InNervate AR: Dynamic Interaction System for Motor Nerve Anatomy Education in Augmented Reality

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Abstract. Augmented reality applications for anatomy education have seen a large growth in its literature presence for 3D model education technology. However, the majority of these new anatomy applications limit their educational scope to the labelling of anatomical structures and layers, and simple identification interactions. There is a strong need for expansion of augmented reality applications, in order to give the user more interactive control of the anatomy education material. To meet this need, the mobile augmented reality application, InNervate AR, was created. This application allows the user to scan a marker for two distinct learning modules; one for labelling and identification of anatomy structures, the other one for interacting with the radial nerve of the canine forelimb. The first module matches other existing anatomy augmented reality structures. The second module is unique, because it allows the user to play an animation of the anatomy models, to show what the normal range of motion for the muscles of the limb is, based on the motor innervation of radial nerve. Next, the user can select where to make a cut along the length of the radial nerve, to cause a nerve deficit to one or more of the muscles of the limb. Based on this user input, the application will then play a new animation of the changed range of motion of the canine thoracic limb. A formal user study was run with this new application, which including pre- and post- knowledge assessments. Our initial data analysis showed that qualitative students' responses and quantitative data were significantly positive. This implies that the application may prove to be educationally effective. We are going to expand the scope of the application based on the analyses of user data and feedback, and develop educational modules for all of the motor nerves of the canine forelimb.

Keywords: Anatomy · Augmented reality · Educational technology

1 Introduction

Due to the increased accessibility of educational technologies, the curriculum for higher education anatomy has seen rapid reformation, (Biassuto et al. 2006). Traditionally, anatomy courses are primarily taught with the methods of didactic lectures and cadaver dissection. The anatomy classroom teaching materials are characterized by static, two- dimensional images. Laboratory involves dissection guides, animal

C. Stephanidis (Ed.): HCII 2019, CCIS 1033, pp. 359–365, 2019.
https://doi.org/10.1007/978-3-030-23528-4_49

cadavers, and aids such as plastinated anatomical models (Peterson 2016). However, decreased laboratory funding and laboratory time, and increased technology development, have led to limiting animal use to only teaching procedures which are considered essential (King 2004; Murgitroyd et al. 2015; Gurung et al. 2016). With the evolvement learning theories in the classroom, as well as the growth of 3D technology, there is a need for those who work in the anatomy higher education field to re-examine the learning tools that are used in anatomy courses (Azer et al. 2016).

One of several new trends to emerge in anatomy education technology is augmented reality applications for anatomy education. Augmented reality is defined as a technology that superimposes a computer-generated image on a user's view of the real world, thus providing a composite view. This technology is usually developed as an application, and can be used with mobile devices. However, the majority of these new anatomy applications only focus primarily on labelling of anatomical structures and layers, or simple identification interactions (Jamali 2015; Kamphuis 2014; Ma 2016).

It is important that anatomy content in augmented reality (AR) be expanded from simple identification questions, and labelled three-dimensional structures. As a step toward this expansion, the goal of this was to build an AR application for mobile devices, which explores the selected topic: deficits to canine muscle movement, in response to motor nerve damage. This concept is difficult for students, due to the requirement of mental visualization of the anatomical structures involved, and the need to employ critical thinking for exam questions involving clinical reasoning scenarios. Rather than making another simple interaction and labelling interface, is project allows the user to take a more interactive roll in what information is being presented by the anatomy AR application.

1.1 Visual Spatial Ability and Learning Anatomy

Visual-spatial ability has been defined as the mental manipulation of objects in three-dimensional space. When learning anatomy, spatial visualization is important, as students must learn spatial relationships and interactions between anatomical structures. This knowledge is crucial for surgical skills, because anatomy education gives the baseline skill set for accurate diagnosis in organs and body systems (Azer and Azer 2016). The amount of cadaver contact has been reduced in higher education, and so new three-dimensional models are being created to compensate. 3D modeling tools allow the user to the add or remove structures and observe them from different angles in three-dimensional space, thus enhancing the teaching process of complicated anatomical areas (Gurung et al. 2016).

1.2 Critical Thinking in Higher Education

One of the goals of InNervate AR is to deepen the learning that a student can gain from their interaction with the anatomy content in this application. By taking the anatomical material beyond pure identification, and into more complex and dynamic interaction, an element of critical thinking can possibly be introduced. According to Abraham et al. "critical thinking is the process of actively and skillfully applying, relating, creating, or evaluating information that one has gathered." The ability to think critically is vital to science education, and is crucial for life-long learning (Abraham 2004). Kumar and James support this argument by adding that critical thinking is a rational process, with personal reflection to reach a conclusion. This approach to learning has become a high focus in educational research (Kumar 2015).

1.3 Mobile Devices and Augmented Reality for Anatomy Education

Augmented reality (AR) has been granted a large literature presence in higher education. One example of mobile AR study was a multi-university study with a specific mobile application, HuMAR. The intent of implementing HuMAR was to teach general human anatomy to students. Overall, they hoped to measure the user experience of the application, in three different anatomy courses, across three different universities. They performed a pilot test, and after analyzing their pre- and post-surveys, they determined that this mAR application could be effective in motivating and improving student learning (Jamali 2015). Another research project tested to see if mobile augmented reality (mAR) could be implemented in a Turkish medical school anatomy class, as an educationally impactful tool. The researchers concluded that mAR decreases cognitive load, increases academic achievement, and can make the learning environment more flexible and satisfying (Küçük et al. 2016).

In terms of the user interface of AR, most projects seem similar in nature. The Miracle system is described as providing an identification of structures interaction and "a meaningful context compared with textbook description (Kamphuis 2014)". The work done by Chien et al. includes a system that has "pop-up labeling" and an interactive 3D skull model, that the users can rotate to view different angles of the model. They also found results showing that the 3D display of AR helped students improve their spatial memory of the location of anatomical structures, as compared to a traditional 2D display. (Chien 2010). The MagicMiror project of Ma et al. is mapped to the users own body, but it is still a simple point and click interface. The user is quizzed based on definitions and asked to identify structures (Ma 2016). There is a lack of understanding of how AR can support more complex learning in anatomy, and how to ensure that the AR system has strong usability in a classroom environment (Kamphuis 2014; Cuendet et al. 2013). But as seen in the review by Lee et al., this technology has a large potential to serve in education, as it can make the educational environment more engaging, productive, and enjoyable. Furthermore, it can provide a pathway for students to take control of their own learning and discovery process (Lee et al. 2012).

2 Methods

The focus of this application was the bones, intrinsic muscles, and motor nerves of the canine thoracic limb, with a specific learning module for the radial nerve. All of these concepts are included in the undergraduate VIBS 305 Biomedical Anatomy course curriculum at Texas A&M University. All of the anatomy content was created and animated with special attention to anatomical correctness. InNervate AR was designed as a marker-based system. This means that the camera of the mobile device detects a shape on a piece of paper, known as the marker, and then the application loads the programmed learning module that corresponds to that marker. To accomplish this marker recognition, InNervate AR was built on a Samsung Galaxy smart phone with Google ARCore software, utilizing image recognition developments from Viro Media. The first scannable marker brings up the labelling and identification module. The second scannable marker brings up the learning module that explores motor nerve deficits. The user is allowed to "cut" nerves on the limb with a swipe of the finger on the mobile device, with a corresponding animation following the user's action. This animation will demonstrate changes to motor innervation of the limb, based on where the nerve cut occurred. For example: the user will view the muscles and nerves on the limb, and an animation will demonstrate normal muscle movements for a healthy range of motion. Afterwards, the user will be able to cut the nerve supplying motor innervation to the limb, and then a new animation will play, demonstrating which muscle action deficits now exist, because the muscles will or will not move, depending on its location in relationship to the damaged/cut nerve (Fig. 1).

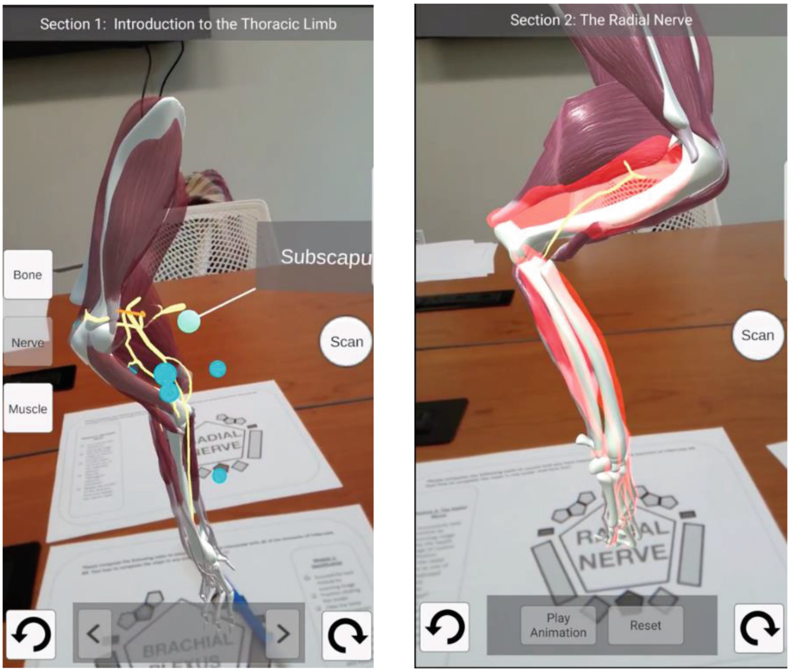

Fig. 1. Screen captures from the InNervate AR application show what the user sees during the labelling (left) learning module and the radial nerve animation (right) learning module.

2.1 Study of Knowledge Gain

Within the quasi-experimental design of this study, the non-equivalent groups design is being followed. This means that no randomized control group exists, but a pre- and post- test is given to groups of people that are as similar as possible, in order to determine if the study intervention is effective or not in learning. The pre- test was written to include anatomy knowledge questions, a free response question, demographics questions, and Likert-Scale based questions about their anatomy education experience. The post- test was written with five knowledge-based questions, three of which mirrored the anatomy knowledge questions of the pre-test, with the same concept being asked in a different way.

2.2 User Study Sequence of Events

Participants were eligible to participate in the user study as long as they had completed the Texas A&M VIBS 305 Anatomy course within the timeframe of the previous 2 academic years. All participants were given 90 min maximum to complete the activities of the user study. The participant was provided with a mobile device (SAMSUNG Galaxy) and a corresponding paper handout for how they were to proceed with interacting with InNervate AR. This handout asked them to perform specific tasks, in a defined sequence, in order to ensure that the user had interacted with all parts of the application. After completing their interaction with InNervate AR, the participant was asked to complete a post-activity questionnaire (Fig. 2).

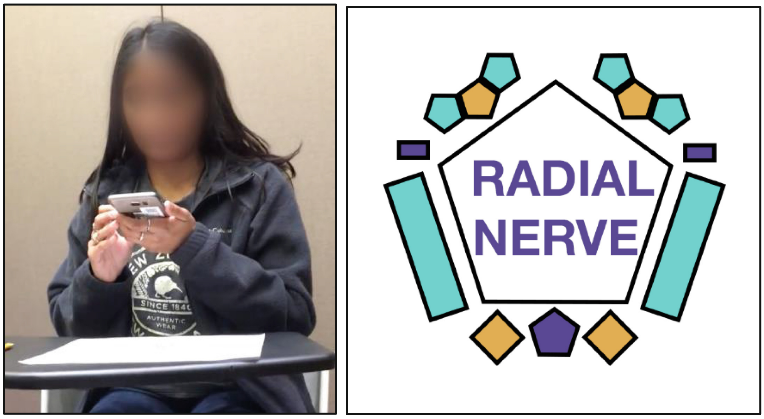

Fig. 2. A user study participant is scanning marker (left) for the radial nerve animation learning module. This marker is pictured on the right.

3 Results and Discussion

After the user study was completed, all of the data was compiled and analyzed. There was a total of 22 participants in the user study for the Innervate AR application. Five of the participants were male, and 17 were female. 11 of the participants obtained an "A" in the TAMU VIBS 305 Anatomy course, 9 of the participants obtained a "B" and 2 participants obtained a "C" in the course.

3.1 Participant Testing Results

In the pre-questionnaire, the participants had 3 anatomical knowledge test questions. In the post-questionnaire, the participant had 5 anatomical knowledge test questions, 3 of which were matched to the pre-questionnaire test questions. In other words, the same content was tested on in those 3 questions, but asked in a different way. The scores of the participants were analyzed, and 77.27% of the participants' scores improved on the 3 matched questions, after using the InNervate AR application. 18.18% of the participants made the exact same score on the matched anatomy questions, and 4.55% of the participants had a lower score in the post-questionnaire on the 3 matched questions. This data appears to suggest that the majority of the participants saw an improvement in their knowledge of the anatomical content.

The participants seemed to enjoy their use of InNervate AR, and all of them gave positive feedback about their user experience. Some of the verbal comments of the participants during their use of the InNervate AR application were:

"Very interactive compared to other apps I've tried...You can't always go into the lab, and even then, you can't see through the muscles to see branching." (User ID:1008)

"Nice way to look at the anatomy from different angles... Most apps don't have what would happen if something is wrong, they just have the structures" (User ID: 1009)

"This would have been so nice. It's one thing to look at a 2D lab manual, but I just really like the animation part too, because that's what I always struggled with. Is it a flexion, is it an extension etc.…I love that you scan it, not just something you look at, it's so interactive." (User ID:1018)

4 Conclusion

We were interested in studying how this more dynamic augmented reality tool for anatomy education could benefit learning for anatomy students. The results of this user study have demonstrated that InNervate AR does have the potential to have a positive quantitative impact on anatomical learning. In addition, the positive qualitative response of the users shows that this is a tool that the students enjoy using and are eager to have included in their curriculum. For future work, we plan to use the feedback and data from this study as a guideline to further expand InNervate AR to include all of the motor nerves of the limb as learning modules. In addition, we are going to conduct in-depth studies considering how spatial visualization and critical thinking affect learning anatomy using AR.

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