A NOVEL SOLUTION BASED ON VIRTUAL AND AUGMENTED REALITY FOR BIOMECHANICS STUDY

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This paper contains the implementation details of a solution aimed to improve the learning process during the biomechanics study. The original aspect of the paper consists in the usage of Virtual and Augmented Reality to assess the quality of their benefits in the educational area. The Virtual Reality setup contains two scenarios due to the cybersickness that was encountered while testing and developing the application. The Augmented Reality version contains both markerless and marker-based approaches and we provide details about the challenges and drawbacks of each scenario.

Keywords: Virtual Reality, Augmented Reality, Medical Imagistics

1. Introduction

Lately Virtual Reality (VR) and Augmented Reality (AR) have seen popularity surges. The large number of hardware and software solutions are offering new methods to develop special designed applications. VR and AR are discussed topics for many years and their development is in the best time. They can be used on various areas to create new experiences that will keep the user engaged. Our focus is on healthcare and more exactly we are presenting a novel solution for biomechanics study. Only an AR application was initially considered, but with the current tools available on the market this would be a great opportunity to design and develop a system that targets both. The aim is to test these applications on various users and based on their feedback to assess the impact of each technological system.

Healthcare is one of the beneficiaries of the development of AR and VR. Their main advantage is that they can simulate various operations/scenarios that look very realistic that can be effectuated in a safe environment. For example, medical personnel can be trained on various OR (Operating Room) procedures to get accustomed with the process before entering into a real situation. For example, *OssoVR*[3] is a solution that provides realistic hand-based interactions in an

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[3] http://ossovr.com/

immersive training environment for virtual surgeries of orthopedic and spine therapies.

In the next sections, we'll asses the state of the art on the usage of VR and AR based solutions available in healthcare and will continue with the details of our proposal. The chosen solutions are described along with their benefits and drawbacks. Sensitive issues such as cybersickness have been addressed and alternative solutions are presented. The results section contains brief data regarding the feedback obtained after user testing. Although the number of biomechanics notions is a reduced one, we consider that the obtained results are a confirmation that this idea has a high potential for future development.

2. State of the art

At the start of this project, we reviewed the state of the art of the available solutions based on Virtual and Augmented Reality in healthcare. We considered with priority the newer publications and we selected the year 2014 to be the threshold. A total of 77 papers were reviewed where we found 34 to contain relevant data for our research. The data was divided based on their publication date to ensure that newer solutions are taken into consideration. In Fig. 1 are showcased the topics of the reviewed papers.

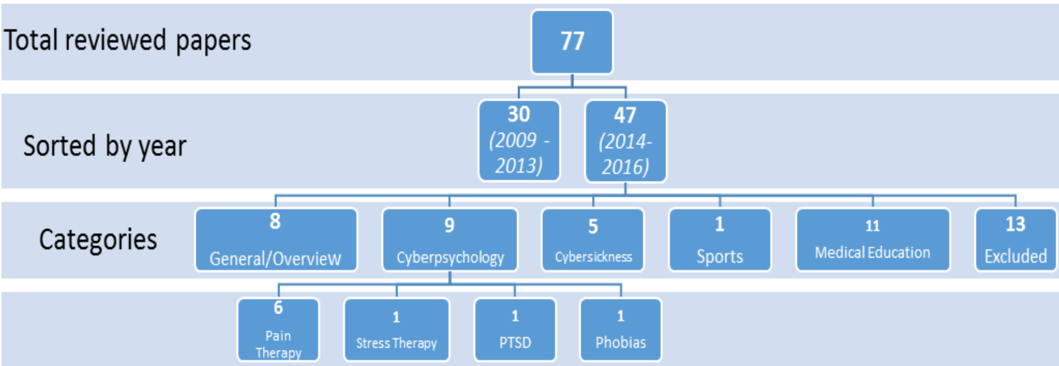

Fig. 1. Schematic view of the studied scientific papers
**PTSD- Post Traumatic Stress Disorder*

After an analysis of the studied scientific papers we could observe that the biggest interest is for the medical education field and that the majority of the papers are focused on the medical imagistics. The next topic of interest is cyberpsychology where the pain therapy had the leading role in the encountered topics. Since the area of our research is mostly related with the medical education field, a closer attention was given to this category where 11 scientific papers were selected. The first one [1] contains three examples of AR solutions used for medical training:

a. Visualizing human anatomical structure with AR. The solution is the *magic mirror 'Miracle'* project that augments CT data onto the body of a trainee. The display is a TV and the tracking is acquired with a Kinect device.
b. Visualizing human 3D lung dynamics with AR. A system that allows real-time visualization of the lung dynamics superimposed directly on a patient in the OR.
c. Training laparoscopy skills with AR. The AR laparoscopy environments offer realistic haptic feedback that is crucial for training the necessary skills.

The second scientific paper [2] presents a video see through solution based on AR HMD (Head Mounted Display) for medical procedures, such as maxillofacial surgical clinical study, orthopedic surgical clinical study and AR magnetic guidance of endovascular device. The third paper [3] presents an instructive HMD system that uses a vision finger tracking technique applied to medical education. Reference [4] presents a virtual reality surgical simulator (Gen2-VR) where 3 different scenarios are considered for the experiment design: "*the user interacts with simulation scenario presented on a computer monitor*", "*the user interacting with the simulation scenario within a HMD, but without distractions and interruptions*" and "*the user interacts with the simulation scenario within a HMD with distractions and interruptions*". Reference [5] presents applications of AR in OR. For example, augmenting the visualization for surgical navigation. Four situations of augmented guidance were approached in that scientific paper, based on the medical imagistics modality: augmented X-ray guidance, augmented ultrasound guidance, augmented video and SPECT (Single-photon emission computer tomography) guidance and augmented endoscopic video guidance. Reference [6] presents a stereoscopic viewer of the results obtained from vessel segmentation based on 3D magnetic resonance angiography images. The solution uses Unity game system for development, Oculus Rift to display the VR content and Leap Motion controller to track the user's hands movement. An educational solution that uses VR for image guided deep brain simulation neurosurgery is presented at reference [7]. Another solution based on VR is available at [8] where the 3D technologies and the stereoscopic visualization is used in medical endoscopic teleoperation. The last 3 scientific papers [9-11] refer at different areas of development of a solution based on AR for in situ visualization of craniofacial region with volumetric datasets (MRI – Magnetic Resonance Imagistics or CT – Computed Tomography images). In these papers, two approaches are available for AR visualization: a semi-automatic markerless augmented reality approach and a markerless AR environment. The markerless live tracking is done based on the registration between the 3D reference model and the 3D model captured by the tracking sensor [9].

These solutions were a starting point to design our own proposal. A detailed description for it is available in the next chapter with a brief comparison between our solution and the projects mentioned in this chapter.

3. Our proposal

Based on the state of the art and the current available technologies we developed a solution that uses VR and AR for biomechanics study. These technological systems are an opportunity to be used as a learning platform. With a moderate additional time, we can have the chance to test one approach over the other in separate scenarios thanks to the versatility of the current game system engines like Unity. With VR we can isolate the user from the external factors since the user usually wears a HMD and can have a pair of noise cancelling headsets eliminating external disturbance factors. On other side, in the AR scenario the user is highly immersed, making the experience more realistic. Our aim is to test these scenarios and observe which one has a higher impact.

Biomechanics is the study of mechanical laws relating the movement and structure of living organisms. Our focus will be only on the human biomechanics and will cover basic notions. The presented applications can be considered a proof of concept and further additions can be applied, in case it proves its success. The solution contains 4 simple lessons that cover different areas. The first one contains information about human anatomy, followed by (hypothetical) anatomical planes that are used to transect the human body to describe the location or the direction of the movements. The third lesson contains 6 reference points situated on wrist, elbow, shoulder, hips, knee and foot joint and their position versus their neighbors. The final lesson presents basic movements such as: *flexion/extension* of the upper and lower limbs and the whole body, the *adduction* and *abduction* of the left hand and foot and the *pronation* and *supination* of the right hand.

The lessons use realistic 3D models that were obtained from medical images [12]. Rigged models of bones, muscles and skin were obtained based on the segmentation of a CT dataset of a woman that was diagnosed with melanoma. The benefit of this approach was the fact that we could obtain anatomical realistic data for a zero cost. However, the process could benefit from some improvements. As a result, the bones model was the one that was obtained the easiest and has the best fidelity with the anatomical data. The muscles and skin were more complex, where the muscles models required the most work and attention. The current version of the application uses only the bones model as they are sufficient to present the basic biomechanics notions. In the future, we can add more information and maybe even the simulation of muscles deformation that occurs during movement.

Our proposal uses the latest technology and aims to provide a mobile, cost effective solution for the study of biomechanics. We consider 4 scenarios to be used with this application, where 3 of them have a similar structure. Similar with [6] the solution is developed using Unity. For VR display we used a Cardboard viewer on top of a Samsung S6 device. This was chosen instead of an Oculus Rift as the compatible graphical card for Oculus Rift development has very high specs and comes with high additional costs. This requirement is because the Oculus Rift device doesn’t have a processing source and relies on the attached workstation capabilities. However, we consider that our approach will be affordable by many students since mostly everyone owns a smartphone device as opposed with the costly Oculus Rift device. A Cardboard viewer or similar are available at small prices (~15 USD) or can be manufacturer at home based on instructions. Similar with [9-10] two approaches were considered for the AR environment (markerless and marker based). Looking at the experiment design cases, the proposed solution has the options in the same lines with reference [4]. They considered the use of 3 scenarios: on a computer, with a HMD with interruptions and with a HMD without interruptions. For the proposed solution the following design approaches were considered: with HMD without interruptions (using additionally noise canceling headsets), with HMD without interruptions and without a closed environment (to avoid cybersickness), on a mobile device with marker-based AR and on a computer/TV screen with markerless AR where the user can see the virtual models on top of their body as an overlay. The fourth scenario is comparable with *magic mirror ‘Miracle’* project, where the user can see the anatomical structure on top of a user’s image. The advantage of the implemented solution is that the whole body is displayed with the anatomical 3D model imposed over the user’s image, replicating the user’s movements. However, this scenario doesn’t have the lessons implemented as the rest of them since the method of interaction, visualization and setup is completely different. More details about each setup and results are offered in the next two chapters.

4. Virtual Reality

The project’s VR setup consists of a Cardboard viewer that is attached to a Samsung S6 smartphone. The resolution of the device is 2560x1440 pixels with approximatively 577 ppi density hence the quality of the displayed scene in stereoscopic rendering is not significantly affected by this type of display. The hardware capabilities are currently sufficient since during the implementation and testing of the VR setup no framerate issues were encountered. Usually VR rendering is a costly one due to stereoscopic rendering but in this case no performance issues were encountered as the scene was fairly simple with a reasonable number of elements. The setup is showcased in Fig.2. This was developed using Unity game system, version 5.6.0b.10.

Fig. 2. Cardboard viewer and Samsung VR setup

The scenarios based on VR have as result two separate applications: one with a classroom background and one without any closed space. This division was necessary as while testing the application some users felt uncomfortable after a few seconds due to the cybersickness. This was diminished when the VR scene was changed to an open space environment. The applications are displaying the information at runtime in distinct positions, to maximize the potential of the rendered environment. For example, in the application with the classroom environment we chose to display the information on a board, similar with the reality, to maximize the immersion of the user. The 3D elements that are displayed in the VR classroom application are imported from *Props for the Classroom* package from Unity Asset Store [https://www.assetstore.unity3d.com/en/#!/content/5977].

Both applications have the same method of interaction. A pointer element (red dot) was used and it was drawn all the time in the center of the camera space. Since the display was stereoscopic on the device, the center was considered the center of an eye. The user could use it to navigate through the menus or to select various elements from the 3D scene. The viewer has a mechanism that taps the device's screen and replaces a generic select button.

The lessons are grouped under an empty game object and each of them contains different elements necessary for the display. First lesson (Anatomy) contains panels that use images with the anatomical information as textures. To select a bone, a set of 'fake targets' is used. The scene contains 15 capsules that have attached a material that makes them invisible for the user. When the pointer is intersecting with a capsule (using ray casting), a panel is set as visible (Fig.3A). Each capsule covers an individual body part such as: head, humerus, femur, hand, forearm, thoracic cage, hips, tibia and foot.

The second lesson (Planes/Axes) contains 3 planes that represent each anatomical plane (transverse, sagittal and coronal) and 3 text elements with their names. The text elements have, similar with the previous lesson, 'fake targets' attached to them. Invisible capsules are placed over the text and when the user is directing the pointer to a certain type, the selected plane is animated in 3D space over the bones virtual model (Fig.3B).

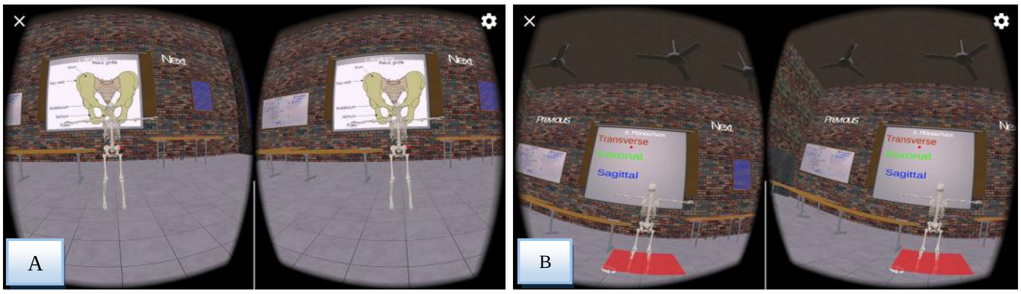

Fig. 3. Anatomy (A) [4] and Planes (B) lessons in VR

The third lesson (Reference Points) displays 7 additional 3D elements over the bones model as seen in Fig.4A. There is one human heart model and six spheres. Each sphere represents and individual point in the 3D space. The points location (proximal or distal) is measured based on the center of the body hence the heart was selected as reference. This time, no 'fake targets' were required since the selection was based on the main camera raycast hit on the displayed spheres that represented each individual point. The points were places on the main joints of the upper and lower limbs and user would see a text with the position of each selected point in the VR scene.

The fourth lesson (Movements) contains 3 text elements and corresponding 'fake targets' similar with the second lesson. When the user is directing the pointer over a certain text, the model will be animated according with the selected movements type. Three movement types were included: *flexion/extension*, *adduction/abduction* and *pronation/supination* (Fig. 4B). They came in set of two since one is complementary with another. For example, one movement starts with the flexion and ends with the extension of a limb.

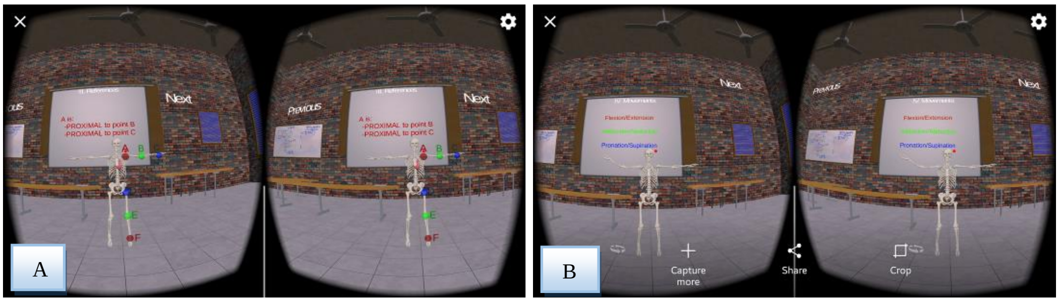

Fig. 4. Reference Points (A) and Movements (B) lessons in VR

[4] Pelvic girdle texture image source: https://upload.wikimedia.org/wikipedia/commons/e/ea/Pelvic_girdle_illustration.svg

5. Augmented Reality

The AR setup includes two separate scenarios: marked based and markerless. Although the initial idea was based on a markerless setup there was an opportunity to test the potential of a marker-based solution as well. The usage of the applications is completely different in these two scenarios. If the marker based one is somehow similar with the VR solution as presented above, the markerless one has a different use case.

The marker-based solution was developed using Vuforia[5]. This leading AR platform supports a multitude of devices and has many AR specific features, such as: objects recognition, cylinder targets, image targets, user defined targets and VuMarks targets. The support for Vuforia was available for Unity for some time but as a separate unity package. However, starting with Unity version 2017.2 this became integrated into Unity, making the development process easier. This application is built using a single Unity scene, it contains an *AR camera* that is specific to Vuforia while the default *Main Camera* is deleted. This special camera has a *Vuforia Behavior* script attached. Two directional lights are added, one for the camera and another one for the scene. We created a new Image Target object for our bones model to a new target database on the Vuforia account. The scene contains the main 3D model, similar with the VR setup, represented by the human bones model. The additional 3D objects necessary for the lessons were included as sub elements of this model to make sure that any transformation is applied to all rendered models. The additional 3D models needed for the lessons were imported from the VR project via prefabs.

The lessons have a similar structure with the VR solution, but the method of interaction is different. Fig. 5. displays parts of the biomechanics lessons in a marker-based AR environment. The main difference is related with the user interface. If in VR the user had a viewer that was used to select various elements based on a virtual pointer’s location, this time, we could actually select the options based on the button functionality of the object. This was the case for the text-based lessons such as Planes/Axes and Movements. For the ones that had to interact with the additional 3D elements, we continued to use the ray casting functionality but with different parameters. To achieve a correct model rotation around the Y axis (similar with VR) we had to change the *World Center Mode* from *Camera* to *First Target*. Another interesting feature of Vuforia image target is the possibility to activate extended tracking. This means that we can see large models and see their details without needing to have the actual image target in the camera view. We consider this is a feature with high potential since we were able to closely see the model details. In consequence, a few bugs were found in the

[5] https://www.vuforia.com/

model that weren’t previously observed with classical modeling tools (3DS Max and Blender).

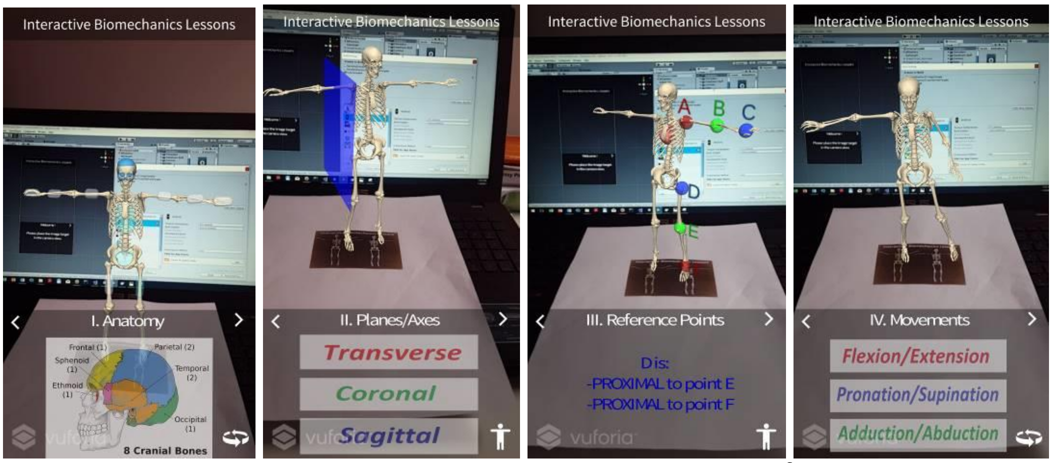

Fig. 5. Lessons in marker-based AR environment[6]

A markerless AR application was our initial idea for this project. This would track the motion of the whole body of a user and the 3D models that are placed as an overlay on top of the user’s image would be animated accordingly. It is similar with the *magic mirror ‘Miracle’* project but it combines the real environment with virtual 3D models of the whole body. The most known method to acquire the skeletal motion tracking was using a Kinect device. This sensor was used and mentioned in many scientific papers. Some of them were included in the state the art presented in this paper [1] [9]. However, our aim was to provide a full mobile solution as the Kinect device requires an Xbox or an Windows PC for middleware processing and is connected with wires. Also, the skeletal data should be shared to the display device over network which can potentially lead to synchronization issues. On the other hand, new solutions for skeletal tracking started to appear on the market. One of them is VicoVR[7], a sensor that has its own processing source and communicates without wires with Android and iOS devices. Unfortunately, the retail product is already sold out. Apart from this, our proposal aimed to be a solution available for a large number of persons and to achieve this we needed a scenario where the setup and usage was as simple as possible without having to purchase expensive sensors. For research purposes, we created the application from the markerless scenario. The AR is displayed on a laptop that has a Kinect V1 sensor attached. The solution is developed in Unity.

[6] Source of cranial bones image from AR anatomy lesson: https://upload.wikimedia.org/wikipedia/commons/3/39/Cranial_bones_en_v2.svg
[7] https://vicovr.com/

The Kinect support is enabled using *Kinect with MS-SDK* unity package. Additionally, OpenCV is used to position and scale the 3D model based on the image of the user. The support was enabled via *OpenCV for Unity* package. We used face detection bounds to compute a scale ratio that was applied on the rendered model. The version that included only the OpenCV version was supported to an Nvidia Shield tablet, but that didn't contain the Kinect full body skeletal tracking. Fig. 6. displays the experimental results of the implementation.

As a future perspective, a solution that is based only on computer vision would be a more suitable tracking solution for our idea. However, there are a few scientific papers that mention the usage of computer vision as a solution for skeletal tracking and their process is just at beginning since further research is needed. Also, even though the computing power is consistent on the mobile devices, they still don't support an extensive use of the resources. One of the main problem for mobile devices, while using expensive computational applications, is that they heat excessively, making the device hard to use and after a while experiencing performance issues.

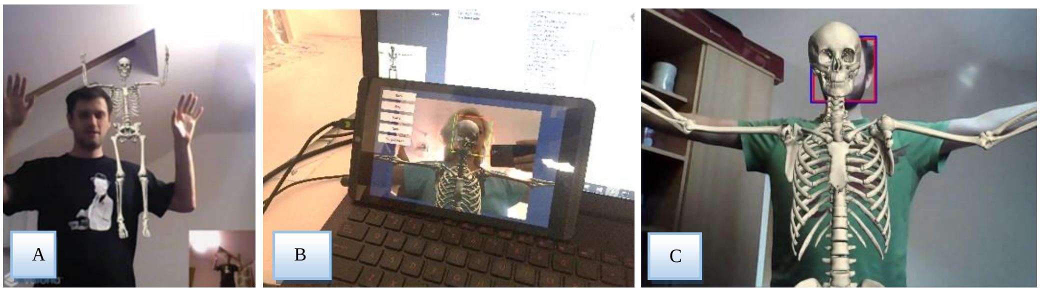

Fig. 6. Markerless AR setup: A. Only with Kinect functionality, B. Only with Open CV and C. Kinect and OpenCV setup

6. Results

The results were assessed for the applications that contain predefined biomechanics lessons: (1) the VR application with classroom background, (2) the VR application improved for cybersickness (alias BlueSky - related with the background color of the virtual environment) and (3) the marker-based AR application. The users had to complete feedback questionnaires before, during and after testing each application. The feedback was composed of 3 categories: general user feedback, simulator sickness and presence questionnaires. Our experiment included 5 users and all of them knew what VR is, while only one didn't knew about AR. Also, 3 out of 5 respondents said that they have previously tried VR applications and that they didn't feel sick after they have used them. Two users said that they rate the overall experience *good* while 3 responded that they considered it *very good* as feedback obtained after testing the applications described by this research. Also, 4 users agreed and strongly agreed that the lack of interruptions from the VR applications is beneficial while another one completely disagreed with this.

Simulator sickness questionnaire were applied before and after each VR scenario application to assess the level of cybersickness. This questionnaire (Kennedy et al. 1993) contains a list of 29 symptoms that are experienced by users in virtual reality systems[8]. The pre-exposure questionnaire was applied to be able to track the sickness symptoms that a user might have that are unrelated with the test. Each question related with sickness symptoms has 4 potential answers: None (0 points), Slight (1 point), Moderate (2 points) and Severe (3 points).

The presence questionnaires were given after each tested application to assess the level of presence the users felt for each scenario. The hypothesis of the research was the fact that the AR applications are giving a higher level of presence to the user's compared with the VR one although the VR medium had the opportunity to eliminate as much as possible external disturbance factors. The presence questionnaire was imported from the revised version of the *Witmer and Singer* presence questionnaire[9] and it contains 19 questions with 7-points Likert scale answers. Each answer was graded with values from 0 to 6.

The overall score results of the simulator sickness and presence questionnaires, as gathered from the users, are showcased in Fig. 7.

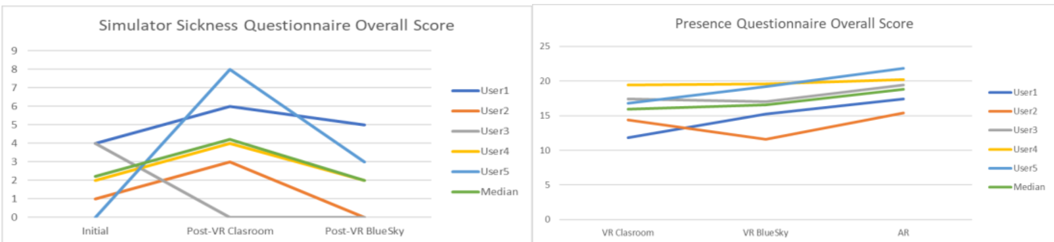

Fig. 7. Simulator Sickness and Presence questionnaires results

7. Conclusions

In this paper we presented a novel solution based on virtual and augmented reality for biomechanics study. The solution has 4 experiment design scenarios: two for VR and two for AR. If for VR we had to create an additional scenario due to the encountered cybersickness while testing and developing, the AR scenarios had completely different structure and utilization methods. The

[8] https://www.twentymilliseconds.com/html/ssq-scoring.html
[9] http://w3.uqo.ca/cyberpsy/docs/qaires/pres/PQ_va.pdf

marker-based application had the same structure of the lessons with the VR setup while the markerless version was left more to an experimental result.

The results of the tests effectuated on the applications that contained the predefined biomechanics lessons show us that the initial research assumptions were true. The VR classroom application has a lower cybersickness effect compared with the one with the classroom elements while the AR application has a higher level of presence. Similar, the VR application with the classroom background has in its turn a higher level of presence compared with the one that did not have any background.

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