Learning Your Moves: A Gait Motion Virtual Reality Educational Tool for Physiotherapy Students

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Abstract

Physiotherapy students need to repeatedly observe patients' gait motions in order to learn how to make an analysis of impairments and formulate the most suitable rehabilitation plan. Traditional teaching methods are limited to 2D content, such as the use of videos and textbooks. The 2D videos have several limitations. For example, the 2D nature itself, distracting elements on the videos, and the need for patients' consent. Given the 3D nature of the human gait motion, this dissertation focuses on understanding the benefits of immersive Virtual Reality (VR) as a way of physiotherapy students to learn how to analyse gait motions. The base for any gait motion analysis is to compare said gait motion with what is considered to be a normal gait motion.

To answer the objectives of this dissertation, an approach is proposed that allows students to visualize gait motion in a VR immersive space, learn how to diagnose different gait motions and how they are affected differently by several neurological diseases. A VR tool is created to demonstrate this approach.

The evaluation is made by a mixed-design user study on the two versions of the tool. These two versions are a VR tool and the same tool in a window, icon, menu, pointing device (WIMP) interface.

Results of the evaluation reveal that VR version is, among the participants, the preferred version between the two. The evaluation also shows the benefits both versions brought in terms of visualization and learning.

Keywords

Virtual Reality; Physiotherapy Education; Gait Motion.

Resumo

Os alunos de fisioterapia precisam de observar repetidamente os movimentos de marcha dos pacientes para aprenderem a analisar e a definir o plano de reabilitação mais adequado a cada caso. Os métodos tradicionais de ensino utilizam apenas plataformas 2D, tais como vídeos e livros didáticos. No entanto, os vídeos 2D apresentam várias limitações, tais como a própria natureza 2D, elementos de distração e a necessidade de consentimento dos pacientes. Dada a natureza 3D do movimento da marcha humana, esta dissertação foca-se na compreensão dos benefícios da RV imersiva, como forma dos alunos de fisioterapia aprendem a analisar estes movimentos, por comparação com o movimento de marcha considerado normal.

Para responder aos objetivos desta dissertação, é proposta uma abordagem que permite ao aluno visualizar o movimento da marcha num espaço imersivo de RV, aprender a diagnosticar diferentes movimentos da marcha e a forma como estes movimentos são afetados de modo diferente por várias doenças neurológicas. Neste contexto é criada uma ferramenta em RV em consonância com estes objetivos.

A avaliação é realizada através de um estudo *mixed-design* com utilizadores, para as duas versões da ferramenta. Essas duas versões consistem numa ferramenta de realidade virtual e essa mesma ferramenta num interface para utilização em ecrã 2D (WIMP).

Os resultados da avaliação revelam que a versão VR é a preferida pelos participantes. A avaliação também mostra os benefícios que ambas as versões trazem em termos de visualização e aprendizagem para os estudantes.

Palavras-chave

Realidade Virtual; Educação em Fisioterapia; Movimento de Marcha.

Contents

List of Tables

List of Figures

Acronyms

2D	2 Dimensional
3D	3 Dimensional
Covid-19	Coronavirus disease
KHD	Kinetic Digital Human model
MB	Motion Builder
Mocap	Motion Capture
P1-P4	Professor 1-4
RLANRC	Rancho Los Amigos National Rehabilitation Center
S1-S5	Student 1-5
U1-U10	User 1-10
UI	User Interface
VR	Virtual Reality
WBLT	Web-based Learning Tools
WIMP	Windows, Icons, Menus, Pointer interface

Chapter 1

Introduction

There have been several advances in the field of virtual reality that lead to a substantial increase of studies and research on whether or not the use of virtual reality could improve or solve challenges on different domains, such as Engineering, Health, Social Sciences, Military Training, among others [1][2].Virtual reality became recognized as a tool for teaching, able to improve the performance of professionals and users. The use of virtual reality technology, with the purpose of education in the Health domain, is one of the biggest sectors being researched. Anatomy teaching is an example of one most common subject of said researches [1]. Despite the amount of research done on virtual reality education, the use the use of virtual reality for physiotherapy education is still largely unexplored. This dissertation targets exactly said uncharted area by applying virtual reality to physiotherapy education. Specifically to aid the teaching process of undergraduate students on the elaboration of a gait motion analysis.

1.1 Motivation

One important skill physiotherapy students need to acquire is how to analyse a gait motion. This analysis is taught by repeatedly observing gait motions affected by different health conditions, such as a disease or genetics. Here lies the base for the motivation of this dissertation, specifically the need for physiotherapy students to analyze 3D movements, repeatedly, in order to learn.

The gait motion analysis is important for different physiotherapy areas, each in its own way. The analysis enables physiotherapists to identify changes in the gait motion the patient has, or could have, based only on a first observation. Along with an objective examination, the gait motion analysis allows physiotherapists to create the most adequate rehabilitation plan for a specific patient, ensuring that the created plan answers the patient's needs. It is common that physiotherapists interventions fix several aspects that are reflected in the gait motion so, usually, the gait motion is the last phase of treatment. This last phase focuses on the changes present in the patient gait motion after the intervention.

For patients who have neurological pathologies, the gait motion becomes one of the rehabilitation's main focus. For these patients, even small gains result in a huge difference in their independence, and life quality. The more functional the gait motion is, the more gains from the rehabilitation the patient will have. To that end, it is important, firstly, to have a good analysis and, secondly, a good approach/intervention that aims to optimize the potential of a given patient in order to improve the patient's autonomy, independence and life quality.

The gait motion is the first thing physiotherapists and students note when they see a patient for the first time. From that first impression, students should be able to start a clinical reasoning based on the observation which will reflect the several changes on the gait motion. When students arrive to the internships, they are not yet capable of doing this analysis in a precise and efficient manner, as well as starting the clinical reasoning based only on observation.

1.2 Problem

Physiotherapy students are taught how to analyse the human gait motion using videos and textbooks, which have several limitations. The lack of patient's anonymity or unreliability due to unwanted distractions that might change the focus of students, are examples of such video limitations. Students are limited to study using the 2D information provided by videos and textbooks, which can prove challenging when trying to perceive such complex 3D movements as the gait motion. For this reason, when students arrive at the internships, although theoretically prepared, they struggle to make an efficient and precise gait motion analysis.

1.3 Approach

The approach chosen to tackle this problem is providing students' visualizations of gait motions in a virtual reality immersive space to aid in the learning of how to analyse different gait motions and how differently these are affected by specific neurological diseases.

To understand the limitations faced in Physiotherapy Education, user studies were conducted by interviewing both Professors and students. From those studies, several limitations were appointed and guidelines were created.

These limitations helped formulate the following research question: Can immersive VR (camera control freedom, wide reachable spaces, large range of motions, non-stationary user postures, 3D perception) provide any positive impact on how physiotherapy students view and learn gait motion?

To demonstrate this approach, a tool was developed to immerse physiotherapy students in a virtual reality environment giving the user control over the visualization of time and space. A humanoid figure performs the gait motion for the visualization. The humanoid consists of an avatar that simulates human gait motion affected by a disease. The avatar's movement can be repeated, stopped and rewound as the user pleases. The tool also lets the physiotherapy student move and look freely to achieve the best view of the humanoid's movement in order to make the analysis. The same tool was developed for a WIMP interface with the same features and functionality to compare the immersion VR provides to the display from a 2D computer screen.

The whole development had a User centered design, iteration after iteration of prototypes were created where users tested the demos and gave feedback for improvement on the next iteration.

A mixed-design study was made to compare the two versions of the tool in terms of user experience and analysis performance. The user experience comparison was based on a questionnaire with open questions. The analysis performance was based on the time and score results from the tests. These tests were conducted with five physiotherapy students testing the VR tool and the WIMP tool while other five only tested the WIMP tool. For both tools, students were given a tutorial on how to control the assigned tool, then a pre-test was made followed by a practice mode where they could see the solutions and try to make a new analysis of a gait motion and, finally, a post-test in the end.

1.4 Goal/Contributions

This dissertation has three main objectives. The first objective is to understand how gait motion analysis and rehabilitation planning is being taught and what its current limitations are. Secondly, the creation of a design and developing of a virtual reality tool that will aid students with the visualization and learning of different gait motions. Finally, this dissertation aims to analyze, by comparison, the VR tool with the tool in a WIMP interface in terms of user experience (learning, design, engagement) and the learning outcome.

1.5 Thesis outline

The introduction should give an overview of what this dissertation is about, the motivation behind it as well as what is the contribution and the approach to achieve it. The second chapter, “Related Work”, aims to discuss research previously done and what can be used for this dissertation. The third chapter, “Understanding Learning Gait Motion Analysis” is a detailed description of the user studies done prior to the development of the prototype. These studies’ goal was to understand the limitations faced in physiotherapy education today and to formulate design implications and guidelines based on the results. The fourth chapter, “Prototype”, describes the tool developed, detailing each module and how it came to be.

The fifth chapter “Results”, firstly explains in detail how the user tests were conducted and the procedure. Then the outcome is discussed. The last chapter, “Conclusion”, enumerates the contributions of this dissertation and summarises the limitations found and what future work can be done to tackle them.

Chapter 2

Related Work

Given the objective of this dissertation, the related work starts with the subsection 2.1 “Visualizing 3D Motion” subsection which aims to showcase the importance of 3D visualization and the power of VR as a 3D motion visualization tool. The subsection that follows 2.2 “VR for Education” aims to answer the question “why should we use VR for education purposes” and to deliver an understanding on what has been done specifying some virtual reality systems that focus on enhancing Medical Education. The subsection 2.3 “VR for Physiotherapy” shows how VR has been used for Physiotherapy to answer the question “What has Virtual Reality brought to Physiotherapy?”. It also showcases what other technologies have been used to enhance physiotherapy education and what challenges they aimed to surpass.

2.1 Visualizing 3D Motion

The first studies presented in this subsection were chosen as a means to understand the importance of visualising 3D movements in a 3D space, even if said visualization is displayed by a 2D media. Kakizaki et al. [3] propose a method to apply precise digital human models to the field of physiotherapy in order to visualize and analyse the gait motions of patients with conditions like hemiplegia. It aims to be a quantitative-based method and therefore would enable physiotherapists to determine, for example, that the rotation of the ankle is half of the target value. The focus is on improving students’ understanding of the gait motion on disabled patients and be easily used in physiotherapy facilities, using a camcorder and a laptop. The digital human model used was a full 3D kinematic model which allowed patterns and postures to be studied in the Cartesian space and Joint space by applying forward and inverse kinematics to the Kinematic Digital Human (KDH) model. Neither still photographs, nor video footage, can directly provide such rich information. To classify the gait motion, the method used was the Rancho Los Amigos National Rehabilitation Center (RLANRC) which is widely used in the field of clinical kinematics for physiotherapy. The RLANRC phases can be compared to the normal gait and both the patient and the physiotherapist can share and discuss information, such as joint displacements or target sites for treatment making use of the 3D visualization the KDH model provides. Although the method was only executed with one patient and not with students, the author concluded based on the result, that the model can be used as a tool for physiotherapy education programs.

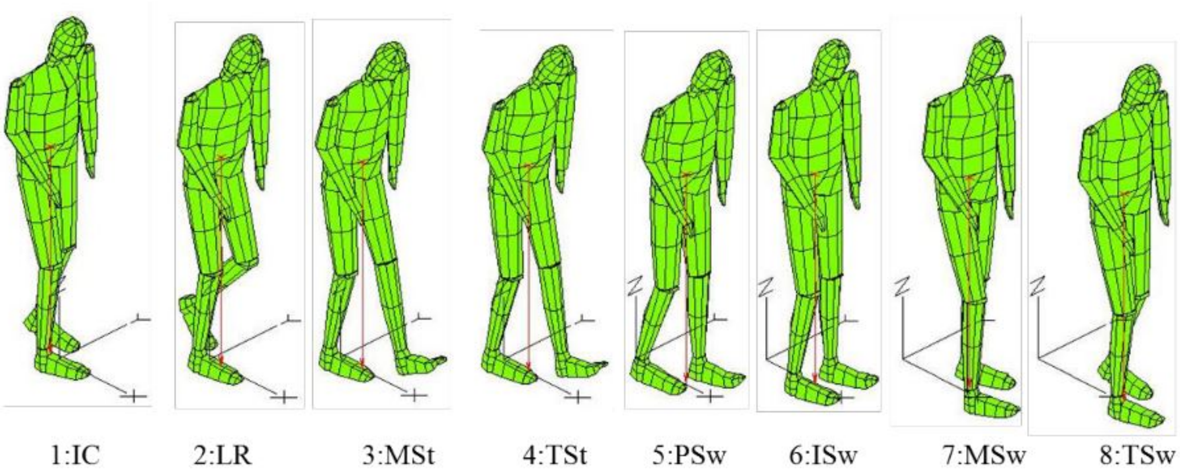


Figure 2.1: KDH model - Visualizations of gait motion KDH model in 3D space.[3]

Kakizaki et al. [3] show how the Kinetic Digital Human model enhances the visualization of gait motion in 3D, as it makes possible to visualize a 3D gait motion in a model instead of the commonly used 2D video. Kakizaki et al. concluded that despite visualizing 3D motion on a flat medium (visualization done through a 2D display) the 3D space has benefits on the learning of movements and in the understanding of what movements are being wrongly executed.

Alves et al. [4] proposed an interactive system called Winning Compensations. The system is an example for how visual feedback interfaces in 2D can increase patient's engagement and enhancements to the upper-limb physical rehabilitation process. It consists of a Kinect One, a computer to run the application and a screen to display information to both physiotherapist and patient. The information given to the patient is the real time feedback to better perform the exercises. For the physiotherapist, the information given is quantitative data, such as the number of compensatory movements executed by the patient. A set of three different exercises were implemented: Target Reach, Line Draw, and Shape Draw. For the evaluation of the system, participants performed the three exercises in a random order. After each of the exercises, participants had to fill in a Usability Scale regarding that exercise. To gather additional insights, semi-structured interviews with each participant were conducted.

Results of the System Usability Scale showed that the interactive system achieved scores of perceived usability between 74 and 78.17. In regards to the feedback of the interface, the posture of the patient was pointed out by the physiotherapists as a very strong feature of the system. The authors concluded that the system can bring positive aspects to the physical therapy paradigm.

Another study revealed that the use of a 2D display MotionMA [5] is difficult, even for experienced weight lifters to accurately estimate angles of the arm and elbows in a Biceps Curl exercise. MotionMA is the prototype system presented by the authors to address this issue. It is a system that automatically extracts a model of movements demonstrated by one user making use of the “Demonstration interface”. As a way to improve the model accuracy, the “Tweak interface” can be used. Once the model is ready the user selects a bone to visualize. Once selected, plots of each axis of the bone are displayed. It is also in this phase that the user selects which bones shall appear in the “feedback interface” customizing the system to specific goals. The “Feedback interface” uses the extracted model and compares with the model extracted in real-time, once the user issues a voice command to start the analysis. The system then provides feedback by colouring the Kinect model that is being displaced and by making use of traffic lights as shown in Figure 2.2.

Figure 2.2: MotionMA - Performance interface. Information regarding static bones is displayed on traffic lights whilst the ranges of motion of dynamic bones are displayed on dials. The user can see the video recording of the demonstration and his own skeleton as tracked by the Kinect with each bone in a diffetent colour depending on its score. The interface also displays the repetition count and warnings when the speed is too fast or too slow [5]

The system evaluation conducted, resulted in high scores for the modelling and analysis of the system. The results did not prove that the model is entirely accurate but indicate that the system is able to extract a model of controlled and repeatable movements accurately and that the extracted model makes sense in range and general rotation. A limitation of the system is the fact that the algorithm used to extract the model was only evaluated with a single user, given that the system was designed for remote collaboration between several users. The following article was published in 2015. Physio@Home [6] the same as the previous utilizes a 2d display. The target demographic are patients that do physiotherapy exercises at home or without a physiotherapist around. The aim is to explore different kinds of visual guidance in order to give the patient the best feedback on the exercises being done. The goal would be preventing re-injuries from badly executed physiotherapeutic exercises. The system used Vicon cameras for body tracking, instead of other technologies, for example, a Kinect due to the device’s inaccurate tracking and skeleton placement. A dynamic on-screen movement guide called the Wedge constitutes the system. The evaluation was based on the accuracy of the exercises executed by the participants. As a guide for the participants, either a video recording of the exercise or the Wedge was used. For the visualization on the Wedge, four different approaches were tested single view with video playback (VideoSingle), single view with Wedge visualization (WedgeSingle), multiple views with video playback (Video-Multi) and multiple views with Wedge (WedgeMulti). Being that the most accurate was when the Wedge makes use of multi-camera views (WedgeMulti). The authors concluded that the reason for the better results with the WedgeMulti was its top-down view, which aided participants in the abduction/adduction movement, the Top-down Angle and Nearest Arm guides that allowed participants to better keep their arm aligned. Results showed that participants performed the exercises with the least error using the system instead of the video recording.

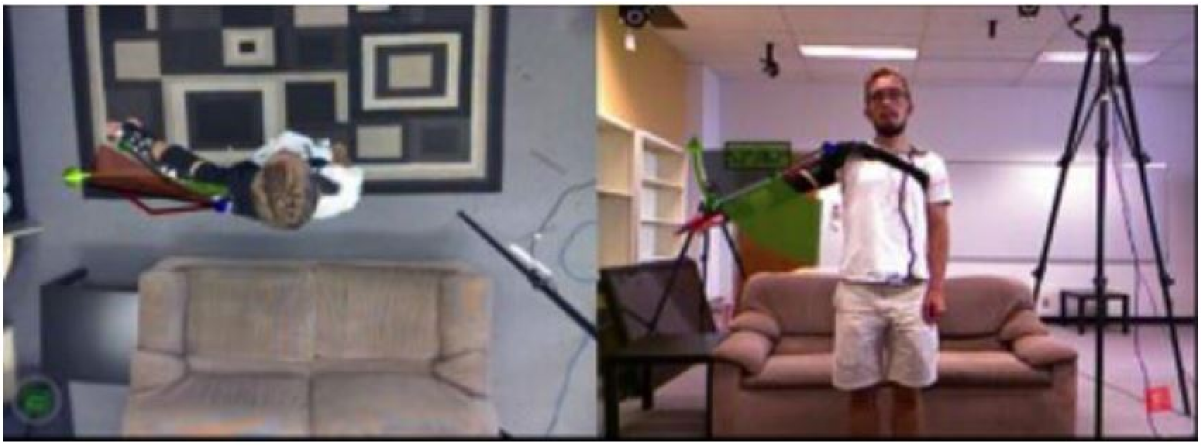


Figure 2.3: Physio@Home - Top (right) and front (left) camera views, as displayed on TV screen in front of user. [6]

Much like the previous system, another one that provides feedback for the exercises being done is YouMove [7], which focuses, not only on providing feedback, but also on teaching series of movements. YouMove is a full-body movement training system and the most important contribution was an augmented reality mirror implementation which allows to easily record full-body movements that can be used as a training system. Training is possible by recording movements to instruct a trainee including several stages with different and growing difficulties. The authors emphasise that the mirror and the tracking are essential to the training system that uses the recorded video and 3D movement data to teach trainees through 5 stages of difficulty. Feedback is given by a scoring system at the end of each stage. The authoring system allows users to record their own full-body movements and create exercises from those videos making use of key-frames as points to check the correctness of the trainee's body position. The authors state that yoga, physiotherapy, and many types of dance are examples of what the system can be used for. Although it was not tested for physiotherapy, the ballet dance moves and abstract moves were tested. Results showed that learning with the mirror incremented scores, resulted in an increase of more then a factor of 2 in comparison to learning by a video demonstration. (confusing sentence) The authoring system proved easy to use as well as not time consuming, giving experts a tool to create 10-minute exercises for trainees in a matter of 1 or 2 minutes.

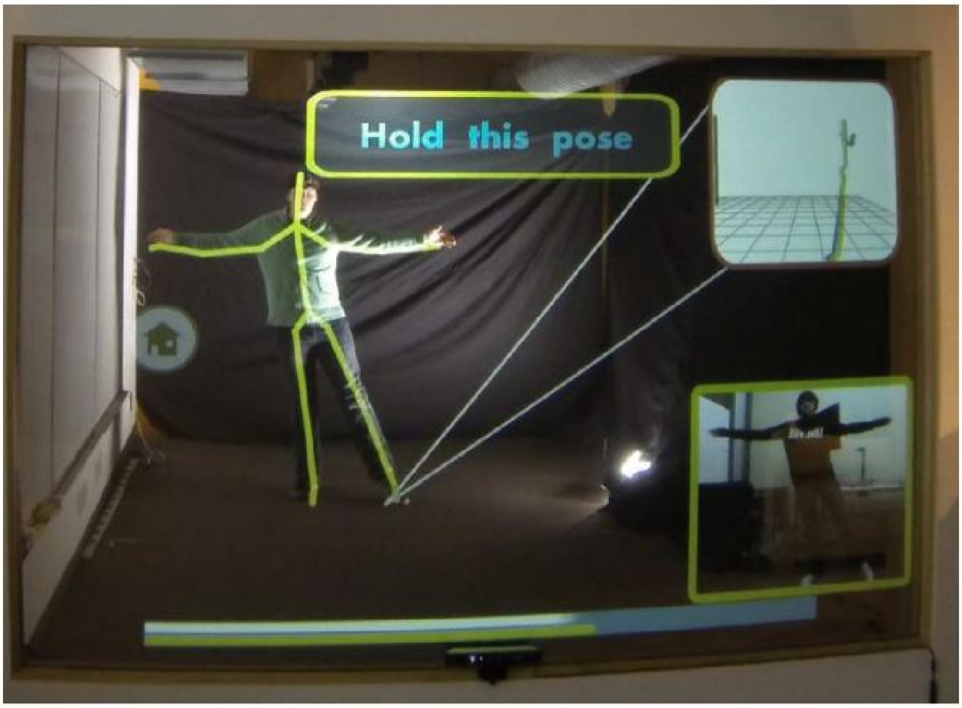
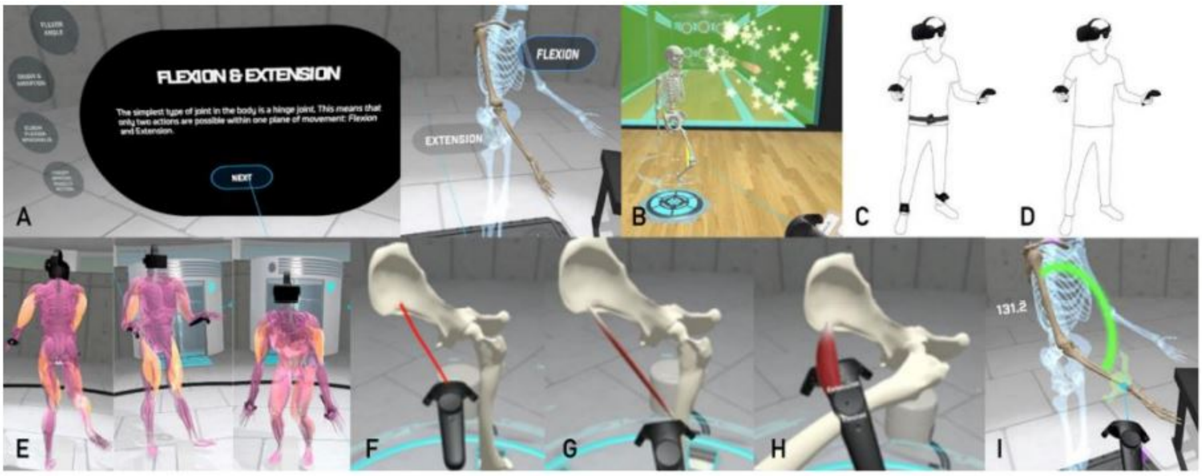


Figure 2.4: YouMove - YouMove allows users to record and learn physical movement sequences. An augmented reality mirror provides graphic overlays for guidance and feedback. Note that for this photo the virtual viewpoint was vertically repositioned to account for the offset of a head-mounted camera, and floor lighting was used to reduce glare. [7]

Some limitations of the system, stated by the authors, come from the use of just one Kinect, movements that cause a large amount of occlusion are difficult to track. This could be solved by using multiple Kinects. The importance of visualizing 3D motion is shown in the examples above, where even though said visualization was done through a 2D display it proved capable of aiding in physiotherapy teaching or enhancing the correct performance of physical rehabilitation movements. The study that follows is an example of immersive 3D motion used in VR to aid in the students understanding of dynamic muscle movements. Muscle Action VR [8] is an embodied learning VR system that allows users to learn basics biomechanics of human anatomy by moving their own body with VIVE trackers. In the “Muscle Tracking Lab”, the user can see what muscle is flexing or extending presented via a virtual mirror. The virtual mirror can show different perspectives if a different camera is selected in the lab. Users can learn about the muscles while using them. Another option to learn the biomechanics of the system delivered is the “Sand Box Lab”. The Sandbox gives the user the tools to generate muscles on different body parts, activating those muscles and creating specific actions by making use of the VIVE controllers. A 3D line drawn by the user is used as input on the creation of a muscle and each muscle can be individually contracted or relaxed. A “Guided Lesson Lab” and a “Game Lab” are also provided. The first is a guided lesson about directional terms and basic biomechanics of muscles. “Game Lab” is a dodge ball game that testes the knowledge of the muscles and movements covered in the application where the user points at muscles on the skeleton to contract or relax in order to move to avoid the ball. The authors believe the application contributes to teaching three-dimensional spatial awareness and foundational biomechanics in anatomy education.



The simplest type of joint in the body is a hinge joint. This means that only two actions are possible within one plane of movement: Flexion and Extension.

Figure 2.5: Muscle Action VR - (A) Guided Lesson Lab, (B) Game Lab, (C) VIVE Game Lab Setup for Muscle Tracking Lab, (D) VIVE Setup for other Labs, (E) Various Mirrored Views in Muscle Tracking Lab, (F, G, H) Muscle drawing and activating in Sandbox Lab, (I) Flex angle lesson. [8]

Coffey et al. conducted a study [9] that aimed to harness the power of VR as a data analysis tool to answer questions such as how to best visually depict and interact with motion data and explore situations where the data requires an analysis of both spatial and temporal relationships. This focus led to an introduction of a taxonomy of fundamental design variables for depicting these data. A user research was conducted to evaluate users in two measures, mean time taken to complete a task and accuracy. The task used for the analysis included two parts. The first detected collisions of two highlighted features with opposite discs while the second indicated which feature point was the first to collide by touching a button on the multi-touch table. Several combinations between interactive, animated or static space with interactive, animated or static time were tested. They noticed that the most accurate combinations come at the cost of more time taken. These results led to the creation of three design guidelines: users should have direct control of the time displayed in the visualization (when possible). Static time designs should be avoided and the combination of Animated Space with Interactive took less time than the combination with interaction in both dimensions, which might represent a go-to combination due to the faster analysis, although other time designs are likely to be just as accurate.

2.2 VR for Education

The papers that follow will approach the questions “Why should we use VR in education?” and “When to use VR?” just what V. S. Pantelidis [10] tries to answer. The paper discusses reasons why VR should be used and presents its advantages and disadvantages. One major advantage is motivation, since it grabs and holds students’ attention. VR can change the way of interacting with the subject matter by allowing the learner to learn by doing (constructive approach). The primarily disadvantage is the cost. The time needed to learn how to use the software and hardware is another disadvantage. The major contribution of the paper is a ten step model to determine when to use VR and when not to. It should be used when, a simulation could be used, using the real thing is dangerous, inconvenient, a model is as good as the real thing teaching, interacting with the model motivates more than otherwise, among others. On the other hand, VR should not be used when it is not possible to substitute the real thing, interaction with real humans is crucial and VR is too expensive to justify using considering the expected learning outcome. M. Hussein and C. Nätterdal conducted a comparison study [11] to determine what the benefits of VR in education are. The study aimed to answer two questions, firstly, what are the important characteristics of VR technology in education? Secondly, what are the benefits of using VR in mobile education? To answer this, the authors proposed a comparison between a VR educational application and that same application on a non-VR mobile device. The authors created both astronomy teaching applications having the same layout and information displayed, in order to make sure both applications would be fairly evaluated. They opted for a qualitative research approach to have a better understanding of the users. They found out that the immersive experience made the users more concentrated on the VR because of the sense of exploration and involvement. A benefit found is that VR paints a picture of the subject being taught. In this case specifically, the scale of the planets can be experienced by the users. VR proved very effective in subjects that require immersion and deeper learning in comparison to the mobile application. Merchant et al. [12] conducted an analysis to examine the effect and impact of selected instructional design principles in virtual reality technology-based instruction. The analyses were separated into three: games, simulation, and virtual worlds. Game-based learning environments were more effective than virtual worlds or simulations. The paper points out this fact as a key contribution to the field of using VR for instruction due to the fact of limited evidence of effectiveness. Another contribution was in the area of collaborative learning environments. It was found that students performed better when working individually. The authors noted that none of the previous reviews focused on the effects of the feedback. Most prior works did not point out which kind of feedback was used, making it difficult to compare. The authors appealed for the need of including information on the design of feedback in virtual reality-based instruction. Huang et al. proposed a questionnaire to evaluate learner acceptance of VR learning environments [13].A high performance real-time interactive software (VR4MAX) was used to build a prototype 3D VR learning system. 167 students participated in the questionnaire survey. Three important features of VR were pointed out, Immersion, Imagination, and Interaction. Experimental results showed that immersion and imagination both predict perceived usefulness. The interaction was not found as a predictor of perceived usefulness. Overall, the results supported the suggestion that 3D VR features encourage the development of learners' spatial awareness only when the learners perceive the learning experience as useful and the system as easy to use.

To answer the questions made at the beginning of this subsection, VR should be used when it is not possible or dangerous to use the real thing. In the case of physiotherapy students, it is unthinkable to bring a classroom to a patient's rehabilitation session, but the need for physiotherapy students to observe is still very much real. VR naturally brings immersion and can boost deeper learning, as was concluded by M. Hussein and C. Nätterdal [11]]. VR allows students to learn by doing, as pointed out by V. S. Pantelidis [9]. This is reflected in the need of physiotherapy students to observe the patients' gait motion. The research that follows is a showcase of particular VR systems that have been developed to better understand VR's potential for medical Education.

Marks et al. [14] studied the application of virtual reality in the area of anatomical education, specifically the nasal cavity and its airflow. The implementation of the application proposed followed three steps. The first step was creating the nasal cavity constructed from MRI scans. The second was the geometry used in the airflow simulation. Finally, the creation of the VR tool and incorporation of the 3D model and the flow simulation into it. Only preliminary studies were conducted due to the completion of the VR model in an advanced stage of the semester. The feedback acquired from the studies indicated that VR is useful and has advantages for the students in terms of engagement, understanding and retention. Falah et al. [15] described the development of a virtual reality 3D visualization system for anatomy education. The systems aimed to enhance medical education, and by using VR technology the system for teaching anatomy overcame limitations of traditional methods. This specific study focused on the human heart. For the enhancement of the visualization, additional techniques have been used, such as providing interactive navigation through the model, adding navigational tools (rotating, enlarging, minimising, resetting) and providing anatomical information for each structure. The system was evaluated by medical doctors that covered several medical aspects. The results were encouraging, leading only to minor improvements for the final version. Jang et al. [16] found that previous studies on learning with virtual 3D models were inconsistent on how direct manipulation in VR impacts learning anatomy, and how direct manipulation may be moderated by spatial ability. The study presented focused on investigating those aspects. A virtual inner ear model was created by a licensed otolaryngologist to be used in the VR machine for testing. Then medicine students either directly manipulated the virtual anatomical structure or passively viewed the interaction in a stereoscopic 3D environment. The testing was conducted in pairs so that the student who was directly manipulating the model had a matching student who was passively viewing the interaction. Results demonstrated that participants in control of the presentation had the best results. The results suggest that direct manipulation of the virtual environment facilitated embodiment of the anatomical structure and helped participants maintain a clear frame of reference while interacting, which particularly supported participants with low spatial ability. Given the short time frame of the study, students in the viewing condition could not have had enough time for viewing to be effective. Another question that remained unanswered by the authors is, if the participants passively viewing were seeing an optimal performance, would the results have been different?

Nazir et al. [17] conducted a study pursuing an alternative to the pedagogical model being used for learning canine anatomy. In that pursuit, an Anatomy Builder VR system is presented that was used to examine how VR systems can support embodied learning in anatomy education. The Anatomy Builder VR is a system that allows users to interact either with individual bones or groups of bones. The version used for a pilot test focused on the assembly of a canine pelvic limb. An "anti-gravity" field allows users to place a bone without the need to hold it, enabling the user to see the bones from all angles. The pilot study compared the Anatomy Builder VR to a traditional bone box method. The goal for both approaches was to identify bones and assemble them the way they would be in a living dog. College students without ever taken an anatomy class were recruited for the pilot. Results were positive on using the VR system. About 90% strongly agreed to enjoying using virtual reality, and 9.1% agreed as well. For the identification of bones, both approaches had very similar results. Generally, although participants spent less time assembling bones in VR, a large amount of time was spent adjusting the orientation of bones in the 3D space. One of the most well received features was the use of the “anti-gravity” field, which is not possible in the traditional method.

The studies above show the potential of VR for education, however, it is important to point out that those studies are for Anatomy teaching and not for Physiotherapy teaching.

Despite not being in the medical field the following study conducted in 2018 by D.Allocat et al.[18] to teach a 3D model of a plant cell, is fairly important to highlight given the VR evaluation done and its similarity to what is used in this dissertation. For this study, 99 participants were assigned to one of three different learning conditions: textbook, video and a VR application called “Lifeliqe Museum”. The learning materials used the same text and 3D model for all conditions. The participants were asked to perform a Knowledge test before and after learning. Participants in the traditional and VR conditions had improved overall performance. Participants in the VR condition also showed better performance for ‘remembering’ than those in the traditional and video conditions. The Web-based learning tools evaluation scale also found that participants in the VR condition reported higher engagement than those in the other conditions. Overall, VR displayed an improved learning experience when compared to traditional and video learning methods. The Web-Based Learning Tools evaluations scale (WBLT) used by D. Allocat et al. [18] is the result of a study R. Kay [19] made to re-examine the Learning Object Evaluation Scale for Students, originally developed by Kay and Knaack (2009). The evaluation scale was created to access three key constructs: learning, design, and engagement. Over 800 middle and secondary school students participated in high quality, pre-designed lessons intended to accentuate the use of WBLTs. Data collected from the new WBLT Evaluation Scale demonstrated good internal reliability, construct validity, convergent validity and predictive validity.

Freina and Ott [2] 2015 survey focused on scientific literature in the use of Virtual Reality in Education, advantages and potential uses. The survey showed that VR and immersive VR elements had been mostly used for adult training in special situations or for university students. Some of the advantages gathered from the survey is that immersive VR allows a direct feeling of objects and events that would be otherwise out of reach, is safe, and avoids potential dangers. The authors conclude that there has been very little research on younger children, possibly because their cognitive and physical development can be affected by the use of VR. Disabled people is another not so common subject of the analysed papers. Authors suggest that VR could especially help intellectually impaired people because learning in a virtual environment that reproduces the real one can minimize the problems related to learning transfer. The health domain is a very common subject for VR research. However, most of the research found in the domain is for anatomy education. In 2017 Kavanagh et al. [1] made a systematic review of VR in education. This review was divided into two distinct analysis to gain a better understanding of where issues lay and what educators expect to gain with the technology. The first analysis focused on investigating the applications and motivations behind the authors who have designed and implemented education VR systems. The second investigated the issues and limitations found by the authors of those systems. Figure 2.6 shows the subject areas of the selected papers. It is notable the significant percentage of Health-related papers, indicating that this trend increased from the survey made in 2015 by Freina and Ott [2].

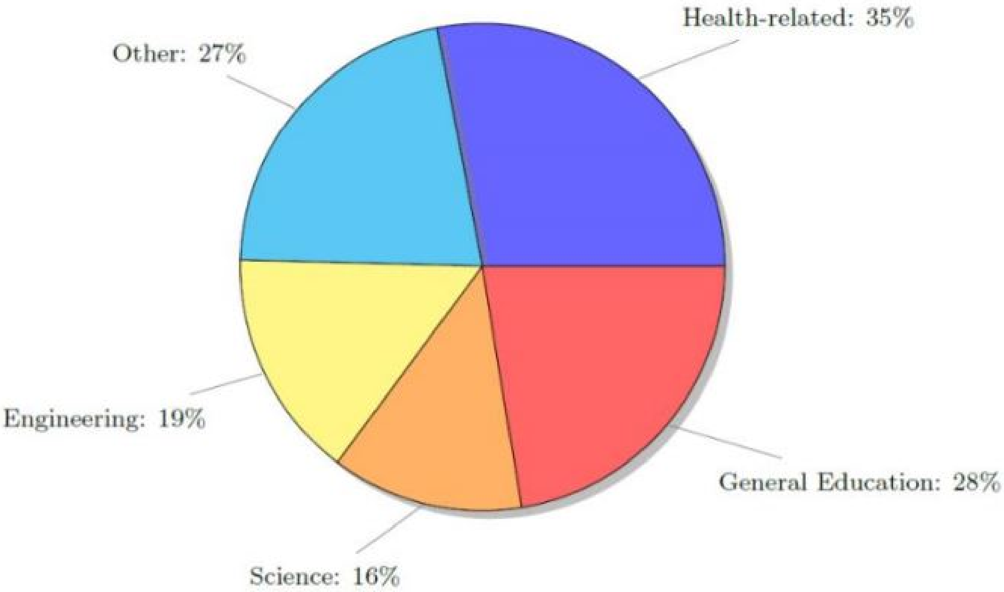


Figure 2.6: VR Application domains - Application domains of the 99 papers analyzed over the course of two thematic analyses. Note that a paper could potentially belong to multiple application domains. [1]

The first analysis showed that there were tendencies to use VR only in specialized situations like simulations and training purposes. Kavanagh et al. [1] found that most of the work analysed was weakly grounded in solid pedagogical reasoning. Most of the research was motivated by an intrinsic factor, such as immersion, which was the most commonly mentioned factor. The review found that papers mentioned several times that students were motived by the novelty of VR. The novelty was appointed as an important factor to improve student motivation. This is mentioned as something for future projects not to rely on, as novelty is a short term effect and will likely decrease with continuous use. Figure 2.7 shows how most papers did not base their research on pedagogical factors.

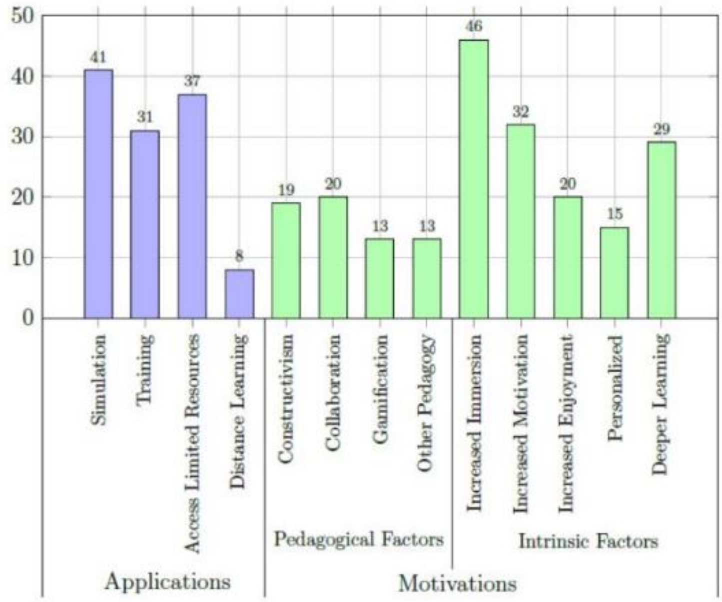


Figure 2.7: VR Issues and limitations - Reported applications and motivations (obtained via thematic analysis) of 90 papers applying VR to education. [1]

In the second analysis, the authors focused on the issues and limitations, showing that the occurrence of software usability issues was particularly prevalent. Software usability issues are issues in the interface design, the quality of interaction, and readability. Some issues regarding the lack of realistic environments were appointed by students, which were justified by authors as a consequence of lack of time and resources.

2.3 VR for Physiotherapy

This subsection aims to expose how VR has been used for physiotherapy. Some examples are shown bellow of VR systems that can be used for physiotherapy rehabilitation. Hülsmann et al. [20] propose a novel pipeline to detect and classify error patterns in motor performances and provide real time feedback. The pipeline and feedback were exemplified in a CAVE-based VR coaching environment. The feedback has verbal information that has been predefined, as well as automatically generated visual augmentations. After comparing the created pipeline with two popular approaches, the authors concluded the pipeline created was superior. The two compared approaches were k-Nearest Neighbor, combined with Dynamic Time Warping (KNN-DTW), as well as a recent combination of Convolutional Neural Networks with a Long Short-term Memory Network. The CAVE was in an L-shape and showed a virtual mirror where the user's motion is mapped to an avatar. An advantage of using such an avatar is, for example, the highlighted augmented feedback it facilitates, showcased in Figure 2.8.

Figure 2.8: CAVE-based VR coaching - The hollow back is highlighted on the avatar inside the virtual mirror. The perspective of the mirror image is rotated to enable the user to observe his errors without the need to change his body's orientation. [20]

The system was not tested for physiotherapy specifically since it was tested inside a CAVE- based sports training environment. However, the authors state that the squat and the Tai Chi push are full-body motor actions that are used in the context of rehabilitation.

A large number of studies have been carried out regarding how VR could improve the physiotherapy practice both for physiotherapists and patients. An example of such a study was conducted by Luque-Moreno et al.[21], where the aim was to evaluate VR as a tool to enrich physiotherapy treatments in patients who suffered a stroke. It focused on lower limb rehabilitation and on factors like walking speed, kinematics, and functionality. Two patients were used in an intervention that took 15 sessions, one hour of VR treatment and one hour of a conventional physiotherapy program. The results suggest that VR can contribute to the treatment, improving kinematics and functionality of the lower limbs and consequently lead to an increase of the gait speed. The first participant had an improvement of 0.16m/s and the second 0.34m/s, which makes both results clinically significant. The authors concluded that the combination of conventional physiotherapy with VR can be effective in improving the functional stability and performance of the lower limbs while walking. Fung et al. [22] developed a virtual reality locomotor training system for gait motion rehabilitation on post-stroke patients. Virtual environments are synchronized with the speed of a treadmill. The environment itself is projected onto a screen in front of the patient, and the treadmill speed is affected by the patient's voluntary acceleration and deceleration. This is achieved by the feedback provided by a potentiometer tethered to the patient. Three different scenarios were used for testing: corridor walking, street crossing and park stroll, and 3 levels of difficulty. In the first, patients are asked to walk within a time period with no changes in the slope and no obstacles. In the second level, the patient should maintain the gait speed while slope changes occur both in the up-down and the left-right planes. Lastly, in the third level brings the obstacles are added to the environment, patients should anticipate locomotor adjustments to avoid them. Lastly, in the third level, obstacles are added to the environment and patients should anticipate locomotor adjustments to avoid them. The results showed that, with practice, patients can increase gait speed and adapt their gait to changes in the physical terrain, which represent levels 1 and 2. However, the results were not capable of predicting if the system is able to answer the level 3 demands of patients being able to anticipate and avoid collisions with obstacles. Another similar study was done by Mirelman et al. [23] but focused on Parkinson's disease and its effects on the gait motion and not on post-stroke gait motion. The aim of the study is to enhance complex walking and reduce the risk of falling. To achieve this, the approach proposed by the authors is gait training, making use of Virtual Reality and a treadmill. The VR was projection-based. The speed, orientation, size, and shape of the obstacles were changed according to each patient's needs. For example, if in a first trial the patient is able to clear all obstacles, the difficulty is increased. When an obstacle is hit, visual and auditory feedback is given along with the score.

Figure 2.9: VR for Parkinson rehabilitation - A participant walking on the treadmill with a safety harness (without body weight support) while viewing the virtual environment. Sample feedback can be seen (eg, red bars: negative feedback and lights in the picture: positive feedback). [23]

The method used for testing consisted of 18 sessions on a treadmill training with four different test conditions: usual gait, dual-task gait, where patients are required to walk while performing another task, gait during endurance testing and obstacle negotiating. Results showed that the gait speed significantly improved and the author concluded that the treadmill with VR is a viable approach to be used in patients with Parkinson's disease. Several limitations were pointed out, for example, the size of the sample and the gains may have been due to a placebo effect or the attention the patients received. As a result, the authors considered the study as a pilot study. Corbetta et al. [24] conducted a systematic review of over 15 trials and 341 participants, where the effects of virtual reality-based physiotherapy rehabilitation on post-stroke patients were studied. It focused on answering two questions. First, if the use of VR based rehabilitation improves walking speed, balance and mobility more than the standard rehabilitation. Secondly, it aims to answer if adding virtual reality-based physiotherapy rehabilitation to the standard rehabilitation improves the effects on gait, balance and mobility. The authors concluded that using virtual reality, based physiotherapy rehabilitation, to some extent or fully, shows greater benefits in walking speed, balance and mobility. Adding VR time to the rehabilitation also brings some benefits, but further research is needed to determine if these benefits are clinically worthwhile.

None of the VR research shown in this subsection has an application of VR interactivity for physiotherapy education, only for rehabilitation. The studies that follow show how some other technologies aimed to improve physiotherapy education.

The Augmented Studio is a good example of how such technologies improved the education of physiotherapy. Reinoso et al. Reinoso et al. [25] aimed to answer the question “How can Augmented Reality enhance physiotherapy teaching and learning?”. Students struggle translating knowledge from books to a dynamic understanding of body movement mechanics. Augmented Studio was the proposed solution, as it used body tracking to project anatomical structures over a moving body. The proposed solution also supports annotations drawings by a mouse input that can be used by the teacher to point out important joints and muscle connections. The pilot test conducted was successful. It consisted of 9 students, 2 teachers and 1 observing teacher. The task was to attend a 15 minutes class and then answer a questioner to evaluate the system for the purpose of education. Authors concluded that the system enhances student’s learning experience and communication between teacher and students. One suggestion of a participant was to have several layers of muscles and a second suggestion was to highlight certain muscles by rendering them in different colours.

Figure 2.10: Augmented Studio - projected skeleton model on a student volunteer. [25]

The use of online technologies in health education, physiotherapy included, has been well-accepted as they are effective tools for enhancing student learning. The study conducted by Macznik et al. [26] aims to review such technologies used for physiotherapy teaching and learning, and how they are effective and perceived by the user. From 4,133 articles, 22 of them met the criteria to be accepted for analysis. The most commonly investigated technologies were websites and discussion boards. Websites included web-based tutorials or online repositories with videos. Results showed that websites improved practical skill performance. On the other hand, discussion boards were found to improve knowledge acquisition, critical and reflective thinking in addition to increasing students’ awareness of core professional values. There was a small amount of evidence of barriers in the use of online technologies. However, some issues found included difficulties with an internet connection, insufficient interactive material, or simply preference for paper-based materials. Another study that shows the potential of using tools for the enhancement of teaching techniques is SpinalLog [27]. Traditional classroom approaches to teach techniques for spinal mobilization makes students practice on each other what has been demonstrated previously by an instructor. This paper introduced SpinalLog, a novel tool for teaching spinal mobilisation. The tool itself is a spinal manipulation simulator that senses forces on the vertebras and provides visual feedback on a GUI and passive haptic feedback through foam demonstration. Simultaneous vs delayed feedback, high vs low shape and deformable vs rigid sensors were design aspects that were evaluated in a controlled user study. The authors found that simultaneous feedback is beneficial for the performance of the task, with minimal lag. The sensor deformation facilitated the exertion of force at the correct baseline level, but the amplitude of the pulses was weakly affected. Although the shape of the device had little effect on the task itself, it was the most important feature in regards to the participant's perception. Overall the results highlighted the potential of the use of SpinalLog as a teaching aid practice tool.

2.4 Discussion

This last subsection of the related work will discuss the contributions and how they show the importance of 3D visualization, the relevance of immersive visualization and how VR has been used for education and physiotherapy. A paper that should be highlighted is Kakizaki et al. [3] due to the fact that their study has similar goals as this dissertation. Despite the fact that user tests with students were not done, the study's goal is to improve physiotherapy education of the gait motion. The authors also propose the use of the system for rehabilitation due to its accessibility, where only a camera and a laptop is necessary. In fact, how the authors validated the system was through its rehabilitation use. Both the patient and the therapist can visualize on a computer screen a 3D model of the gait motion created. This facilitates the visualization of the model and incites discussion on whether or not the movement is being executed correctly. This example shows the power of visualizing the movement in a 3D space despite the 2D user interface. 2D interfaces like the one used in the Kakizaki et al. system [3] are used in several of the systems from the researched contributions like, Winning compensations[4], Physio@Home[6] and YouMove[7]. Although they lack the purpose of education, they reinforce the importance of 3D motion visualization.

Several of the research focus aims to surpass limitations from 2D videos by providing a 3D space visualization Kakizaki et al. [3] An important example in this regard is the direct evaluation by comparison between a VR application called "Lifeliqe Museum", 2D videos and textbook by D.Allcoat et al. [18] where the video had the poorest results.

Visualizing in a 3D space though a 2D display is what this dissertation's WIMP tool aims to do. An example of what can be done for 3D motion visualization is MotionMA [5], since it enables the visualization in real time of the user's movement. The 3D motion data is analysed and the system gives feedback about the limbs that are poorly executing the movement. YouMove [7], (which is a similar example), also has indicators of the importance of the 3D motion visualization, once taken into account the better results from the rehabilitation exercises. Physio@Home [6] had a dynamic on-screen movement guide called the Wedge, tested with different types of visualization. The one that showed better results was the WedgeMulti, not only between the visualizations, but also compared to a 2D video. WedgeMulti's different cameras gave the user a better understanding of the movement. With the different angles, the user was able to more easily create a 3D motion representation in his mind of the movement being executed.

If multiple views and visualising motion in a 3D space gives a better understanding of the 3D motion, VR immersion gives the potential for visualizing such movements in a 3D immersive space. How can VR immersion be used for visualizing motion data? Muscle Action VR [8] is a good example of what can be done in VR for education with motion visualization. The VIVE trackers enable the user to learn muscle movement by moving with them. Bruner et al. [8] believe the application's immersive environment contributes to teaching three-dimensional spatial awareness and fundamentals bio-mechanics in anatomy education.

Another similar approach was Hülsmann et al.'s [20] contribution. Although it was not used for educational purposes) the CAVE-based VR brought an immersive visualization that is used to train users on sports movements. Visualizing 3D Motion has shown to increase the perception of the movements, facilitate discussions and improve movement understanding. It is not a novelty that VR has been used for educational purposes. There are several areas that benefit from the use of VR for teaching. Health is a domain that the amount of VR research is vastly increasing as the systematic review from Kavanagh et al. [1] shows. Some examples of successful uses of VR in this domain are Marks et al, [14] a contribution that proposed a system to teach the Nasal cavity and its airflow. Falah et al. [15] proposed a 3D visualization system for students to learn the human heart, Jang et al. [16] to learn the inner ear anatomy and Nazir [17] to teach canine anatomy. It is important to notice that all these systems teach anatomy and that although the Health domain is one of the most researched for VR applications, few have been for physiotherapy education. Figure 4.23 shows that general Medicine education (anatomy included) is the most common VR researched area in the health domain followed by Surgical Education, Physical Education, Nursing education and finally Rehabilitation with only two systems that did not focus on teaching but on rehabilitation instead.

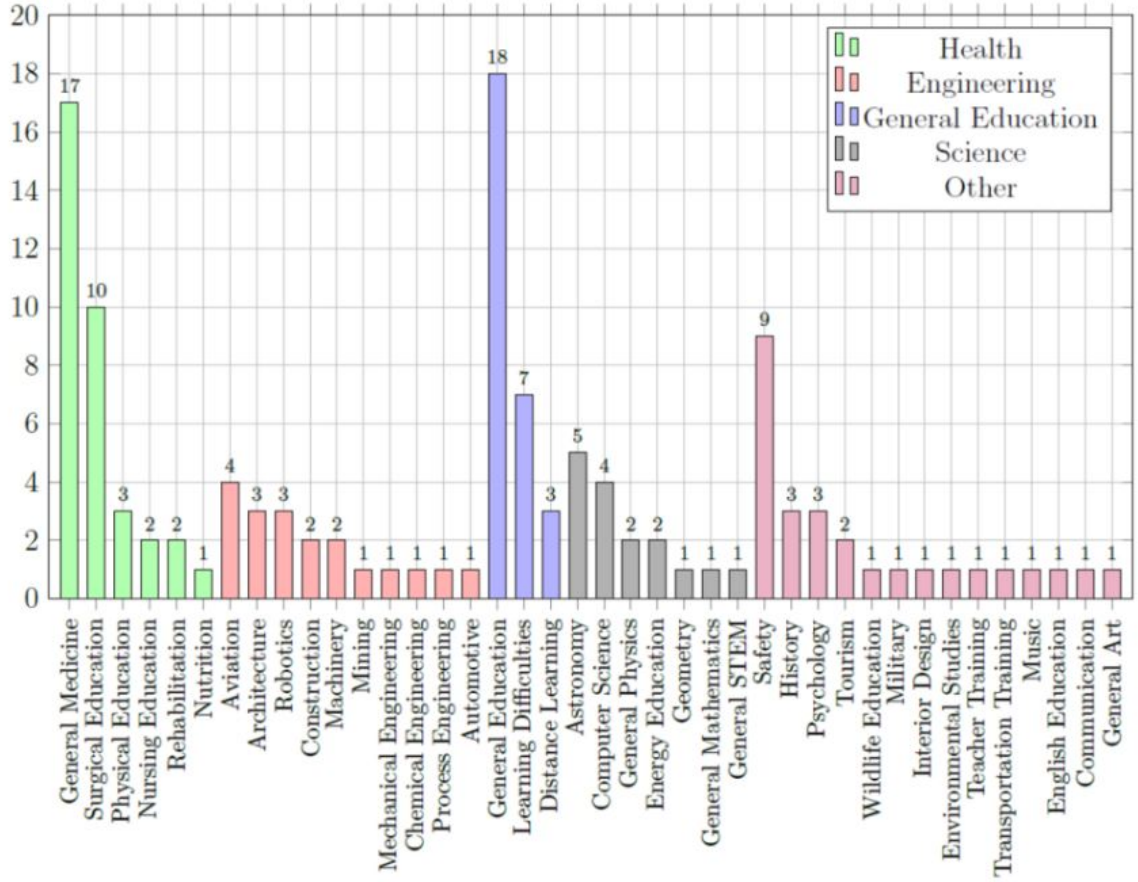
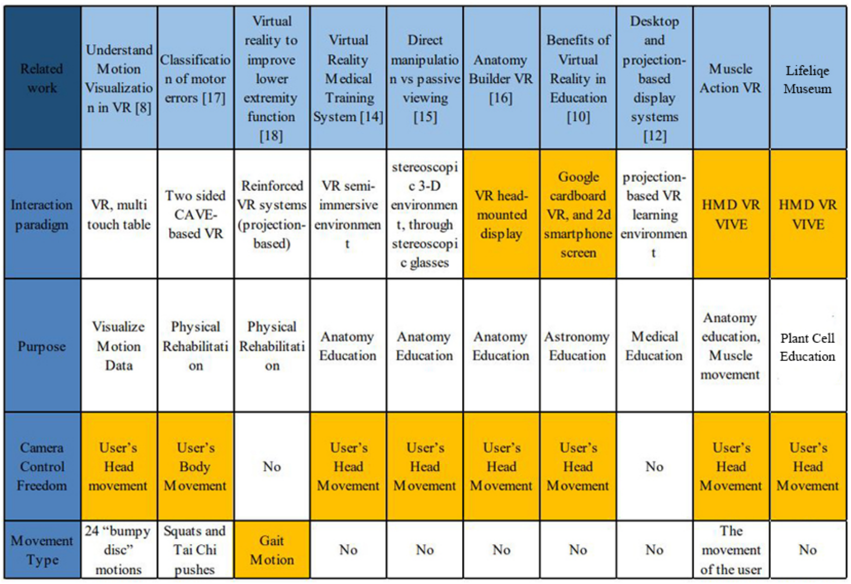


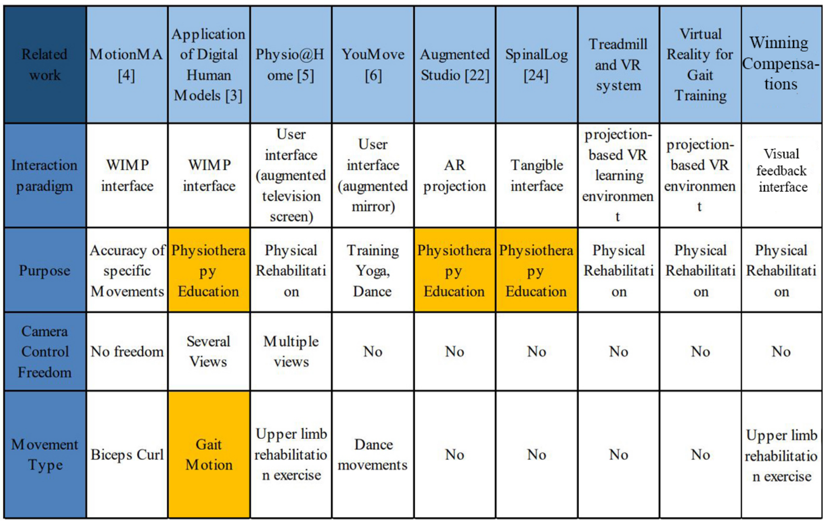
Figure 2.11: Systematic Review - Application Domain Breakdown. The individual application domains of 99 papers implementing virtual reality in education.[1]

No research on VR for physiotherapy education was found. But some VR systems are being used to enhance physiotherapy itself like the F.Hülsmann et al. [20] contribution already mention contribution already mentioned for immersive visualization. Luque-moreno el al. [21] and Fung et al. [22] contributions focused on the gait motion rehabilitation of post stroke patients and Mirelman et al. [23] contribution on the gait motion of patients with Parkinson's disease. As Corbetta et al. [24] concluded in their systematic review, adding VR physiotherapy to standard rehabilitation brings benefits in walking speed balance and mobility. VR proved to be a useful tool to be used in physiotherapy rehabilitation from the examples mentioned. Physiotherapy education had some studies done with other technologies like Reinoso et al. [25] that used Augmented Reality to enhance physiotherapy teaching, SpinalLog[27] that teaches spinal mobilization and the commonly used websites with web-based tutorial and online repositories with videos. From students' performance to improving knowledge acquisition and reflective thinking, all these technologies proved able to enhance in some way Physiotherapy education. If Anatomy Education had several beneficial VR contributions, and other technologies have been able to enhance Physiotherapy Education, why should Physiotherapy Education not be able to use the same benefits VR brings to teaching? The importance of 3D motion visualization was explored and the power of VR as a 3D motion visualization tool justify this proposal. Tables 2.1and 2.2 that follow, summarise the contributions analysed by features and highlights in orange what contributions have similar goals to that of this dissertation. The absence of a system that has VR and the purpose of physiotherapy education is noticeable.



Related work	Understand Motion Visualization in VR [8]	Classification of motor errors [17]	Virtual reality to improve lower extremity function [18]	Virtual Reality Medical Training System [14]	Direct manipulation vs passive viewing [15]	Anatomy Builder VR [16]	Benefits of Virtual Reality in Education [10]	Desktop and projection-based display systems [12]	Muscle Action VR	Lifeliqe Museum
Interaction paradigm	VR, multi touch table	Two sided CAVE-based VR	Reinforced VR systems (projection-based)	VR semi-immersive environment	stereoscopic 3-D environment, through stereoscopic glasses	VR head-mounted display	Google cardboard VR, and 2d smartphone screen	projection-based VR learning environment	HMD VR VIVE	HMD VR VIVE
Purpose	Visualize Motion Data	Physical Rehabilitation	Physical Rehabilitation	Anatomy Education	Anatomy Education	Anatomy Education	Astronomy Education	Medical Education	Anatomy education, Muscle movement	Plant Cell Education
Camera Control Freedom	User's Head movement	User's Body Movement	No	User's Head Movement	User's Head Movement	User's Head Movement	User's Head Movement	No	User's Head Movement	User's Head Movement
Movement Type	24 "bumpy disc" motions	Squats and Tai Chi pushes	Gait Motion	No	No	No	No	No	The movement of the user	No

Table 2.1: Systems developed for the contributions that researched 3D Visualization and their features.



Related work	MotionMA [4]	Application of Digital Human Models [3]	Physio@Home [5]	YouMove [6]	Augmented Studio [22]	SpinalLog [24]	Treadmill and VR system	Virtual Reality for Gait Training	Winning Compensations
Interaction paradigm	WIMP interface	WIMP interface	User interface (augmented television screen)	User interface (augmented mirror)	AR projection	Tangible interface	projection-based VR learning environment	projection-based VR environment	Visual feedback interface
Purpose	Accuracy of specific Movements	Physiotherapy Education	Physical Rehabilitation	Training Yoga, Dance	Physiotherapy Education	Physiotherapy Education	Physical Rehabilitation	Physical Rehabilitation	Physical Rehabilitation
Camera Control Freedom	No freedom	Several Views	Multiple views	No	No	No	No	No	No
Movement Type	Biceps Curl	Gait Motion	Upper limb rehabilitation exercise	Dance movements	No	No	No	No	Upper limb rehabilitation exercise

Table 2.2: Systems developed for the contributions that researched 2D visualizations and their features.

Chapter 3

Understanding Gait Motion Analysis

This chapter discusses the two major user studies done prior to the development of a prototype. Both studies aimed to answer three research questions: The first question “How is gait motion analysis taught?”, the second question, “What is the role of 2D videos and their limitations in the context of teaching gait motion analysis”, and the third question, “Are practical exercises used to teach gait motion analysis? If so, which ones?”. The first user study was conducted through interviews with four university physiotherapy professors, P1, P2, P3 and P4. The second user study was conducted through interviews with five physiotherapy students S1, S2, S3, S4, and S5. Subsection 3.3 presents the results from the interviews after using affinity diagrams to group them into two major groups, results that help understand how gait motion is taught and results that show what limitations are present in gait motion education. The last section shows the guidelines created based on these interviews for the development of the prototype.

3.1 User study 1: Interviews with Professors

The interviews were conducted on four physiotherapy university professors. The preparation of the interview was done considering the three goal questions referenced at the beginning of the chapter, making use of seven open questions and several sub-questions to narrow down and guide the interview in order to answer the three goal questions. Each interview took about 15 minutes; one was made via skype and the others were in person. The sample consisted of two University Professors from the Cooperativa de Ensino Superior Egas Moniz, P1 and P2, and two University Professors from the Escola Superior de Saúde do Instituto Politécnico de Setúbal, P3 and P4.

The highlights, that came from the notes taken from each of the interviews are presented below. The answers from the interviewees were further analysed using affinity diagrams which are showcased further along in Section 3.3.

3.1.1 Interview guide

The reasoning behind this guide is the need to understand the perspective of professors regarding the difficulties in the teaching and learning of physiotherapy. The study goal was to get to know the global context on gait motion teaching, what tools are being used, as well as procedures and exercises currently in place.

To that end, all questions from the guide are open questions to allow interviewees to express and share information that might not have been thought of before. On the other hand, the sub-questions made sure that from every interview the goal questions were being answered. The semi-structured interview method allowed this agility on getting new information and generating conversation but also making sure the set goals were met. (Appendix A.1)

3.1.2 P1 - Egas Moniz Professor

P1 teaches the theory of what characterizes a normal gait motion, which is a course given at the beginning of the students' curriculum. The most important topics discussed in the interview would have to be the fact that students do indeed need to know how to analyse a gait motion and that no matter what the pathology, a gait motion analysis is always a direct comparison with a normal gait motion.

To showcase pathologies, P1 uses videos that come with several limitations. Firstly, the logistics of having to ask patients to be recorded. Secondly, the necessity P1 says to have to record from several angles, given the 2D limiting nature of the videos, ending up having to show three videos. Another topic mentioned was the two types of causes that affect the gait motion: The musculoskeletal (causes like accidents and injuries) and the neuromuscular (diseases like Parkinson). Students are evaluated on what characterizes a gait motion by a written exam.

3.1.3 P2 - Egas Moniz Professor

P2 is a neuromuscular physiotherapy professor and states that it is the course that most analyzes gait motion. During practical classes, students start by analyzing the already taught by P1 normal gait (in which a student performs the gait). They are taught references on how to observe and analyze the gait pattern (among students). Through the projection of videos of patients' gait motions, the students learn focal points for a gait, to analyse pathological gait motions, how to identify them and relate them to the patient's clinical condition.

Limitations of the videos appointed come mainly from the environment that distracts the students from the purpose of the video. The acquisition of the videos is not the most efficient or ethical given that patients need to be recorded in a rehabilitation setting.

Third-year students do internships in various institutions and in different areas (internships of three weeks) in which they need to make a complete report on one of the patients they observe. When carrying out the reports, one of the parameters required to evaluate is the gait motion. The gait motion analysis on the report has several parameters like walking cadence, step symmetry, weight transfer, among others.

3.1.4 P3 - Instituto Politécnico de Setúbal Professor

P3 explained that similar to the approach in the Egas Moniz, students acquire a theoretical knowledge that is afterwards used in the internship. The course where these bases are taught is called "Analysis and study of human movements" (given by P4).

The interview's most important highlight would be the use of the same basis for the gait analysis, by direct comparison with a normal gait motion, as in the Egaz Moniz physiotherapy curriculum. Limitations pointed out were the fact that students do not have any contact with patients before the internship. Other difficulties students face also come from the fact that there is no correct movement, every gait motion is different from the other so sometimes the analysis based on observation can get a little subjective.

3.1.5 P4 - Instituto Politécnico de Setúbal Professor

P4 explained that there are two types of analysis of the gait motion, qualitative and quantitative. The latter is based only on observation while the quantitative makes use of a laboratory to measure gait motion data and generate graphs with the motion curves. The use of this laboratory is restricted for master students, therefore it will not serve a purpose for this dissertation. On the other hand, the qualitative type and the way it is taught is important to highlight. The qualitative part is taught in theory and trained in the ability to analyze based on students' observations. Students are divided into groups to analyze each other's movements. Here students use videos to train at home, analysing how the movement works. These videos have a limitation mentioned by P4, given the fact of only showing a 2D view. Another limitation appointed is that students have difficulty in this initial part of learning because we all have different movements. It is difficult to perceive the normal movement as well as, based on these observations, perceive what differs from normal.

The laboratory is only used for students to evaluate students. Very rarely do patients go to the premises. Students are evaluated in 15 minutes where there is a randomly chosen movement "task" for each student in which the student has to, based on the observation, analyse what differs from a normal movement. It is done one student at a time.

3.1.6 Lessons Learnt (Professors)

All professors mentioned that the foundation for any gait motion analysis is to compare it to a normal gait motion, therefore the theory and knowledge of what characterizes a normal gait motion is essential for the analysis of pathological gaits. This answers the first question of the chapter "How are gait motion analysis and different pathologies taught?", since the way a parkinsonian gait or a hemiplegic gait is analysed is the same way, through comparison with a normal gait.

As for the second question, "What is the role of 2D videos and their limitations in the context of teaching gait motion analysis?", several limitations were appointed. Despite these limitations, three of the interviewees use videos in their lectures due to a lack of a better solution.

The last question, "Are practical exercises used to teach gait motion analysis, if so which ones?" also got answered. Videos are used for students to train and learn analysing movements on their own or in a lecture, like P2 stated, where it is asked that students identify focal points of the gait motion.

The lack of contact with patients prior to the internship is reduced by the use of videos, however said videos bring their own limitation for the education of physiotherapy.

3.2 User study 2: Interviews with Students

The interviews were conducted on five third year physiotherapy students. What characterizes these students is the fact that they have had internships, where they were requested to make an analysis of the gait motion based on the observation.

These interviews were all in-person, recorded and notes were taken. The highlights presented below showcase the most important information gathered from each of the interviews. The affinity diagrams, presented in Section 3.3, analysed all the answers from these interviews.

3.2.1 Interview guide

This guide had a similar structure to the professors' interview guide. All the questions are open questions and backed up with the sub-questions as well.

The main goal of this study is to understand, from the students' perspective, what limitations or difficulties they faced while learning gait motion analysis. The interview had a similar set-up to the interviews with professors, having six instead of seven open questions. (Appendix A.2)

3.2.2 S1 - Egas Moniz Student

A Highlight from the interview with S1 is for example a practical lecture where students analyzed, with a substitute professor, a carpet sprinkled with powder to allow footsteps to be analysed. Only some students had this opportunity since it was a substitute professor giving the lecture. S1 stated that some students were able to see videos in the theoretical lecture, although those videos were not handed to them for further analysis.

At the time of the interview, S1 had never had contact with a patient with a neurological disease. During the internship, S1 did have to make an analysis of patients' gait motions (not with neurological disease) and was evaluated in the report.

One major difficulty S1 faced in learning was having a good idea of the movement, in order to visualize and perceive it.

3.2.3 S2 - Egas Moniz Student

In the internship, S2 only had contact with stroke patients. In the Neurological theoretical lectures, the professor shows a video asking students to identify what is wrong. He also asks them to identify pathologies and explains what the students did not detect or notice.

One of the video limitations appointed by S2 is the lack of quality and the existence of only one view. S1 states that to analyse gait motion it is necessary to observe the motion from several angles.

3.2.4 S3 - Egas Moniz Student

S3 explained that the tools used for teaching were presentation slides and videos of a pathological gait motion where the professor explains the video gait. S3 had to make an analysis of the gait motions for the first time in the internship. S3 felt a limitation on eye observation because “you feel that slow-motion could help you better understand the movements”. The slides did not help to have a perception of the pathologies neither the videos used, as they were not recorded in a proper environment. In the videos there were people and obstacles that caused distractions, thus making it harder to observe.

3.2.5 S4 - Egas Moniz Student

S4 had in the neurological course example videos of patients and people mimicking pathological gait motions. Like the other students, the internship was the first time S4 had to make an analysis.

The difficulties and limitations described by S4 start with the imitation videos, as they may not represent reality very well, since we all have small changes in the gait motion.

S4 experienced difficulty in the internship because S4 had to ask the patient to walk several times to observe from the various necessary views (frontal plane, sagittal plane and transverse plane). Which was not ideal for the patient.

Another difficulty was the lack of coordination/perception of the three views at the same time, as a lot of information is given and can become difficult to analyse. The lack of contact with patients with pathologies prior to the internship was also mentioned as a difficulty.

3.2.6 S5 - Egas Moniz Student

S5, as with the rest of the students, learned from slides and videos of a pathological gaits.

Limitation of the videos is that “you feel that you easily forget”. S5 had trouble retaining information from videos but states they do help to understand the movement. In practice lectures, they only detect changes to the normal gait amongst each other and a pathological gait is rare in a student. It is complicated to teach because students have no patients to observe. On the other hand, as stated by S5: “If the analysis is among us, we only see the compensations that we all have and not pathologies”.

S5 pointed out that a limiting factor was only having contact with pathologies during the internship.

3.2.7 Lessons Learnt (Students)

The answers from the interviews with students confirmed the information gathered from the Professors interviews, specifically the way gait motion analysis is taught, the role of 2D videos and practical exercises present in physiotherapy education.

In general, all students interviewed had the same learning experience, where theory is given, making use of slides and videos, and then the requirement for them to know how to do the analysis in the internship. Some students had a more practical lecture where they analysed each other's gait motions. Although the lecture was described as a good exercise, it still lacked the pathological gait motions.

As for the use of videos, several limitations were appointed. For example, the fact that they are only allowed one view or that students are not permitted to analyse the videos at home. Videos may have helped to understand the movement, but did not help the students to really visualise or remember what characterizes each pathology.

Students arrive at the internship without knowing exactly what to look for by observation, ending up asking patients to walk several times.

3.3 User Studies Results

This section will discuss the nine interviews conducted and the affinity diagrams used to group the highlights from the interviews. The first affinity diagrams helped group, the information gathered about the theory, the practical and the subjects being taught on gait motion. The second affinity diagrams were used to better understand the limitations faced by students and professors.

3.3.1 Affinity diagrams - How is gait motion taught?

Theory

The theory is the same in both universities. First, references and characteristics of a normal gait motion are taught. After the fundamentals course in gait motion, both musculoskeletal and neuromuscular areas have specific courses where it is further taught how those causes affect gait motion. The use of slides and videos to learn was mentioned by all students. Professors explained through the videos the theory and characteristics of gait motions.

Practice

Some practical exercises are done to learn to analyse gait motion, either student to student or the use of videos where students are asked to analyse the gait. In the internship, students are evaluated on their ability to analyse gait motion. That analysis is part of the report students have to write at the end of the internship.

Subjects

Students should learn what characterizes a normal gait motion and how to analyse it based on the observation of any gait, when comparing it to the normal. They should know that there is no correct gait, and everyone is different and through those differences, students need to distinguish from what is considered normal to what is a compensation. Furthermore, students should know how gait motions are affected by the two types of gait motion pathologies, musculoskeletal and neuromuscular.

3.3.2 Affinity diagrams - Limitations

Education

The fact that there is no correct gait motion represents a difficulty for students in a sense that, especially in the first stages, it is hard to distinguish what characterises a normal movement from what is an individual character from the observed subject. There is no consistency nor ways to tackle individual appreciation from each student.

Logistics

Logistic problems appointed are all related to patients. The fact that there is no means of bringing patients to a classroom, and the constant need for patient approval to be recorded are problems. Students' inaccessibility to said videos since professors cannot share the patients' videos and the fact that the. internship ends up being the first time students have real contact with patients are also logistics problems that were appointed.

Videos

Video limitations started from its 2D nature, where several interviewees stated that they need to have at least three recordings for one gait motion, since having three views is fundamental to make an analysis of movement based on the frontal, transversal and sagittal planes. Other limitations appointed were the environment, where videos were recorded that sometimes could distract the students from the purpose of the video, in addition to the quality of the videos and difficulty to retain information.

Learning

All students stated that the lack of contact with patients, prior to the internship, revealed to be a difficulty when faced with the need to make an analysis. During the lectures, students stated that it was difficult to visualise the movement, as only the use of videos and slides were used.

3.4 Design Guidelines

Taking into account the limitations, difficulties, and what has to be taught, guidelines were created for the development of a prototype.

Use normal gait as baseline

First, and most important, is the fact that any gait motion analysis is done comparing it to the normal gait motion. This means that the approach for any pathology would be the same.

Neuromuscular causes will be the focus

The gaits affected by neuromuscular causes will be the focus of the prototype, given that the course of the neuromuscular diseases is the one that most uses the analysis of gait motion.

Freedom to see the motion from different angles

It is important to have some freedom to see the pathologies from different angles. The environment has to be minimalist to avoid distractions.

Simulate internship

Lastly, the prototype should simulate an internship analysis to prepare the student.

Chapter 4

Prototype

This chapter discusses the Gait Motion Analysis Tool prototype, starting with the approach chosen for the development, followed by the Architecture where, firstly, the modules are presented and explained how they are connected and secondly, the detailed explanation of each of the modules. The last subsection of this chapter explains how the prototype came to be, the iterations of the development and the formative studies done during the developing process.

Before going any further, it is important to briefly explain what the Gait Motion Analysis Tool is capable of and what is its intended use.

Based on observation, the objective, when using the tool, is to analyse gait motions. Both versions have the same features and two modes: practice and test. The difference between these modes is the help given on performing the gait motion analysis. In the practice mode, aids are available, aids such as a “ghost” of the normal gait motion, slow motion or additional views. The test mode tries to be the closest to that of an internship analysis experience, where there is only the patient performing the gait. The way the analysis is performed is the same for both modes; selection of limbs and articulations that behave differently than a normal gait motion, where the user should pick the correct reason for each selection made. The selection of the limbs feature was the result of a discussion in an interview with P2 using storyboards (Appendix B). The selection of reasons on the “Overall Selections” is also part of the analysis using the tool. “Overall Selections” are important factors of the gait motion analysis that are not linked to any specific limb or articulation, such as, walking cadence and step symmetry. The overall selections feature was created when taking into account physiotherapy students’ feedback received during development.

4.1 User-Centred Design

The approach chosen to develop the prototype is User-Centered, which means that the final users (physiotherapy professors and students) were the focus during the development. The user studies conducted with the interviews (presented in the previous chapter), resulted in important guidelines. Guidelines that were followed and created a basis for the design of the prototype.

Once the basic concepts were constructed, storyboards were drawn to use as facilitators for a discussion in an interview with P2 to validate the idea for the prototype. From there, the development started. The iterative process of creating a functional prototype, for both versions, worked in the following manner: each iteration was refined from the previous based on user feedback from demos.

Given the Covid-19 pandemic in 2020, the iterations came to a stop on the VR version, having full focus on the WIMP version development during the quarantine period. The same process of iteration was kept and demos were created. Based on feedback from user tests on the demos, version after version of the tool was developed.

Afterwards, the VR version was developed as an adaptation of the WIMP tool. Considering that it was not possible to easily have demos tested, videos were recorded instead. Those recordings of the VR tool were sent to several "testers" to have some feedback, hence the iteration process for VR continued in this manner.

The sections that follow describe the functional version of the prototype. The last section, 4.12 describes the iterations and how the prototype came to be.

4.2 Architecture

The architecture of the prototype is represented in Figure 4.1. This subsection explains how each of the modules are connected to each other.

The first part of the work is the motion data capture (mocap) and processing. For the motion capture, Vicon cameras were used at the Biomedical Laboratory from the Department of Biomedical Sciences and Medicine at Algarve University. Unity 3D was used for the development of the Gait Motion Analysis tool for physiotherapy students making use of the "SteamVR SDK" to develop the HTC related modules. The "Unity database" is where the animations, scripts, avatar textures and all important assets are stored. The "Unity Scene Managing Module" is the module that agglomerates all update() functions for the tool to work. This module is also responsible for the scene being rendered, the menus and how they should work between themselves, and all of the logic behind the humanoid avatar; for example how the tool stores a selection the user has made. The output is sent to the respective display, either a computer screen on the WIMP version or the HTC VIVE headset for the VR version. The "WIMP Interface Input Processing Module" only exists in the WIMP version of the tool. It is responsible for processing all the input received from the user. The "Mouse Input Module" is responsible for the controls and inputs for the user in the WIMP version. The "HTC Input Processing Module" is where the inputs for the VR version are processed making use of SteamVR scripts and bindings for the controllers specifically made for the prototype. Lastly, the "HTC VIVE input Module" is responsible for all the SteamVR scripts necessary for the Headset inputs and the "HTC VIVE Controller Module" is responsible for the inputs gathered from the VIVE controllers in the VR version.

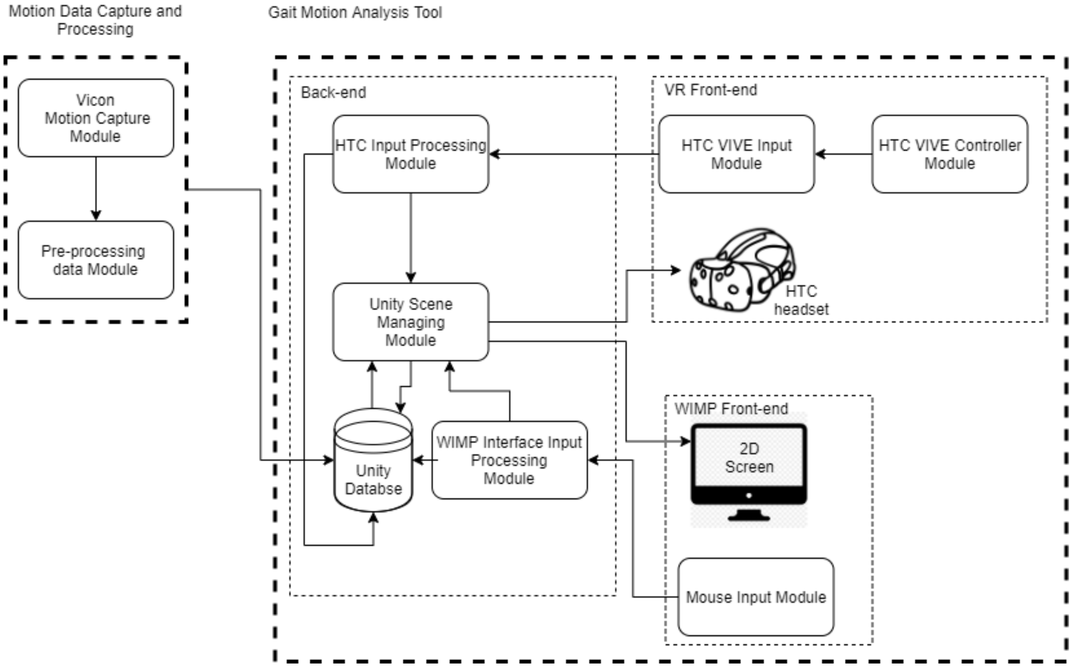


Figure 4.1: Architecture of the Gait Motion Analysis Tool Prototype.

4.3 Motion Capture

The motion capture (mocap) was done at the Biomedical Laboratory from the Department of Biomedical Sciences and Medicine at Algarve University using Nexus Vicon Cameras. A physiotherapy student S5, mimicked three pathologies, the normal gait and a T-pose.

Figure 4.2: T-pose motion capture

The pathological gait motions acquired were a hemiplegic gait, a parkinsonic gait and a scissor gait.

The laboratory used markers (reflective sensors) and the Vicon Motion Capture Software to record the mocap data. The movement of the student was recorded using cameras placed at different angles that capture the translation of each sensor (marker). Once recorded, the mocap data was cleaned up and automatically added missing keyframes to markers by using the Nexus software. Lastly, the mocap data was exported as .C3D files.

4.4 Pre-processing Data

The C3D files were imported into Autodesk Motion Builder(MB). The MB software allows the visualization of the recorded data from the reflective sensors attached to the performer's body. The next step was to setup an actor using the T-pose mocap data (called Optical data in MB). An Actor is an asset used to preview motion data and to connect motion data to a character model.

The setup consists firstly of aligning the actor with the markers in the T-pose (from the C3D optical data) (Figure 4.3), followed by the attribution of the respective markers to each part of the body of the actor by creating a marker set Figure 4.4).

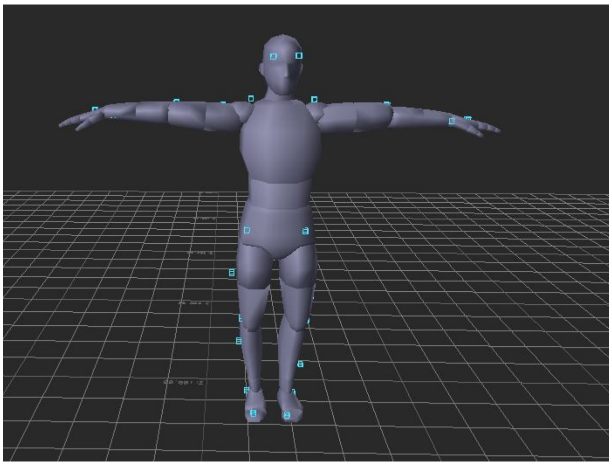


Figure 4.3: Actor placed to match optical mocap data.

MarkerSet

	Object(s)	Oriented
LFHD	C3D:LFHD	☐
RFHD	C3D:RFHD	☐
LBHD	C3D:LBHD	☐
RBHD	C3D:RBHD	☐

Figure 4.4: MarkerSet to bind markers to actor in T-pose.

Since each marker has its own reference, once the markers are bonded to each part of the actor the setup is done. The actor is ready for new optical motion data to be imported that will make the actor follow the markers in accordance with the marker set created.

The next step is to import an avatar (called character in MB), characterize it and select the actor as the source for the avatar motion. The avatar is animated as the actor in that “take”. Each “take” represents an optical data file from the motion capture and the same process was done for all optical data files. The following step was to plot the animations to the avatar (character). Once plotted, the actor and the optical data were deleted, leaving only the avatar with the intended animations. After this step, the avatar and the animations were exported from Motion Builder as a .fbx file.

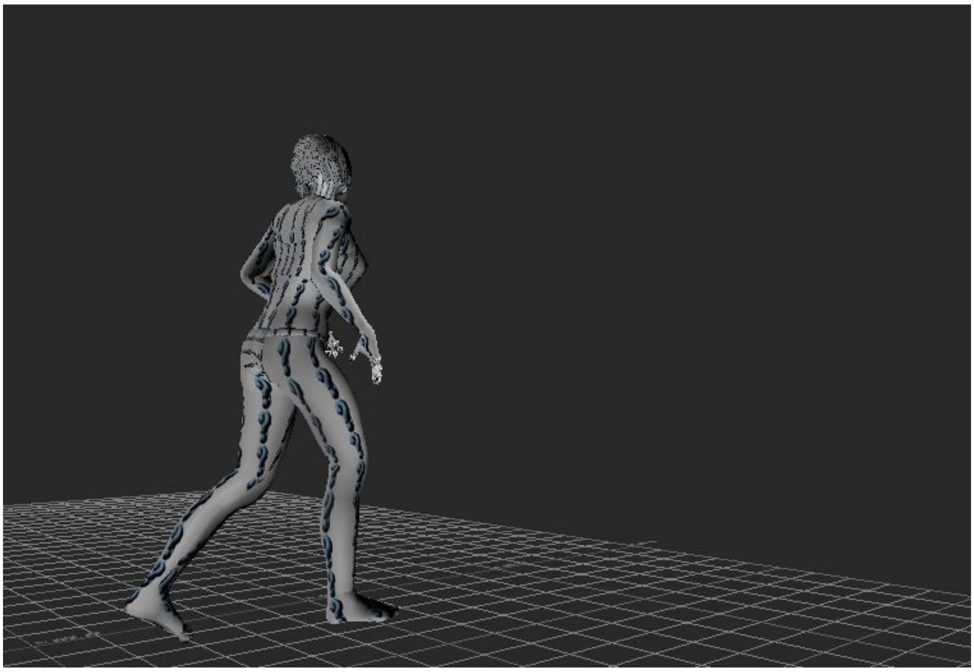


Figure 4.5: Avatar ready to be exported with the animations.

Before going to Unity, the .fbx file is used in Autodesk Maya to create animations clips for Unity. The need to have an avatar brought from Motion Builder to Maya was due to the fact that the animation Clip for Unity needs to have a Control Rig associated. Adding the Control Rig was a straight forward process using Maya. Once exported to Unity as .fbx, the animations are ready to be used as a .anim for any avatar, with the needed changes in the hierarchy; however, since the same avatar was used throughout the whole process, no further changes were needed. Some minor adjustments were required to fix the animations; the toes not behaving properly and, in the case of the Hemiplegic gait, the affected hand not being closed as a fist as it should be. These issues happened due to the optical data residual noise and bad tracking of the actor extremities. Both adjustments were made by manually editing the animation clip keyframes modifying the rotation of the affected areas in the Unity editor, Figure 4.6.

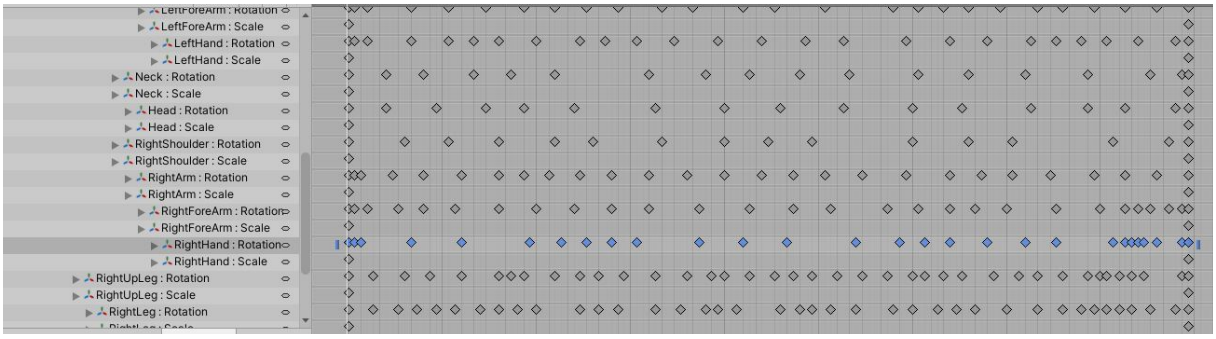


Figure 4.6: Animation clip keyframe fix.

4.5 Unity Scene Managing Module

This is the module that runs the tool; part of it are scripts that handle the change of scene, the update functions and the logic behind both the menus and the avatar. Both VR and WIMP versions use the same scripts for the logic behind the tool. The difference is the way they are controlled, receive and process input, which is explained further along in this chapter in their respective modules. To further explain the whole tool and how the scenes connect to each other, no better place to start then the Main Menu scene.

The main menu is fairly simple and was prepared with the User tests for the evaluation in mind. It disposes of four buttons, tutorial, pre-test, practice and post-test. Each time the tool is started, it randomly selects a pathology for the pre-test and a random pathology for the post-test. The pathology from the pre-test and the remaining pathology (the one not randomly chosen for any of the tests) are available in the practice mode.

In the WIMP version, the scene itself has an event system, a canvas (with buttons) and a camera. The VR version is slightly more complex, since some scripts were created, for example, to replace the event system. These additions are explained in detail in the “HTC Input Processing Module” subsection that follows.

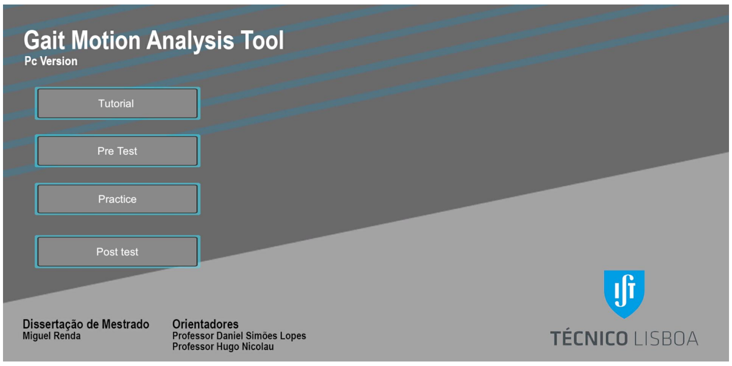


Figure 4.7: Main Menu WIMP version

If the tutorial button is selected, the tutorial scene is loaded. This scene has the same assets as the other pathologies scenes.

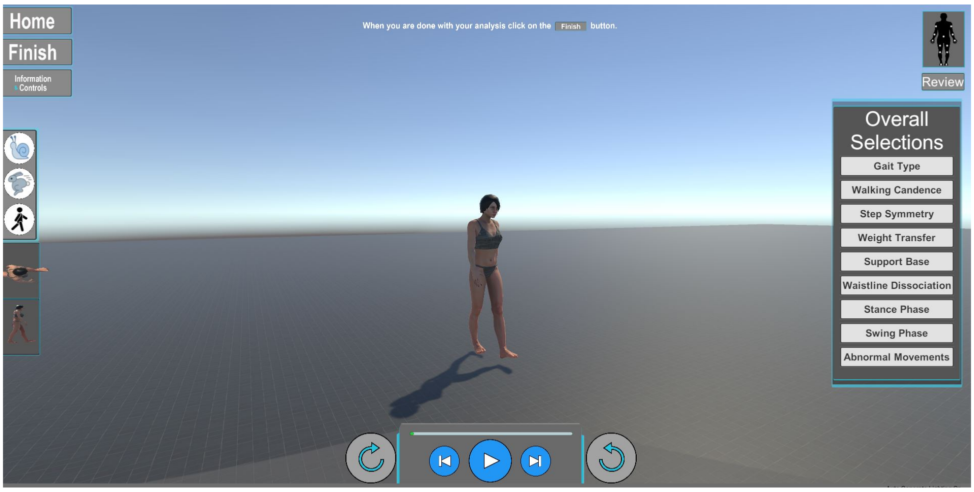

When you are done with your analysis click on the Finish button.

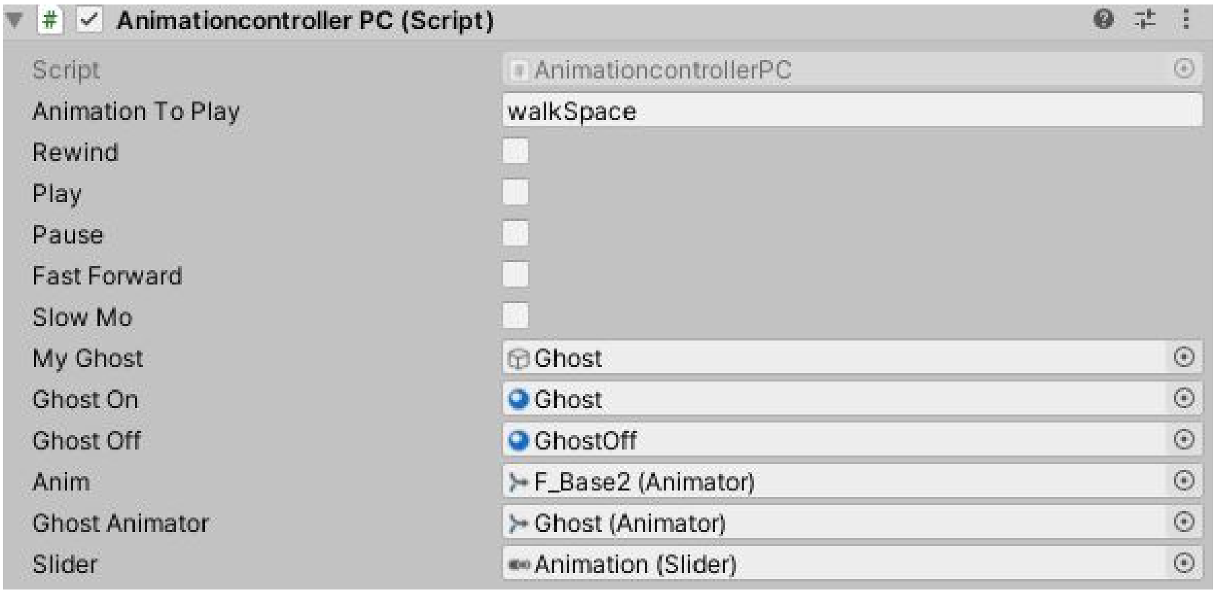
Figure 4.8: Tutorial Scene WIMP version

Figure 4.9: Tutorial Scene VR version

The avatar's parent GameObject has attached a script called "AnimatorcontrollerPc" (Figure 4.10) that controls the animation from both the avatar and the ghost of the normal gait. The "Animation To Play" field is a public string that changes from scene to scene to play the respective pathology. As for the case of the tutorial scene, "walkSpace" is the chosen gait with root motion on the animation. The animation played by the Ghost(animator) is always the same animation, the normal gait. Since it is intended for the ghost to be always where the avatar is, there is no use for root motion, so the animation clip used by the ghost has a different name which is called "Walk".

The Slider is an AnimationSlider from Unity that gives feedback to the user on where the animation is in the animation timeline. This script is also responsible for handling animation related aids, like turning the ghost on and off. The avatar has several child game objects, cameras for additional views, the ghost, and parts of the avatar mesh, such as hair and nails. Among the child GameObjects, the Rig is the most important to highlight since it is where the animator applies the rotations for each bone from the animation. It is also where thirteen GameObjects were added to work as colliders for the selections.

Those thirteen colliders were placed at the arms, forearms, hands, pelvis, hips, knees and feet.



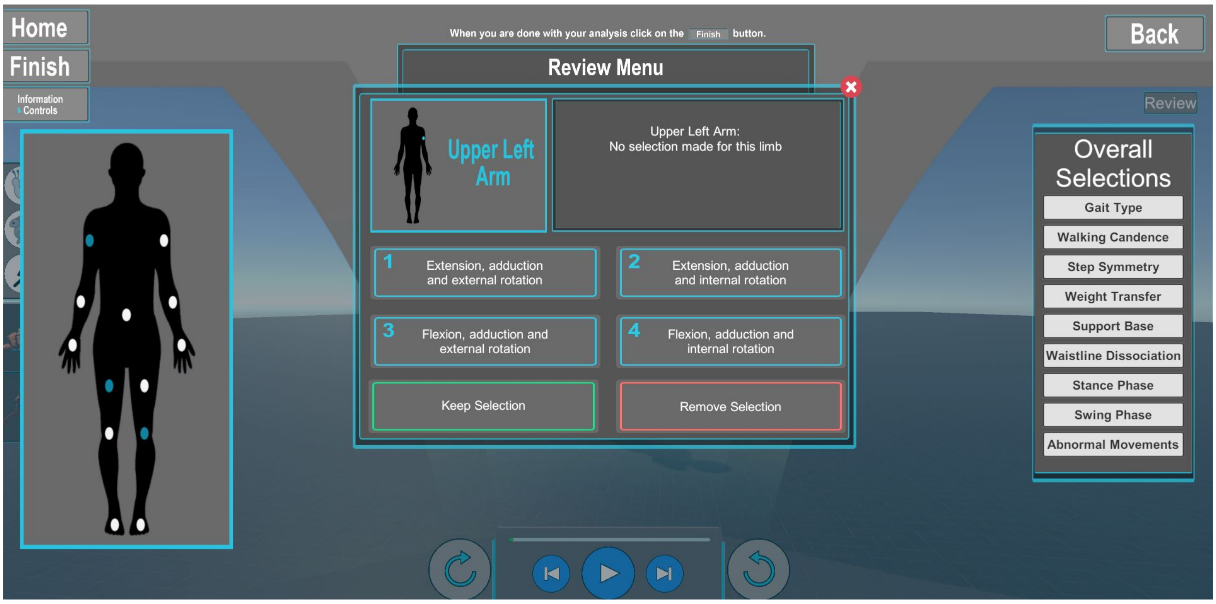
Animationcontroller PC (Script)

Script	AnimationcontrollerPC
Animation To Play	walkSpace
Rewind	☐
Play	☐
Pause	☐
Fast Forward	☐
Slow Mo	☐
My Ghost	Ghost
Ghost On	Ghost
Ghost Off	GhostOff
Anim	F_Base2 (Animator)
Ghost Animator	Ghost (Animator)
Slider	Animation (Slider)

Figure 4.10: Animation Control Script

The Home button allows the user to go back to the main menu scene at any time, although all progress done is lost. The finish Button is used when the user wants to finish the analysis and see the resulting score. The information button has the information on what the goal is (select limbs and articulations that behave differently from a gait motion) and the controls for the respective version of the tool.

On the top left of the WIMP version, there is a button called “Review”, which is not present in the VR version, since the Review menu is presented instead as a physical “Wall” in VR. Shown in Figure 4.9 behind the avatar. The Review Menu also allows the selection of the limbs and articulation, as well as simply checking what selections have been made.

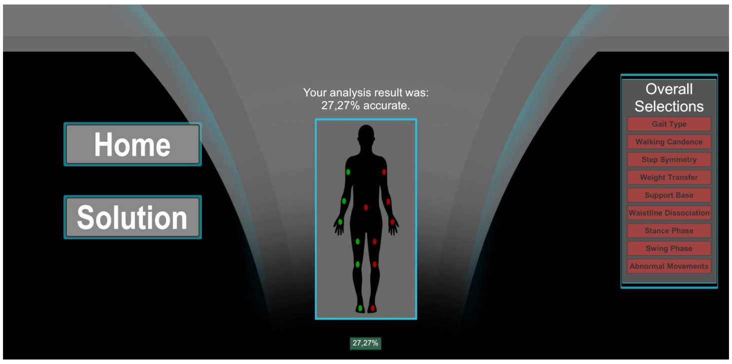


When you are done with your analysis click on the Finish button.

Upper Left Arm:
No selection made for this limb

Figure 4.11: Review Menu WIMP version

Once the user finishes the analysis, the score menu appears, showing the percentage of correct selections made (Figures 4.12 and 4.13). At the score menu, there is the option of going to the main menu or seeing the solution.



Your analysis result was:
27,27% accurate.

Figure 4.12: Score WIMP version

Your analysis result was:
59.09% accurate.

Figure 4.13: Score VR version

The solution works in the same manner as when making selections, where the user either uses the Review Menu or the direct selections on the limbs and overall selections to see, in the solution case, what is the correct solution. Red represents selections that were incorrect while green indicates the correct ones. The Review Menu of the selections also shows the selected options and not just the correct solution.

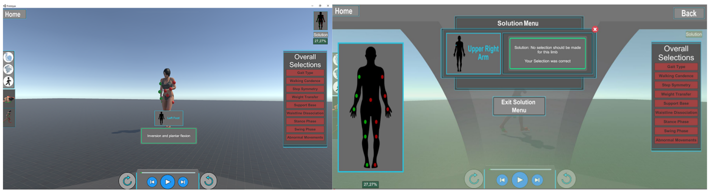


Figure 4.14: Solution WIMP version

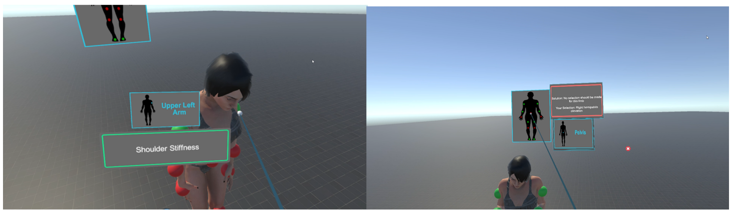


Figure 4.15: Solution VR version

The other scenes work the same as the tutorial, given that all scripts for the logic of the tool have been designed so that changing fields in the Unity Editor creates a completely different gait motion to analyse. Other scripts important to mention are the scripts that connect the collider in each limb to the respective button on the Review Menu which changes the colour of the buttons and colliders to blue. All of these scripts have made use of public references to each other to allow the selection in one place to change the other. “ClickOn” is one of such scripts that is present in all of the colliders.

As for the differences between test and practice, the way it is implemented is by using a public static boolean variable that changes depending on the button clicked in the main menu. Once in a pathology scene, each aid uses an awake() method to check if it is a test. If so, the GameObject for each aid self-disables.

4.6 Unity Database

There are in total five scenes: one for the main menu, the tutorial scene that shows the normal gait motion, and one for each of the pathologies, Hemiplegic, Scissor and Parkinsonian. All of the scenes use the same assets, except the main menu scene which only has four buttons. The animations clips are all in the same animator controller attached to the avatar, being that the ghost animator is an Animator Override Controller that overrides the avatar controller. The difference between scenes is the text and options for reasons. The text is stored in each button as a Text component and the right solutions for each of the selections are stored in each limb (collider) or button in the case of the Overall selections. The selections made for one pathology are lost once the user returns to the home screen. All buttons were created in Photoshop and converted to 2D sprites in Unity. The avatar used in the tool is a free asset from the Unity store and the information and controls were also created in Photoshop to be used as a panel.

4.7 HTC Input Processing Module

To be able to process the inputs from the HTC Headset and controllers, the SteamVR library was added to the project. One of the prefabs from the library is the “[CameraRig]” that replaced the main camera.

This prefab sets up the HTC headset, controllers and the playable area. Steam makes it possible to calibrate the room and controllers for any VR application.

To process inputs a pointer was created and added to the “Controller (right)”, a child of “[CameraRig]”. The Pointer is a GameObject that has a script “Pointer”, a Camera and a Line Renderer as components. The “Pointer” script has 3 public variables, a “default length” float for the maximum length the line will have, a GameObject “Dot” that is located at the end of the line and a reference to the script “VRInputModule”, which was also created.

The camera is an inactive component but is essential for the “VRInputModule” script. This script is a component of a created prefab called “VREventSystem” that also has as a component an Event system.

The “VRInputModule” script is a class that inherits from “BaseInputModule” from the UnityEngine EventSystems namespace. This script has a reference for the pointer camera. As the target source, it has the right hand (right controller) and its click action is GrapPinch from the default bindings.

The two scripts connect to each other firstly by the “VRInputModule” in the “Process()” method that gets data based in the camera attached to the pointer. The “Pointer” script uses the public method “Getdata()” to get the “PointerEventData”. The “Pointer” update() method always calls the “UpdateLine()” method where if there is no Hit from a created raycast, the length of the line will stay the same as the default value. If there is a hit, the line will only be the length of the distance to the hit point and the dot will always be placed at the end of the line.

The “VRInputModule” script is also responsible for the press and release of the button. The methods “ProcessPress()” and “ProcessRelease()” are both called during the “Process()”. The last requirement was to set the “Event Camera” on all canvas (to be able to select UI buttons) as the Pointer (camera). The default GrapPinch click action worked for all the buttons, but for the colliders of the selections in the limbs and articulations, the approach was to add an “AddOnStateDownListener()” to the “AnimationControllerRigth” script. The script checks if the collision happened with a GameObject form the “ClickableObj” layer if so, calls the “ClickMe()” method from the collided GameObject.

An Action Set was also created for each controller by Using the SteamVR Input window in the editor and the binding UI from Steam. Both action Sets are activated in the beginning, when the Main Menu scene is loaded.

4.8 HTC VIVE Input Module

In this subsection, the inputs from the headset are showcased. The interaction the user has in terms of movement on the tool is achieved through the HTC headset. One of such movements is the control over the camera, which is based on the head movement of the user. The position of the user is also achieved by the position of the headset in relation to VIVE the Base stations.

In regards to virtual inputs, specifically, the two canvas “Home” and “Overall selections”, both are accessible using the right controller. Each canvas has the Pointer(Camera) as its event camera. Both canvas move with the Main camera (from the HTC headset), so it is always one click away regardless of the user’s position.

The “Home” canvas menu has the “Home”, the “Finish” and the “Information and Controls” buttons as displayed below in Figure 4.16.

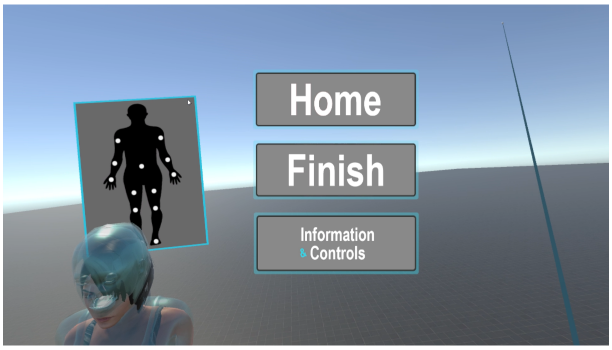


Figure 4.16: Home Menu VR

All the buttons from both canvases work in a similar way by using the OnCLick() method accessible from the Unity Editor, where each button calls the method to perform its action from the respective script of each button. The Overall selection buttons also have Event triggers components for when the pointer is hovering, performing the intended function in a similar faction as the Onclick() method. An example is shown in Figure 4.17 where the reason for button 2 appears when the pointer hovers the button.

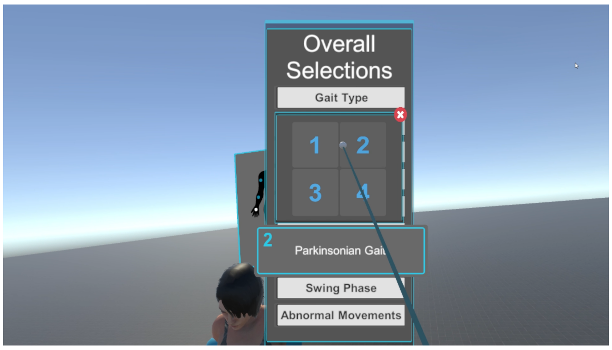


Figure 4.17: Overall Selections VR

The position and movement of the user are achieved by the SteamVR Scripts using the “[CameraRig]” prefab.

4.9 HTC VIVE Controller Module

The controllers are responsible for all the interaction between the user and the avatar. It is also the controllers that allow the selection of either buttons or limbs for the analysis. The position of each controller is tracked and displayed through a model in the prototype. Therefore, the movement of the upper limbs of the user is reflected on the position of the controllers in the scene, allowing the user to point with the right controller and select.

For each of the controllers, a script was created to handle the inputs, “AnimationControllerRigth” (mentioned in the HTC Input Processing Module subsection) and “AnimationxcontrollerLeft”. Listeners for states Down and Up from the buttons of the controllers were added to both scripts. The buttons on the controllers are displayed in Figure 4.18.

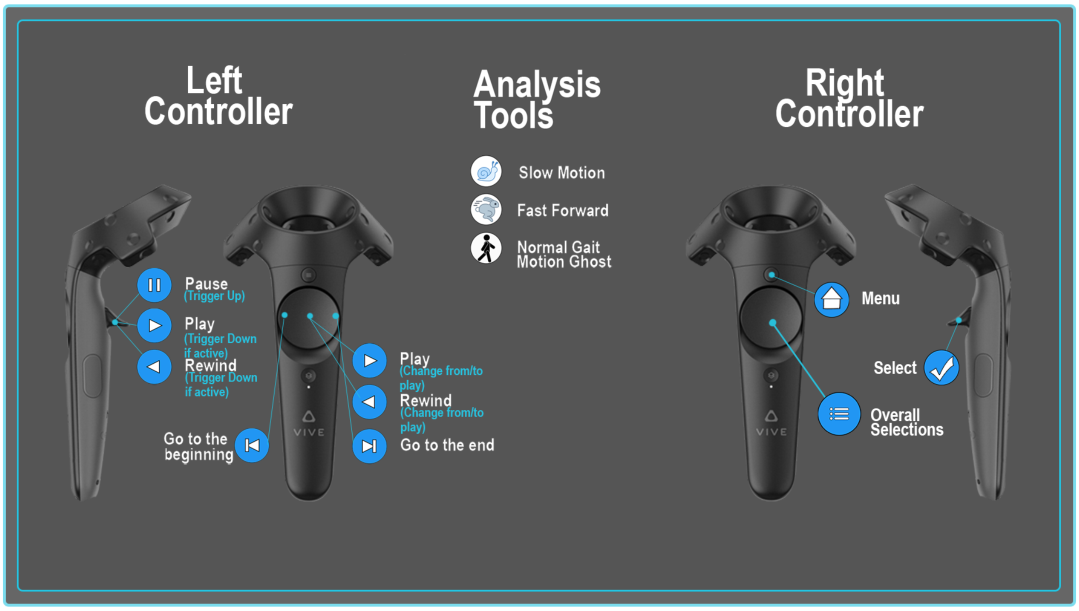


Figure 4.18: Controllers Buttons layout VR

All the buttons have event listeners for the state “Down”. The Left trigger also has a listener for the “UP” state that changes between, Play/Rewind and Pause. The position of the left controller pad and the state “Down” work together to provide three separate buttons: one that goes to the beginning or the end of the animation and another (center) that changes between Play or Rewind. As for the aids, Slow Motion, Fast forward and Normal Gait Motion Ghost, these work as virtual buttons that are placed in a panel on the right side of the left controller. These buttons are clickable with the pointer from the right controller. The extra views are placed to the left of the Overall selections on the right controller as illustrated in Figure 4.19.

Figure 4.19: Normal Ghost aid and extra View aid positioning in VR

4.10 WIMP Interface Input Processing Module

The input for the WIMP interface uses the default EventSystem from Unity3D scenes. As for the movement of the user, a GameObject called “FPSPLayer” was created. A component called the “SmoothFollowScript” allows the user to follow the Avatar as the avatar does the animation. The Main camera is a child of the “FPSPlayer” GameObject. The main camera has a script component called “MouseRaycast” that is responsible for the selection of limbs and articulations. Every time the left button of the mouse is clicked, a raycast is created to check if there is a collision with one of the selectable limbs. This is done by using the ScreenPointToRay() method.

Also as a component of the main camera, the script “MouseLook” is responsible for the drag inputs from both the x and y axis. The “MouseLook” passes the data to the “SmoothFollowScript” to handle the proper positioning and rotation of the parent object. It is also in the “SmoothFollowScript” that the zoom input from the mouse scroll wheel is handled. The LateUpdate() method updates the “FPSPlayer” object position after processing the several mouse inputs. It is also used in late update to avoid lagging behind the avatar.

4.11 Mouse Input Module

The mouse controls and button layout are as displayed in Figure 4.20. The logic behind all buttons is the same. Some use event triggers to, for example, hover on the Overall Selections that enables a pop up to appear showing what reason is selected, if any. The scripts “MouseLook” and the “SmoothFollowScript” check if the buttons were pressed or released by using the Input().GetButtonDown/Up () and Input().GetAxis(“Mouse ScrollWheel”) methods from the UnityEngine namespace.

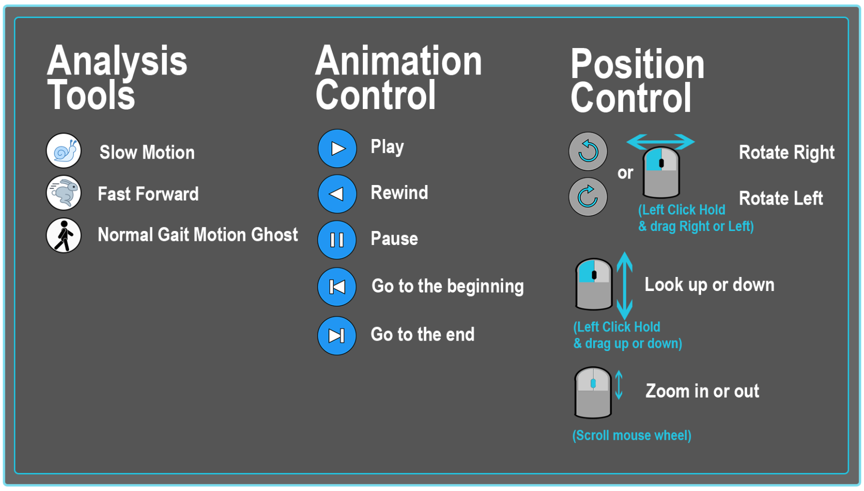


Figure 4.20: Controls for the WIMP interface

The control over the animation is not made by any physical button but with virtual buttons in the interface by clicking the mouse. When the animation control panel at the bottom of the screen is hovered, the rewind button appears under the play button. The rotation buttons are on each side of the animation control panel. These two buttons change the position of the camera, which is the same as dragging the mouse while left clicking. Using the buttons or clicking and dragging has the same result, which is rotating around the avatar.

When you are done with your analysis click on the Finish button.

Figure 4.21: WIMP interface buttons layout

4.12 Prototype Iterations / Formative User Studies

This subsection explains the process taken to reach the functional prototype explained above, t. The approaches chosen, the changes made throughout the process, the formative user studies and the iterations of the prototype.

First Prototype

From the User studies resulting guidelines, the need for visualizing 3D animations in a 3D environment was clear. Therefore, the first step was to create that environment and give control to the user over space and time, not only following the guidelines from the interviews, but also basing the development on the research, specifically Coffey et al. [9] on this subject of giving control to the user over the space and time. The first prototype demo was fairly rudimentary, it only disposed of control over the space and time of the animation.

On the WIMP version, the movement used the WSAD, or the arrow keys on the keyboard, to move in space and right-clicking and dragging the mouse to look. For the control over the animation, keyboard keys were also used, for example, “P” to play. The VR version had the basic movement using the prefab “[CameraRig]” and the controller buttons input used to control the animation worked in a completely different manner as the final prototype (Figure 4.22).

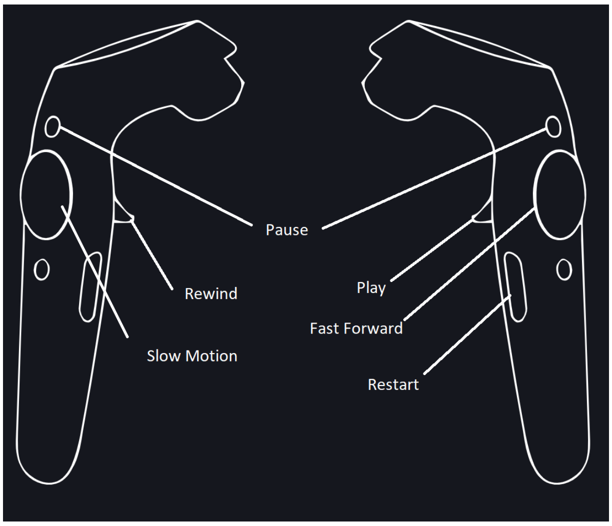


Figure 4.22: First Demo VR controllers

First Demo

The second iteration of the prototype had some aids implemented, like the ghost of the normal gait. The animations being used at this point were standard animations found in Unity Store and not the goal pathological animations. This second iteration had a VR demo, where a user tested the prototype and later the dissertation supervisors verified if the development was going in the right direction. This test focused on the movement of the user and control over the animation.

Alongside the development of the second iteration of the prototype, storyboards were created as shown in Appendix B.1. These storyboards were used in an interview with P2 to discuss ideas on how the tool should work, which pathologies should be used, which aids should the tool have and what limbs are the focus on a gait motion analysis. Some of the important aspects discussed were the existence of the “test mode” without any aids. Overall, the idea for the prototype was well received by P2.

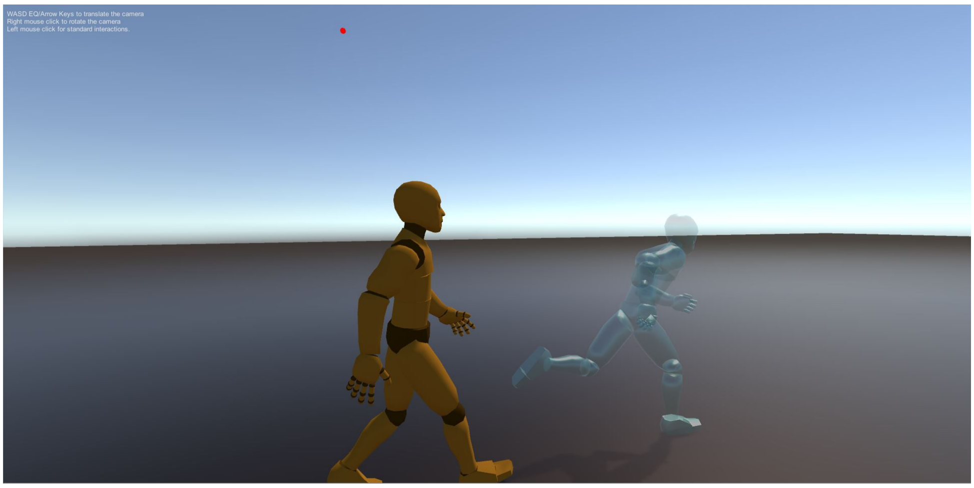

WASD EQ/Arrow Keys to translate the camera
Right mouse click to rotate the camera
Left mouse click for standard interactions.

Figure 4.23: First Demo

Start of User Interface development and Motion capture

The following step was to prepare the User Interface (UI) and how the logic behind the tool would work. For that purpose, some interface storyboards were created as seen in Appendix B.2. Alongside with the development of the UI, it was essential to prepare the animations since they are the basis for the tool. Given the importance of accurate representations of the gait motions, a proper system for body tracking was required. This topic has been discussed by [5], where for Physio@Home, Vicon cameras were used for the body tracking, instead of other technologies, like a Kinect due to the device's inaccurate tracking and skeleton placement.

Accordingly for the mocap, the first approach was to acquire the data in the Lisbon Biomechanics Laboratory. S5 mimicked the pathological movements so that the mocap was recorded using fourteen infrared Qualisys ProReflex MCU 500/1000 cameras. The mocap data needed cleanup since some markers disappeared in some frames. The first step for the cleanup is the creation of a model where each marker is connected and named according to its location. The model is improved take by take, minimizing the number of manual inputs needed to place the markers correctly. Despite that, all the takes needed some manual input to fix missing markers. All this process is done in the Qualisys Track Manager Program. The takes were processed and the output was .tsv files with several tables for each of the takes.

Gait motion Animations

Using the .tsv files, the process of animating started. The idea was to create animation clips using the rotation for each limb and articulation and the translation only from the root (Hips).

The table used for the rotations was called Reference Frame of Segments, which had a rotation matrix for each limb and frame. Here the development ran into some setbacks. The motion capture was done in a right-handed referential and Unity uses a left-handed referential. Furthermore, in the mocap, the local axis for each articulation had a different orientation. The approach chosen to tackle this problem was to create empty Game Objects in Unity and rotate them so that after making the transition from right hand to left hand, the local axis of each articulation would be ready to receive the input rotation values from the mocap data. After rotating, the objects were placed in the hierarchy of the avatar's rig to enable the rotations applied to affect the mesh of the avatar.

To create the animation clip, the .tsv file is read in a script and each matrix for each frame is transformed in a quaternion so the data does not lose degrees of freedom. The quaternion is changed from right hand to left hand. Lastly, the script writes in the animation clip the quaternion rotation values.

This process is flawed since there was no real data on how the local axis, from the motion capture, is oriented or positioned in the avatar. The only reference point was an image of a skeleton with the local axis from the acquisition.

This problem could be solved by having a T-pose or a similar position where it would be possible to reference and understand the needed rotations for each limb/articulation. Without it, the process was based on trial and error, the legs and feet managed to work properly but the rest of the body had no real logic consistency when compared to the logic behind the legs and feet. The translation of the root motion also worked.

Covid-19 Setback

Since this setback happened during the quarantine caused by the 2020 Covid-19 pandemic, it was impossible to acquire the needed T-pose mocap. Another attempt was made by requesting another file format like .fbx that would more easily be used to create the animations, but the version of the Qualisys Track Manager Program equipped in the Lab was not able to export as an .fbx.

At this point, the opportunity to capture new movements at the Health, Aging and Kinetics Laboratory from the Department of Biomedical Sciences and Medicine at Universidade do Algarve appeared since this dissertation's author lives in the region. From there, the process went smoothly, as explained in the "Motion capture" and "Pre-processing Data" modules.

Iterative process on the WIMP version

The development for the VR iterations came to a stop given the pandemic. The WIMP version had several iteration prototypes that were tested and, by means of the feedback received, improved upon. The first iteration resulted in some major changes on how the controls would playout. All the keyboard inputs were removed and visual buttons were added instead. This way the user does all the inputs with a mouse.

From iteration to iteration, based on the feedback, small but important changes were made; changes like the placement of buttons, size, colors, among others. All changes aimed to give users the easiest learning experience and control of the tool. Some changes important to mention would be the creation of the buttons for rotation around the avatar. Through the test demos, it was found that for some users the mouse input (click and drag) was more intuitive than the buttons for the rotation. This resulted in adding both ways of rotation by giving the user the choice. Another important change resulted from some concerns mentioned by physiotherapy students who tested the demo and the need for overall selections, since some selections did not make sense being related to a limb or articulation.

Iterative process on the VR version

The VR version was then developed adapting the WIMP version, since it was the goal from the beginning that both versions had the same aids, goals and animations. The changes were made in the controls and interaction with the menus and buttons. The position of the buttons and menus also had some iterations, although it was not possible for users to test physically the VR demos. Videos were made showcasing the tool in VR and the feedback came from "users" seeing them. This resulted in some changes, for example, the positioning of the additional views aid that was previously placed in a virtual wall was placed instead on the left controller, as in this way, it is always with the user. Another change was the always display of the overall selections in the right controller, opening a menu in the headset canvas to select them.

The left controller also worked as a canvas “displayer” since the first iteration proved to be unusable with the selections of each limb appearing in the place of the limb, like the WIMP version. If the placement of the selection canvas was in world coordinates and the user moved, it could become hidden behind other objects. Also, if several selection canvases were selected, in addition the avatar animation, it would create a lot of cluster. The selections also could not appear in the headset canvas since it would block the view of the animation and as it is intended that the user makes a selection based on the observation, it would have been counterproductive. Given these limitations, the solution was to place the selections on the left controller, as shown in Figure 4.24.This way the user has control over where these selections appear and reduces cluster on the scene.

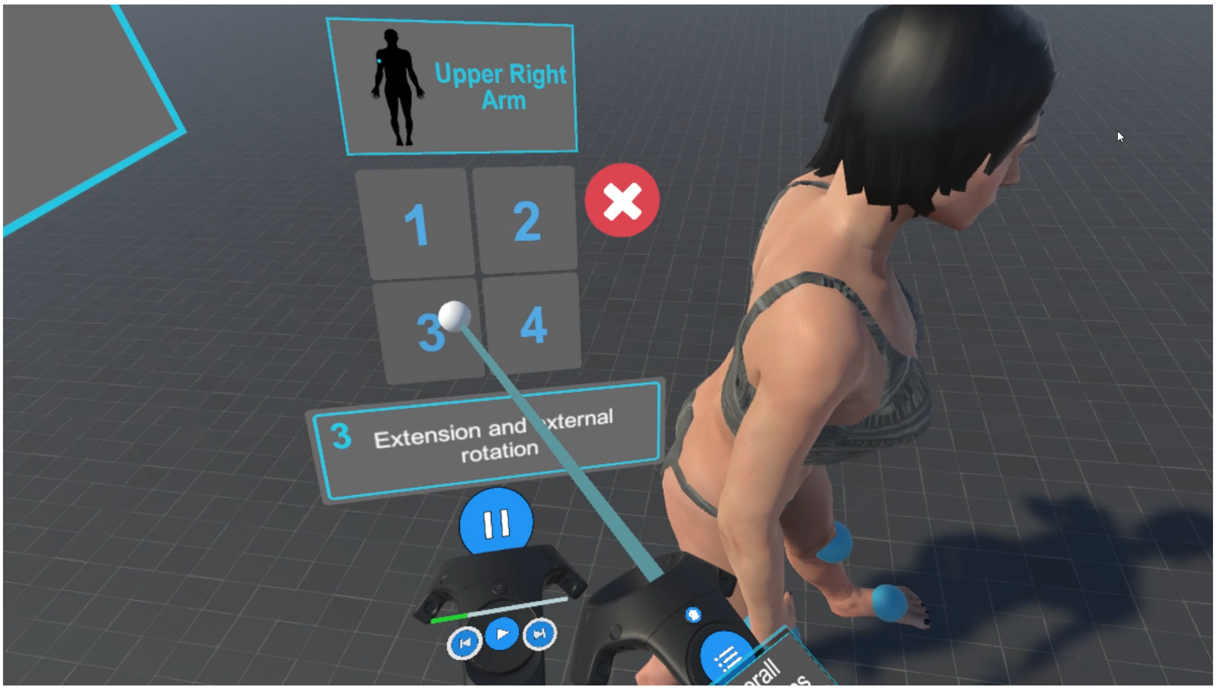


Figure 4.24: Selections in VR

Last iteration and final changes

Before doing the user tests, a functional prototype (WIMP version) was used to be tested firstly by a physiotherapist and secondly by P2, a neuromuscular physiotherapy professor. The goal of these two demos was to test the content and assure that there were not any theoretical inconsistencies on what was said to be the correct selections. Both demos had positive feedback, and with P2’s feedback, some changes were made to the selections for each pathology.

After those tests, both versions had the final iteration and the prototype was built as standalone applications for Windows. For the WIMP version, a Web version was also created preparing for the case of test users not having Windows.

Chapter 5

Evaluation

This chapter describes how the user tests were conducted, as well as the participants and their characteristics, the procedure, the equipment used and, lastly, the results and their discussion.

5.1 Research Questions

The research questions that the user tests aimed to answer were as follows:

1. Does VR improve the gait motion analysis performance of physiotherapy students more than a WIMP Interface?
2. Is VR better than a WIMP Interface to learn how to analyze gait motions based on observation?
3. Is VR better than a WIMP Interface to visualize gait motions?

5.2 Participants

The sample was constituted by ten physiotherapy students (ages 19 to 22, six male and four female) all with the same theoretical background. They had the base courses to learn what characterizes a normal gait motion, which means that they knew the theory of how to make a gait motion analysis based on observation. None of the participants had previous contact with patients, meaning that they have not done the internship at the point of testing. From the VR tests, one of the participants had previous experience with VR.

The most important characteristic the participants had to have was the fact of not having had the internship but knowing in theory how to analyse gait motions. This was a restrictive condition but a necessary one since the goal of the tool is to prepare students for the internship by teaching what and where to look, during a practical gait motion analysis.

Given the Covid-19 pandemic, which also delayed the tool development, the tests were conducted in the Summer of 2020. Gathering participants in these conditions proved to be challenging, since Universities were closed for holidays and students were neither near the Lisbon area nor willing to participate due to Covid-19. The participation on the WIMP tests also brought some challenges. Students were on holidays and did not have their computer nor internet.

All these participants were obtained using direct contacts made by the author of this dissertation. Another attempt was made with a physiotherapy professor to help in contacting students, which was unsuccessful as the semester had ended and many students were on holidays. Other attempts were Facebook groups and Instagram stories. For the VR version, a gift card was given to a random winner among the participants. Despite the attempts to encourage participation, only five students participated in the VR version.

5.3 Apparatus

The VR equipment used was a HTC VIVE. The headset weighs 550 g and displays a 3D environment via two OLED displays (1080 x 1200 pixels per eye, 90 Hz) with a field of view of 100 x 110 degrees. HTC VIVE controllers, and wireless adapter. A Canon EOS 750D and a tripod to record videos of the participants tests were also used.

Furthermore, as safety measures, disposable hygienic hair caps and disposable hygienic eye masks were used. The use of disinfectant for the plastic components of the HTC and sanitary masks was mandatory. For the WIMP interface, it was requested that each user have their own computer and the use of a mouse, which would keep the interaction with the tool consistent between users.

5.4 Study Design

User tests

The user tests adopted a mixed-design approach. The tests had two conditions, the VR and the WIMP versions of the tool. The between-subject was conducted with five users testing one of the conditions and the other five testing the other condition. The Within-subject approach had five users testing both conditions. The five users that tested the VR version afterwards also tested the WIMP version. This was not performed as it should have been, since the ideal process would have been to have half the sample starting with one of the conditions and the other half with the other (the reasons why it was not performed as it should have been is further explained in Section 5.5). Nonetheless, by having the same participants testing both versions, comments and insights of the participants' preferred version were gathered. In each of the conditions, the participants performed the same test.

Data Analysis

A comparative descriptive analysis of the two versions was made. The answers from the questionnaire provided comments and insights relevant for the comparison. Furthermore, for context, the average time from pre-tests and post-test were calculated in addition to the averages scores. The mean rating from the (WBLT) evaluation scale [18] was also calculated for the learning, engagement and design components of the tool. Despite the small sample of participants, a Mann–Whitney U test was performed to analyse if there was a significant difference between the two versions for the variables pre-test time, post-test time, pre-test score and post-test score. An Wilcoxon signed-rank test was also performed to analyse if the difference between time and score from the pre-test to post-test of each of the version was significantly different.

5.5 Covid-19 compromises

User tests

The user tests suffered some challenges due to the Covid-19 pandemic. For the VR tests, some compromises had to be made in order to have tests. One of such compromises was to reduce the time of the test itself in order to be able to test the most students possible.

The intended approach to test the tool was a between-subject design, where each group would have at least 15 participants and the test itself would have been dived into parts. The first part would have consisted of a pre-test followed by sessions where the participant used the tool to learn how to make an analysis and a final session where the participant had a post-test. Given the location of the testing laboratory (Tagus Park) and the Covid-19 related logistics, all tests were performed during the same day, since it was impossible to have students going to the laboratory on other occasions. This impossibility was due to various reasons: students going on holidays, the logistic needed to approve personal outside the University to access the laboratory, as well as the transportation to the laboratory itself. This compromise reduced the testing sessions to one, although maintaining the same structure as the intended design (pre-test, practice and post-test).

The Within-subject study was only performed according to the availability from part of the VR participants to test the WIMP version. To conduct the Within-subject study as it should have been, the participants that only tested the WIMP version should have also tested the VR version which was not possible due to time constrains, logistics and location of the users (none were near Lisbon).

When it was clear that there would be a shortage of participants, another compromise was made, changing the study design to a more qualitative approach. This change came with its own challenges. Since qualitative feedback was needed, a questionnaire was prepared with an (WBLT) evaluation scale [18] and open questions presented in Section 5.6. The existence of this questionnaire was also a compromise, since it was not feasible to interview the participants that tested the two versions. Semi-structured interviews would have been better suited for the qualitative evaluation. The impossibility to interview the participants came from the fact that participants did not want or did not have more time to spend on interviews. An interview, in addition to a test, would have led some students to give up on the participation, since some were hesitant on participating when hearing the time the test would take. The questionnaire allowed participants to fill it on their own terms, after the experience. In this way, it was possible to gather the participants' opinions through the open questions.

Data Analysis

The intended analysis would have been to conduct the statistical independent-samples t-test to determine if a difference exists between the means of the time and score of the two versions. More specifically, to determine whether that difference between these two groups (VR and WIMP) is statistically significant in terms of performance. Given that the tests were conducted after the end of the semester and only five students were in the Lisbon area, available and willing to go to Tagus park to test the VR version, an independent-samples t-test analysis was not applicable. Nonetheless, some statistical tests were performed and analysed.

This small testing sample led to changing the intended data analysis from a statistical data analysis to a descriptive comparison.

5.6 Procedure

The user tests were the same for both versions. Participants started by signing a consent form (Appendix C) followed by the test itself that consisted of four phases and a final questionnaire. The pathologies were chosen at random for the pre-test (Phase 2) and post-test (Phase 4) as well as for phase 3 by exclusion. The characteristics of each phase are presented and explained below:

- Phase 1 - Tool tutorial: (8 minutes) At this stage, it is intended that students become familiar with the tool so they know how it works and how to control it. Here the scene ”Tutorial” takes place making use of the normal gait motion to showcase the tool features.

- Phase 2 - Initial test: (No limit - Timed) This test aims to determine the ability to analyze a pathological gait movement, before practical learning, using the tool.

- Phase 3 - Learning using the tool: (30 minutes) The student will have access to the tool to explore and analyze two types of pathological gaits, starting with the gait analysed in the pre-test, followed by a second pathology, both using the practice mode.

- Phase 4 - Final test: (No limit - Timed) By observing a new pathology, which the student had not previous access to, the final test aims to assess whether the user’s analysis capacity increased after the learning phase. Regarding the estimated time for each phase, the procedure was as follows. Phases 2 and 4 had no time limit, facilitating each student the possibility to take the tests according to their needs. The time used by each student in each of these phases was, however, measured in order to assess whether there are significant differences in the time used by students to perform the same tasks. In phase 3, practice mode, all students will have the same time (30 min), in order to guarantee an equal opportunity to learn. The answer to the final questionnaire was carried out individually by the user after the experience through a questionnaire on google Google forms. The average time for each test was 60 minutes.

- Questionnaire: This questionnaire is used to evaluate the user experience, specifically the learning, the engagement and the design aspects of the tool with the Web-based learning tools (WBLT) evaluation scale [18] presented below. This scale presents several statements and the participant chooses a degree of agreement that most suits the experience had, in a five point Likert scale.

Learning

These are the statements regarding the learning component of the tool:

1. Working with the learning object helped me learn
2. The feedback from the learning object helped me learn
3. The graphics and animations from the learning object helped me learn
4. The learning object helped teach me a new concept
5. Overall, the learning object helped me learn

Design

These are the statements regarding the design component of the tool:

6. The help features in the learning object were useful
7. The instructions in the learning object were easy to follow
8. The learning object was easy to use
9. The learning object was well organized

Engagement

These are the statements regarding the engagement component of the tool:

10. I liked the overall theme of the learning object
11. I found the learning object engaging
12. The learning object made learning fun
13. I would like to use the learning object again

Open questions

Following the evaluation scale the questionnaire also has some open questions facilitating a more qualitative feedback of the user experience.

14. Name 3 aspects that you consider most positive in the tool you just tried.
15. Did you experience any difficulty in using the tool? (if yes, what was the difficulty?)
16. Is there any aspect of the tool that you would like to see improved and / or changed? (if yes, what aspect (s) would you like to see improved in the tool?)
17. What is your opinion about the possibility of using this tool in the degree in physiotherapy?
18. Do you want to comment on another aspect of your experience with the tool?

Additional questions for within-subject approach

The questionnaire that was made by participants, that tested the WIMP version after testing the VR version, had thirteen additional questions. Those questions were specific questions created to compare both versions of the tool. The first twelve new questions were the same statements to those of the evaluation scale, expect the tenth statement, since the theme is the same in both versions. Instead of the five point Likert scale, the participants choose the preferred version for each of the statements, or none of the versions.

”Which version of the tool do you prefer in terms of learning in each of the following statements”:

19. Working with the learning object helped me learn

20. The feedback from the learning object helped me learn

21. The graphics and animations from the learning object helped me learn

22. The learning object helped teach me a new concept

23. Overall, the learning object helped me learn ”Which version of the tool’s design do you prefer based on each of the following statements.”

24. The help features in the learning object were useful

25. The instructions in the learning object were easy to follow

26. The learning object was easy to use

27. The learning object was well organized ”Which version of the tool do you prefer in terms of engagement for each of the following statements.”

28. I found the learning object engaging

29. The learning object made learning fun

30. I would like to use the learning object again A final open question was created to allow participants to give additional comments or suggestions.

31. Considering your experience with both tools, is there any other comparative aspect you would like to share?

Covid-19 Measures

The VR tests were done following sanitary and safety rules and instructions given by the DGS (Direção Geral da Saúde) and the Tagus Park facility Management Unit. A day was scheduled for testing and all phases were performed by one student at a time divided into one hour slots. A waiting room was also prepared in case of any delay.

Additional care done due to COVID-19 was as follows:

- The laboratory windows and the door were open to permanently ventilate the space.
- Participants used the equipment in the laboratory one at a time to ensure that they were not in the same space.
- The equipment (controllers and headset) was disinfected with a specific suitable product for every new user.
- The use of a hair cap and sanitary mask was mandatory.
- The user was equipped with an eye mask to avoid direct contact with the HTC sponge.
- Hand Sanitizer was made available to all users.

Some of the measures put in place were followed by the article from Forbes magazine ”How To Disinfect Your VR Equipment During The COVID-19 Pandemic” [28].

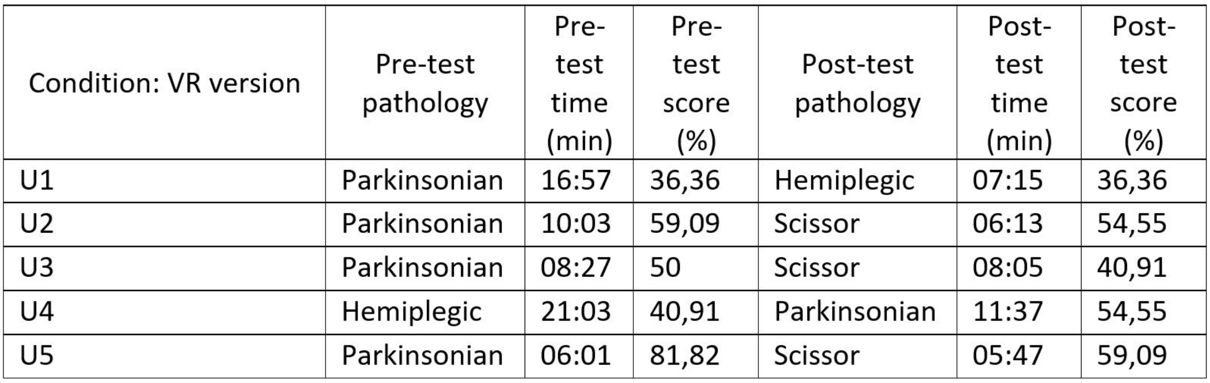
Tests for the WIMP version were done in Zoom sessions with each user performing the test remotely, given the situation of the COVID-19 in Portugal.

5.7 Results

In this subsection, the results gathered from the tests are showcased, starting with the VR results from users U1-U5, followed by the WIMP version results from users U6-U10. As explained in the Procedure Section, the five users that participated in the VR test also tested the WIMP version. Results from those tests are shown in the subsection 5.7.3

5.7.1 VR Version Results

The results from the VR version tests are displayed in the table below (Table 5.1).



Condition: VR version	Pre-test pathology	Pre-test time (min)	Pre-test score (%)	Post-test pathology	Post-test time (min)	Post-test score (%)
U1	Parkinsonian	16:57	36,36	Hemiplegic	07:15	36,36
U2	Parkinsonian	10:03	59,09	Scissor	06:13	54,55
U3	Parkinsonian	08:27	50	Scissor	08:05	40,91
U4	Hemiplegic	21:03	40,91	Parkinsonian	11:37	54,55
U5	Parkinsonian	06:01	81,82	Scissor	05:47	59,09

Table 5.1: VR Version Results

As previously explained in the Procedure Section, the pathology chosen for each of the tests is randomized. The mean score from the pre-test was 53.64% accurate. The mean score for the Post-test was 49,09% accurate. As for the time taken, the pre-test had an average time of 12 minutes and 30 seconds. As for the post-test, the average time was 7 minutes and 47 seconds. All the users performed the post-test faster than the pre-test, some reducing the time taken, such as the participant U4. As for the score, only one (U4) improved from the pre-test to the post-test.

The tool's learning component evaluation from the questionnaire using the WBLT evaluation scale [18] is displayed bellow (Figure 5.1).

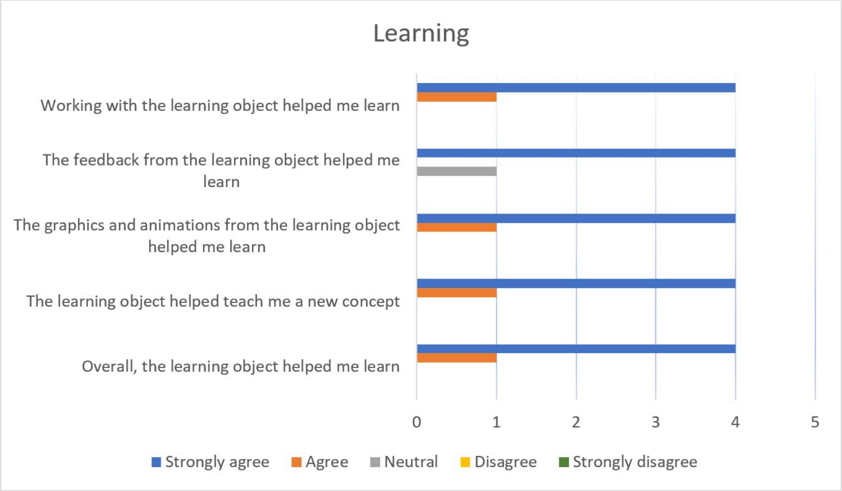


Figure 5.1: WBLT Learning Rating VR Version

The average WBLT rating for the VR tool's learning component is 4.76, being that ”Strongly Agree” represents 5 and ”Disagree” 1. All statements had a positive accordance except for one participant that was neutral on whether or not the feedback given from the learning tool helped the user learn.

For the design component (Figure 5.2), the average WBLT rating is 4.4. In terms of design all statements were received with a positive response.

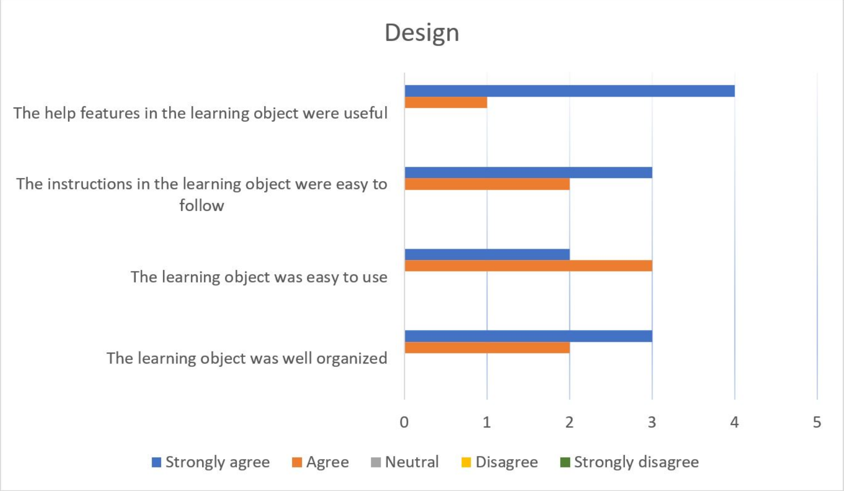


Figure 5.2: WBLT Design Rating VR Version

For the engagement component (Figure 5.3), the average WBLT rating is 4.6. All engagement related statements had ”Agree” or “Strongly agree” responses.

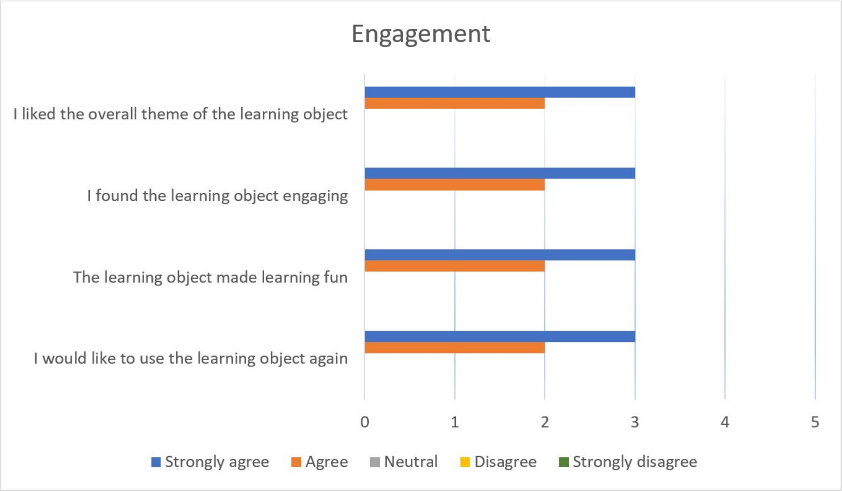


Figure 5.3: WBLT Engagement Rating VR Version

Several comments were gathered from the open questions. Among some of the aspects mentioned as most positive in the tool were: the liberty of movement, the easiness to focus on a specific part of the body, the level of detail, the freedom to repeat movements, the visualization in all planes, the interaction (mentioned by several participants) and, noted by two of the participants, the good learning process.

Regarding the difficulties faced during the test, only one participant mentioned feeling some difficulty handling the controls in the beginning.

As for aspects that participants would like to see improved, the focus was mentioned and a suggestion was made to change the humanoid's body and have more options for the selections. However, the focus issue was not mentioned as a difficulty, which was probably due to the damaged strap on the HTC headset because it did not allow for a tight grip on the user's head.

All participants had positive responses to the possibility of using this tool in the physiotherapy degree. One suggested that it could be used in evaluations: ”I think it would be important as a learning and evaluation tool. It is captivating and helps a lot in the detailed learning of gait movements”.

Another commented in the final question: ”Very captivating in the way of learning to observe the gait pattern”.

5.7.2 WIMP Version Results

The results from the WIMP interface user tests are displayed bellow (Table 5.2).

Condition: Wimp version	Pre-test pathology	Pre-test time (min)	Pre-test score (%)	Post-test pathology	Post-test time (min)	Post-test score (%)
U6	Parkinsonian	17:43	59,09	Hemiplegic	11:12	59,09
U7	Scissor	06:54	9	Hemiplegic	07:11	50
U8	Scissor	13:12	40,9	Hemiplegic	17:34	68,18
U9	Scissor	06:40	36,36	Hemiplegic	06:10	68,18
U10	Parkinsonian	11:10	77,27	Hemiplegic	10:18	77,27

Table 5.2: WIMP Version Results

The average time for the pre-test is 11 minutes and 7 seconds, while the post-test is 10 minutes and 29 seconds. On average there is an improvement from the pre-test to the post-test, although not all participants had an improvement on the time needed to complete the task (U8, U7). The mean score from the pre-test is 44,524 and the post-test mean score is 64,544. The mean score had an improvement (20.02% difference) from the pre-test to the post-test. It is notable that all users either improved or maintained the score from the pre-test.

Figure 5.4 shows the learning component evaluation from the questionnaire of the WIMP version.

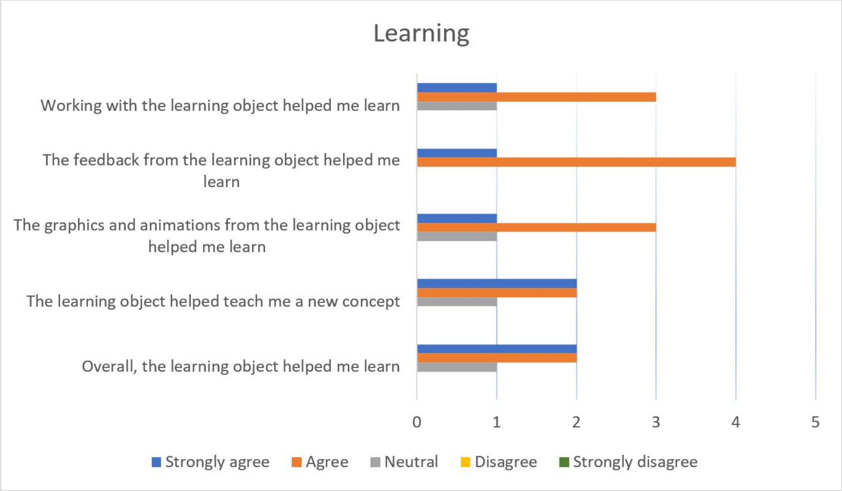


Figure 5.4: WBLT Learning Rating WIMP Version

Regarding the learning component, the average WBLT rating is 4.12. Although there are no negative responses, all of the statements regarding learning did have one neutral response. Figure 5.5 shows the design component evaluation from the questionnaire of the WIMP version

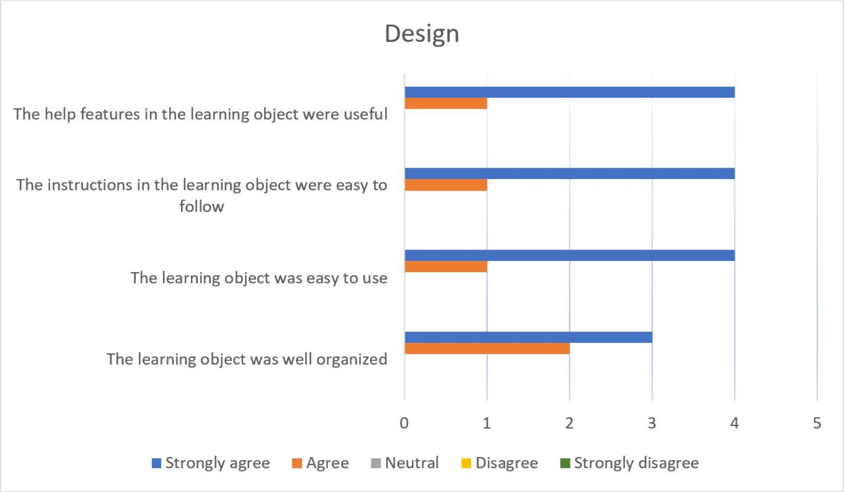


Figure 5.5: WBLT Design Rating WIMP Version

The average WBLT rating is 4.75 for the design component. All statements add a positive response. The figure that follows (Figure 5.6) shows the engagement component evaluation from the questionnaire of the WIMP version.

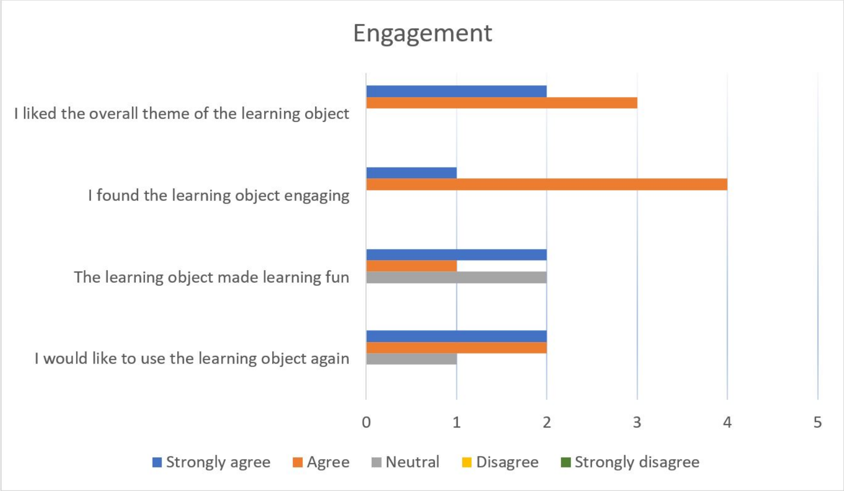


Figure 5.6: WBLT Engagement Rating WIMP Version

For the engagement component, the average WBLT rating is 4.05. The statement ”The Learning object made learning fun” had two neutral responses whereas the statement ”I would like to use the learning object again” had one.

Regarding the open questions, several participants mentioned the 3D visualization that allowed observation from several angles. One of the participants praised ”the ease with which you can use the tool’s features and the way the tool arouses curiosity to better analyze your knowledge and test it”. Another aspect that was mentioned as being one of the most positive of the tool was the rewind feature.

There were no difficulties appointed, however, an aspect to improve that was mentioned was the resolution. This was due to the fact that if the screen is too small the layout gets distorted. Another aspect that was noted by one participant was that some abnormal movements had no selection associated.

All participants had a positive response to introducing the tool in the physiotherapy degree. Some statement examples are: ”In my opinion, it would be an asset to analyze the gait and enhance students’ learning.” and ”It would help in teaching regarding the practical understanding of certain pathological gaits that are more difficult to understand”.

In the final open question, a comment was given by one of the users ”It showed the positive impact that technologies can have on teaching”.

5.7.3 WIMP Version after VR Version Results

The results from the WIMP version user tests for the participants that already tested the VR version are displayed below (Table 5.3).

Condition: Wimp after VR version	Pre-test pathology	Pre-test time (min)	Pre-test score (%)	Post-test pathology	Post-test time (min)	Post-test score (%)
U1	Scissor	10:02	54,55	Hemiplegic	08:55	36,36
U2	Parkinsonian	06:53	86,36	Hemiplegic	06:00	72,73
U3	Parkinsonian	05:24	63,64	Hemiplegic	07:13	90,91
U4	Parkinsonian	13:49	40,91	Scissor	09:56	13,64
U5	Parkinsonian	03:35	86,36	Scissor	03:42	77,27

Table 5.3: WIMP Version after VR Version Results

The average time for the pre-test was 7 minutes 56 seconds and the average score 66,36%. For the post-test the average time was 7 minutes and 9 seconds and the average score 58,18%. Only one of the participants (U3) improved the score from pre-test to post-test.

The Figure 5.7 shows the WBLT rating for the learning component of the tool.

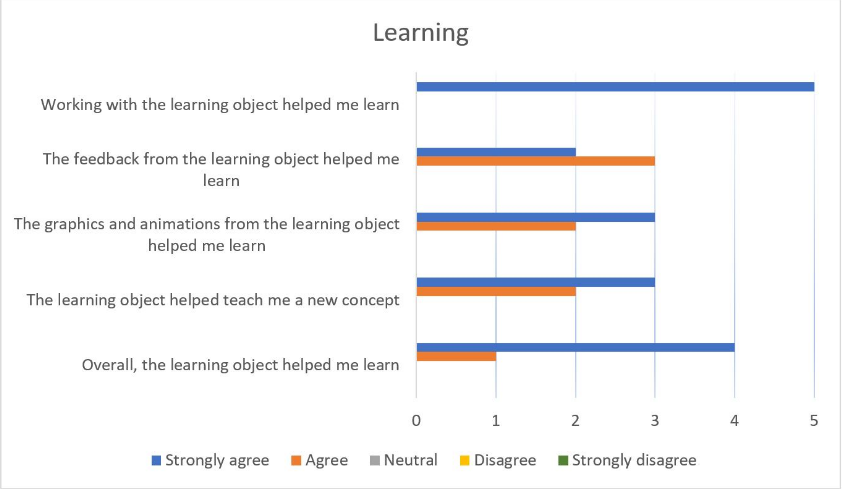


Figure 5.7: WBLT Learning Rating WIMP Version After VR Version

The average WBLT rating for the tool’s learning component is 4.68. All participants strongly agreed that working with the tool helped them learn. All other statements also had ”Agree” or ”Strongly agree” responses.

For the design component (Figure 5.8) the average WBLT rating is 4.85.

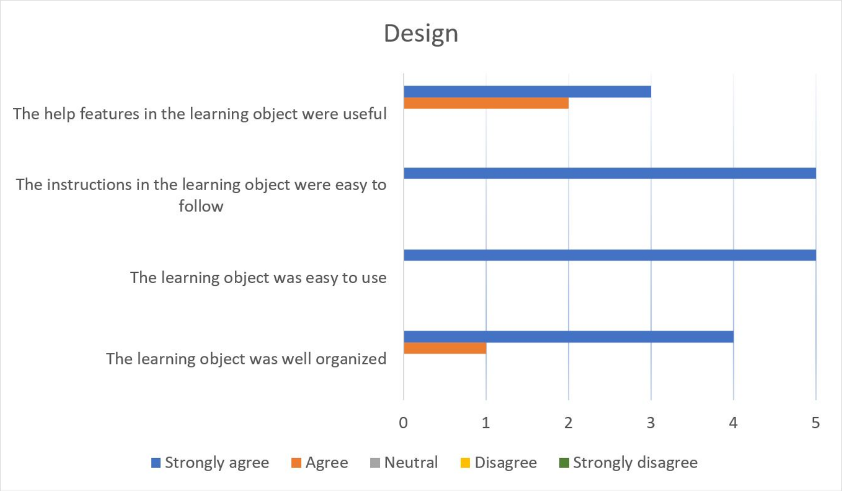


Figure 5.8: WBLT Design Rating WIMP Version after VR Version

All participants strongly agreed that the instructions were easy to follow and that the tool was easy to use. The other two statements also only had positive responses.

The Figure 5.9 shows the WBLT rating for engagement component of the tool.

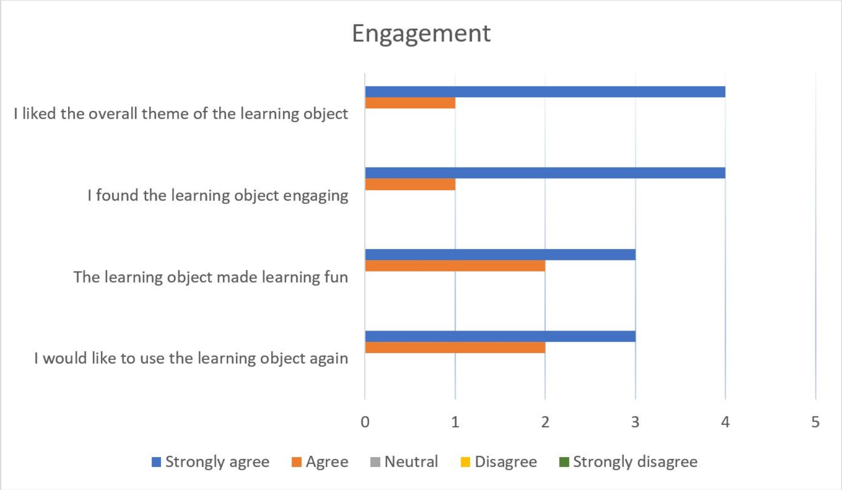


Figure 5.9: WBLT Engagement Rating WIMP Version after VR Version

The average WBLT rating is 4.7 for the engagement component. There were no neutral nor negative responses for any of the engagement statements.

Some of the positive aspects participants shared were the interactivity, the fact that the tool was easy to use and familiarize with. In fact all participants except one, commented on the fact that the interactivity was easy. One participant also stated that the tool motivates learning.

A participant had some difficulties with the controls at first but with time it got easy.

As for improvement aspects, the participants mentioned adding more pathologies and improving the animation realism.

All participants see the WIMP version as a welcome addition to the physiotherapy degree. One of the comments was ”I believe that it is very educational and helps to learn a lot compared to videos and theory explained verbally. Having this eye contact is halfway to understanding the various changes in patients”.

Some additional comments left by participants were that the tool was very captivating and very interactive.

The Figure 5.10 shows the preferred version of the tool regarding the learning statements.

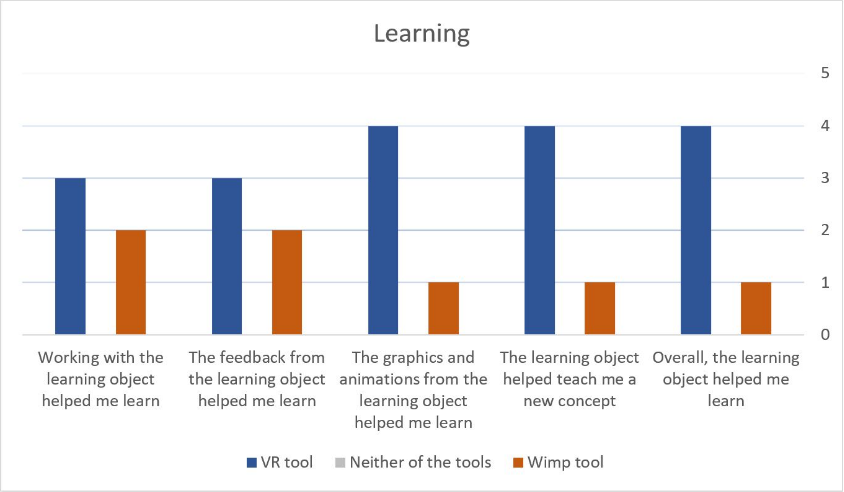


Figure 5.10: Preferred Version for Learning Statements

The VR version is the most preferred version for the five learning statements The Figure 5.11 shows the preferred version of the tool regarding the design statements.

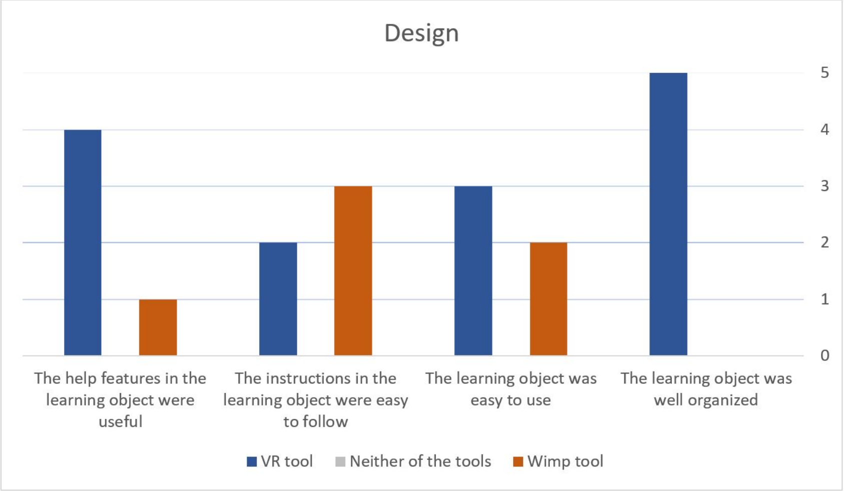


Figure 5.11: Preferred Version for Design Statements

The WIMP version is the most preferred version for the second statement and all participants choose the VR version as the most well organized. The Figure 5.12 shows the preferred version of the tool regarding the engagement statements.

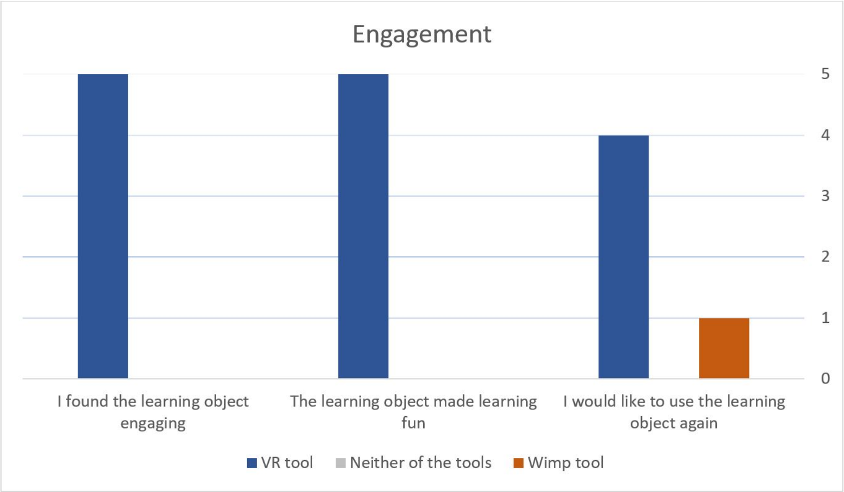


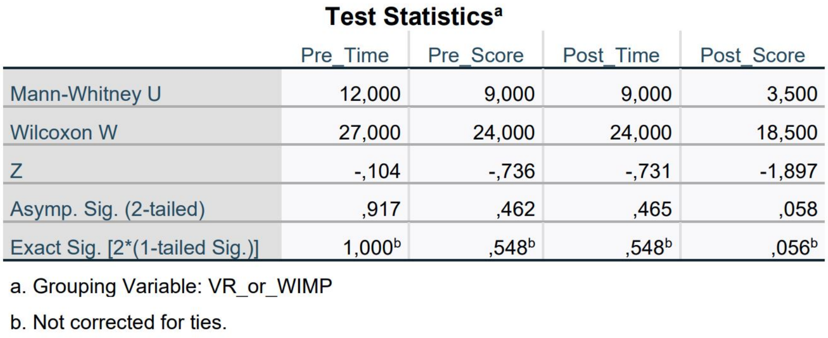
Figure 5.12: Preferred Version for Engagement Statements

All participants found that the VR version was more engaging for learning and the version that made learning the most fun. The statement ”I would like to use the learning tool again” had one of the participants preferring the WIMP version.

The only comment left by one of the participants was: ”For a person who has more difficulty using technology, the computer version will probably be easier. However, the virtual reality version is more captivating to use and you can see more in detail”.

5.7.4 VR and WIMP Versions Statistical Results

The Mann-Whitney test was conducted to compare VR tests to the tests from participants that only tested the WIMP version (Between-subject). Results show no significant differences for any of the times nor scores as displayed in 5.4.



Test Statistics[a]

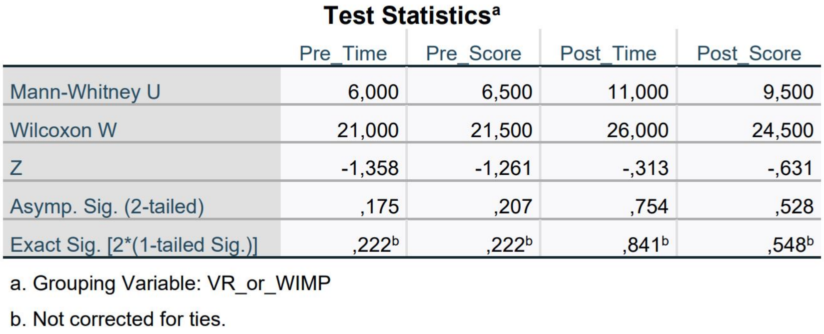
	Pre_Time	Pre_Score	Post_Time	Post_Score
Mann-Whitney U	12,000	9,000	9,000	3,500
Wilcoxon W	27,000	24,000	24,000	18,500
Z	-,104	-,736	-,731	-1,897
Asymp. Sig. (2-tailed)	,917	,462	,465	,058
Exact Sig. [2*(1-tailed Sig.)]	1,000[b]	,548[b]	,548[b]	,056[b]

a. Grouping Variable: VR_or_WIMP

b. Not corrected for ties.

Table 5.4: Mann-Whitney Test (Between-subject)

The Mann-Whitney test was conducted to compare VR tests to the WIMP tests from participants that tested both versions (Within-subject). Results show no significant differences for any of the times nor scores as displayed in Table 5.5.



Test Statistics[a]

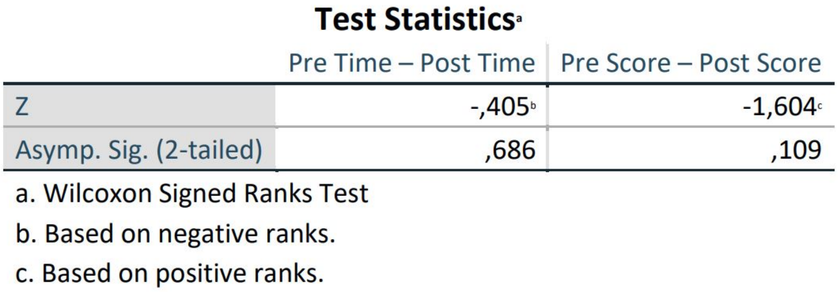
	Pre_Time	Pre_Score	Post_Time	Post_Score
Mann-Whitney U	6,000	6,500	11,000	9,500
Wilcoxon W	21,000	21,500	26,000	24,500
Z	-1,358	-1,261	-,313	-,631
Asymp. Sig. (2-tailed)	,175	,207	,754	,528
Exact Sig. [2*(1-tailed Sig.)]	,222[b]	,222[b]	,841[b]	,548[b]

a. Grouping Variable: VR_or_WIMP

b. Not corrected for ties.

Table 5.5: Mann-Whitney Test (Within-subject)

The Wilcoxon signed-rank test was conducted to see in the WIMP tests if there was a significant difference on the time or scores from pre-test to post test. For this test, the results from the participants that only tested the WIMP version were included. Results show no significant difference for any of the times nor scores as displayed in Table 5.6.



Test Statistics[a]

	Pre Time – Post Time	Pre Score – Post Score
Z	-,405[b]	-1,604[c]
Asymp. Sig. (2-tailed)	,686	,109

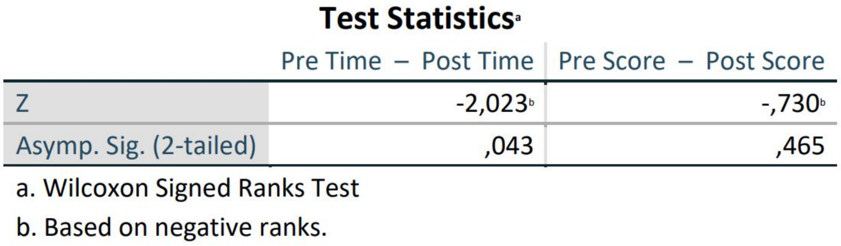
a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

c. Based on positive ranks.

Table 5.6: Wilcoxon signed-rank Test (WIMP Version)

The Wilcoxon signed-rank test was conducted to see in the VR tests if there was a significant difference on the time or scores from pre-test to post test. Results show that there was a significant difference on the time taken to perform the pre-test compared to the post test. Having higher time on the pre-test. (Table 5.7)



Test Statistics[a]

	Pre Time – Post Time	Pre Score – Post Score
Z	-2,023[b]	-,730[b]
Asymp. Sig. (2-tailed)	,043	,465

a. Wilcoxon Signed Ranks Test

b. Based on negative ranks.

Table 5.7: Wilcoxon signed-rank Test (VR Version)

5.8 Discussion

This subsection starts with an overall discussion of the results of both versions. Further along the Between-subject tests and the Within-subject tests are discussed and compared. Lastly the research questions created for the user tests are answered.

Both versions had a positive average WBTL rating. The benefits of visualizing in 3D was discussed in previous researches [3], [8] and [18]. In accordance to said researches, it is noticeable that for both versions of the tool, the ability to see the movement from several angles was always mentioned as one of the most positive aspects of the tool.

Regarding the difficulties of both versions, one of the participants had some difficulty with the controls but said that with time it got easy. Taking into account the open questions about the possibility and viability of having any of the tool's versions featured in the physiotherapy degree, the participants' responses suggest not only that it would improve learning but also make it more engaging. One even stated that it could be used as an evaluation tool.

The statistical tests did not show any significant differences on the time or score for the WIMP version but did show a significant improvement on the time of the VR version from pre-test to post test (Table 5.7).

5.8.1 Between-subject tests

In this subsection the results from the tests performed by the ten users are discussed, where five tested the VR version and five tested the WIMP version. Regarding the time performance, the average time taken was most improved using the VR version, where there was an improvement from 12 minutes and 30 seconds to 7 minutes and 47 seconds (pre-test to post-test). On the other hand, the WIMP version had the most improvement regarding the score performance.

It is important to explain that the learning goal of using any of the versions of the tool were not the patterns present in specific pathologies but instead the how to perform a gait motion analysis, ”where” to look for differences in the normal gait, as well as which aspects should also be taken into account, such as the step-symmetry and waistline dissociation.

The randomized selection of the pathology was implemented to assure exactly this but could have had the opposite effect. The idea was that all gait motion analysis rest under the same ideology of comparing what is being observed to that of a normal gait. In that case, regardless of the pathology presented, the process would be the same. But prior pathological pattern knowledge that students might have were not taken into account as some students already knew that, for example in the Parkinsonian gait, the feet have no dorsiflexion so selections were made based on knowledge instead of observation.

All participants that tested the WIMP version had (randomly chosen) the Hemiplegic gait for the post-test. Given the context explained above and the fact that the sample was only five users, there is no way of generalizing which version was better in terms of performance.

The WIMP version WBLT average rating is 4.3 and the VR version average rating is 4.59. Therefore, the VR version statement agreement, on average, is closer to ”Strongly Agree”, opposed to the average of the statements from the WIMP version that is closer to ”Agree”.

Comparing each component individually, for learning, the VR takes the lead with an average of 4.76 against the 4.12 of the WIMP version. The learning component is the one that has the highest rating from all of the components of the VR tool. The design component is the highest component from the WIMP version components, having a 4.75 average rating, which is higher than the VR version design rating of 4.4. As for the engagement component, 4.6 is the average rating for the VR version where the WIMP’s average rating was 4.05.

Summarizing, results suggest that for the participants in question, the VR version had overall better learning and engagement components whereas the WIMP version had a better design.

From the statistical tests, there were no notable significant differences.

5.8.2 Within-subject tests

In this subsection, the results from the tests performed by five users are discussed (users that after testing the VR version also tested the WIMP version).

Regarding the time performance, the average time taken was most improved using the VR version. However, the WIMP version had a faster time from the pre-test, having an average of 7 minutes and 36 second compared to the 12 minutes and 30 seconds of the VR version. Only one participant from each version improved the score form pre-test to post-test. But it is important to highlight that the score average was higher for both pre-test and post-test on the WIMP version.

The notable improvements, both in time and score, when comparing the two version, could be a result of participants seeing the same pathologies again and performing the same task.

The average rating for the WIMP version given was 4.74, higher than the VR version. Where the learning component is concerned, the VR version takes the edge having an average rating of 4.76, where the WIMP had 4.68. The Design component has an higher average rating of 4.85 on the WIMP version, where the VR has 4.6. For the engagement, the WIMP also has the highest average rating of 4.7 versus 4.6 of the VR version.

When it came down to selecting which version participants preferred, it was found that the VR version was on average better to learn, the most engaging and the most well designed, except for the instructions on the tool, favouring the WIMP version.

The performance improvements (score and time) and the preferred version (VR) cannot be generalized since the within-subject design was not performed as it should have been. The ideal approach would have been to also test the VR tool with the participants that only tested the WIMP version and see if the VR version is still the preferred one. Unfortunately, this was not possible due to time restrictions, Covid-19 and participants’ availability.

From the statistical tests, there were no notable significant differences.

5.8.3 Research Questions

The research questions that the user tests aimed to answer shall be answered in this subsection, starting with the first one: ”Does VR improve the gait motion analysis performance of physiotherapy students more than a WIMP Interface?”. The participants that used the VR version before the WIMP version did have better results on the ladder. It is, however, inconclusive if the VR test performed before had any impact on the outcome. As explained in the Between-subject tests subsection 5.8.1 , there is no way of generalizing which version was better in terms of performance based on a small sample of five participants.

Regarding the second question, ”Is VR better than a WIMP Interface to learn how to analyze gait motions based on observation?” Both Within-subject and Between-subjects comparisons suggest that the VR version of the tool was the one that had the strongest learning potential. The WBTL rating scale showed that for the participants in question, the VR version was always the one with the highest rating for the learning component. Regarding the other components, when compared to the Within-subject tests, the engagement rating was also higher for the VR version. As for the engagement rating of the WIMP version after testing the VR version, the WIMP version had a higher rating but, when given the choice among the two versions, the participants preferred the VR version for all aspects expect for the instructions given by the tool.

The third question ”Is VR better than a WIMP Interface to visualize gait motions?”, in terms of visualization, both version were praised on the possibly of seeing the movement from several angles. However, the participants also commented on the liberty of movement of the VR tool and how easy it was to focus on a specific part of the body, as well as the level of detail as being the most positive aspects of the tool, which were not a factor on the WIMP version.

Chapter 6

Conclusions

This chapter presents the conclusions of this dissertation followed by a final discussion of the research problem. Limitations are presented and ideas on how to tackle them in future work.

6.1 Conclusions

The lack of students' contact with patients prior to the internship and the 2D information, such as videos and textbooks used to teach how to analysis a gait motion, proved to be limiting for both learning and teaching.

These limitations led to the formulation of this dissertation's research problem: Can immersive VR (camera control freedom, wide reachable spaces, large range of motions, non-stationary user postures, 3D perception) provide any positive impact on how physiotherapy students view and learn gait motion?

In order to answer this question, two major contributions were developed, the VR version of a tool to help physiotherapy students learn how to make a gait motion analysis and a WIMP version of the same tool.

The user tests allowed an evaluation of the tool itself, focusing on three components: learning, design and engagement. The tool was well received by the users in both versions. Overall, the VR version was the preferred version by the participants in terms of learning and engagement, only falling short on some aspects of the design component when compared to the WIMP version.

Answering the research problem of the dissertation, user feedback suggests that the freedom, wide reachable spaces and 3D perception, only present in VR applications, brings improvements to viewing gait motions, since several of these aspects were mentioned by participants as the most positive aspect of the tool. Where learning is concerned, the participants did feel they have learnt by using the tool. Some even stating, as one of the most positive aspects of the tool: ”the good learning process”. The limitations from videos and textbooks were also addressed, as one of the participants stated: ”I believe that it is very educational and that it helps a lot to learn compared to videos and theory explained verbally.”

6.2 Limitations and Future Work

The major limitation of this study was the small sample of only five users to test the VR version. It proved to be limiting because it made it impossible to have a statistical analysis of the results (time and score) that would allow the generalization of the sample to a broader population.

Another limitation was also related to user tests, specifically, the way they were conducted with the randomized pathologies. Some selections might have been made based on knowledge instead of observation.

For future work, a further user testing could be made with more participants, where the post-test would be separated from prior sessions using the tool instead of an one-hour slot for everything. Removing the randomized feature or performing a pathological gait pattern knowledge test prior to testing to access what was and what was not selected based on observation, could fix the ambiguity of the results.

With a bigger sample, the between-subject study could be conducted to, not only determine in terms of performance (time and score) whether there is a significant difference between the two versions, but also generalize which version is the preferred in terms of learning design and engagement.

The current prototype of the tool only has three pathological gaits, which is a limitation but also a future work opportunity. By improving and integrating the process of acquiring pathological gait animation, it would be possible to create a version of the tool that would allow professors to prepare any pathology for students to learn with or even be evaluated. This would help future students to be better prepared for internships, and thus make a faster and more efficient analysis, which would minimize students requests for patients to repeat movements.

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Appendix A

Interviews

A.1 Professors Interview

Guia de Entrevista a Professores Sobre análise para deteção de marchas patológicas sua aprendizagem em Fisioterapia

Miguel Renda

81061 Instituto Superior Técnico

Entrevistas de 5 a 10 minutos a pelo menos dois professores de Fisioterapia

Introdução:

Sou aluno do Instituto Superior Técnico e estou a realizar a minha tese de mestrado sobre como resolver as limitações existentes no ensino do movimento de marcha em fisioterapia. Estou a ser orientado pelo Professor Daniel Simões Lopes e pelo Professor Hugo Nicolau.

Solicitei a marcação desta entrevista uma vez que o estudo que estou a desenvolver é fundamental compreender a perspetiva dos professores sobre as dificuldades ou aspetos que se podem melhorar no ensino e estudo da fisioterapia.

Pretende-se perceber o contexto global do ensino dos movimentos de marcha e obter informações sobre as ferramentas utilizadas neste ensino e sobre a forma como estas ferramentas são utilizadas assim como conhecer os procedimentos e exercícios pedidos aos alunos.

Objetivos:

(nota: não explicitar formalmente os objetivos aos entrevistados para não condicionar as respostas)

- Perceber como é ensinado a análise para deteção de marchas patológicas e o que caracteriza diferentes movimentos de marcha.
- Compreender o papel dos vídeos 2D e suas limitações no ensino de análise para deteção de marchas patológicas.
- Conhecer os exercícios práticos feitos para aprender e treinar a analise para deteção de marchas patológicas.

Perguntas:

No ensino da fisioterapia, nomeadamente no que respeita aos movimentos de marcha os estudantes devem saber fazer análise para deteção de marchas patológicas com base na observação?

Como é feita a análise para deteção de marchas patológicas?

- Em que consiste exatamente uma análise de deteção de marchas patológicas?
- Que membros se deve ter em atenção para fazer uma análise de deteção de marchas patológicas?
- E relativamente à velocidade, ângulos, posicionamento de membros e articulações?

O que é importante aprender para fazer análise para deteção de marchas patológicas?

- Características do movimento de marcha?
- O que observar no movimento para fazer o diagnóstico?

Como é ensinada a análise para deteção de marchas patológicas?

- Os movimentos de marcha são ensinados de diferentes maneiras em função das diferentes patologias que os possam influenciar? (exemplo: se a maneira como se ensina movimentos de marcha afetados pela doença de Parkinson é diferente da maneira como se ensina movimentos afetados por um AVC)
- Que ferramentas são usadas neste ensino?
- Vídeos?

Limitações?

- Onde sente que os alunos sentem mais dificuldade na aprendizagem dos movimentos?
- Onde é que os alunos sentem mais dificuldades com a utilização das ferramentas de ensino?
- Que limitações e problemas a utilização dos vídeos trazem?

Como são avaliados os alunos na sua capacidade de analisar e detetar marchas patológicas?

- São simulados movimentos?
- Os alunos diagnosticam-se uns aos outros?
- São realizados exercícios de avaliação?

Sugestões de técnicas que na sua opinião melhor dariam resposta ao ensino da análise para deteção de marchas patológicas?

Agradecimento:

Muito obrigado pela sua disponibilidade e partilha de opinião.

A.2 Students Interview

Guia de Entrevistas a Alunos Sobre análise para deteção de marchas patológicas sua aprendizagem em Fisioterapia

Miguel Renda

81061 Instituto Superior Técnico

Entrevistas de 5 a 10 minutos a pelo menos dois professores de Fisioterapia

Introdução:

Sou aluno do Instituto Superior Técnico e estou a realizar a minha tese de mestrado sobre como resolver as limitações existentes no ensino do movimento de marcha em fisioterapia. Estou a ser orientado pelo Professor Daniel Simões Lopes e pelo Professor Hugo Nicolau.

Solicitei a marcação desta entrevista uma vez que o estudo que estou a desenvolver é fundamental compreender a perspetiva dos professores sobre as dificuldades ou aspetos que se podem melhorar no ensino e estudo da fisioterapia.

Pretende-se perceber o contexto global do ensino dos movimentos de marcha e obter informações sobre as ferramentas utilizadas neste ensino e sobre a forma como estas ferramentas são utilizadas assim como conhecer os procedimentos e exercícios pedidos aos alunos.

Objetivos:

(nota: não explicitar formalmente os objetivos aos entrevistados para não condicionar as respostas)

- Perceber como é ensinado a análise para deteção de marchas patológicas e o que caracteriza diferentes movimentos de marcha.
- Compreender o papel dos vídeos 2D e suas limitações no ensino de análise para deteção de marchas patológicas.
- Conhecer os exercícios práticos feitos para aprender e treinar a analise para deteção de marchas patológicas.

Perguntas:

Como é feita a análise para deteção de marchas patológicas?

- Em que consiste exatamente uma análise de deteção de marchas patológicas?

- Aprendeu em que ano?
- Aprendeu como a marcha é afetada por doenças ex: parkinson? (Neuro)

Como é que lhe foi ensinada a análise para deteção de marchas patológicas?

- Que ferramentas são usadas neste ensino?
- Vídeos?
- Observam doentes?

Onde usa a análise para deteção de marchas patológicas?

- Estágio?
- Tem contacto com doentes?

Limitações?

- Onde sentiu mais dificuldade na aprendizagem dos movimentos?
- Onde é que sente mais dificuldades com a utilização das ferramentas de ensino?
- Que limitações e problemas a utilização dos vídeos trazem?

Como foi avaliado na sua capacidade de analisar e detetar marchas patológicas?

- São simulados movimentos?
- Estágio?

Sugestões de técnicas que na sua opinião melhor dariam resposta ao ensino da análise para deteção de marchas patológicas?

Agradecimento:

Muito obrigado pela sua disponibilidade e partilha de opinião.

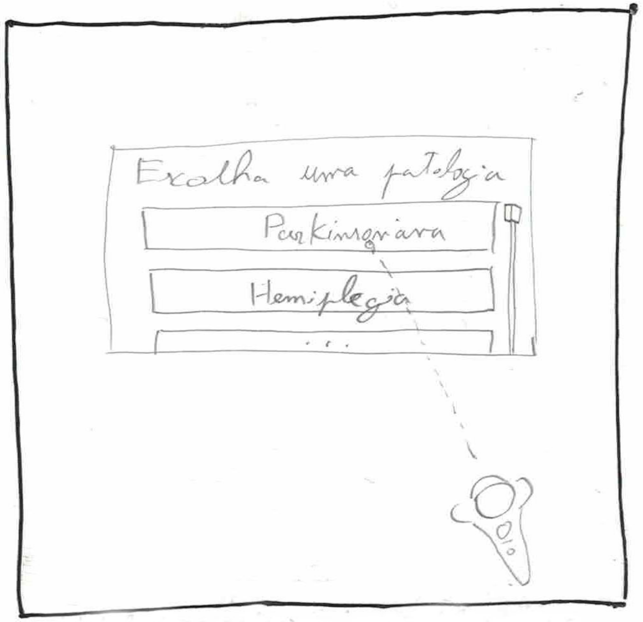
Appendix B

Storyboards

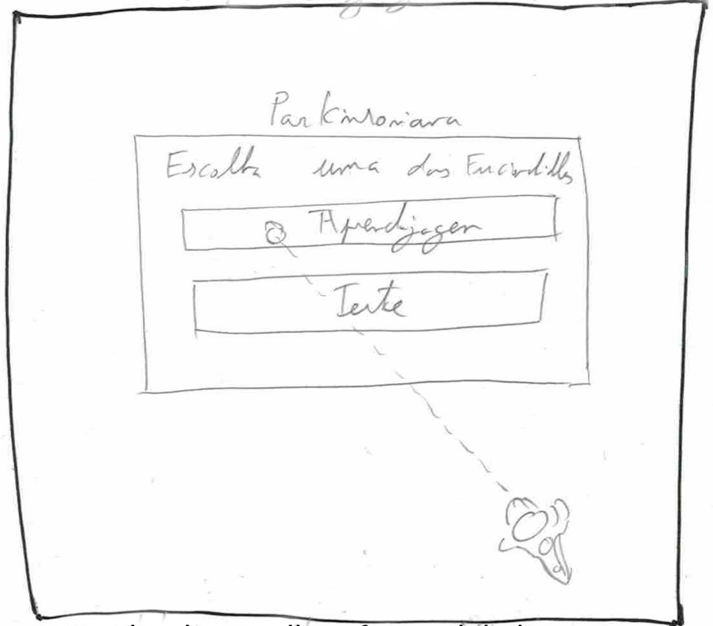
This appendix shows the storyboards made during the development process.

B.1 Storyboards Prototype Idea

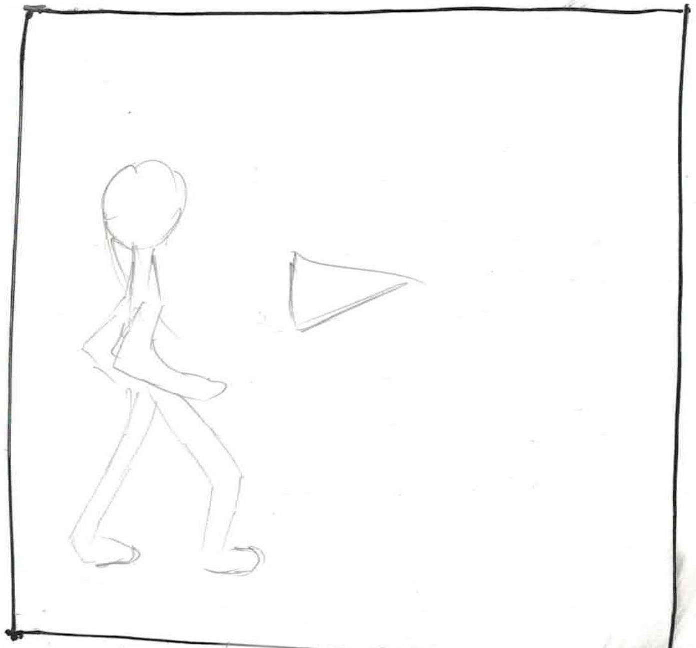
Aprendizagem - Modo Seleção



O Utilizador seleciona a patologia que quer.



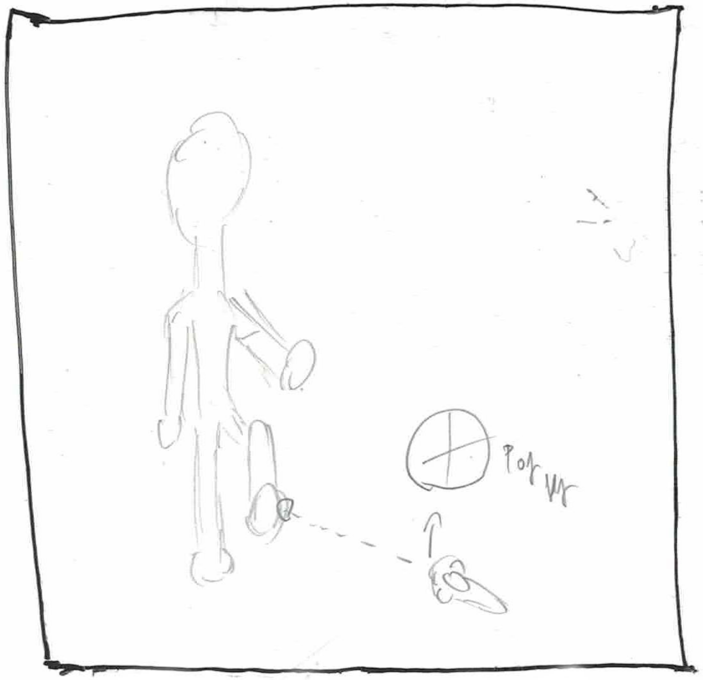
O utilizador escolhe a fucionalidade que quer.



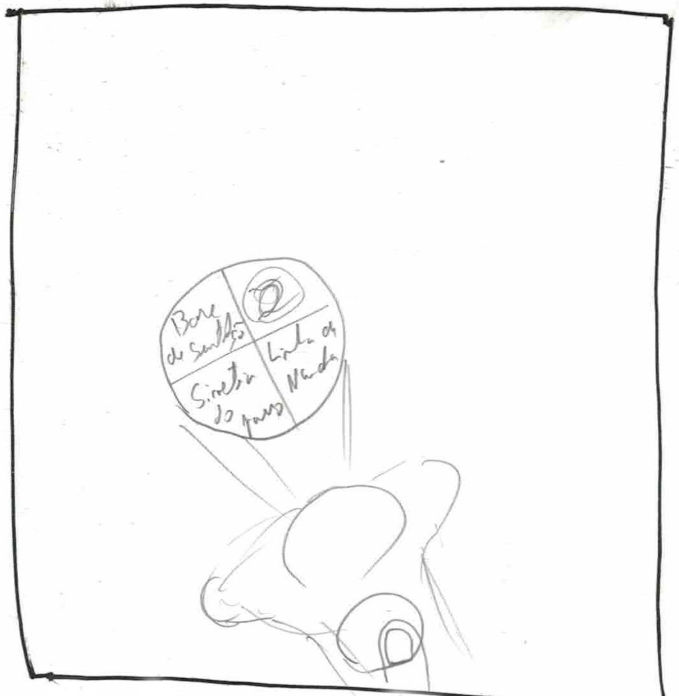
A animação do avatar começa

O utilizador liga os auxiliares e põe a animação em pausa. Dentro dos auxiliares temos:

- Pegadas
- Avatar da marcha "normal" (fantasma)
- Linha da marcha

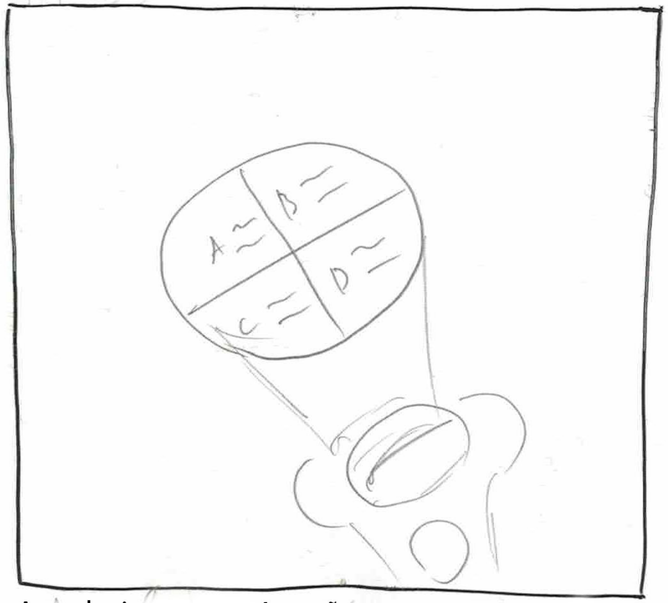


O utilizador seleciona um dos membros que não esteja posicionado conforme a marcha "normal"

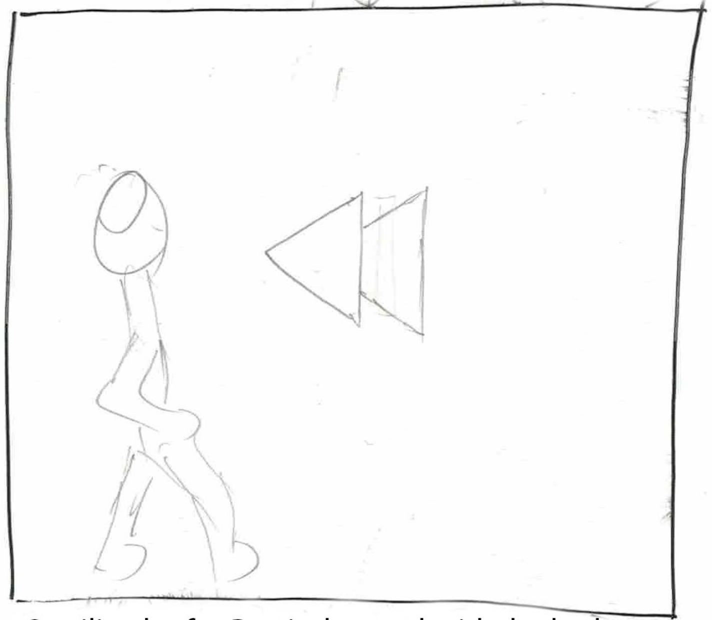


Um pop-up de seleção rápida aparece para que o utilizador selecione a razão da sua seleção

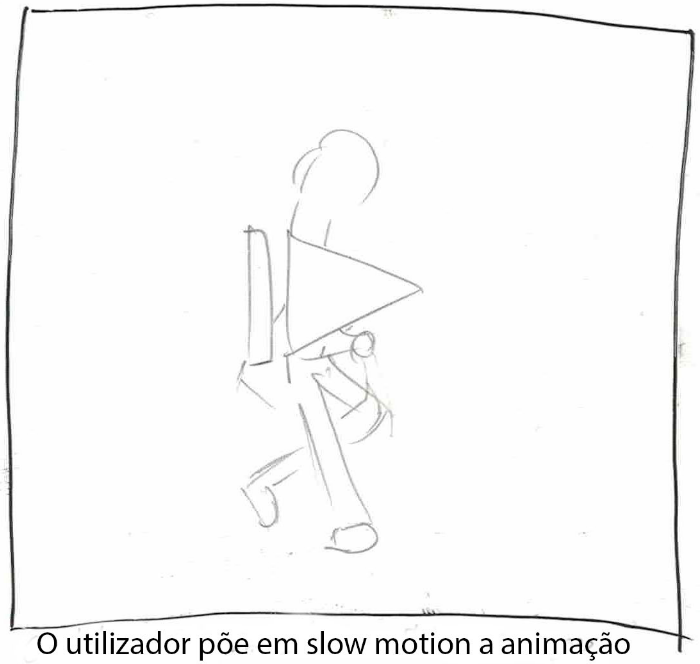
Aprendizagem Modo-Selecção



Ao selecionar uma 4 opções aparecem
para selecionar a justificação da seleção do membro



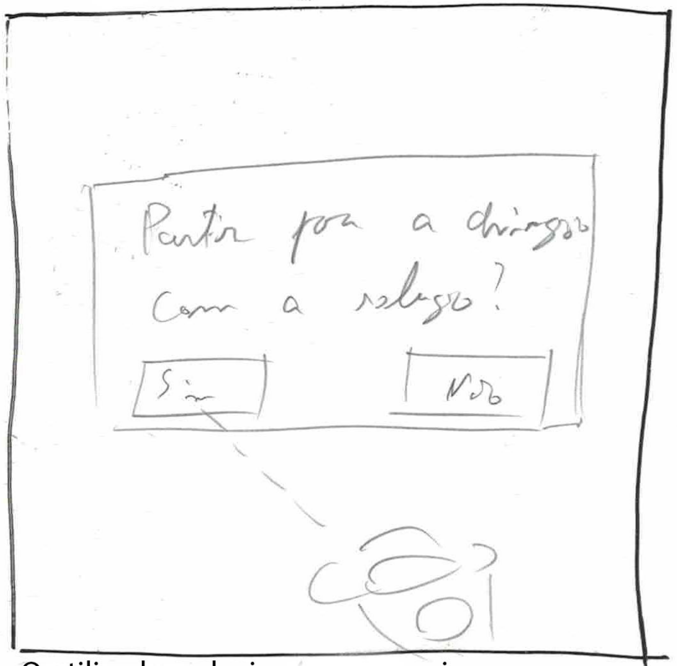
O utilizador faz Rewind em velocidade dupla para
voltar ao inicio da animação



O utilizador põe em slow motion a animação

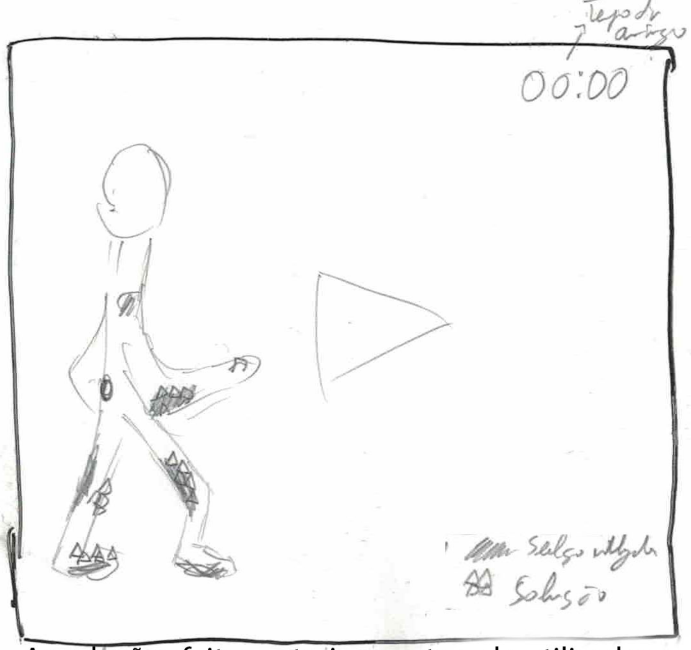
O utilizador termina a vizualização depois de
ter feito todas as seleções onde pensa que a
a marcha teve anomalias

O utilizador vê um review final das suas seleções
e pode ainda seleceionar anomalias não detetadas
na marcha

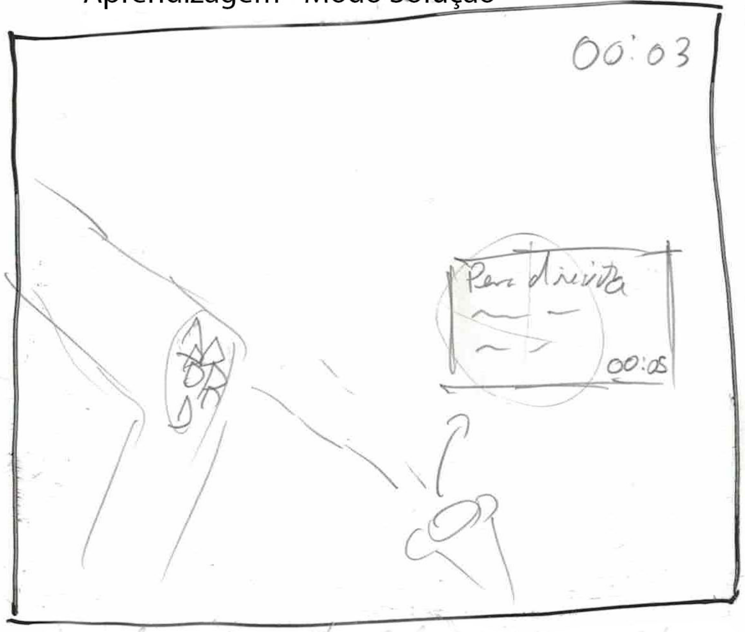


O utilizador seleciona que quer ir para o
"Modo Solução" da aprendizagem

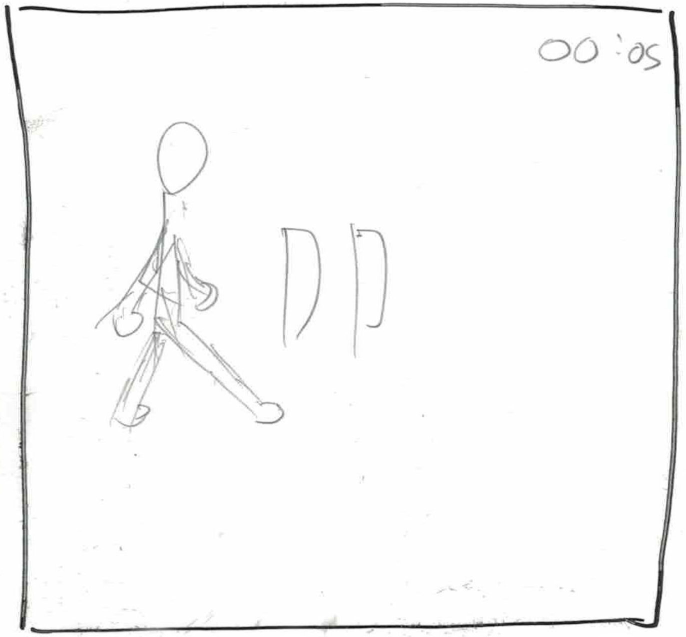
Aprendizagem - Modo Solução



As seleções feitas anteriormente pelo utilizador aparecem destacadas no avatar tal como a solução



Ao selecionar uma das soluções aparece o porquê de ser uma das anomalias na marcha e indica o momento em que acontece na animação. Para que o utilizador possa verificar



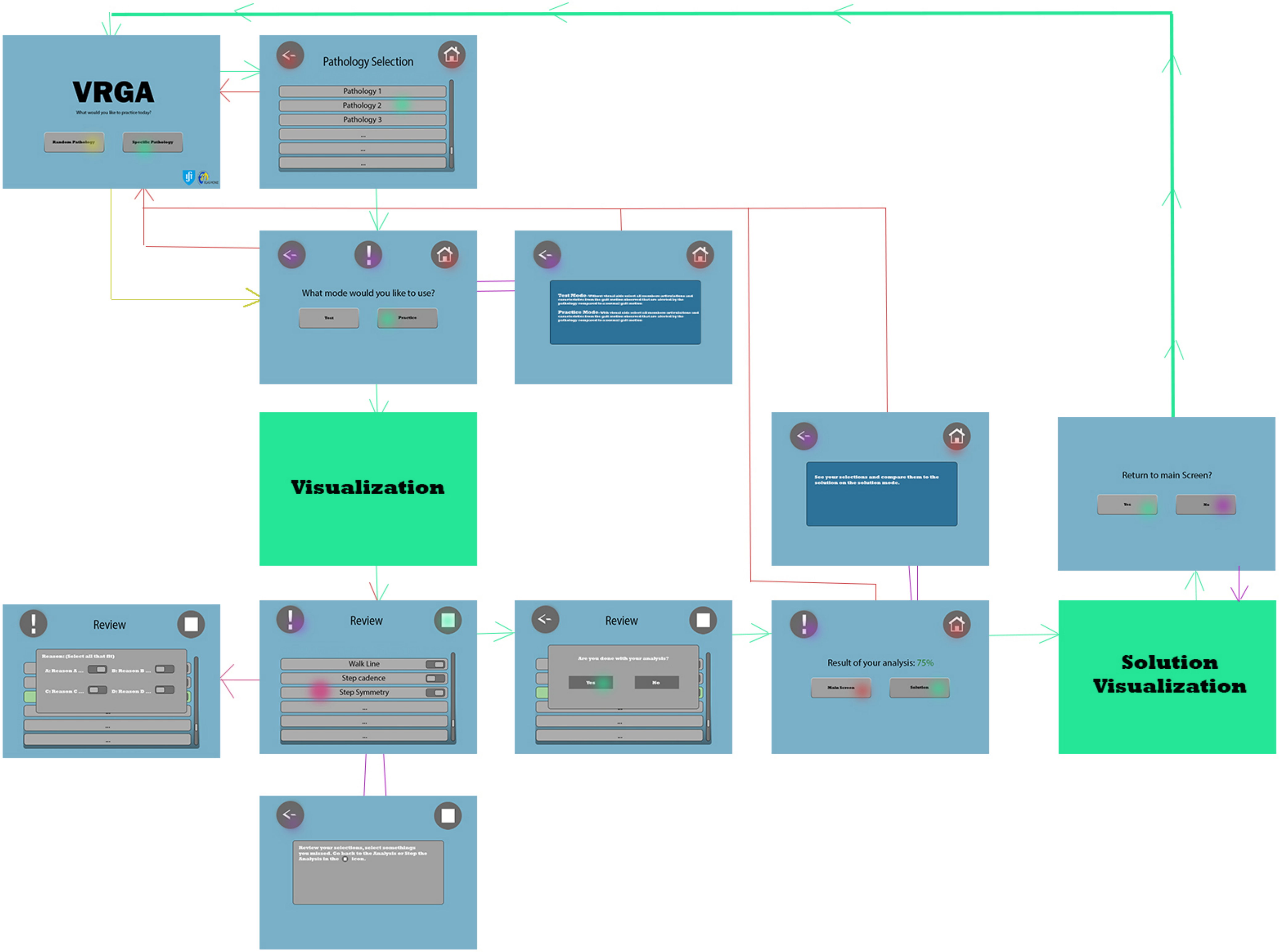
O utilizador pára a animação no momento indicado e analisa o que tinha falhado na sua seleção

O utilizador termina a vizualização depois de ter visto tudo o que falhou e acertou na sua analize do movimento

A funcionalidade "Teste" funciona da mesma maneira que a aprendizagem sendo que não tem os auxiliares à analise do movimento como as pegadas, linha da marcha, fantasma da marcha normal. O utilizador tem que selecionar da mesma maneira membros que estajam mal posicionados e outras falhas na marcha.

Depois aparece como na aprendizagem o Modo solução

B.2 Storyboards Prototype User Interface



See your selections and compare them to the solution on the solution mode.

Review your selections, select somethings you missed. Go back to the Analysis or Stop the Analysis in the ■ icon.

Appendix C

Consent Form

TÉCNICO
LISBOA

Consentimento Informado

Exmo.(a) Sr.(a),

No âmbito do Mestrado em Engenharia Informática e de Computadores do Instituto Superior Técnico, sob a orientação do Professor Doutor Daniel Simões Lopes e do Professor Doutor Hugo Nicolau, solicita-se autorização para a participação no estudo *“Learning Your Moves: A Virtual Reality Educational Tool for Physiotherapy Students”,* como aluno de fisioterapia de 2º ano (ano letivo 2019/2020) com o objetivo de testar ferramenta de aprendizagem da análise da marcha em realidade virtual.

O estudo consiste na utilização de óculos de realidade virtual HTC Vive em que ir-se-ão realizar quatro momentos de testes da ferramenta em que, o primeiro, irá consistir num tutorial da ferramenta e na autoaprendizagem do manuseio da mesma por parte do participante, no segundo ir-se-á estudar um tipo de marcha patológica, no terceiro será proposta a exploração livre da ferramenta com duas patologias e, no quarto, ir-se-á realizar um teste de uma terceira marcha patológica, desconhecida do participante, que visa inferir se adquiriu nos testes anteriores, a capacidade de analisar adequadamente quando deparado com uma nova patologia. Pretende-se, através da realização destes testes experimentais, entender a interação do participante/interface e recolher dados relativos à capacidade de aprendizagem e análise da marcha através da ferramenta em realidade virtual. A realização dos testes terá lugar no Campus do Tagus Park, do Instituto Superior Técnico, em Oeiras e terão uma duração de aproximadamente 1h por participante.

A participação neste estudo é livre e voluntária e a sua não participação não lhe trará qualquer prejuízo. Este estudo pode trazer benefícios no âmbito do ensino da marcha a alunos de fisioterapia através da experiência em realidade virtual bem como progressos ao nível da aplicabilidade da engenharia informática, nomeadamente, da realidade virtual em prol da investigação e da educação no contexto da saúde. Os dados serão recolhidos através da recolha dos resultados, filmagem dos procedimentos na utilização da ferramenta e ainda através de questionário final.

Consentimento Informado

A informação recolhida é anónima e confidencial e destina-se unicamente a publicação e será tratada pelo mestrando Miguel Alexandre Aço Renda. No seguimento das provas públicas de defesa da dissertação em causa os participantes poderão ter acesso aos resultados do estudo contactando o mestrando.

(Riscar o que não interessa)

ACEITO/NÃO ACEITO participar neste estudo, confirmando que fui esclarecido sobre as condições do mesmo e que não tenho dúvidas.

Nome completo do participante:

____

____

(Assinatura do participante)

Data: ___________________, _____ de _____________ de 2020.