Original article

Multimedia Application: Virtual Reality with 3D Graphics for Interactive Environment in Medical Education

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Abstract

Technology evolution and the need for teaching modernization led to the design of virtual reality applications in medical education. The current study aims to create an interactive environment by using three-dimensional (3D) models of the human arterial system. 3D arterial models allow undergraduate medical students to easily memorize main arterial branching pattern after intra-arterial navigation. The students have the ability by using the application for enjoyable interaction during navigation for learning process and continue or repeat the intra-arterial navigation. The study compares two students' groups by using the criterion whether or not they have followed the anatomy of the arterial system course and were successfully examined to it. The results showed no difference in experience in the evaluation of virtual reality application between the two groups, as well as no gender differences. Digital applications, although complex, offer great advantages, such as learning without jeopardizing human body and the possibility of multiple repetitions, that allows students fully understand the educational subject.

Keywords: interactive, multimedia, three-dimensional, application, virtual reality, game, graphical user interface, medical education, digital information, communication.

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Abbreviations:

VR: Virtual Reality

3D: Three-Dimensional

Introduction

The anatomy course has a substantial role in students' medical education (Sergovich, Johnson and Wilson, 2010). Scientific and educational demands, as formed by the technological revolution and the constantly changing of medical practice over the last decades, have necessitated the modernization of medical education (Eppler et al., 2017). First-year undergraduate medical students of anatomy classes are struggling to understand through lectures the complexity of the human anatomical structures (Alexander et al., 2009) and learn anatomy by studying illustrated textbooks (Luursema et al., 2006) prior to utilize their knowledge into clinical practice (Allen, Bhattacharyya and Wilson et al., 2015). In several Medical Schools worldwide, a significant part of the anatomy teaching, includes the human arterial system. In Greece, in the Department of Anatomy and Surgical Anatomy of the Medical School of the Aristotle University of Thessaloniki (AUTh), anatomy is taught traditionally, by dissecting cadavers. The dissection is a timeless, unsurpassable and irreplaceable educational tool (Moore, Wilson and Rice et al., 2017), as it provides a clear aspect of the anatomical structures and their spatial orientation within the body. Although dissection is the classical teaching method in several Medical Schools worldwide, many laboratories of anatomy focus on the development, implementation and improvement of supplementary tool (Codd and Choudhury, 2011) based on digital learning technologies (Mayes and Fowler, 1999; Ferrer-Torregrosa et al., 2015) and three-dimensional (3D) models (Allen, Bhattacharyya and Wilson et al., 2015). Although the training process using cadaveric material is the "gold standard" for anatomy teaching, there are financial and ethical reasons that force many Medical Schools in developing countries to use interactive material for medical education (Otton et al., 2017).

Over the last decades, the depiction of anatomical structures has significantly improved after the systematic use of laparoscopic monitoring and imaging techniques, such as magnetic resonance imaging, computed tomography scanning and 3D imaging (Reidenberg and Laitman, 2002). Recently, the creation of stereoscopic learning environments by using 3D vessel models rotated on all axes (Otton et al., 2017) or environments of augmented or virtual reality (VR) (Kashif et al., 2015; Gauthier, Corrin and Jenkinson, 2015) enable user interaction with the model displayed on the screen and the easier learning of anatomy (Lu, Li and Sun, 2010; Falah et al., 2015; Codd-Downey et al., 2016). Hounsel et al. (2010) proposes a model to identify education and/or training emphasis for 3D Virtual Environments. An experiment evaluated the impact of two typical features of virtual learning environments on anatomical learning for users of differing visuo-spatial ability (Luursema et al., 2006).

The undergraduate medical students have investigated the morphology of the human arterial system, using traditional teaching methods. The creation of a 3D VR environment can improve the understanding of arterial anatomy and enhance the learning of the branching pattern. The aim of the current research is to create an interactive environment by using 3D models of the human arterial system for the anatomy education. The purpose is not to substitute typical educational activities, but to augment them by offering computational support and access to context- related content in the existing environment. The main advantage of the current original VR application, unique in Greek Medical Schools, is the use of intra-arterial navigation (immersion and travel into the arterial lumen), as well as the study of the 3D morphology and branching pattern, in a similar way to an invasive procedure.

Materials and methods

A 3D environment was designed for the students' familiarization with the arteries of the human body. The virtual arteries were created with Blender, the free open-source software (version 2.79 for Mac OS 64 bit) based on Natsis' book (2006) for the arterial models' 3D reconstruction (Shimamura et al., 2015). The development of 3D model has been evaluated by a professor of anatomy. A full year was needed to complete the 3D model, as the arterial tree had a complex morphology with points of stenosis, enlargements and curves. Furthermore, a computer-simulated 3D learning environment was created, where the students can learn and interact with the arteries. In order to develop the application, the 3D arterial model had to be integrated to the virtual environment. The application was programmed using a flexible and accessible engine, the Unity 3D cross-platform game engine, for the creation of virtual environments with which students can interact and in which can navigate (D'Aoust, 2014).

The Waterfall Model (Software Development Life Cycle model is a sequential software development process) of five phases was applied (analysis, design, implementation, testing and maintenance) in the current application. Each phase was completed before proceeding to the next one, and each stage was repeated, until the completion of the process. This is the reason for which the Waterfall model is recursive (Bassil, 2012).

Analysis Phase

Undergraduate medical students of the Medical School of AUTh were the target group. The students regardless their gender, were educated on the human arterial system course and branching pattern (group 1) or not (group 2). Users have information technology skills and access to a desktop computer or a laptop. The research application is to create an interactive environment by using 3D arterial models that allow students to navigate into the arterial lumen (intra-arterial navigation) and investigate the 3D morphology of the vessels.

The current study examines the intragroup differences based on the following research questions and hypotheses:

Q1. Was the application easy to use?

Q2. Is the 3D model of the application more realistic compared to the two-dimensional images of the book?

H1. There are no visual differences between the answers related to design properties
H2. There is no statistical difference between assessment responses for the proposed application
H3. The application use, make you understand and become familiarized with the arteries of the human body.
The current descriptive analysis about groups, tries to prove that they are equal. The independent sample t-tests will be used to confirm or reject the hypotheses.

Design Phase

The 3D arterial model was integrated into an interactive environment to allow intra-arterial navigation and observation on 360-degree (Figure 1) by using the computer mouse. Once the user entered in the application, the starting point for the exploration of the human arterial tree was the aortic arch. The arteries' terminology appeared on signs.

User's representation was chosen in the first-person perspective (allowing to perceive in a gamified environment through the eyes of the character) (Denisova and Cairns, 2015) in order to ensure a deeper immersion into the environment (Chittaro, Ieronutti and Ranon, 2004; Marsh, Wright and Shamus, 2004). The user has free navigation in the application; this move causes a higher sense of presence rather than a directed navigational status (Clemente et al., 2014). Moving towards other spots by browsing with the arrow keys on the keyboard, by left-clicking on the desired switching point or by selecting the interactive 3D map on the right side of the screen, the user can freely navigate anywhere (Bowman et al., 2001) in the arterial system and control at any time its position (Sayers, 2004). The user can alter its position and course after selecting any artery on the right side of the screen, on the interactive 3D map, following points of stenosis, enlargements and curves. At the left bottom another map showed enlarged the twenty-five basic arteries.

An intra-arterial runner game (Figure 2) (avoidance of passing platelets) was created for user motivation (Jung et al., 2015; Jamil, AsadUllah and Rehman, 2016). In case of collision with the platelets, a sound of explosion is heard, the goal is to memorize the arteries 'terms. Furthermore, the user during intra-arterial navigation has the chance to answer some questions based on Natsis book (2006) to maintain a constant alertness within the interactive environment. In this way, a link from theory to practice is achieved as the best educational and learning method process. The correct answers are depicted with a green colour, while the false are coloured red. At the end of the process, the total number of correct answers is displayed.

Implementation Phase

The first improvements of the application were made following the observations and comments of the scientific committee of the Department of Anatomy and Surgical Anatomy, by using the interview technique. The application was installed in a computer and five research fellows of the anatomy lab were asked to navigate through it and achieve specific goals. Before testing the participants, they

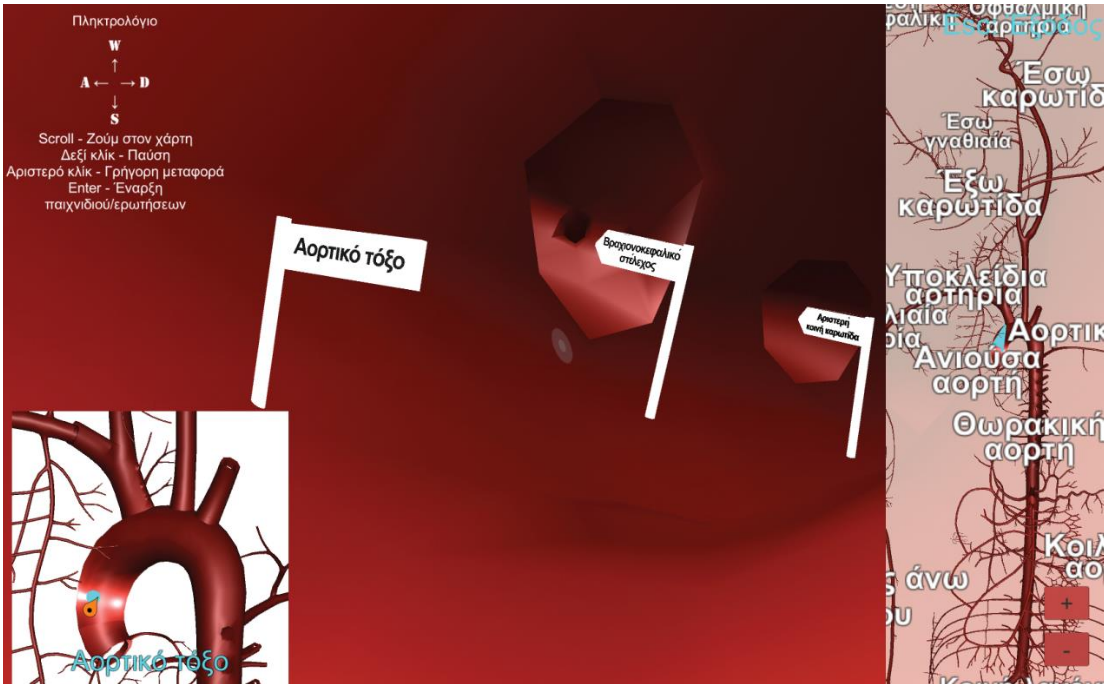

Figure 1: The visual layout contains 3 panels. The lower left panel depicts where in the arterial tree the point of view is located anatomically, the main viewer window provides a first-person view of the immediate arterial lumen and intra-arterial branches, the right panel provides a relative view of the arterial tree in more linear fashion. The application: 1) Keyboard (in Greek depicted: Πληκτρολόγιο), scroll-zoom in the map, right click-pause, left click-transfer, enter-start play, 2) Aortic Arch (in Greek depicted: Αορτικό τόξο)

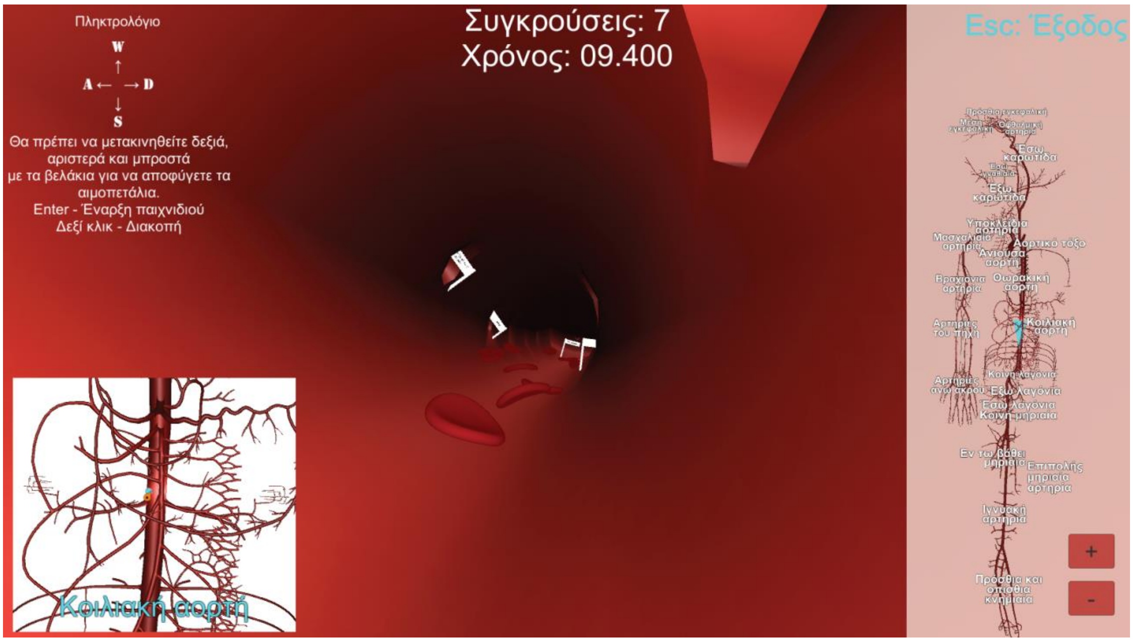

Figure 2: Game with platelet collisions 1) Total time and resulting collisions, 2) Keyboard (in Greek depicted: Πληκτρολόγιο), you should move right, left and forward with the arrow keys to avoid platelets, enter-starting game, right click-pause, 3) Abdominal aorta (in Greek depicted: Κοιλιακή αορτή), 4) 3D interactive human body map with the branching pattern of the human arterial tree

answered if had experience in VR application. It was requested to the users to navigate into the application and describe their experience. An additional goal was to play the running game, as well as to answer the questions inside the educational application. During this experiment, the "Think-Aloud" method was used to understand what the users are thinking when interacting with the system (Rogers et al., 2011). Finally, they were asked to comment on changes and modifications for the application. Following, their comments and observations, the application was extended, and new functions were added to improve the learning process, making it more user-friendly. The participants found VR, an interesting and enjoyable experience. An interactive map was added displaying each main artery that became enlarged at the left of the screen. Another alteration was the ability to press anywhere on the interactive map at the left side and be directly moved to the selected point. Furthermore, a gamified environment with closed-type questions was added to support the learning process within the interactive environment. Colour changes in textures, as well as the addition of a mark showed the exact position of the user at any time within the arterial system.

Testing Phase

In the second part, a questionnaire was carried out with the assistance of the undergraduate medical students. The participants were informed about the educational purpose of the program before the beginning of the process. The anonymity of their data was maintained. Undergraduate medical students were randomly selected based on whether they had been examined in the anatomy of the human arterial system and were divided into two groups: the first one comprised 15 (7 males and 8 females) undergraduate medical students which had not followed the anatomy class of the human arterial system and the second consisted of 15 (6 males and 9 females) students that had been examined to the human arterial anatomy. Both groups received via e-mail an online questionnaire linked to the uploaded on the internet application. The results of the questionnaires were analysed using the program SPSS 17.0 (IBM Corporation, Somers, NY, USA). The study was approved by the Bioethical Committee of the Medical School, 151/332015.

Maintenance Phase

When problems appeared or added new features in the application, then the methodology would be re-applied in order to improve the application’s efficiency and quality. Furthermore, maintenance to verify the proper function of the application and the users’ satisfaction also took place. The contact with the administrator via email was feasible for any kind of information or comment.

Results

Descriptive analysis showed that in both groups the application improved learning effectiveness (first group: 93.33% and second group: 86.66%). A 60% of the respondents had former experience in VR applications. All respondents aware of their position during their navigation in the application (all participants answered 'yes' on question "During your tour, do you know where you are and where do you want to go?"). First group contained 7 males and second 6 males. This means that we may expect a skew in effect by sample design if there were differences in questions which have Likert's scale. To check the t-tests for males and females could be performed. To start with tests the assumption about equal variances for female and male groups must be checked. The results of tests are summarized in Table 1. No differences existed between male and female evaluations. Thus, a skew effect is not expected from gender for research groups and it may be a new understanding in the effect of genders (male vs female) (Jung et al., 2015). The same investigation must be done for "experience in VR applications" because the first group had six inexperienced persons and second group only three. The results summarized in Table 1, show that if difference between groups in main tests will be found, this could be a result of different student's experience with VR. This finding showed that despite on groups inequality by experience the evaluations' results between groups are equal. This means that researchers have to confirm H1, H2 and H3.

Discussion

VR simulation is an effective educational tool in surgical training, as facilitates the understanding of complexity of the endovascular procedures, assisting a surgeon acquires the necessary skills (Alaraj et al., 2013; Mitha et al., 2013; Cheng et al. 2014; Leitritz et al., 2014). Interestingly, this ability was correlated with the fact that VR permits clear demonstration of typical and variable anatomy (Yudkowsky et al., 2013). Estai and Bunt (2016) highlighted the VR use in anatomy education, without performing an in-depth analysis about its teaching potential.

In Ferrer-Torregrosa et. al. (2016) questionnaire study, it was shown that the VR system significantly enhanced students' motivation and comprehension of 3D nature of structures in comparison with the control group. The University of Michigan (2014) has created a VR application of the human body. The program works in a "cave" installation of virtual environment that converts an entire room into a 3D screen. The operator uses a joystick as a scalpel and can observe the anatomical details from a very close distance. In 2016, Chapman Crean College of Health and Behavioral Sciences installed the "Virtual Cadaver" lab that included three anatomical tables, which allowed medical students to rotate anatomical models and study them in three-dimensions. The Western University of Health Sciences in California (2017) has created a VR learning center, where medical students are trained in VR by using: two zSpace screens, a 3D anatomical table, Oculus Rift and anatomical models for an iPad. According to a research conducted in the context of the current investigation

Table 1: Male/Female and intragroup comparisons

Outcome	**H1**	**H2**	**H3**
Male/Female comparisons			
Equal variances test F and p	F=0.691 p=0.241	F=1.072 p=0.459	F=0.648 p=0.206
Equal variances test outcome	Equal variances assumed	Equal variances assumed	Equal variances assumed
t and p	t=0.883 p=0.385	t=-0.705 p=0.486	t=0.107 p=0.915
comparison outcome	no difference	no difference	no difference
Experience comparisons			
Equal variances test F and p	F=1.7 p=0.157	F=1.987 p=0.101	F=0.14 p=0.256
Equal variances test outcome	Equal variances assumed	Equal variances assumed	Equal variances assumed
t and p	t=1.762 p=0.044	t=-1.871 p=0.035	t=2.274 p=0.015
comparison outcome	**difference**	**difference**	**difference**
Group comparisons			
Equal variances test F and p	F=0.724 p=0.277	F=0.488 p=0.096	F=0.689 p=0.248
Equal variances test outcome	Equal variances assumed	Equal variances assumed	Equal variances assumed
t and p	t=-0.265 p=0.793	t=0.231 p=0.409	t=-0.535 p=0.597
Comparison outcome	no difference	no difference	no difference

* Outcomes were proposed using 0.05 level of significance

concerning the anatomy education in Greece, the Medical School of National and Kapodistrian University of Athens uses the “Anatomage” Virtual Dissection Table and the other Medical Schools use alternative advanced technologies, such as robotics for surgical specialization. Medical School professors in Greece teach anatomy based on cadaveric material derived from body donation programs after written informed consent. Five out of seven Medical Schools in Greece have a course in Medical Informatics in their curriculum, fact that shows that they have conceived the new reality learning process, the VR and its applications in anatomy education.

The 3D VR application is more realistic than the two-dimensional image of a book. Students' familiarization with 3D arterial models is achieved after an interaction with them. This interaction is accomplished with the user's browsing in the arterial lumen and reading the signs with the name of each artery in real time. Through an interactive map on the right side of the screen, the user can be transferred to any artery of the human body. Additionally, the game of avoiding platelets gives a motivation for interaction and fun (Jung et al., 2015), as the user navigates inside the artery. Additionally the user has the chance to repeat many times the navigation game and learn the arteries terminology. According to the results of the current survey, the users are satisfied and the effectiveness of learning in a VR space improves the learning process. The analysis showed that both studied groups are equal by size. Each group contained 15 students, which are studying on the same semester. The results in Table 1 confirmed that there are no differences between male and female evaluations of questions. In other words, the researcher may not expect a skew effect gender for researched groups. The same investigation has to be done for experience comparison because first group has 6 unexperienced persons and second one only three. Furthermore, the research showed that independently of their participation in groups, no difference was recorded in responses to H1, H2 and H3. The novelty and real value of the VR teaching and learning application is the existence of an interactive map, as well as the knowledge of the exact position of the user at any time (Bowman et al., 2001; Sayers, 2004; Clemente et al., 2014) and possibility of free movement. An important finding of the current research is that regardless of the gender, no difference is recorded in the use of VR space, while other studies highlighted gender dimorphism (Jung et al., 2015).

After reviewing the literature, a 3D immersive human anatomy application for mobiles and tablets was found, the so-called Anatomyou VR (Juanes, Ruisoto and Briz-Ponce, 2016), while the described VR application in the current paper is for computers without the use of VR headsets. Another application depicted arteries with the most vascular structures hidden from the user (the arteries appear gradually as the user proceeds) (Nicola, Virag and Stoicu-Tivadar, 2017), contrariwise to the current application in which the whole arterial tree appears at once and it was on the user selection which artery will navigate. The incorporation of new tools and technologies in anatomy education encourages the development of new, supplementary methods and techniques. VR applications can improve teaching and learning procedure by supporting and not by replacing dissection. Their greatest contribution in learning rests on their graphic quality and user-friendly design, although their complexity. The greatest advantage of such applications is that medical students can learn without jeopardizing human body and are able to perform many repetitions until they understood the educational subject (Huang and Liaw, 2011) and afterwards they can dissect cadavers.

Conclusions

Based on the current results, undergraduate medical students regardless of whether they had been examined to the human arterial system, they find useful and easy to use a 3D application to understand the arterial tree. Education with 3D models offers immersion and unique experience as the user has intra-arterial navigation and 360-degree observation. Additionally the current 3D VR application in Greek Medical Schools may act as a supplementary tool for the anatomy learning and teaching. In the near future, the translation of the application in English will allow its wide use, as well as the construction of a similar 3D VR model for the internal organs of the human body will facilitate the anatomy learning. Further research is needed to further clarify if VR could be an acceptable supplementary anatomy teaching tool or obtain a more prominent role in anatomy education.

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