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InNervate AR: Mobile Augmented Reality for Studying Motor Nerve Deficits in Anatomy Education

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Abstract: Augmented reality applications for anatomy education have seen a large growth in their literature presence as an educational 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 dynamic control of the anatomy material within the application. To meet this need, the mobile augmented reality (AR) 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 as it relates to the movement of the canine forelimb. A formal user study was run with this new application, which included the Crystal Slicing test for measuring visual spatial ability, the TOLT test to measure critical thinking ability, and both a pre- and post- anatomy knowledge assessment. Data analysis showed a positive qualitative user experience overall, and that the majority of the participants demonstrated an improvement in their anatomical knowledge after using *InNervate AR*. This implies that the application may prove to be educationally effective. In future, the scope of the application will be expanded, based on this study's analysis of user data and feedback, and educational modules for all of the motor nerves of the canine forelimb will be developed.

Keywords: Anatomy Education, Mobile Augmented Reality, Educational Technology

1. Introduction

Due to the increased accessibility of educational technologies, the higher education anatomy curriculum 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 and two- dimensional images. Laboratory involves dissection guides, animal 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; Pujol et al., 2016). With the evolvement of learning theories in the classroom, as well as the growth of 3D interactive 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 & Azer, 2016).

One of several new trends to emerge in anatomy education technology is mobile augmented reality (Mobile AR) applications. 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. Mobile AR 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). However, the majority of anatomy AR applications 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 Mobile AR be expanded from simple identification questions, and labelled three-dimensional structures.

Mobile AR allows students to dynamically interact with digital content that is integrated with current print-based learning materials.

We developed a mobile AR application called *InNervate AR* for smart mobile devices, which explores the selected topic: deficits to canine muscle movement, in response to motor nerve damage. This is a concept that is often frustrating to undergraduate anatomy students because it requires mental visualization of the anatomical structures involved. *InNervate AR* also supports students' critical reasoning skills, while learning about motor innervation of the canine limb. This paper describes the development of *InNervate AR*, as well as the user study to test its effectiveness as an anatomy learning tool.

2. Application: InNervate AR

2.1 Design

InNervate AR includes two learning sections, which are incorporated in user study handouts. Canine cadavers are used in many undergraduate school anatomy courses, as well as the course that participants in this study have used in their coursework. Therefore, the anatomy of the canine was used in this anatomy mobile AR application.

- Section 1 involves labelling and identification of the structures of the canine thoracic limb. This was purposefully developed to make sure that InNervate AR offered the same baseline tools for user experience and learning as the existing anatomy applications that are available. Figure 1-1 shows the view of the participant during both learning modules.

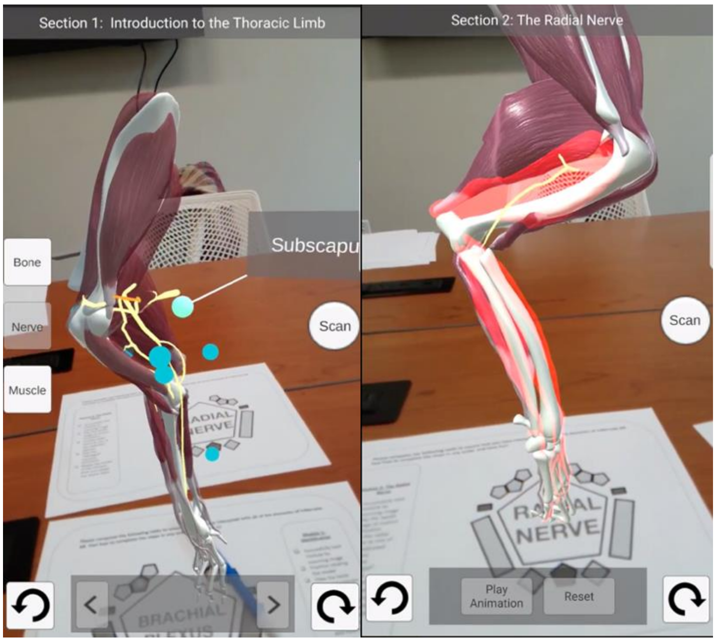

Figure 3-41 The view of InNervate AR participant during the labelling module (left) and the radial nerve animation module (Right).

- In Section 2, the user dynamically interacts with a musculoskeletal system of the canine thoracic limb, and plays animations of a healthy canine limb's range of movement. They can then visualize "damage" to different areas of the nerves of the limb, and be educated on what deficits exist. The "damage" is cuts to the nerve with the swipe of a finger on the device screen, and the resulting muscle action deficits are displayed with before and after animations of the muscles' ability (or inability) to move. Thus, the user can explore different combinations of affects upon the anatomy, and become more actively engaged in the educational process of the mobile AR application.

2.2 Development

For the radial nerve animation module, a total of five animation sequences were created. The first animation sequence was the entire healthy range of motion of the canine thoracic. The other four scenarios involved changes in movement capabilities of the limb, based on the motor innervation provided by the radial nerve. These four radial nerve scenarios represented different possibilities of damage that could have occurred to the radial nerve. Due to the infinite number of possible damage scenarios to an organic animal's nerves, the number of nerve damage scenarios was narrowed down to a more finite set of 4 ranges. These 4 ranges would produce the most visually distinctive results between each of the scenarios. This was done so that the scenario possibilities would not overwhelm the user.

InNervate AR was designed as a marker-based system with Google ARCore software, utilizing image recognition developments from Viro Media. 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 (see Figure 3-2).

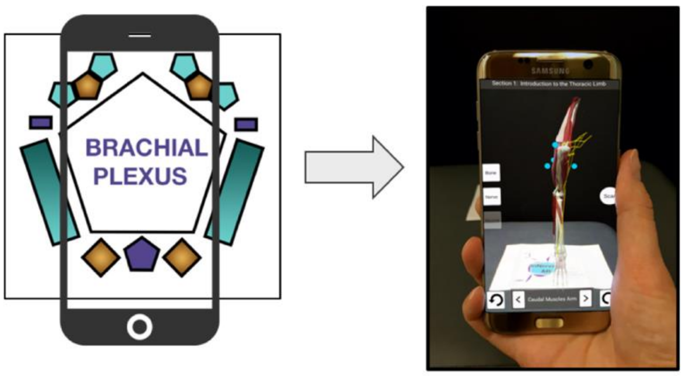

Figure3-42 The process of image recognition to load the InNervate AR application

2.3 Learning Scenario

Anatomy students struggle with combining several layers of their knowledge together to make logical conclusions about motor nerves and their relationship to the muscles which they innervate. An example of this difficulty is when the students are asked to answer an exam question about which muscle movement deficits would exist based on the information provided about an injury to a specific section of the thoracic limb. When answering that question, the student has to complete several mental steps. First, *they must correctly mentally visualize the muscles and nerves of the thoracic limb*. Next, *they must recall which motor nerves are located in the injured section of the thoracic limb*. Afterwards, *they must recall which muscles are specifically innervated by the motor nerves in that area of the thoracic limb*. By processing that information, they can recall what the actions of those muscles are, and then describe which muscle movements will be impaired. The final consideration that they must make is if the nerves which were damaged continued further down the limb, because if so, then further deficits might exist distally due to the linear relationship between nerve signals and the muscles that they communicate with.

InNervate AR was designed to give students a learning platform for seeing a 3D representation of these clinical reasoning scenarios. The AR technology allows the students to view all of the anatomical structures together, and then actually see how they work together when healthy, or become impaired with damage.

3. User Study

3.1 Study Procedure

Students from the a Texas A&M physiology course were recruited for a user study with InNervate AR. This course is the class that Texas A&M students are required to take in their degree plan after completion of their required anatomy course. Each participant was given 90 minutes maximum to complete the activities of the user study. First, the participant was asked to complete a pre-activity questionnaire. The participant was then asked to complete the timed Crystal Slicing Test (Ormand et al., 2013). They had 3 minutes to complete the test. The participant was next asked to complete the 38 minute Tobin and Capie 1981 TOLT (Test of Logical Thinking) test (Tobin & Capie, 1980).

After completion of the TOLT test, 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. The handout had a place for them to check-off when they had completed a task within the application. This handout also had image markers that Innervate AR could scan, to bring up the different learning modules that are built into the application.

The participant's duration of use of the application was recorded. The participant was free to ask the user study facilitator questions about navigation of the application. While the participant was using the application, another mobile application on the same device was recording the screen of the device. The participant's interaction with the mobile AR application was also recorded on video with a camera. After completing their interaction with InNervate AR, the participant was asked to complete a post-activity questionnaire.

Within the quasi-experimental design of this study, the non-equivalent groups design was 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. 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. The post-test also included Likert-Scale based questions about their experience with the InNervate AR system, as well as place to write additional feedback. The objective of these questionnaires was to obtain quantitative data based on the anatomy knowledge questions, and qualitative data based on the Likert and free-response questions.

3.2 Data Analysis

The data from all of the user study participants was compiled and analyzed for patterns and trends. This involved grading the users' performance on the learning instruments used in this study, and identifying similarities and differences in the qualitative answers given during the pre and post questionnaires. We specifically wanted to identify how the critical thinking scores, and the visual spatial ability scores of the users effected their change in performance on the anatomical knowledge questions after using *InNervate AR*. Furthermore, the screen recordings and video recordings of the study were reviewed to analyze the overall user experience of the study participants.

4. Results & Discussion

4.1. Participant Demographics

There was a total of 22 participants in the user study for the *InNervate AR* application. All of the participants were Biomedical Sciences majors at Texas A&M University, and had taken the TAMU VIBS 305 Biomedical Anatomy course within the two previous academic years. Five of the participants were male, and 17 were female. When asked, 18% of these participants answered "Strongly Agree" and 59% of them answered "Agree" to the statement "I consider myself to have a high level of critical thinking ability."

4.2. Participant Crystal Slicing Test Results

The highest possible score that a participant could make on this 3-minute test was 15 points. Only 9.09% of participants scored a 10 or better on this test. The majority of the user study pool (54.55%) made a score in the point range of 7-9. The next most common point range (22.73%) was a score of 5 or 6. The remainder of the participants (13.64%) scored less than 5 points. This data demonstrates that the participants in this user study had average or low visual spatial ability in general.

4.3. Participant Test of Logical Thinking Results

With an allotted time of 38 minutes, the highest score that a participant could make on the TOLT was 10 points. A perfect score of 10 was made by 40.91% of the participants. A score of 9 was achieved by 31.82% of the participants. A score of 8 was made by 9.09% of the participants. Only one participant (9.09% scored a 7 on the test. The remaining participants (13.64%) scored a 6 or lower on the TOLT. This data showed that the participants trended toward having high critical thinking skills.

4.4. Participant Anatomical Knowledge Scores 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 shows that the majority of the user study participants showed an improvement in their performance on the matched anatomy knowledge questions in the post-questionnaire.

4.5 User Experience with InNervate AR

In the post-study questionnaire, a series of Likert-Scale questions were asked in regards to the participants' perception of *InNervate AR*. The users' responses to these questions were all positive. Some of the categories they were asked to rate were: the usefulness of the application as a visual aid for the spatial relationships between the anatomical structures, the flow and user interface of the application, and the usefulness of the application to practice critical reasoning scenarios.
The participants were also given free response questions. The first question asked: "What did you like least about the *InNervate AR* application?" Common themes to how the participants answered this question included: no "zoom" feature, problems with how to cut the nerves, and problems with selecting the labelling spheres. The second question asked was "What did you like most about the InNervate AR application?" The most frequent responses to this question included: getting to visualize the actions of the muscles with the animations, the graphic aesthetic of the application, how easy the application was to use, and the accuracy of the anatomical content. The last free response question asked the participants if they had any further suggestions about the *InNervate AR* application. The responses included adding the ability to compare the healthy and damaged animation scenarios side-by-side, adding even more details about the muscles in the labelling module, and further customizing the visual user interface of the tool.
Finally, some of the verbal comments of the participants during their use of the *InNervate AR* application were:

> *"Oh man I wish I had had this when I was in anatomy lab...because it really connects it all together, especially with all of the bones articulating and everything being there. I remember having to draw so many layers. (ID: 1001)."*

> *"This is super helpful, I just can't get over it, it's one thing to see the words on paper, but to see a cut branch! (ID: 1001)."*

> *"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 (ID:1009)."*

5. Conclusions and Summary

The goal of this project was to create a mobile anatomy AR application, InNervate AR, which provides more dynamic interactions than other mobile AR applications that have been previously created. This mobile AR technology is innovative because rather than having another simple viewing interaction and labelling interface, the user was able to take a more interactive roll in what information was being presented by the application.

The results of this user study showed an extremely positive response from the participants, both in their qualitative feedback data, as well as their anatomical knowledge improvement. The majority of the participants tested for a high critical thinking ability, and there was one student with an average or low visual spatial ability. Therefore it was difficult to investigate how the base critical thinking ability could impact on learning anatomy using mobile AR. In terms of spatial visualization, there was no significant difference between high spatial visualization students and low spatial visualization students. The qualitative feedback from the participants demonstrated areas where the *InNervate AR* application could use improvement, such as problems with how to cut the nerves, and problems with selecting the labelling spheres. However, the responses from participants were overwhelmingly positive in many categories. They enjoyed getting to visualize the actions of the muscles with the animations, the graphic aesthetic of the application, how easy the application was to use, and the accuracy of the anatomical content.

It is planned to use the data and feedback from this study as a guideline while further expanding *InNervate AR* to include all of the motor nerves of the limb as learning modules. Any future user studies will be completed in a classroom setting, so that a larger participant population can be guaranteed, and statistically significant results can be achieved. Furthermore, the limitations such as a low number of matched anatomy knowledge questions, and gender bias will be addressed. Future user study and application design will also be more error tolerant, so that user errors with the technology, or differences in user background will not have huge consequences when analyzing results (Rouse, 1990).

This study was a wonderful learning opportunity because it showed the great potential that *InNervate AR* has for anatomy higher education, and brought to light what weaknesses in the technology and research study design should be worked on in the future. It our hope that this initial push for expansion of anatomy content in mobile AR will hopefully encourage other researchers to add additional interactive content to their educational tools, and strengthen the presence of this technology in higher education anatomy curricula.

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