and, thus, improve the long-term use of the interface.

After the thresholds are set, the patient can start practising the movement he wishes to achieve, receiving active feedback while performing. The form of dynamic feedback to be delivered to the patient was a theme of the debate. The main concept was found to be valuable to increase exercise performance: A notification type of feedback, where the user was warned if he was deviating from the pre-recorded ideal movement. The notifications and the markers came in the form of transparent dummy body segments associated with the movement being practised. The purpose of these notifications was to promote movement correction while practising the chosen exercise.

Finally, the display, after the exercise repetitions are over shows an exercise review visualization, with a player (similar to the recorded movement preview), with the capability to go through all repetitions performed and the addition of error highlights. These highlights appear on the player progress bar, allowing the user to skip the timeline to points where the system detected threshold limits crossed for faster and easier analysis by selecting an error highlight in the form of a pin. Exercise highlights can also have different descriptions, divided in *Errors* and *Corrected errors*, having different highlight pins associated.

General exercise metrics can also be displayed by clicking an expandable window, represented by a bar in the bottom right corner, labelled *Performance Index*.

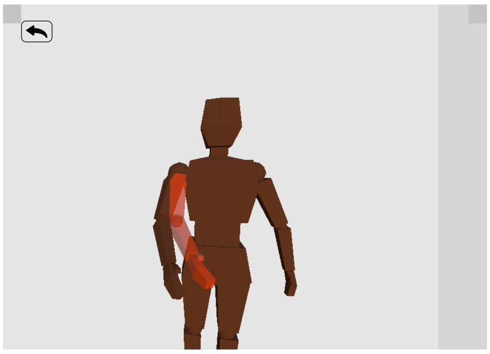


Figure 3.9: Low-Functionality Prototype: Exercise Dynamic Feedback Notification (1) and Guide (2) Interface Options

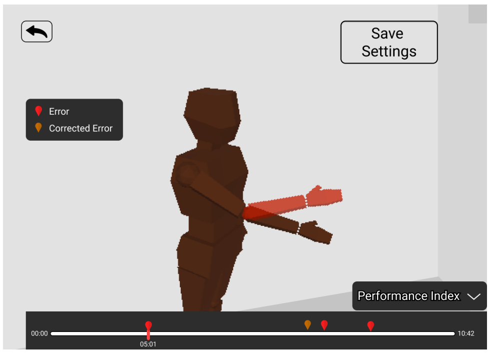


Figure 3.10: Low-Functionality Prototype: Exercise Feedback and Review Interface

3.4 Storyboard

One of the biggest obstacles to technological and interactive rehabilitation solutions is, as was determined in the ARCADE development process, the ability and willingness of professional therapists to use more complex solutions to achieve similar problems. With this in mind, presenting a new interface like this can be overwhelming.

In the spirit of providing a more complete picture of how this system would fit in a routine physical therapy appointment, we designed a storyboard representing the flow of a therapy session and how our system would insert itself into it.

In this Storyboard, we hand-drawn eight scenes, portraying eight moments in a physical therapy session where our system is being used:

The first scene represents the **initial discussion with the patient**, where the therapist defines, according to the specific needs of the patient, the movement to be practised;

The second scene depicts the starting **analysis of the patient condition**, related to the movement. In this stage, the clinician assesses the segments and joints in the motion to be exercised;

The third scene looks to show the **placement of the trackers** in the chosen segments;

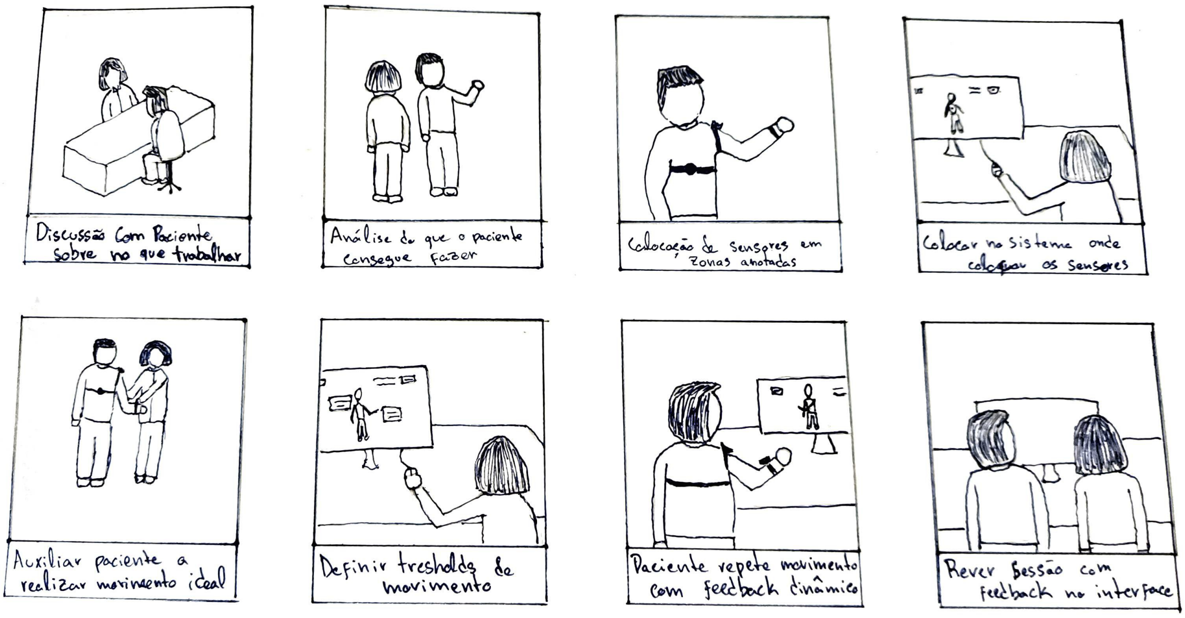


Figure 3.11: Therapy Session Flow Storyboard

The fourth scene portrays the professional using the interface to **select where the trackers were placed**;

The fifth scene represents the patient **recording the ideal movement** desired, with the required assistance from the therapist in order to successfully execute it;

The sixth scene depicts the therapist **configuring the compensatory movement thresholds** desired;

The seventh scene shows the **patient repeating the movement desired**, with dynamic feedback;

Finally, the eighth and last scene portrays the therapist **reviewing the exercise** alongside the patient.

Our aspiration was for the therapists with whom we would present our prototype to relate to the scenes depicted in this Storyboard and would, to a greater degree, understand the role of our system in their daily work when conducting rehabilitation treatments for stroke victims.

3.5 Feedback Sessions

On separate occasions, we conducted sessions with professional physical therapists with the purpose of receiving feedback on our concept to define what designed features would be kept, removed, or altered.

To maximize our time with the therapists, we decided on the following structure:

A brief introduction where we establish what our proposition is, the motivation behind it and how we want to resolve it;

Following that, we presented the **the Storyboard** where we demonstrate how the system would fit in a standard physical therapy recovery.

Lastly, we exhibited the **Low-Functionality Prototype**, representing our main ideas and features.

In all of these stages, we asked questions and gave therapists space to talk about what we were presenting, considering the goal of these sessions was to try and get the professionals to be commenting more time than we spent on presenting.

When introducing the project, we started by stating the motivation behind our work. We then briefly explained how we wanted to take on this problem, explaining what we wanted out of our interface. Taking advantage of the themes explored in this phase, being stroke rehabilitation and interactive rehabilitation, we tried to get some information about the therapist's experience within these.

One widely consensual take on stroke rehabilitation was, due to the nature of the symptoms, and considering there is usually no need for muscle recovery, the rehabilitation process should be catered to patients' needs. According to the professionals we have talked to, this needs to be improved in current solutions that have surfaced in recent years. Most solutions that reach physical therapy clinics have fixed exercises, which results in the absence of adaptability to what patients want requires. This is most evident in stroke rehabilitation due to the different manifestations of hemiparesis symptoms.

When asked about the different strategies used in compensatory movement restrictions, namely Criteria (restricting most compensations in order to re-learn a movement correctly) versus Functionality (making sure patients can carry out a task despite the compensations used), clinicians, for the most part, came back to the aspect of the individuality of treatment: there are no superior intervention methodologies. The diversity of methodologies results in a better intervention considering patients that suffer from a neurological disorder, as is the case with stroke victims afflicted with hemiparesis, who have different needs, limitations and preferences. These include, but are not limited to, motor and cognitive limitations, functional capabilities, and stage of treatment (as the functional method could be more adequate for the initial stages, while, in later phases of treatment, improving criteria of movements could be more important, as per one of the therapists) or even the way patients are receptive to new treatment methodologies, namely ones that include new technologies.

On the topic of patient reception to new interventions, it was abundantly clear that people in different age groups have, customarily, different reactions to technological-based rehabilitation solutions. Older patients, generally, show higher resistance to these solutions and frequently become overwhelmed with them due to interface or equipment complexity.

When presenting the Storyboard, clinicians confirmed that the scenarios illustrated a realistic course of affairs appropriately for a physical therapy appointment. One professional also gave us some insight on the approximate duration time each of these scenarios would take, such that we could confirm its viability:

Discussion with Patient	Analysis of Patient Condition	Placement of Trackers	Select Tracker Location in System	Recording Ideal Movement	Configuring Compensatory Movement Tresholds	Patient Exercise Rocording	Reviewing the Exercise	Total
5 mins	1 min	1 min	1 min	1 - 5 mins (depending on the patient's condition)	5 mins (in a worst case scenario)	8 mins	5 - 10 mins	28 -37 mins

Table 3.2: Approximate duration times of Storyboard scenarios

In the case of the first scenario, it does not need to take place, as sometimes, in cases of follow-up consultations, the therapist is already familiarized with the patient's goals. It is also worth noting that some of these scenarios' duration depends significantly on the patient's capacities and limitations. If the last scenario were to go for longer than 10 minutes, it would be too exhausting for the patient.

In the last phase of these sessions, we exhibited the Low-Functionality prototype. Some observations were made as we went through the designed screens, promoting clinicians' commentary:

- There are joints from where more commonly compensatory movements originate, but there is no irrelevant joint or associated movement;
- Getting a general number for which to set compensation thresholds for all joints simultaneously was an appealing concept (the one we inquired about), but it was hard to visualize for a therapist;
- The presented list of possible compensatory movements in the specified joints covers all possible upper-body compensations associated with task-oriented exercises;
- Dynamic feedback while exercising would be more compelling in the form of a guide, telling the patient where to move next, rather than as a notification;
- In the final exercise revision screen, apart from exercise performance metrics, it would be interesting to know what compensatory movements took part in the origin of the exercise errors committed by the patient;
- It would be of interest to also be able to visualize postural misalignments;
- Notwithstanding the autonomy of exercise practising this system could promote, even with the possibility of lowering costs for clinics, having professionals treat multiple patients at the same time would impair the quality of treatment tremendously since patients have better results while having the focus of therapists' attention, being able to detect problems with movements the system could not cover.

- The impact of a tool of this nature could be very positive in two aspects: Being a modern novelty challenge could impact patient motivation and having a movement record and review feature, something nonexistent in current physical therapy solutions.

3.6 Discussion

With the feedback given in these sessions, we were able to validate our concept design and its potential, gaining insight into the factors to consider when developing the final prototype. One of the focal points of our project, the exercise personalization, to allow for therapeutic interventions to cater to patient rehabilitation needs, was also the most praised feature of our presentation session. As we proposed earlier, it was evident that this aspect of our system addresses demand in areas of physical therapy, like neurological physical therapy, where patients have had or currently have neurological diseases or injuries. These result in patients having various symptoms, which are mostly different in each clinical case. Utilizing a tool of this nature allows patients to record any movement and review their exercise practice on it, permitting them to better understand their movement and errors associated with it and, possibly, accelerate its correction and enable faster rehabilitation progress.

The personalization of compensatory movement restrictions was also well-received in our study. Learning how important the ability of a program to adapt to different methodologies of intervention can be corroborated by the significance of this component. Besides Functionality, giving a patient choice over the exercise, he will practice, like standard stroke rehabilitation intervention methodologies permit, contributes to patient motivation during the course of its recovery.

Besides verifying these aspects of our approach, we also identified a key obstacle for interactive rehabilitation systems in the first phase of the feedback sessions. This factor was the frequent unwillingness of people from older age groups to work with modern and technology-based rehabilitation systems, being regularly overwhelmed either by the interface or by the equipment used to run it. Considering most strokes occur in older people, being age one of the most prominently associated factors with stroke incidence [44], we needed to dedicate development time to ensure we achieve a simple and perceptive interface with easy-to-use equipment.

During the second phase, we determined that this system should not be used to promote patient exercise autonomy considering leaving patients to exercise alone would drastically decrease the quality of treatment. Furthermore, due to the nature of the motor and, in some cases, cognitive impairments, some of these patients need supervision solely to be able to practice the exercises required. Moreover, compensatory movement restriction should be associated with a specific list of compensatory movements. The proposed compensatory movement list we managed to verify in these sessions was the following:

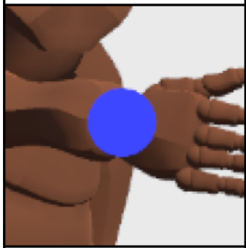
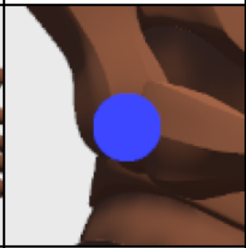
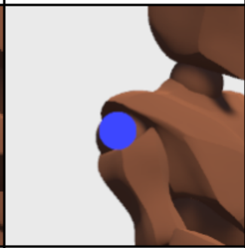
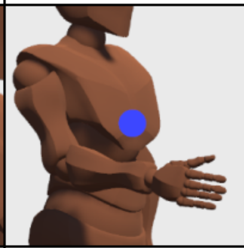
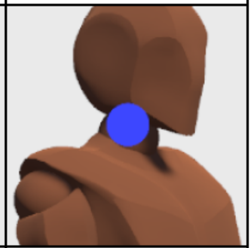
WRIST	ELBOW	SHOULDER	CHEST	NECK
				
. Flexion/Extension . Radial Deviation/ Ulnar Deviation . Supination/Pronation	. Flexion/Extension	. Flexion/Extension . Abduction/Adduction . Lateral Rotation/Medial Rotation . Horizontal Flexion/ Horizontal Extension . Circumduction	. Flexion/Extension . Lateral Flexion (Left)/ Lateral Flexion(Right) . Rotation (Left)/Rotation (Right)	. Flexion/Extension . Lateral Flexion (Left)/ Lateral Flexion(Right) . Rotation (Left)/Rotation (Right)

Table 3.3: List of Proposed Compensatory Movements

This phase also brought a new concept of a form of dynamic feedback. One of the participating therapists proposed a feedback visualization where the user was presented with a guide, where the patient would indicate where to move its arm next to achieve to ideal movement. This compelling idea was later confirmed to be valuable in the following session. Bearing this in mind, we re-imagined the exercise repetition visualization, considering that a similar form of marker could be used to guide a user's arm: a transparent dummy body segment associated with the movement being practised. The big difference between this visualization and its predecessor was when the marker appeared. In the notification form, the marker would only appear when an error was committed. In this new concept form, the marker would appear before the movement got to the point it represented, conducting the patient into doing the desired movement. At the end of this process, we intended to consider both options in the final prototype development.

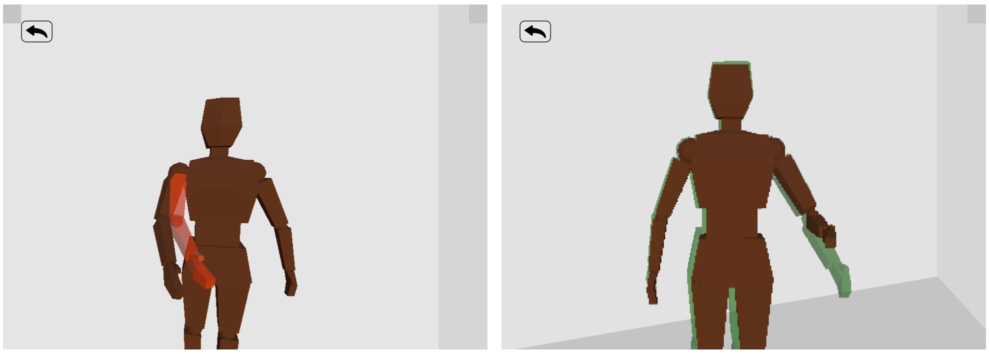


Figure 3.12: Comparison Between Exercise Dynamic Feedback Notification (1) and Guide (2) Interface Options

Another contribution to the visualizations was the suggestion of including the compensatory movements associated with an error in the error description in the final exercise review visualization. At this point, we had an idea of metrics to use in that visualization interface, as we previously explained in the ARCADE project description, considering their study on the matter. Nevertheless, this was a suggestion we intended to keep in consideration for the development of that particular interface. A postural check representation was also described to be good for movement quality analysis, however, we have later concluded that the possible movement changes to affect posture were included in possible chest compensatory movements, something we would already decided to monitor and represent.

4

System Overview

Contents

Considering the state-of-art research work accomplished and the experimental study made to achieve a concept design that would allow us to achieve our proposed goals, in this chapter we describe the development process of our system's final prototype.

This process includes the choice of development environment to work with, the integration of the motion tracking technology we have chosen, the HTC Vive Trackers, to operate and the development of the visualizations that compose our interface.

4.1 Unity 3D Environment

The chosen development environment for the development of our software was Unity3D. This choice had in its foundation the fact that it is an engine known for its simple and easy-to-use interface, that supports visual scripting (a big help when developing User Interfaces (UIs)), has a big community of supporters that provide open-source libraries, and the growing number of features that support the development of interactive applications, due to having a very active development team. Furthermore, it facilitates the integration of supported platforms and technologies, such as motion tracking technologies. These technologies include but are not limited to, the HTC Vive system.

Another big reason to choose Unity3D as a software development environment is that this was the environment used in the development of ARCADE [1] and its predecessor application. Despite having made the decision to go with a 3D representation for our visualization, making it so that we could not utilize ARCADE's software development as a foundation for our project, this would leave the open option of leveraging particular elements, such as models or scripts from the project, if the case ever arose.

4.2 System Architecture and Vive Trackers Integration

The Vive Tracker is a wireless tracked accessory that provides highly accurate motion tracking within a specified tracking space. This device is usually used in the development of Virtual Reality (VR) games and applications, making it so a person can attach this device to any object and create a wireless and seamless connection between the object and the virtual experience (in this case, the HTC Vive VR system.

The HTC Vive system itself consists of a VR headset, an Head Mounted Display (HMD), being the system's main component, used to track head movements and provide a display that delivers an immersive visual experience to the user. This system also regularly includes two hand-held controllers, tracked in the same space, who extend different input options to the user, and two Base Stations (BSs) that communicate with each other, creating a tracking area where they communicate and get the various types of inputs provided by other Vive devices. The primary type of data processed by the BSs is the position tracking information, in the form of position and rotation inputs, provided by the tracked devices, including the HMD, the controllers and even any existing Vive Tracker.

In this project, our concept was designed to include only Vive Trackers, being themselves tracked with the use of BSs. The other devices in the HTC Vive System are not relevant to our interface. Admittedly, we would not have use for the inputs provided by the controller, desiring a scenario where hand tracking is possible while having the hand free to participate in the chosen exercise. At the same time, we are developing an interface, preferably displayed on a computer screen or, ideally, a monitor. Having that in mind, an HMD would not serve any purpose as it would act as a heavy and uncomfortable head position tracking device if used while not blocking the user's vision.

With the involved devices defined, our ideal architecture for this system would be the following:

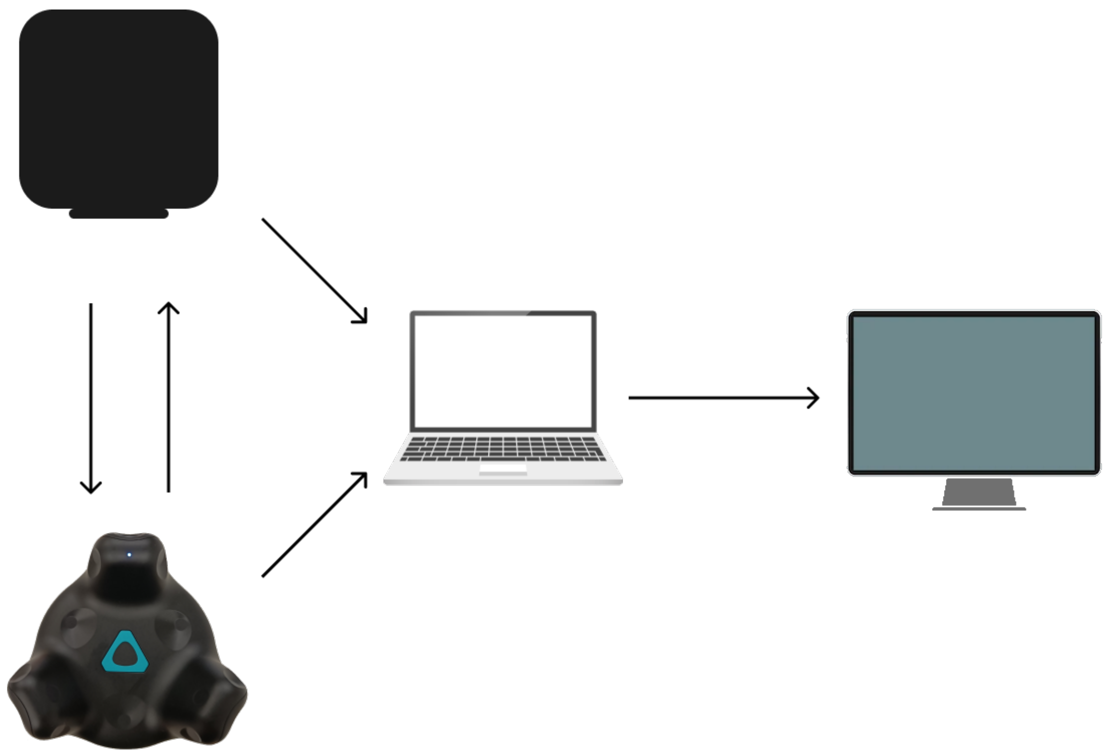


Figure 4.1: Ideal System Architecture

In this architecture, simple communication is made, between the trackers and the BSs, in the form of position inputs, while the BSs transmit the trackers' position information to a computer, running our system, and the tracker sends identity and status information to the system, as well. With this information, the system runs and transmits the visual interface to a display for a better interactive experience.

When trying to implement this architecture, we encountered two complications: There is a dependency of the HTC Vive system on running information through the HMD, and Unity3D, despite having HTC Vive integration, it does not have a Vive Tracker Input profile.

After gaining some understanding of how the HTC Vive communication functions, we came to a conclusion that the fact that HTC Vive is a system built for VR interactive applications makes it so that tracked devices connected to the system have to transmit their position information to the HMD, so it can display in real-time, a manifestation of those devices. All information is then transmitted from the HMD to the connected computer.

Vive Trackers, on the other hand, were conceived in recent years and were then made to be added to existing Vive environments. As a consequence of this addition, Vive trackers connect to the system through USB dongles, which physically connect to the computer running the system.

This reality seems ideal, considering trackers can send their position information directly to the system. The only issue is, without the BSs, the trackers cannot find this information, and without an HMD, the BSs do not track devices.

Furthermore, the HMD has a pressure sensor inside the protective foam around a nose support groove to detect if the HMD is in use or not. When the sensor is inactive, the connected BSs stops tracking.

All things considered, in order to make the Vive Trackers work without having to use an HMD, and after experimenting with several setups, we arrived at a functional architecture:

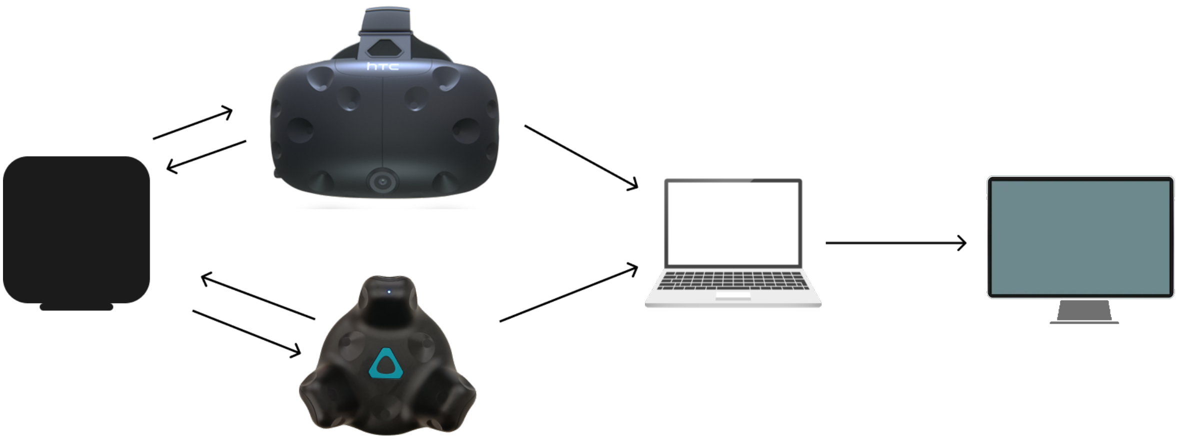


Figure 4.2: Final System Architecture

In this architecture, we set up our system in a way that is connected to the HMD, just like it would if we were planning on using it for a VR application. To deceive the HMD into considering it is being used, we utilized rubber bands to put pressure on the pressure sensor at all times. Additionally, the BSs are connected just as they usually would, sending pulses of Infrared signals to be detected by sensors on tracked devices (in this case, the Trackers), and the trackers are then free to communicate and send their position to directly to the system.

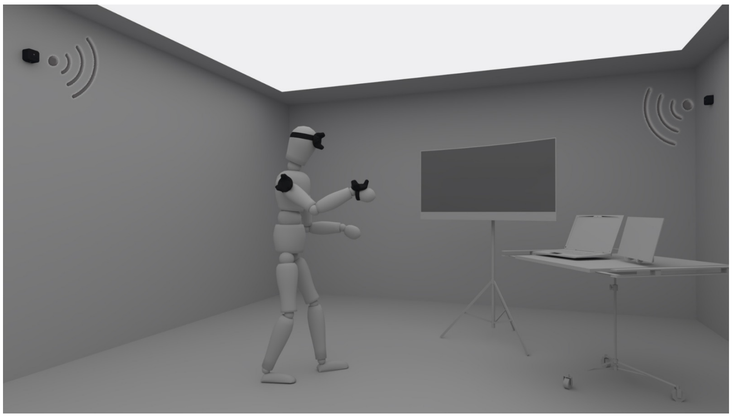


Figure 4.3: Hardware System Setup

With this problem resolved, the system now needs to recognize input from the Vive Trackers. To solve this issue, we searched for a user-made, community shared, Vive Tracker Input profile script. After creating and populating Action Maps to translate the data received into recognizable values for the system, this script worked as a standard motion-tracked device Input profile.

4.3 Body Movement Tracking

In order to represent Motion Tracking in our design concept, an Avatar, representing the user of the interface, in this instance, a patient, was required. To create this avatar, on a first occasion, we defined some design guidelines:

- The avatar has to be humanoid. This entails an avatar with human form and characteristics;
- The avatar has to be gender and ethnically neutral;
- The avatar has to be rigged. This presupposes the existence of an attached and mapped bone structure.

In current times, there is a duality in the humanoid character design nature. To create a better relation between the user and the interface, the greater the extent of similarities between the patient and the avatar, the more significant the impact on intervention reception, motivation or even in learning and familiarity with the interface. These similarities come in the form of human characteristic detail, making the avatar design much more complex. Well, different people possess different characteristics, and the representation of these brings forth two inconveniences: Multiple versions of an avatar would have to be created to get as approximate as possible to multiple people's characteristics, and having to force the input of personal data in the system, in order for the program to select the adequate version of the avatar correctly.

Having this in mind we decided to create a gender and ethnically neutral, trying to get as close to the human form as possible. To visualize how this representation, we took inspiration from the concept of a **mannequin**. This idea came in view of the fact that some mannequins already achieved the goal of human body representation while remaining gender and ethnically neutral. To achieve this we created a first, very simplistic version of an avatar, using the Blender 3D graphic development tool.

While progressing with the development of our program, we updated the avatar. The main reason for this change was a lack of functionality provided by the attached avatar Rig, where the bone structure could not be relied on to keep its form, despite the fact that its chained hierarchy structure. To solve this we found a free character model, in an open-source community model library. This model had a more complex Rig structure, with a more detailed Mesh (the visual representation of an object, in this case, the avatar, formed by arranged triangles in 3D space, creating the impression of a solid object) coming closer to a human representation than our original model did.

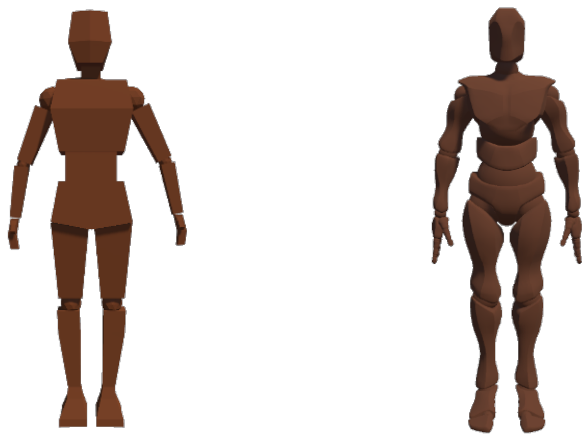


Figure 4.4: The Evolution of the Avatar Design

Concerning how to move this avatar, to emulate the movements a user would perform while utilizing our program, we had to set up the Vive Tracker to represent movements in all body segments that could intervene in a chosen movement.

To track the positions of so many segments, we needed to infer the positions of some of them, making use of the tracked positions of other segments. For this to be possible and to avoid getting an overwhelming amount of trackers on a patient, we had to resort to the use of Inverse Kinematics (IK).

IK uses kinematic equations to determine the joint parameters of a manipulator so that the end of a kinematic chain moves to the desired position [45]. A good example would be to consider that by moving the wrist of an avatar, due to the changes in its position it is possible to calculate the position of the forearm and, to an extent, part of the position and rotation of the elbow, arm and shoulder. Having this in consideration, and through some experimentation, we arrived at a setup to be able to track every compensatory movement involved in any one arm upper-body motion.

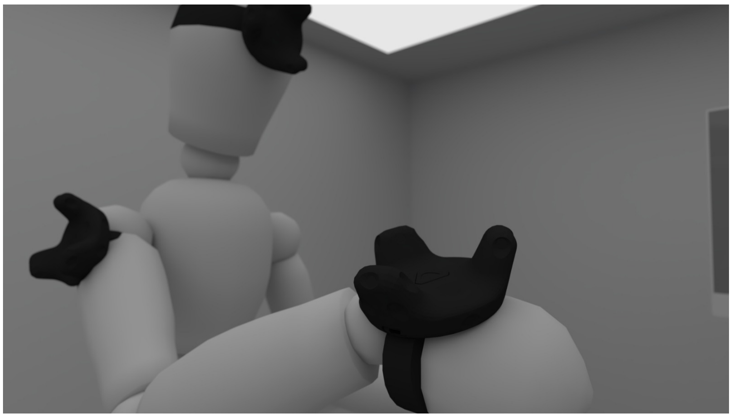


Figure 4.5: Tracker Placement Setup

In this setup, we placed made use of three trackers: one placed in the base of the top of the hand in question, near the wrist, to track the position of the wrist while being able to track possible wrist movements (if it were in the wrist itself it would not be able to capture information regarding movements such as wrist flexion, deviation or supination), while also correctly calculating the position and of the forearm; one in the outside of the top of the arm, near the shoulder, where it can track the arm and shoulder movements, while also calculating chest position and rotation; and the last tracker placed in the forehead, tracking neck and head motion.

For the system to make the transition from input position data to moving the avatar, according to that data, we implemented a 3 layer animation process, where the avatar visualized mesh segments would follow the IK calculations, which in turn would use it's target object to follow an object updating with the tracked positions of the Vive Trackers. To implement this, we inserted bone constraint scripts (which tell the system what bones of the avatar Rig should be considered for IK calculations and executes them) in the bones corresponding to the placement of the trackers. This script created a target object used to guide the IK process. We then made this object follow the application object containing the Action Maps that carry out the position data interpretation, according to the Vive Tracker Input profile added in a previous stage.

Due to the complexity of the IK calculations and possible imperfections in the avatar's rigging, we observed that when adding the representation for the shoulder tracking, along with the IK constraints it came with, the avatar would show irregular arm and shoulder positions. These affected the whole arm's position and, consequently, all the tracking made by the hand tracker. Moreover, it seemed to disturb the position of the chest and thus the position of the head and neck, tracked by the head tracker. We suspect this is due to both IK scripts partially affecting the same bones, having the shoulder tracker IK intercepting with both wrist and neck IK scripts.

As a result, we decided to remove the visualization of the shoulder tracking, achieving full one-arm upper-body movement representation, except for some elbow and shoulder elevation motions. This imperfect visualization was a compromise to keep the program's functionality, as the shoulder tracker still gave the position data necessary to detect movement errors and general compensatory movements later on.

Considering the setup we ended up with, we decided to remove the tracker placement screen previously planned. This interface could eventually be replaced with an arm choosing interface to let the system know what arm to track or, eventually, both.

4.4 Movement Recording and Visualization

To make sure the avatar moves according to the position of the trackers attached to the patient's body, considering the possible differences in size and position between the avatar in the application space and the user in real space, we developed a calibration algorithm that adjusts the size of the avatar according to the patient's height, and its position in the applications X and Z axis. This calibration script also changes the camera's position to keep the same aspect ratio and follow the avatar's position in the application space.

To record the movement made by the patient, and after exhausting several other methods to do it, we used a UnityEditor class called GameObjectRecorder, usually working as an animation creating tool in an application development environment. This tool populates an empty animation with an animation curve obtained by reconstructing the changes of all the elements of a GameObject, taking snapshots of these positions in every frame.

In this interface, considering our record method only populates the animation and its methods to extract the snapshot bindings do not return a usable data format, we decided to make our own snapshots. To achieve this, we stored the position and rotation of the three tracker objects in a group of static lists, to be later used by other visualization scenes within our program.

After some exercise check errors occurring in the development of a later interface, we decided only to store unique positions, meaning, if a position is at a distance of less than a set tolerance radiuses we defined, the system will not store the position. This change makes it so that a slower movement does not have proportionally more stored positions than the same movement, recorded at a faster speed of motion, reducing the length of the lists, the algorithm's complexity and the resulting complexity of future algorithms that use these lists.

Considering that movement tracking will be required only in some of the system's interface visualization screens, we manually initiate and turn off the motion tracking manager environment, OpenXR.

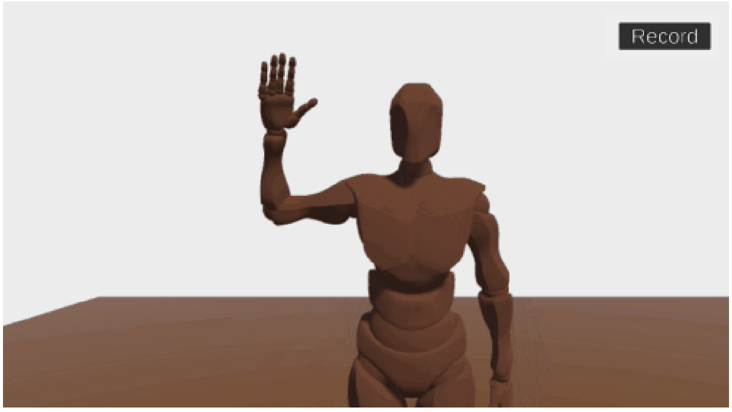


Figure 4.6: Record Movement Interface

The UI for this visualization features a simple record button that allows the user to start and stop recording the chosen movement.

After the second press of the button *record*, the program changes to a *movement review* interface visualization scene, where the user is presented with a UI constituted by the media player we developed, allowing the patient and therapist the option of reviewing the movement recorded, before advancing to the next visualization scene.

Figure 4.7: Review Movement Interface

In this interface, we scripted a fully functional media player, giving the users the freedom to visualize the recording in an intuitive way, considering we took inspiration from the most common media player format in current days. This media player interface is composed of a play/pause button that plays or pauses the animation where the movement curve from the recorded snapshots was stored in, an interactable progress bar, giving the users the option to skip to a certain part of the animation, as well as giving visual information of the current progression state of the animation, compared to its length, a timer on the left of the bar, describing the time passed from the beginning of the played animation and the animation length time on the right of the bar.

Additionally, this UI presents a *proceed* button to press when the users are satisfied with the recorded movement and a *back* button, giving the users an option to return to the last screen, to repeat the recording of the chosen exercise motion.

4.5 Compensatory Movement Configuration and Monitorization

The most significant factor that makes our system adaptable to different intervention methodologies is the configuration visualization scene, where therapists have the option of setting compensatory movement thresholds for the previously recorded movement. In this screen, a group of movements, previously defined (table 3.3), associated with five different segments of the body, are available for selection. The therapist conducting the clinical session can then set a limit for the compensation selected, being presented with an intuitive representation of the limit.

The UI the user is greeted with is a selection interface, with the five segment options of compensatory movement origin. These segments are the Wrist, the Elbow, the Shoulder, the Chest and the Neck.

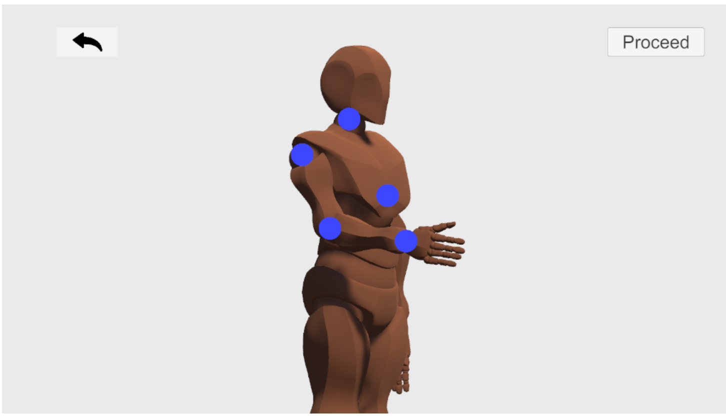


Figure 4.8: Compensatory Movement Configuration Interface: Segment Selection

When selecting one of the segments, the visualization changes to a set of sliders associated with each possible movement for that particular segment. These movements are grouped in pairs of *opposite movements*, having a slider on each side of an axis. There is also a percentage value, associated with the slider bar, representing the range of motion between the ideal movement and the average human limit for that motion.

The threshold limit is represented by a transparent dummy body segment, corresponding to the movement associated with each slider. This representation is a more visual illustration of what the motion restriction would look like.

To animate the thresholds, we associated a rotation axis from an avatar joint to each pair of *opposite movements*, where the rotation direction specifies the pair's movement. To set a new threshold, the system resets the dummy segment to the original position by applying the stored current rotated angle in the opposite direction it was previously rotated. In addition, the program uses a predefined maximum value of rotation angle, depending on the movement in question, to associate the percentage value, set by the user using the slider, to an angle in the range of motion limited by said angle. Subsequently, it computes the rotation needed for the new computed angle. With this last determined rotation quantified, the program applies it to the dummy segment to reach the desired threshold visualization.

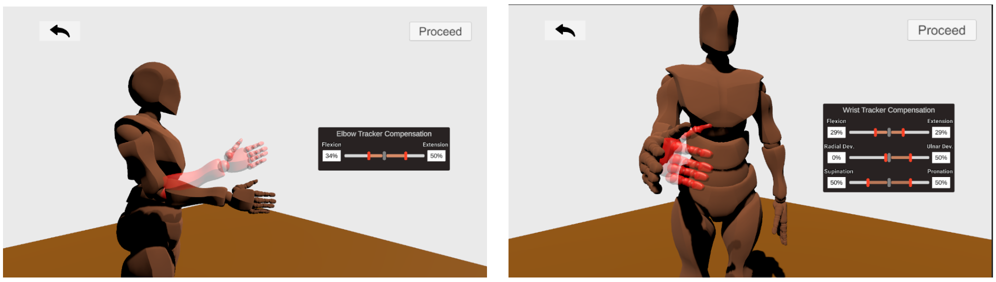


Figure 4.9: Compensatory Movement Configuration Interface: Elbow Movement Configuration (1) and Wrist Configuration (2)

The following table represents the rotation movement associated with each compensatory motion, defining the segment associated with the motion, the axis on which the rotation that originates the movement acts on and the direction of rotation (positive or negative, around said axis):

In this table, the values corresponding to the shoulder Flexion and Extension and Horizontal Flexion and Extension are the same. This happens due to the intricacy of the human shoulder and the technical definitions of shoulder movements in the medical community. To distinguish these two movement pairs, computationally, we can verify the condition of simultaneously verifying the rotation in the Y axis, as expected, and the rotation on the Z axis. It is, depending on this last one, that the movement differs in its definition.

4.6 Exercise Repetition and Biofeedback

Following the Compensatory Movement Configuration Interface, the system is ready for the patient to start exercising. It is at this point that the system prepares for another recording, this time with accompanied by some other processes running simultaneously.

This System has a similar UI to the Record Movement Interface, with a similar avatar calibration and an *Exercise* button having the same function as the *Record* button. Consequently, pressing this button will start the exercise recording. In addition, this button starts a couple of routines, namely an **Error Check**, the **Dynamic Feedback** and a **Compensation Verification**.

To monitor the exercise and verify the existence of errors, the program uses the stored position lists

Body Segment	Name	Axis	RotationDirection
Wrist	Flexion	Z	N
Wrist	Extension	Z	P
Wrist	Radial Deviation	Y	N
Wrist	Ulnar Deviation	Y	P
Wrist	Supination	X	N
Wrist	Pronation	X	P
Elbow	Flexion	Y	N
Elbow	Extension	Y	P
Shoulder	Flexion	Y	N
Shoulder	Extension	Y	P
Shoulder	Abduction	Z	P
Shoulder	Adduction	Z	N
Shoulder	Lateral Rotation	X	P
Shoulder	Medial Rotation	X	N
Shoulder	Horizontal Flexion	Y	N
Shoulder	Horizontal Extention	Y	P
Chest	Flexion	X	P
Chest	Extension	X	N
Chest	Lateral Flexion (Left)	Z	P
Chest	Lateral Flexion (Right)	Z	N
Chest	Rotation (Left)	Y	N
Chest	Rotation (Right)	Y	P
Neck	Flexion	X	P
Neck	Extension	X	N
Neck	Lateral Flexion (Left)	Z	P
Neck	Lateral Flexion (Right)	Z	N
Neck	Rotation (Left)	Y	N
Neck	Rotation (Right)	Y	P

Table 4.1: Compensatory Movement Rotations (N - Negative; P - Positive)

created in the ideal movement recording as a resource to compare the saved positions to the newly tracked ones. To achieve this, the system uses a radius of tolerance set in the original movement recording, verifying when a tracker intercepts the sphere created with this radius around the stored positions. Every time there is an interception, the program checks if the tracker skipped any of the precedent positions in the exercise timeline. If there was a skip, the system creates an error data object, populating it with information about this occurrence to be used and displayed in a later visualization scene.

Considering that we store a sequence of positions to be intercepted in a certain order, the implementation of Dynamic feedback in the form of a Guide, one of the biofeedback concepts we planned on implementing, was very straightforward. For an experimental first version, we had the program create small sphere objects where the positions to intercept were. When the exercise begins, a group of spheres appears so that whenever the patient successfully intercepts the correct position area, the corresponding sphere target object will change colour from grey to green. If an error occurs, the skipped targets will change their colour to red, making it simple for the user to know they missed the corresponding positions.

While the exercise is repeated, the program also checks for the existence of compensatory movements. To achieve this, every time there is an interception, the system compares the rotation values of the Trackers with the rotation values stored, going through the list of set compensation thresholds. This comparison is made in accordance with the previously specified compensatory movement rotation identities (table 4.1). If the verification is done when an error is detected, the compensation movements returned from this routine become associated with said error.

Lastly, during all of these routines, the system collects data to populate metrics represented in a later interface. These metrics are described in the following chapter.

4.7 Feedback and Exercise Review

The last Interface in our program is an exercise review visualization, where the therapist and the patient are able to review the preciously practised exercise. This visualization scene is composed of a media player UI, similar to the Recorded Movement Review Interface, with the addition of error-related information display and a representation of metrics linked with exercise performance.

The media player, as described before, follows a simple and intuitive design, with a play/pause button, an interactable player bar, a timer and the animation length time. This time, the animation attached to the player is the recording of the whole exercise routine, including all its possible repetitions. This time around, markers representing errors or compensations are populated throughout the video progress bar according to their timestamp.

Figure 4.10: Final Exercise Review Configuration Interface

Upon clicking on these markers, a window containing the error description appears, with the information stored in the error object created while exercising. In this window, it is presented to the users what compensations were associated with the marker and if these compensations were the origin of an error. This last information is verified if the marker was populated by an error object or detected compensations.

Finally, the last feature introduced in this interface is a collapsible window, labelled *Performance Index*, where performance-related metrics are displayed. These metrics were conceived with help from the ARCADE project [1], where, as mentioned in chapter 3, a study of information and metrics was conducted, and a list of optimal metrics for upper-body exercise performance assessment was conceived. In addition to metrics like session time, the number of repetitions and number of errors, we represented a *success* metric. This system metric was designed by Faria et al., describing the general quality of movement, one of the most important metrics to evaluate an exercise. It is represented by a success percentage, which is essentially a percentage of correct repetitions during the session.

$$\frac{correct\ repetitions}{total\ repetitions} * 100 = success\ percentage$$

Figure 4.11: Formula for the Success Percentage

5

User Study

Contents

Our system aims to resolve the lack of solutions offering enough intervention customization to cover the current needs in stroke rehabilitation. To validate this capability, we ran a user study with professional therapists to assess the usability of our system and its adaptability to both therapists and stroke victims.

5.1 Research Questions

With this study, we aim to corroborate the potential of our program. In order to reach the conclusions that would allow us to do that, with this activity, we wanted to answer the following questions:

- Can the program give enough personalization to adapt to stroke patients' upper-body recovery?
- Is the compensatory movement threshold feature technically intuitive for professional use?
- Does the program represent a way to improve therapists' daily work?

5.2 Procedure

For the activity structure, our intent was to briefly present the motivation and proposal behind our project. The goal was to vaguely describe our system's purpose and capabilities in order to set the stage for the next phase. If we did not give a short description, there was the possibility of overwhelming the therapist in a stage where we would want them to be focused. On the other hand, if we went into too much detail about the characteristics of our program, it would hinder professionals from giving reactive feedback since they would expect most of what they would see. To achieve this balance planned on using our early stage Storyboard, considering it still represented an accurate depiction of how therapists and patients would interact with our system, leaving the program itself in a *black box* state.

In the second phase, we planned on having therapists individually try interacting with our system so as not to compromise the experience and subsequent evaluation of other therapists. In this stage, therapists would play the part of both patient and therapist to ensure they interacted with all the interfaces that constituted our system. The goal in this stage was to get **qualitative** analysis on every part of our program. To attain this examination, we asked the therapists to engage in a Think-a-Loud exercise, having dedicated discussion phases between interfaces. We went through the various features and aspects of every visualization.

In a third phase, therapists were presented with a questionnaire to try and collect feedback of a **quantitative** nature.

5.3 Participants

For our participants, we went to the Health and Neurology clinic *Saúdis*. This clinic specialized in neurological physical therapy and neuropsychology services and had a group of several therapists and physical therapy students willing to participate in our study. Unfortunately, due to an unpredictable situation on the part of the clinic, the study was postponed to a date when only 2 participants could attend.

These participants both had more than 20 years of experience in the field of neurological physical therapy and the exercise functions of both therapist and physical therapy professors.

5.4 Apparatus

To run our system in the clinic, we had to bring all the movement tracking equipment there. So, essentially, to conduct the study, we used the HTC Vive system, including the HMD and two BSs, three Vive Trackers and three straps to attach them with. In the study's second phase, a monitor display provided by the clinic was also utilized.

5.5 Questionnaires

With the intent of getting a quantitative set of information, we designed user questionnaire (appendix A), to present the user with, at the end of the individual system interaction. Having this in mind, we separated the form into five parts.

The first 3 parts addressed the characterization of the answering population. These include identity, physical therapy experience and former experience with interactive rehabilitation solutions.

We then proceeded to ask questions concerning their previously made interaction user testing. In this section, we ask standard and identical usability questions concerning each interface they interacted with. In addition, in most interface subsections, we added questions about features or visualization elements specific to those visualization scenes.

Lastly, we closed with a section that discusses general observations about the interactive tool and its viability, limitations and potential on a clinical level.

5.6 Results

To analyze the results of this user study, we separated the information obtained and revised it into different thematic categories, seen in both therapists' participation.

5.6.1 Movement

Considering that users start the interaction with our system utilizing the movement recording interface, there were immediate observations about the movement tracking system:

- Both therapists considered that when considering hemiparesis-originated symptoms, plenty of postural compensations would arise on the opposite side of the affected limbs. This entails that there is a greater importance on monitoring both upper limbs. Moreover, they both defended that upper and lower-body limbs frequently connected, being posture changes, balance evaluation and march patterns some of the most debilitating compensation origins;
- The imperfect representation of elbow and arm segments, due to the removal of the shoulder tracker IK calculations, explained in chapter 4, was quickly noticed by one of the therapists. They explained the importance of correct representation of avatars, even if only in a visualization way: the wrong portrayal of body movements can have consequences in exercise performance, as some patients could have difficulties in performing exercise motions correctly;

  One of the professionals noted that it needed to be clarified if the recording and exercise started or stopped.
- Both clinicians were delighted with how smooth and satisfying the real-time representation of their movements was. This was due to the increased tracking precision of the Vive Trackers, compared to other motion tracking technologies they both used in the past.
- Most stroke rehabilitation interventions prioritize the individual necessities of the patient as he is the one who defines his movement goals. With this in mind, stroke rehabilitation focuses on functional exercises. This means regular arm movements are rare and even recommended, as exercises usually revolve around task-oriented motions.

5.6.2 Visualization

Regarding the multiple visualizations throughout the usability flow of our program, the therapists were in general, very impressed:

- The exercise review interface represented a very easy-to-use feature, something that interactive solutions generally lack. This is due to the fact that most solutions focus on data capture and presentation, but only some have the ability to visualize the performed exercise.
- The compensatory movement threshold configuration was very straightforward and complete. The proposed compensatory movements were all relevant and, in general, sufficient, and the motion limit visualization was easy to interpret and visualize.

- The dynamic feedback approach composed by the visualization of guide targets is the only genuinely viable approach inside the ones we had conceived. The notification format is too process demanding for the patient, as he would not be able to react to corrections in an acceptable way. The guide approach lets the patient plan out his motions, helping towards earlier exercise success. The sphere solution was perceived as a helpful tool but can only sometimes represent the motion to be achieved by the patient.
- The final exercise review visualization is really helpful in supporting exercise analysis.

5.6.3 Adaptability

Both professionals commented that the adaptability of the system was twofold: It allows for exercise personalization, something essential in most neurological rehabilitation practices, and it allows for a lot of adaptability tint the therapist's choice of chosen intervention methodologies, considering the customization present in the monitorization of compensatory movements.

Moreover, both therapists reported they had never seen an interactive rehabilitation tool that approached motor rehabilitation while segmenting the characteristics of a movement in such detail. They also recognized the potential of this system being versatile enough to warrant the consideration of it being used in other types of physical rehabilitation.

5.6.4 Questionnaire Review

The number of participants did not allow for any statistical analysis of the quantitative data provided by the questionnaire. Even so, it is worth noting that, for the most part, the professionals found the visualizations simple, intuitive and useful. Furthermore, they both recognized the potential in how this system could improve movement analysis and provide enough personalization to contribute to stoke rehabilitation adequately.

5.7 Discussion

In the face of not having a significant enough number of participants to warrant sizable importance in its quantitative part, our user study was still of immense importance due to the success of its qualitative phase. This was only possible to conclude due to the qualifications of both participants and the insight that came with it.

Motion tracking brings an interesting and immersive type of interaction. However, it comes with its challenges and requirements. Patients utilizing technology like this, particularly considering the possibilities of cognitive impairment in stroke victims, need an accurate representation of their movements. Our approach of prioritizing functionality over visualization regarding the avatar animation could be better in a real physical therapy session environment, as this can affect the patient's ability to perform the correct movements.

The precision of the motion tracking technology utilized, the Vive Tracker, was considered superior to other technologies participants used in the past. This increased comfortability stems from the fact that the Vive tracker is, in general, more precise than common technologies, such as depth cameras (like the Microsoft Kinect) and with the strap setup, they do not need to be held, as other technologies do (including the Wii remote, and even the HTC Vive controllers), allowing for free range of motion. In spite of these advantages, the uncovered dependency of a Vive HMD to properly work complicates the system's setup.

There is also the apparent reality that, in stroke victims, lower-body limbs can have a frequent and substantial affect on a patient's movements. Being this the case, not monitoring lower-body limbs can lead to deceiving results.

Task-oriented exercises are usually the norm in stroke rehabilitation. Even though our program allows for enough personalization to be possible to adapt some exercises to simulate regular tasks chosen by the patient, task-oriented exercise support, such as in application interactable objects to simulate pick-up and hand fingers motion tracking, would make for valid tools to help with patient intervention reception and motivation.

Visualization in this program was, in general, well received. It was apparent that some basic UI elements were either missing or not optimized. We identified some moments where both therapists showed small but equal levels of disorientation. By analyzing those moments, we pinpointed some possible corrections in the UI that could help with interface perception and usability:

- When calibrating the avatar, there was a 5-second window where it appeared in a strange position. Only after some preemptive attempts to move the avatar and run the calibration we had to tell therapists to wait in place for a brief period while the calibration ran. This could be easily avoided with a *Loading* window appearing while calibration took place;

- Even with a change of colour in the *Record* button, on therapist still had a hard time recognizing when to start or stop the ideal movement. This could be solved by the appearance of a visual element (like the very common red dot) or an instruction pop-up comment on the top right of the screen.

- Some elements like the *Record* and *Exercise* buttons could update their text to give a better indication of their use on a second click.

- The Dynamic feedback could be updated into one of the concepts we had designed. Showing a dummy transparent arm while exercising, for example, would help with the patient's planning process, as they could visualize the actual position their arm should try to achieve.

By observing the professionals interact with our system, even if they overlooked them, we were capable of identifying two main problems with error checking:

- the position verification system had a flaw in verification. Despite having access to and could compare the rotations associated with the positions, considering the positions were stored with positional limitations (unique positions were stored and positions close to each other were ignored), if a chosen movement to record included a segment where the tracked upper-body segment was in the same position, changing it's rotation, the system would never record more than one verifiable position. Therefore we concluded our system and a limited position-only error check.
- if the chosen motion included going back and forth in the same spacial path, due to the individuality of positions stored for verification, the movement would only be monitored in one way, being the arrival of the body segment to the movement's initial position the only verification that would happen on the way back, no matter the deviations or compensations made between the origin and it's furthest point.

These two issues stem from the same problem, an incorrect solution to storing of verifiable positions and consequent error checking.

Nevertheless, throughout the user study, there was a consistent set of feelings around our project's concept, which was later confirmed by the questionnaire analysis: Our project was working in the correct direction to tackle the biggest obstacle impeding most interactive rehabilitation tools from being viable to utilize in neurological physical therapy, which is the lack of system adaptability to patient's particular needs (confirming the **first research question**).

Furthermore, our system also broke up the concept of movement into such detail it could achieve adaptability to most therapist intervention methods to a degree that most interactive solutions generally cannot. The compensatory movement configuration interface was considered technically intuitive from a physical therapists' perspective, giving the therapist the adaptability of intervention methodologies (confirming the **second research question**).

This project was perceived as the basis of what had the potential to be an extremely useful rehabilitation tool that was adaptable enough to be potentially used for other types of physical therapy, such as musculoskeletal physical therapy (confirming the **third research question**).

6

Conclusion

Contents

Stroke is a leading cause of disability, and its rehabilitation process is a very complex procedure. This is, in most part, due to its leading outcome, hemiparesis, which leads to diverse motor and cognitive symptoms, varying between victims. This requires the stroke victim rehabilitation process to be a highly individualized treatment, considering every patient has its own limitations and needs a different treatment focus.

Our project aims to solve the lack of exercise adaptable interactive solutions for stroke rehabilitation, taking into consideration that most of the existing solutions are designed with pre-set exercises that limit the movements a patient can practice.

As a result, we propose a customizable upper-body rehabilitation tool that allows for exercise personalization and monitorization, focusing on allowing the patient to practice any motion desired and for the therapist to use a preferred intervention methodology.

The ensuing developed system was an intuitive interactable program, with the ability to record and review any movement desired by a patient, the capability for a therapist to set the compensatory movement thresholds he deduces are ideal for any actuating body segment, in the practice of the recorded movement, the means for the patient to practice said movement, with the help of dynamic feedback in the form of a motion guide, and review it alongside the clinician, with access to data metrics captured during motion execution.

To evaluate the usability and potential of our system, we directed a user study where we had experienced professional physical therapists interact with our rehabilitation tool. Our findings suggest that the adaptability to both patients, through their need for exercise personalization, and therapists, through the importance of the possibility of using different intervention methodologies, considering the variety in patient characteristics and limitations, is imperative for an interactive system's viability in neurological therapy. Furthermore, rehabilitation solutions, due to the age group most stroke victims are included in, there is a need for simple and intuitive interfaces, which is a challenge due to the complexity of the previously established requirements for a stroke rehabilitation tool. If these conditions are met, the already overly consensual contribution, of motion tracking technology-based solutions, in physical therapy, the automated data collection, analysis and visualization, can be attained and utilized to improve clinical examination and improve motor recovery.

Last but not least, the motion capture utilized in this system, the Vive Trackers, proved to be a cost-effective solution for precise and reliable body tracking.

6.1 System Limitations and Future Work

Throughout the development of this project, some priority decisions and some poorly covered features led to the existence of several limitations.

In a first instance, the inability to make the shoulder tracker IK representation work in conjunction with the other trackers' representation efforts and the decision not to represent the effect of this tracker on the avatar present a problem for future iterations of this project. Notwithstanding the fact that it permits us to test the rest of the system's features with minimal visual consequence, this visual limitation could potentially hinder the rehabilitation process of a stroke patient's physical therapy session.

Some UI elements could be straightforwardly improved, as some can impede a smooth interaction from the users' perspective.

Additionally, trying to build the Unity3D project containing the developed tool, right before the User Study, we realized the GameObject we used to record the avatar's recorded movement could only be used as a development environment tool rather than in a final project build. Even with this animation serving visual purposes only, to turn this system into an actual application, another method of recording the avatar's movement into an animation has to be developed.

As we mentioned in our user-study findings (chapter 5), we detected a problem in the coverage of our error verification routine, needing to properly verify rotation-only motions and movements that share the same spacial positions.

Lastly, our findings, while helping to validate the potential of our system, due to the small amount of user test participants, needed to feature a sufficient amount of data for the possibility of making a proper quantitative analysis.

Future work concerning this project involves improving the dynamic feedback feature, possibly using our concept of using dummy transparent body segments to represent pose and orientation to the target position and correcting the avatar representation, and error verification and recording routines. Moreover, this project could be seen as a modular basis for a more complex solution, including full upper-body or even full-body tracking, as it seems to be an essential step, specifically for stroke patient rehabilitation.

A more complete set of user studies, including more participants and clinical trials involving stroke victim patients, would also be crucial for this program's better usability validation.

Finally, and as confirmed by our user study participants, this solution should be viable to use in other physical therapy areas, representing an interesting solution for those types of physical therapy, that could benefit from it's exercise personalization features, even if this personalization is not as crucial in those areas.

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A

Questionnaire

Questionário de Teste de Utilizador

Este formulário vem no ambiente da realização de testes de utilizador do projeto de dissertação do aluno Francisco Santos Silva, do Instituto Superior Técnico, com vista a obter feedback sobre detalhes técnicos de uma ferramenta de apoio às recuperação de vítimas de AVC.

O formulário não demorará mais de 5 minutos e as informações nele cedidas serão apenas utilizadas para levantamento e análise de dados, decorrentes da utilização experimental do sistema desenvolvido.

Na utilização destas informações como dado de estudo na dissertação, informações de identidade pessoal (como o nome, clínica/instituto onde trabalha, entre outros) serão ocultadas de qualquer documento publicado.

Obrigado pelo seu tempo e ajuda!

Identidade

1. Nome

____

2. Idade

____

3. Instituto/Clínica onde trabalha

____

4. Qual a sua ligação a Fisioterapia?

Marcar apenas uma oval.

- ( ) Sou Fisioterapeuta praticante
- ( ) Dou aulas Fisioterapia ou temas relacionados
- ( ) Ambos

Experiência de Fisioterapia

No caso de já não praticar Fisioterapia, responda às questões em relação ao seu tempo como fisioterapeuta praticante

5. Que tipos de Fisioterapia pratica com maior frequência?

Marcar tudo o que for aplicável.

- [ ] Músculo-esquelética
- [ ] Neurológica
- [ ] Respiratória
- [ ] Pediátrica
- [ ] Dermatológica
- [ ] Saúde da Mulher
- [ ] Outra: ______________________

6. Há quantos anos pratica Fisioterapia?

____

7. Qual o seu grau de especialização na área de Fisioterapia?

Marcar tudo o que for aplicável.

- [ ] Licenciatura
- [ ] Mestrado
- [ ] Doutoramento
- [ ] Pós-Graduação
- [ ] Formação Contínua
- [ ] Outra: ______________________

8. Em médiia, quantos pacientes costuma atender por hora?

____

9. Quantos desses pacientes são vítimas de AVC?

____

10. Qual o tempo médio de uma consulta de fisioterapia no seu âmbito de trabalho?

____

Experiência com tecnologias de Fisioterapia	Responda às seguintes quetões, considerando a sua experiência com ferramentas interativas de Fisioterapia, antes desta sessão.

11. Já trabalhou no passado com sistemas tecnológicos com fins fisioterapeuticos?

Marcar apenas uma oval.

- Sim
- Não

12. Já trabalhou com sistemas interactivos que envolvessem captura de movimento?

Marcar apenas uma oval.

- Sim
- Não

13. Trabalhou com algum sistema de auxilio a recuperação de AVC?

Marcar apenas uma oval.

- Sim
- Não

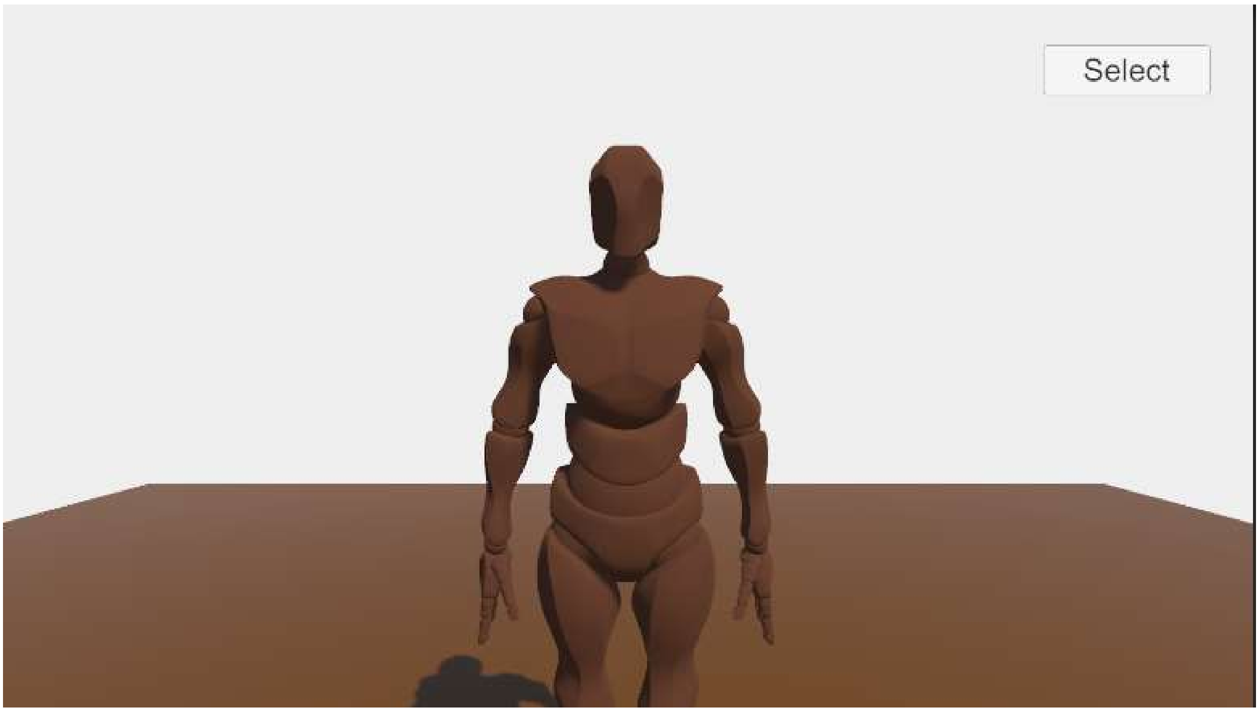
14. Caso tenha trabalhado com alguma tecnologia mencionada nas questões anteriores, apresente os principais obstáculos que encontrou na sua utilização.

Teste de Utilizador

Nesta seção responda às questões, com base na experiência que teve na utilização do programa.

Ecrã de Gravação de Movimento

Responda às seguintes questões relacionadas com o ecrã representado. Escolha as opções que mais se adequam ao que foi a sua experiência com esta interface.



15. A informação existente foi representade de forma simples e preceptível.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

16. Neste ecrã foi fácil entender o que se pretendia alcançar e como o fazer.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

17. Neste ecrã consegui alcançar os objectivos pretendidos.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

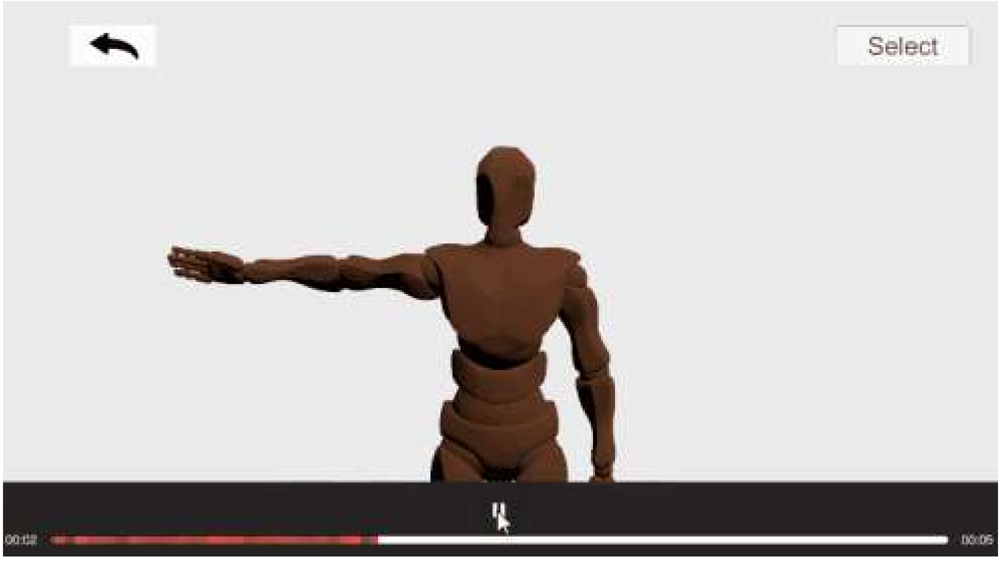
18. Identifiquei utilidade neste ecrã.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

Visualização do Movimento Gravado

Responda às seguintes questões relacionadas com o ecrã representado. Escolha as opções que mais se adequam ao que foi a sua experiência com esta interface.



19. A informação existente foi representade de forma simples e preceptível.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

20. Neste ecrã foi fácil entender o que se pretendia alcançar e como o fazer.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

21. Neste ecrã consegui alcançar os objectivos pretendidos.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

22. Identifiquei utilidade neste ecrã.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente						Concordo Totalmente

23. A barra de reprodução representa uma forma simples e fácil de rever o movimento gravado.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente						Concordo Totalmente

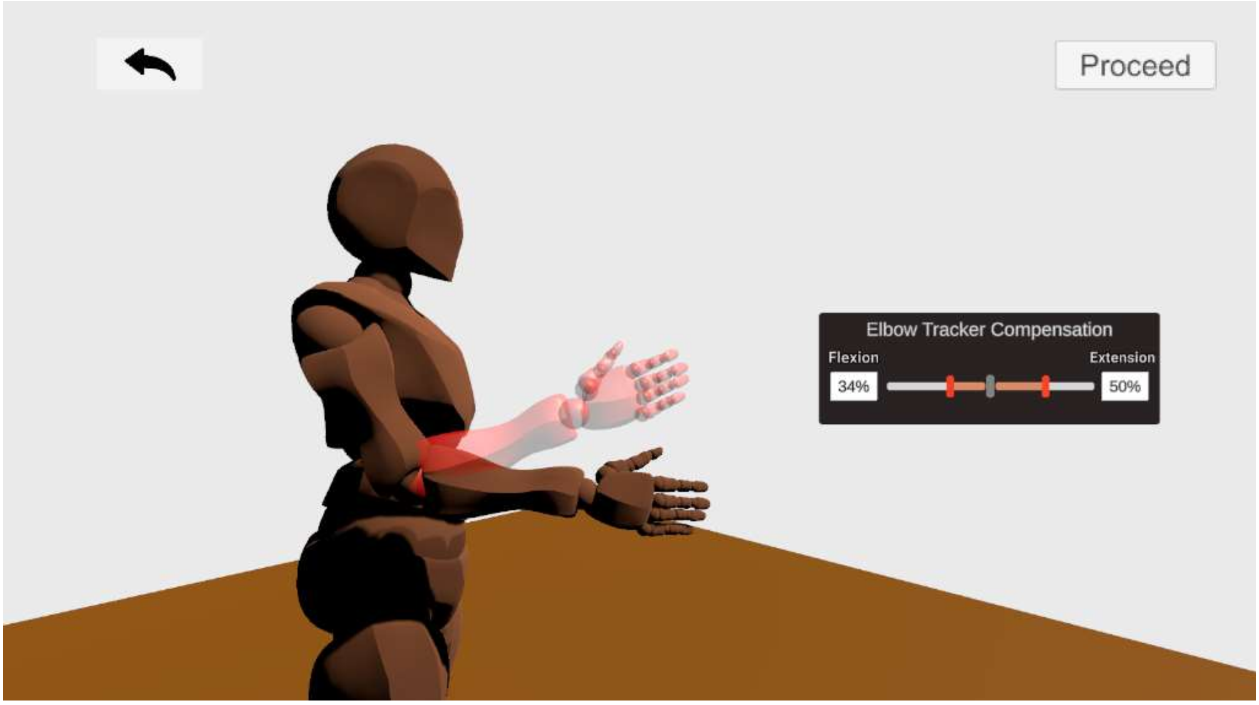
24. O movimento gravado ficou correctamente representado?

Marcar apenas uma oval.

- Sim
- Não

Ecrã de Configuração de Limites de Movimentos Compensatórios

Responda às seguintes questões relacionadas com o ecrã representado. Escolha as opções que mais se adequam ao que foi a sua experiência com esta interface.



25. A informação existente foi representade de forma simples e preceptível.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

26. Neste ecrã foi fácil entender o que se pretendia alcançar e como o fazer.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

27. Neste ecrã consegui alcançar os objectivos pretendidos.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

28. Identifiquei utilidade neste ecrã.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

29. Os movimentos compensatórios representados eram adequados e suficientes.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

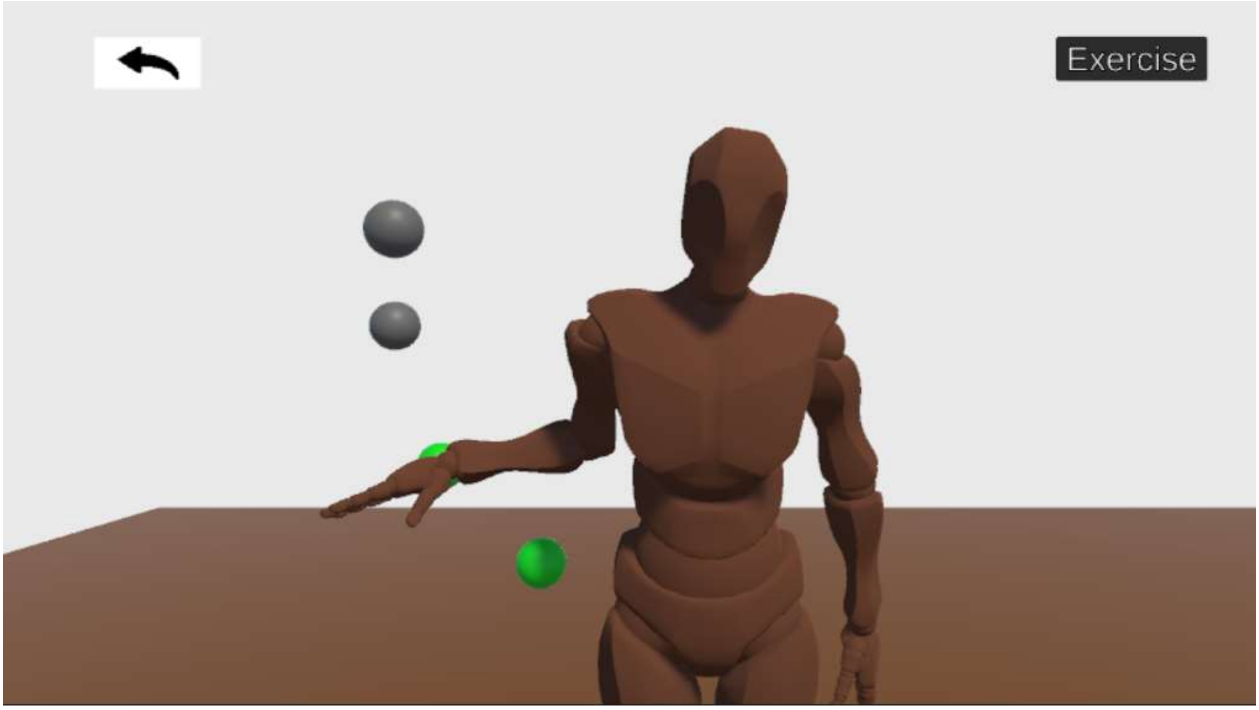
30. A visualização dos limites de compensações para cada articulção é intuitiva.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

Ecrã de Exercício (Repetição de Movimento)

Responda às seguintes questões relacionadas com o ecrã representado. Escolha as opções que mais se adequam ao que foi a sua experiência com esta interface.



31. A informação existente foi representade de forma simples e preceptível.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

32. Neste ecrã foi fácil entender o que se pretendia alcançar e como o fazer.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

33. Neste ecrã consegui alcançar os objectivos pretendidos.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

34. Identifiquei utilidade neste ecrã.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

35. Este ecrã beneficiaria dos seguintes tipos de feedback:

Marcar apenas uma oval.

◯ Guia (representação de onde o paciente deveria mexer o braço a cada momento)

◯ Correção de Movimento (Apenas avisar quando há um erro e onde deveria de estar o braço do paciente nesse momento)

◯ Ambos

◯ Nenhum

Ecrã de Visualização Final

Responda às seguintes questões relacionadas com o ecrã representado. Escolha as opções que mais se adequam ao que foi a sua experiência com esta interface.

36. Neste ecrã foi fácil entender o que se pretendia alcançar e como o fazer.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

37. A informação existente foi representade de forma simples e preceptível.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

38. Neste ecrã consegui alcançar os objectivos pretendidos.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

39. Identifiquei utilidade neste ecrã.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

40. Foi evidente a identificação de erros na gravação.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

41. As métricas associadas a erros indivíduais eram indicadas e suficientemente descritivas.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

42. As métricas gerais da sessão (representadas na barra colapsável lateral) eram indicadas e suficientemente descritivas.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

Observações Finais

Nesta última secção, pretende-se saber o sentimento geral de utilização do protótipo, as suas limitações e a sua potencial viabilidade, num ambiente clínico.

43. Considero que o programa permite personalização de exercício suficiente para integrar o processo de reabilitação de vítimas de AVC.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

44. Considero que uma ferramenta como esta pode levar a melhoria no trabalho diário de terapeutas.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	⬭	⬭	⬭	⬭	⬭	Concordo Totalmente

45. Vejo potencial de melhoria de tratamento de vítimas de AVC, utilizando este sistema.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

46. Imaginar-me-ia a utilizar esta sistema para auxiliar na recuperação de vítimas de AVC, caso este estivesse disponível.

Marcar apenas uma oval.

	1	2	3	4	5	
Discordo Totalmente	◯	◯	◯	◯	◯	Concordo Totalmente

Obrigado!

Muito obrigado por ter tirado o tempo para fazer este teste de utilizador e responder a este questionário! As suas respostas serão muito importantes para a avaliação do projecto.

Atenciosamente,
Francisco Santos Silva