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 study 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 study, 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.

Author Keywords
Virtual Reality; Physiotherapy Education; Gait Motion.

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 [10][6].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 [10]. 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 study 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. This analysis is taught by observing repeatedly gait motions affected by different health conditions, such as a disease or genetics. Here lies the base for the motivation of this study, 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. 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 the 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 theoretical prepared, they struggle to make an efficient and precise gait motion analysis.

This study 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 study 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.

RELATED WORK

The related work discusses previous 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. [9] due to the fact that their study has similar goals as this study. 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 [9] are used in several of the systems from the researched contributions like, Winning compensations[2], Physio@Home[14] and YouMove[3]. They lack the purpose of education but 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. [9] 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. [1] where the video had the poorest results.

Visualizing in a 3D space though a 2D display is what this study's WIMP tool aims to do. An example of what can be done for 3D motion visualization is MotionMA [15] 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 [3] (which is a similar example) also has indicators of the 3D motion visualization importance once taken into account the better results from the rehabilitation exercises. Physio@Home [14] had a dynamic on-screen movement guide called the Wedge tested with different types of visualization and 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 [4] is a good example of what can be done in VR for education with motion visualization. The Vive trackers enable the user to learn the muscles movement by moving with them. Bruner et al. [4] believe the application's immersive environment contributes to teaching three-dimensional spatial awareness and fundamentals biomechanics in anatomy education.

Another similar approach was Hülsmann et al. [7] 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. [10] shows. Some examples of successful uses of VR in this domain are Marks et al, [11] a contribution that proposed a system to teach the Nasal cavity and its airflow. Falah et al. [5] proposed a 3D visualization system for students to learn the human heart, Jang et al. [8] to learn the inner ear anatomy and Nazir [12] 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. 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.

UNDERSTANDING GAIT MOTION ANALYSIS

Two major user studies were 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. The results from the interviews were grouped into two major groups with the help of affinity diagrams, results that help understand how gait motion is taught and results that show what limitations are present in gait motion education.

User study 1: Interviews with Professors

The interviews were conducted on 4 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 7 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 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.

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 main goal of this study was 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.

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 on 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.

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. Students' inaccessibility to said videos since professors cannot share the patients' videos. The internship ends up being the first time students have real contact with patients.

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, using videos and slides, students stated that it was difficult to visualise the movement.

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.

PROTOTYPE

The objective, when using the prototype tool, is to analyse gait motions based on observation. Two versions for the tool were developed, the VR version and the WIMP version. 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 limbs feature was the result of a discussion in an interview with P2 using storyboards. 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. The content of the prototype was discussed in an interview with a neuromuscular physiotherapy professor at the end of development to assure that there were not any theoretical inconsistencies on what was said to be the correct selections.

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.

Architecture

The architecture of the prototype is represented in Figure 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.

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 3 pathologies, the normal gait and a T-pose.

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.

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. From that data it is possible to plot animations to an avatar (character). Once plotted, the avatar and the animations were exported from Motion Builder as a .fbx file.

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. However, 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.

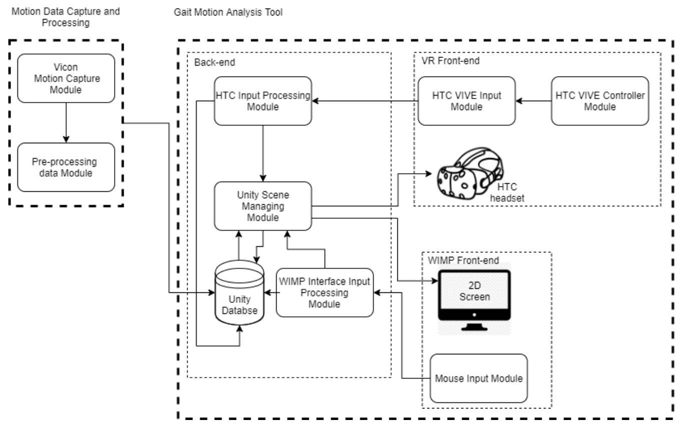

Figure 1. Architecture of the Gait Motion Analysis Tool Prototype.

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 of tool. The difference is the way they are controlled, receive and process input, which is explained further along 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 4 buttons, tutorial, pre-test, practice and post-test. Each time the tool is started, it randomly selects one 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.

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

The Home button allows the user to go back to the main menu scene at any time but 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. The Review Menu also allows the selection of the limbs and articulation, as well as simply checking what selections have been made.

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

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.

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.

Figures 2 and 3 showcase the Tutorial scene on the VR and WIMP versions respectively.

Unity Database

There are in total 5 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 4 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

Figure 2. Tutorial Scene VR version

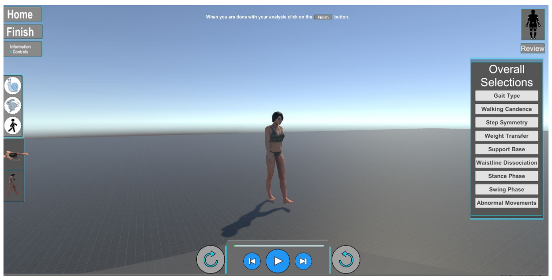

Figure 3. Tutorial Scene WIMP Version.

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.

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]".

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 loading the Main Menu scene.

HTC VIVE Input Module

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 and both move with the Main camera (from the HTC headset) so it is always one click away regardless of the user's position.

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

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.

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 3 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.

The buttons on the controllers are displayed in Figure 4.

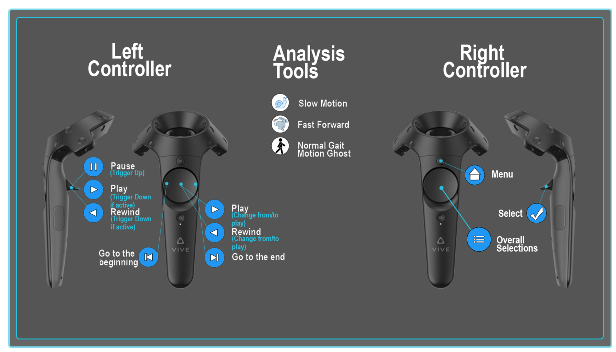

Figure 4. VR Version Controls.

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 method ScreenPointToRay().

Mouse Input Module

The mouse controls and button layout are as displayed in Figure 5. The logic behind all buttons is the same. Some use event triggers for, for example, the hovering on the Overall Selections that enables a pop up to appear showing what reason is selected, if any.

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.

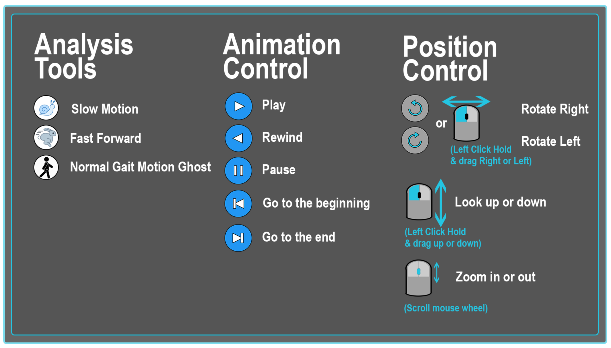

Figure 5. WIMP Version Controls.

EVALUATION

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?

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.

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. It was also used a Canon EOS 750D and a tripod to record videos of the participants tests.

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.

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. 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 as well as the averages scores. The mean rating from the (WBLT) evaluation scale [1] 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.

Procedure

The user tests were the same for both versions. Participants started by signing a consent form 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.

• 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 [1] 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.

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.

Covid-19 Measures

The VR tests were done following sanitary and safety rules and instructions given by the DGS and the Tagus Park facility Management Unit. One day was scheduled for testing. 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. Additionally 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" [13]. 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.

Results

Both versions had a positive average WBTL rating. The benefits of visualizing in 3D was discussed in previous researches [9], [4] and [1]. 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.

Between-subject tests

In this subsection the results from the tests performed by the ten users are discussed, where 5 tested the VR version and 5 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. 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.

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 availability from the participants.

From the statistical tests there were no notable significant differences.

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 results, 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 a 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.

CONCLUSION

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 study'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 study, 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."

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 faster and more efficient analysis which would minimize students requests to patients for repeating movements.

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