CREATION OF INTERACTIVE VR APPLICATION THAT SUPPORTS REASONING SKILLS IN ANATOMY EDUCATION

An Undergraduate Research Scholars Thesis

by

KARLA CHANG GONZALEZ and AMBER ACKLEY

Submitted to the Undergraduate Research Scholars program at
Texas A&M University
in partial fulfillment of the requirements for the designation as an

UNDERGRADUATE RESEARCH SCHOLAR

Approved by Research Advisor: Dr. Jinsil Seo

May 2019

Major: Visualization

TABLE OF CONTENTS

ABSTRACT

Creation of Interactive VR Application that Supports Reasoning Skills in Anatomy Education

Karla Chang Gonzalez and Amber Ackley
Department of Visualization
Texas A&M University

Research Advisor: Dr. Jinsil Seo
Department of Visualization
Texas A&M University

For our creative work thesis, we developed a VR (Virtual Reality) Program that allows a user to view and interact with muscles and nerves of a canine leg that would support students to understand the relationships between nerves and muscles. Using an industry-style pipeline, we developed anatomically accurate models of canine muscles and nerves, which we textured, rigged, and animated for use in an educational virtual reality platform. The end goal of the project is to create and measure the efficacy of a visually dynamic experience for the user, allowing them to generally explore canine limb anatomy, and to specifically visualize deficits in muscle movement, produced by user interaction with the canine nervous system. This tool explores the possibilities of Virtual Reality and seek to improve upon existing methods of higher-level anatomy education.

Traditionally, higher level anatomy education is taught through the use of cadaver dissections, two-dimensional anatomical diagrams and didactic lectures. However, these traditional methods of teaching anatomy have many limitations and are not enough to build a visual-spatial understanding of anatomical structures. Virtual reality is a strong tool that allows students to directly manipulate anatomical models and observe movements in a three-dimensional space.

While the literature has been filled with VR applications that aim to fill this need, many existing tools offer only a static model for the user to explore by rotation, adding and subtracting layers, and viewing labels to learn about the anatomical structure. We seek to increase the level of dynamic interaction that the user has, by allowing the user's touch of the models to change the animation and movement of the three-dimensional models in their environment. Our outcome is a VR learning tool that has potential for further exploration in higher level anatomy education.

Our creative work employs the methodologies of "art-based research". Art based research can be defined as the systematic use of the artistic process, the actual making of artistic expressions as a primary way of understanding. The project was created iteratively while working with content experts, specifically anatomy experts from Dept. of Veterinary Sciences at Texas A&M University.

Implementing anatomy education using virtual reality and developing a universal pipeline for asset creation allows us the freedom to dynamically build on our application. This means that our tool can accommodate for the addition of new muscle and nerves. By continuing to develop our virtual reality application in future works, we can expand the breadth of knowledge a user can gain from interacting with our application.

ACKNOWLEDGEMENTS

We would like to thank our primary advisor, Dr. Jinsil Seo, our graduate advisor Megan Cook, and our 3-D technical advisors Caleb Kicklighter and Austin Payne for their guidance throughout this research. We would also like to thank the Department of Veterinary Medicine and Biomedical Sciences for their continued collaboration with the Department of Visualization.

Thank you also to the Department of Visualization and the Visualization Immersion Reality Lab (VIRL) for providing the necessary equipment and resources to carry out this research.

SECTION I

RESEARCH QUESTION/MOTIVATION/ARTIFACT

Due to increased technology accessibility, higher education anatomy curriculum is undergoing an extensive renovation (Biassuto et al., 2006). Virtual reality applications for anatomy education have been one of several new trends to emerge in education technology, to supplement traditional teaching methods (Moro et al., 2017). In essence, the “traditional” method of teaching anatomy courses involves didactic lectures and cadaver dissection. The classroom teaching materials are characterized by static, two- dimensional images. Laboratory involves dissection guides, cadavers, and aids such as plastinated models (Peterson, 2016). However, decreased funding and laboratory time, and increased technology development, has led to limiting animal use to only essential procedures in higher education (King, 2004; Murgitroyd et al., 2015; Gurung et al., 2016).

We chose Virtual Reality as a platform on which to build an educational anatomical tool because VR solves some of these limitations of traditional anatomy teaching methods. Comparatively, VR is more cost effective than cadaver dissection and maintenance. It allows for increase interactivity and engagement from the student by allowing for direct manipulation of the anatomical structures, and it allows for 3D models to be viewed in their true form in VR as opposed to in a simplified 2D image. VR also allows for the investigation of internal or minute structures that may require cadaver dissection to be viewed otherwise (Jang, 2017).

Problem

Traditional tools such as textbooks attempt to supplement this lack of real-world observation by explaining the musculoskeletal and nervous systems through two-dimensional diagrams. These diagrams lose an entire dimension in detail, often abstracting the processes they attempt to clarify. Three-dimensional mental visualization has been traditionally taught with cadaver use. 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 (Azer & Azer, 2016).

In current practices of anatomy teaching, there is also a lack of existing material that applies the observable action of muscles and nerves in a fully realized three-dimensional space. In the case of cadaver dissections, students must rely on their theoretical understanding of how each muscle should function and move. The plasticization process as well as rigor mortis causes the limbs to stiffen, so it is impractical to use cadavers as a means of understanding the muscles' motion in life. Conversely, it is equally difficult to view the intricacies of these muscle systems on a living specimen, as exterior attributes such as skin, fat, and fur all work to hinder their observation.

Cadavers are a limited resource and access can be limited to undergraduate students. Physical anatomical models offer an alternative to cadavers and attempt to supplement the spatial properties of these structures lost in two-dimensional diagrams, but these models are often very expensive means to conduct a very limited amount of observation, and these models are usually static. Because the amount of cadaver contact has been reduced in higher education, new three-dimensional tools are being created to supplement students' mental 3D understanding of anatomical structures. 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).

For our virtual reality application, our planned interaction is allowing the user the cut a nerve within the canine's leg and view the effect that severance has on the canine's range of motion. The current methods of teaching the relationship between the canine nerves and the muscles which they are innervate rely on textbooks and didactic lectures. As nerves are very complex, severance results in lasting damage to the affected nerves and muscles. For this reason, cutting the nerves on a live specimen is inhumane. In the case of general study, the resources available to teach these concepts in a three-dimensional capacity are underdeveloped. Currently in veterinary medicine, we are limited to understanding the underlying mechanics of the muscle systems rather than observing the nerves and their muscles in motion.

Question

Our research aims to answer some fundamental questions of the limitations and benefits of Virtual Reality. Virtual reality is a strong platform that allows students to better understand 3-dimensional structures, but we will explore how VR aids a student's understanding of anatomy concepts beyond simple structures by incorporating animations that illuminate the mechanical structures and range of motion allowed by the nerves in a canine leg. While VR is a very computationally powerful platform, it is a real time interactive application that can face issues such as lagging which ruins user experience. VR requires some amount of simplification in our models and animations, posing a limitation on the degree of realism and accuracy we can create on our thoracic limb recreation. A certain amount of simplification to anatomical structure of the canine's musculoskeletal and nervous systems must be undergone to present this work as a VR application. We hope to answer the question of whether an abstracted form of this system is a viable educational tool through our application.

How our artifact answers the research question

Virtual reality (VR) is a strong 3D platform for students to practice this direct manipulation of complex anatomical structures (Jang, 2017). In addition, VR provides a highly motivational learning environment, while supporting the learning of those with lower visuo-spatial ability (Jang, 2017; Stepan, 2017). While the literature has been filled with new VR applications that aim to fill this need, the level of interactive control is highly variable (Nguyen & Wilson, 2009). Many of these tools offer only a static model for the user to explore by rotation, adding and subtracting layers, and viewing labels to learn about the spatial relationships of the anatomical structure (Stepan, 2017; Jang, 2017; Nicholson, 2006). We seek to increase the level of dynamic interaction that the user has, by allowing the user's touch of the models to change the animation and movement of the 3D models in their environment. The topic we use to explore this idea is the relationship between canine nerves and the muscles which they innervate.

Our artifact is a working, interactive prototype of a our anatomy tool. Along with our finished product, we will develop and universal pipeline for asset creation, which will allow us the freedom to dynamically build on our application. This means that our tool can accommodate for the addition of new muscle and nerves. By continuing to develop our virtual reality application, we can expand the learning targets for the user interaction. For future explorations, this tool could be implemented in a classroom setting to evaluate its educational effectiveness. Overall, our anatomy tool will be an exploration into the potential of Virtual Reality as a feasible practical tool for education.

SECTION II

LITERATURE REVIEW/BACKGROUND/HISTORY/SOURCES

Movement of the canine musculoskeletal system is driven by its complex relationship to the canine nervous system. The muscles of the canine's body are innervate, or stimulated by the canine's nerves. Contraction and relaxation within the canine's muscle tissue is fully dependent on the specific nerves with which the canine's muscles are innervate to. If the connections between the muscle and nerves are severed, then the innervate muscles will no longer execute their biomechanical function in correspondence with signals from the canine's brain. Scale and extent of the damage is specific to the region along the length of the nerve that is severed. It is possible for the same nerve to be cut on two different subjects at different points along the same nerve to produce dramatically different results in the canine's subsequent range of motion. Research has given anatomists insight into the specifics of what muscles are affected when cutting different points along the nerves. While these facts about the relationship between canine nerves and the muscles they are innervate to are well documented, several limitations to the representation of this research arise from current anatomy presentations. First, the entrance and exit points of the nerves into canine muscle is not fully observable through their common two-dimensional diagrams, leading to misconceptions about the system's structure among anatomy students. Secondly, current three-dimensional models of the canine nervous system are typically static, and lack the dynamic interaction required for a full grasp of understanding the cause and effect relationship between severing a nerve, and its result on the range of the dog's motion. Lastly, in order to apply knowledge of this relationship into medical practice, a veterinarian must identify the location of a severed nerve and the extent of the damage by an inverted process of observing the range of motion the canine can still produce, without observing the underlying nerves or muscles. Thus, it is necessary for tools used in anatomy education to allow students to observe both the nerve damage and the possible range of motion with such damage in parallel in order to generate a holistic understanding of this biological phenomenon.

Two dimensional diagrams found in textbooks depicting the resulting range of motion coupled with three dimensional, static models of the canine musculoskeletal and nervous system are the widely accepted supplements to drawing relationships between these complex systems. However, these representations of a system whose ultimate function lies in producing motion are abstracted and oversimplified. Most anatomy experts attempt to supplement this gap in visual relationships using didactic lectures and cadaver dissections, but the combination of these tools are expensive and reserved primarily for higher education (Peterson, 2016). This problem has resulted in the current rising trend for educational anatomy tools to be developed using devices capable of give spatial understanding of these structures, such as virtual reality and augmented reality.

Previous virtual reality tools attempting to capture the musculoskeletal system and its relationship to the nervous system have fallen short of fully realizing the platform's ability to synthesize the three-dimensional representations of the systems with the motion such systems facilitate. Cardiac VR is a recent application that provides users with a model of the human cardiac system and allows users to gain a better understanding of the "relative size and proximity of various cardiac structures" (Maresky et. al, 2018). The research concluded that it was a effective tool with educational potential which needed further research in order to fully utilize the capabilities of virtual reality, including the potential for greater dynamic interaction. Other example of anatomy tools, such as the more commercial application 3D Organon VR Anatomy, tend to favor labeling and point and click systems. These tools, while applying a spatial awareness that previous two-dimensional teaching methods lacked, still maintain a level of precedent set by textbook learning and diagrams.

History

Since the beginning of its invention, Virtual Reality has grown to be seen widely for its potential in education and training purposes. There have been many case studies which test VR's usability for anatomy education specifically. It is known that VR can provide engaging and intuitive environments for learning visually and spatially complex topics such as human anatomy, biochemistry, and molecular biology. One of the key reasons Virtual Reality can surpass traditional methods of instruction is that Virtual Reality enables users to move beyond "real-world" experiences by interacting with or altering virtual objects in ways that would otherwise be difficult or impossible. (Hoffman, 1997).

While there is much evidence supporting that Virtual Reality is a viable supplement of anatomy education, most studies evaluating the feasibility of Virtual Reality educational tools conclude that it is not yet ready to completely replace traditional methods of teaching. Some of the downsides of Virtual Reality for training and education purposes include cost, acceptance in the medical community, and limitations of technology including achieving realism. An important milestone in the legitimization of Virtual Reality for surgical simulation came in 2001 with the development of MIST (minimally invasive surgical trainer). Researchers at the North of England Wolfson Centre for Minimally Invasive Therapy and Virtual Presence LTD developed MIST, a product that trains and assesses surgical laparoscopic psychomotor skills. MIST is used commercially and provides a successfully validated system for training and assessing surgical skills, using international standards (McCloy, 2001)

Furthermore, many studies comparing traditional methods of education versus new media-based methods conclude that while users who tested out new media methods had overall positive feedback on the experiences, they do not score significantly higher on evaluation exams than the users who followed traditional education methods (Codd, 2011). Most Virtual Reality anatomy programs take advantage of the medium's 3D spatialization of anatomical structures, but their interaction is limited to switching visibility and manipulating the translation of organs, bones, muscles and structures (Fairén, 2017).

Literature Review

When developing a program, it is important to consider what would be the right tool or medium to build upon. Given the costly and time-consuming price of developing a VR tool, it is important to use only use Virtual Reality when this platform allows what other platforms cannot. The most successful Virtual Reality programs are those which take advantage of the medium's unique capabilities. Particularly, a topic that is difficult to present though the use of traditional methods is visualizing the routes of neuronal signaling through 3D space. A study at Colorado State University implemented a VR program in the neuroanatomy laboratory which allowed students to view and manipulate neural networks in 3D space (Heise, 2018). Students had the option of interacting with the virtual reality program, in addition to attending their class where instructors presented 2-dimensional line diagrams and cross-sections to help students visualize this anatomy. Student surveys and observations revealed that students felt VR helped them visualize a three-dimensional neural network much more than a two-dimensional line diagram would. Observations also indicate that the use of VR is highly advantageous when viewing a neural network that is not visible to the naked eye---therefore not visible on a cadaver. Additionally, the student surveys suggest that Virtual Reality increased the student's abilities to evaluate the outcomes of neuroanatomical lesions. This study supports our claim that a Virtual Reality platform can enhance a student's understanding on the effect that nerve damage has on muscle activation and motorization.

Reproducing natural movement of the muscular nervous system is a long sought-after goal for computer graphics research. There are two main frames of thought on how to tackle this problem. The first is to reproduce soft tissue simulations on the basis of aesthetics instead of strict biophysical accuracy. The latter is to simulate muscle contraction through a set of formula which attempts to mimic the biological phenomena that cause muscle movement in a similar way to how the actions would happen naturally. Current research into the latter method has not yet achieved complete accuracy and biomechanical fidelity. A recent example of work attempting to further simulation-based research is "Dexterous Manipulation and Control with Volumetric Meshes", whereby the researchers propose that line-segment primitives oversimplify the problem of muscle contraction and relaxation and that a volumetric simulation would better represent the muscles (Lee et. al, 2018). Volumetric simulation is not a new concept, but previous examples have not met expectations. However, this volumetric system was limited to the control loop they created in order to solve for a juggling action using the muscles of the human torso and arms. Because our project requires representing the effect of cutting multiple different nerves and the cut's effect on the possible range of motion of the canine thoracic limb, our solution to the motion of the muscles needs to handle a wide variety of possible actions and allow for dynamic manipulation of the thoracic limb asset. Therefore, we concluded that the best solution for representing the muscle system would be to use the more traditional line-segment primitives. Additionally, virtual reality applications are currently limited in what is possible for real-time playback. Simulation is only possible if it is implemented as pre-baked, animation clips. Since

Unity is primarily built to handle joint-based hierarchies, we chose to represent natural contraction and relaxation of the muscles using an aesthetics-based approach. Our system's goal is to achieve a believable representation of a severed nerve effect on surrounding muscle in terms of educational learning. We do not propose that our solution has biomechanical fidelity, but rather mimics the motion of a canine limb in a visually informative manner. Computer graphics-based muscle simulations are accurately capturing the more finite details of muscle contractions, but their systems have limited dynamic performance, and are not yet compatible with virtual reality applications.

Augmented Reality in Education

Just as virtual reality offers potential to replace current tools for anatomy education, augmented reality, or AR, has been equally researched in higher education. Where VR attempts to replace the physical world, AR allows the user to interact with the tool on their mobile phone or tablet, and the computer-generated element is overlaid on the physical world (Kesim et. al, 2012). Research in to AR as a supplemental tool has identified it as a effective means of motivating and improving student's learning. A study analyzing the pre- and post-test results of anatomy students using the AR application HuMAR, which teaches general anatomy, concluded students using the application were better able to retain information after using the AR application (Jamali, 2015). When comparing the effectiveness of AR against VR, results conclude that users found greater involvement in VR applications. Because VR replaces the physical world, students were more curious to explore their new environment, reducing external variables and heightening involvement and engagement (Moro et. al, 2017). For this project, we chose virtual reality in order to gain control over environmental factors and increase user engagement with the subject matter.

SECTION III

EXPLANATION OF EXHIBIT/VENUE

InNervateVR: Design Description

InNervateVR focuses on the relationship between nerves, muscles and bones in the thoracic limb of a canine. The application's nerve cutting module handles the major muscles and nerves present in this limb. In addition to the skeletal bones, we have fourteen observable muscles of the canine forelimb: the subscapularis, supraspinatus, infraspinatus, biceps brachii, brachialis, long head triceps, medial head triceps, accessory head triceps, teres major, extensor carpi radialis, flexor carpi radialis, flexor carpi ulnaris, ulnaris lateralis, lateral head triceps, deep digital flexor, superficial digital flexor, lateral digital extensor, and the common digital extensor. Furthermore, our application handles five major nerves that are innervate to the muscles of the canine thoracic limb. The scenarios for the radial nerve, suprascapular nerve, musculocutaneous nerve, and the combination of the median and ulnar nerves are present (Figure 1).

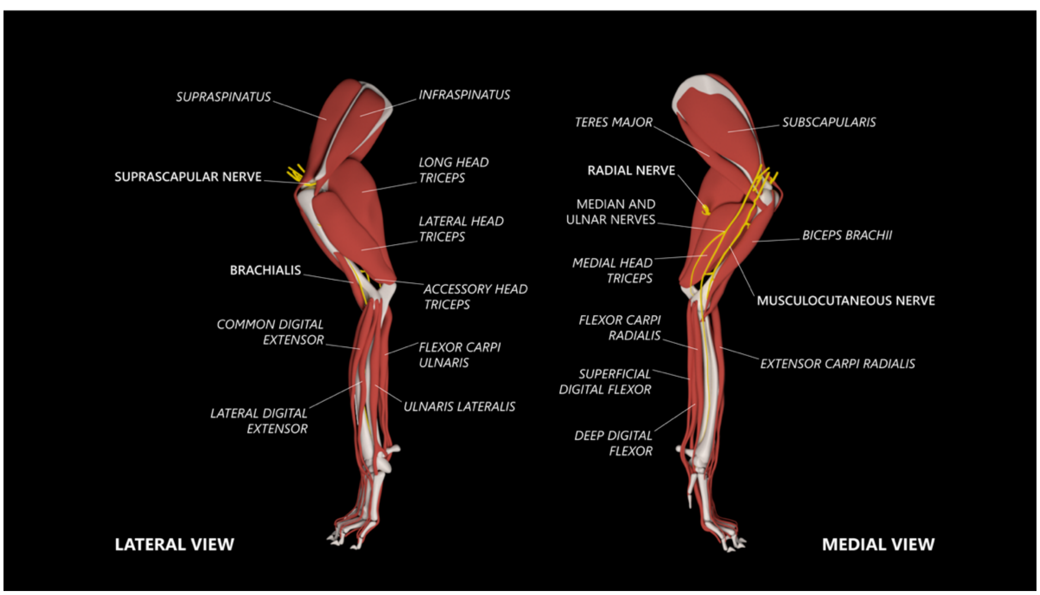

Figure 1. Diagram of the canine thoracic limb's nerves and muscles used in InNervateVR.

The virtual environment of InNervateVR presents the user with a life-sized thoracic limb placed on a pedestal so that the scapula of the limb is at eye-level. Behind the pedestal lie three floating user interface panels. The left-most panel serves to communicate information to the user about how to interact with the thoracic limb, as well as guide them through the program. The right-most panel contains all information and buttons needed to interact with the leg, such as buttons to play and reset animations, change the muscle opacity, and select a nerve with which to interact. The central panel contains a second thoracic limb, which plays only a healthy animation and can be used as a reference with which to compare the damaged leg. To interact with the thoracic limb, the user must point and click near an indicator sphere on each nerve. We only allow the user to damage one nerve at a time, so that the nerve damage is isolated and it is clear which muscles each nerve drives.

Our application was developed using industry standard software, and our artistic direction in our work is driven by achieving a balance between aesthetics and reality. Our aim was to create a tool that is both pleasing to use and an accurate representation of anatomy. The first consideration we had to make was how to represent the muscles. There are divided opinions in anatomy research as to whether or not medical computer graphics models should be exact representations of gross lab dissections or 3D imagery that is more accessible to a general audience. For our purposes, our models needed to clearly represent our target innervated muscles, and any anatomy student, on a medical track or general studies, should be able to observe the models free from distraction. For this reason, we chose an artistically driven modeling process over scans of gross anatomy dissections.

3D Pipeline: Modeling, Texturing, Rigging and Animating

In order to capture all the extreme details of each muscle accurately, all the initial modeling was done in ZBrush, a 3D sculpting software that allows the user to interact with their model much like clay. Each muscle was sculpted directly upon a pre-modeled skeleton in order to represent the muscle's correct origin and insertion points as well as the muscle's overall shape as accurately as possible. Anatomical textbooks, drawings, cadavers, and anatomy professors were used as references to ensure that the muscle models achieved an anatomically correct likeness. The next step in the industry pipeline is texturing. We faced similar considerations when deciding our target for representing the texture of the muscles. One popular method of texturing medical assets is to wrap a detailed image of a dissected cadaver in order to achieve a likeness. However, this method often leads to warped or unappealing textures, as translating a 2D image onto a 3D model leads to image warping and sometimes decreased resolution. We previously determined through modeling that our goal was to represent anatomy in an accessible way while still achieving accuracy. Therefore, we chose to create textures that indicate the muscles' striation and fascia and their placement accurately but without the realism of gross dissections. To emulate the texture of the muscles, we used secondary software. The application allowed us to paint directly on to the surface of our 3D models, which enabled us to capture unique details such as muscle striations and fascia.

With the model textured, the asset was taken into Autodesk Maya to be rigged. Rigging creates a structure that dictates and allows the model to be deformed or moved for animations. This process is vital in configuring an accurate and efficient system for the animators to manipulate. Our biggest consideration for setting up our muscle system for animation was in a key limitation of current computer graphics solutions. Muscles are most often represented in computer graphics as a child of the bones. Thus, as the bones of an rig move, the muscles follow and dynamically contract and relax. While this looks convincing, anatomists view this as a major inaccuracy. In reality, the muscles drive the bones. In order to create this effect, we developed a broken hierarchy rig such that the muscle contraction and relaxation could be animated separately from the bones. Using this method, the muscles still maintained their correct origin and insertion points.

The final rigged system was then animated in Maya. One base animation replicates the movement of a functioning, healthy canine limb. Additional animations represent each possible scenario resulting from nerve or muscle damage inflicted by the application user. Educated anatomy professors and previous anatomy students were our resources for animating the limb accurately. Because animation was integral to our application's learning target, iterations of each damaged nerve scenario were carefully reviewed before we implemented the animation in our final application.

Setup

The exhibit of our creative work and the user's experience is demonstrated in two distinct environments: the external environment containing all of the necessary systems and components to utilize VR and the internal environment within our application. The first component of our exhibit, the external environment, is everything a user can see when they enter the VIRL Lab. This includes the HTC Vive headset, sensors, controllers, the structure built around the system delineating the area in which the user can move freely, and the PC and associated systems that run the application on the headset (Figure 2). This stage of our exhibit is purely functional. The appearance of the external component is influenced by system requirements for creating interactive virtual reality applications. Our focus here is providing a student user with the ability to move about the exhibit free from obstacles or distractions while using our creative work. The second component of our exhibit, the internal environment, is the appearance of the exhibit through the lens of the HTC Vive headset. Due to the nature of VR, we had complete agency in designing the user's experience of their environment within the application. When using a virtual reality application, the user's physical world is completely replaced with a rendered, computer-graphics generated scene (Figure 3). The application's environment is a simple room that is generally void of defining features. This simple layout helps to reduce distractions commonly associated with the newness of VR to some users. The main focus of our exhibit within the application is the interactions between the user and the thoracic limb model. In order to direct the user's attention to the learning target, the canine forelimb will have the most saturated colors within the environment and will be situated atop a visually unique pedestal structure in the center of the room. During the interaction, our user is able to move around the space and view the model about the pedestal's full circumference. In addition to the physical components of our virtual environment, a user interface is needed to aid the user in understanding the different ways they can interact with the environment around them. An intuitive user interface is needed for the user to begin interacting with the canine thoracic limb, and thus focus on the learning goals of our VR application.


Figures 2 and 3: External environment of InNervateVR (left) and internal environment (right).

User Interface

With all new technology, there is a learning curve associated with learning and exploring new systems. As we cannot assume our intended audience of anatomy students will have extensive experience with VR tools, we have designed a user interface that facilities the user's interaction with the virtual environment and introduces to the user the different ways they can interact with the canine limb in a clear manner. The most essential interaction within our program is the user's ability to define a location along a nerve, sever the nerve at said location, and observe how this nerve damage affects the leg's range of movement. Our solution to facilitating this interaction is to provide the user with a "Play Animation" button, paired alongside with a "Reset" button. When pressed, the "Play animation" button will activate the thoracic limb to move in its full, healthy range of motion and come to a stop after two cycles. Each time the user damages a nerve, they can press "Play Animation" to view the resulting motion. If they would like to undo all damages and return their leg to a healthy state, they can press the "Reset" button. To cut a nerve, the user simply needs to point the Vive hand controller at a spot along a nerve, and click to sever it. To better aid the user in understanding the results of their interactions, we have implemented visual feedback which turns the nerves and affected muscles a different color when damaged (Figure 4).

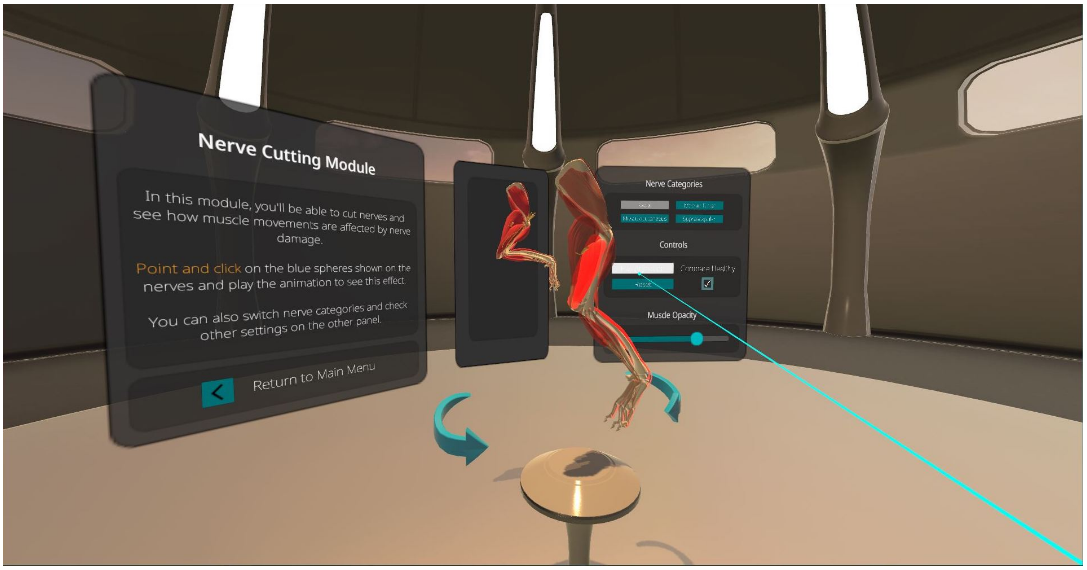

Figure 4: Visual feedback resulting from nerve damage.

We provide the user with a third UI element: a menu list of nerves possible to interact with. By providing the user with a list of nerves to select, the user is prompted to select an option. Each possible selection will reveal small markers along the nerve models, revealing to the user where they can cut along the nerve. Another UI element we are including is a slider that gives the user the ability to reduce or increase the opacity of the leg's muscle models. Many of the canine nerves are obscured within muscles. It is important to see the nerves, but it is equally important for an anatomy student to see where the nerves lie in relation to the muscles they innervate. By providing a slider we will allow the user to alternate between seeing more of the nerves and more of the muscles. We present our User Interface on two floating panels situated on the left and right sides of the leg, slightly pushed further back in space than the leg. This way, the user never loses sight of the leg when utilizing the interface.

AR Findings

Collaborative research between the Department of Veterinary Medicine and Biomedical Sciences and the Department of Visualization is an ongoing endeavor and tools such as our InNervateVR fall under the umbrella of creative works known as Creative Anatomy. Within this sphere of development, InNervateVR has a related prototype augmented reality application developed by Margaret Cook, a graduate student in the Department of Visualization. This AR application is still unpublished, but the AR application's approved IRB user study results informed a few of our early decisions about our planned user interaction. A frequent critique of the AR application was the application's limited ability to compare a damaged limb from a healthy limb with a full range of motion. This feedback led us to create an option for the user to toggle on or off a second limb in InNervateVR that always plays the animation for a healthy range of motion. Through this toggle, a user is able to view the hurt animation associated with the damaged limb side-by-side a healthy animation for comparison. We believe this will greatly improve the user's educational experience, as the difference in the thoracic limb's motion after damage ranges from extreme to finite and minute. Another way in which the prior AR work impacted our planned interaction is rotation features in the user interface. Even though a user is free to move around our thoracic limb asset while in the VR application, the AR application found that many users prefer to remain relatively stationary. By providing users with the option to rotate the leg, we can ensure that the user may view the limb in a three-dimensional capacity even if they choose to stand in place. Both the previous AR work and our InNervateVR application seek to fulfill a similar educational deficit in anatomy education. Their comparison may influence future work research under creative anatomy.

Public Presentation

We chose to present our work at the Undergraduate Research Scholars Symposium on Wednesday, February 27th, 2019. The symposium was held at the Student Memorial Center on Texas A&M University's College Station campus. For our presentation, we prepared a poster which focused on our planned user interaction with our virtual reality application. As our application's anatomy education learning targets are unfamiliar to general conference attendees, we provided diagrams of our thoracic limb asset breaking down the nerves and the innervated muscles. While presenting our poster, we were able to transition between the need for our application in anatomy education, why our application improves previous virtual reality anatomy tools, what muscle innervation is and why it is important to have a spatial representation of nerve damage, and how a user will interact with our application. Many of the attendees we presented to admitted having prior knowledge of virtual reality systems, and they were interested in trying our completed work.

Public Showcase and Future Q&A Session

Due to the space requirements needed to present a virtual reality application, we plan to host a showcase and an informal Q&A session after we have completed our creative work. Our application is made for use by anatomy students and is a collaboration between the Department of Veterinary Medicine and Biomedical Sciences and the Department of Visualization, so we plan to open our Q&A to any students familiar with anatomy or interested in virtual reality applications. Both perspectives will offer us insight into the success of our application in both content and technical appeal. The exhibit for our Q&A session will be at the Visualization Immersion Reality Lab, or VIRL Lab, in the Texas A&M College of Architecture's Department of Visualization.

SECTION IV

REFLECTION

Through our public presentation and Q&A session, we learned that the majority of our audiences believed our VR application was successful in illustrating a complex topic such as innervation. A major critique we received from users was that we did not include a sufficient introduction to our virtual environment. Users that were less familiar with Virtual Reality platforms did not know what to do upon entering the environment; they almost always needed verbal instructions from us explaining the interactions they could do in our environment. Similarly, users who were unfamiliar with anatomy were unsure of what exactly they were observing on the canine leg.

To remedy both of these issues, we implemented an additional tutorial section of our VR application (Figure 5). The tutorial introduces the user to the space by encouraging users to click on certain buttons in a pre-defined order. This not only reveals to the user the interactions possible in InNervateVR, but also allows non-VR users to become comfortable using the Steam VR hand controller systems. Our tutorial also includes a labeling section where we provided the names of each muscle, bone and nerve on our canine thoracic limb. We hope this labeling module will serve as a teaching tool to non-anatomy students as well as a refresher to students with some anatomy experience. Most major changes we implemented after receiving feedback were related to user interaction. If we were to create our artifact again, we would solidify our desired user interaction at an earlier stage of development. Since the user interaction is critical to the success of Virtual Reality, it would have benefitted us to pinpoint potential interaction problems, such as minimal introduction to the virtual environment, earlier.

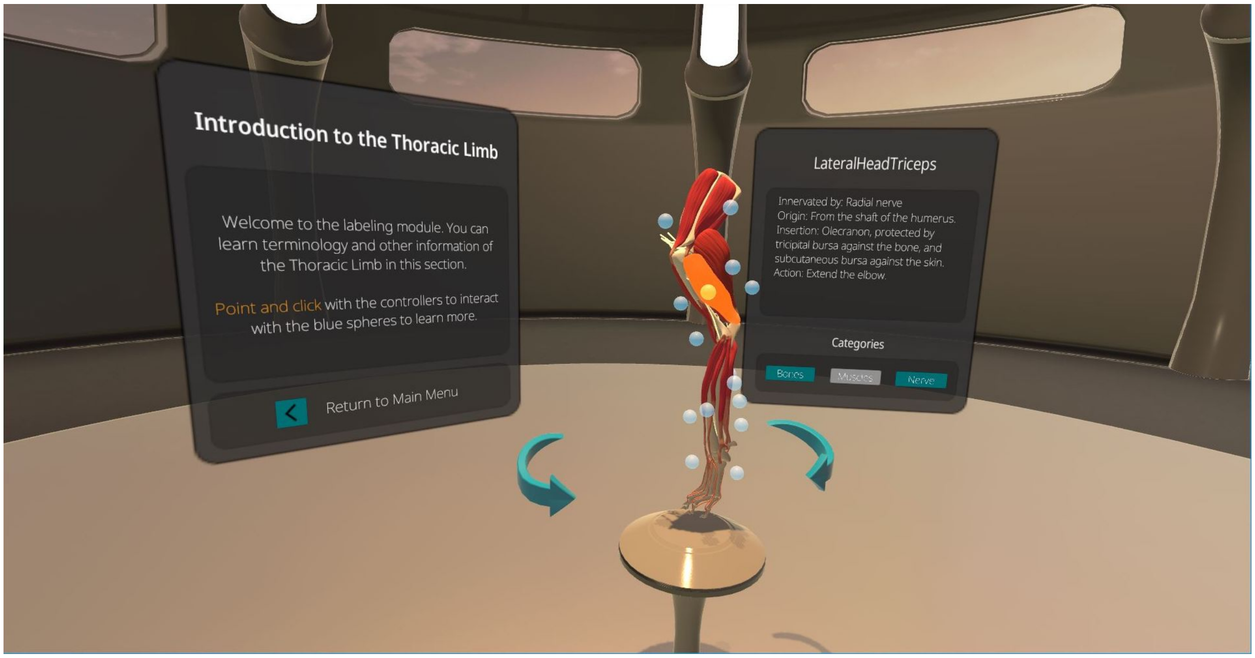

Figure 5: Tutorial portion of InNervateVR introduces user to virtual environment and reviews anatomy concepts.

Conclusions

We believe InNervateVR will be a promising addition to the higher-level anatomy classroom. Ideally, it will be implemented as a lab activity where students receive traditional lectures covering the topics of innervation in the canine thoracic limb, and afterwards they enter our Virtual Environment and truly visualize the complex concept of innervation. Not only will the students' interaction with the canine limb solidify their understanding of their anatomy lectures, but our application allows them to view innervation in its true three-dimensional form. InNervateVR may also serve as a study tool for students to review innervation while preparing for exams. InNervateVR will help students better understand concepts for their exams, and the application will reinforce an anatomy student's overall holistic understanding of innervation, which will carry on to support them in their professions.

Unfortunately, the required cost, space and equipment for virtual reality applications pose a legitimate limitation on the widespread implementation of InNervateVR and other VR Applications into anatomy classrooms. However, through this research and our interactions with personnel from the Department of Veterinary Medicine and Biomedical Sciences, we have learned there are many topics in anatomy education where VR, AR, and other Visualization technologies could fill gaps in tradition methods of education. We have received feedback from anatomy professors and students which supports that InNervateVR does illustrate a topic that is traditionally challenging for students to comprehend. As demand for visualization tools for the medical community increases, and as technology becomes more affordable and accessible, InNervateVR and any ongoing VR projects resulting from it will greatly enhance the teaching of innervation and other spatially-complex topics.

WORKS CITED

Azer, S. A., & Azer, S. (2016). 3D Anatomy Models and Impact on Learning: A Review of the Quality of the Literature. *Health Professions Education*, *2*(2), 80–98. https://doi.org/10.1016/j.hpe.2016.05.002

Biassuto, S. N., Caussa, L. I., & Criado del Río, L. E. (2006). Teaching anatomy: Cadavers vs. computers? *Annals of Anatomy*, *188*(2), 187–190. https://doi.org/10.1016/j.aanat.2005.07.007

King, L. A. (2004). Ethics and welfare of animals used in education: An overview. *Animal Welfare*, *13*(SUPPL.), 221–227.

Murgitroyd, E., Madurska, M., Gonzalez, J., & Watson, A. (2015). 3D digital anatomy modelling - Practical or pretty? *Surgeon*, *13*(3), 177–180. https://doi.org/10.1016/j.surge.2014.10.007

Gurung, P., Lukens, J. R., & Kanneganti, T. (2016). Using 3D modeling techniques to enhance teaching of difficult anatomical concepts, *21*(3), 193–201. https://doi.org/10.1016/j.molmed.2014.11.008.Mitochondria

Peterson, D. C., & Mlynarczyk, G. S. A. (2016). Analysis of traditional versus three-dimensional augmented curriculum on anatomical learning outcome measures. *Anatomical Sciences Education*, *9*(6). https://doi.org/10.1002/ase.1612

Nguyen, N., & Wilson, T. D. (2009). A head in virtual reality: Development of a dynamic head and neck model. *Anatomical Sciences Education*, *2*(6), 294–301. https://doi.org/10.1002/ase.115

Moro, C., Štromberga, Z., Raikos, A., & Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. *Anatomical Sciences Education*, *10*(6). https://doi.org/10.1002/ase.1696

Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastava, R., Govindaraj, S., & Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy and Rhinology*, *7*(10), 1006–1013. https://doi.org/10.1002/alr.21986

Nicholson, D. T., Chalk, C., Funnell, W. R. J., & Daniel, S. J. (2006). Can virtual reality improve anatomy education? A randomised controlled study of a computer-generated three-dimensional anatomical ear model. *Medical Education*, *40*(11), 1081–1087. https://doi.org/10.1111/j.1365-2929.2006.02611.x

Jang, S., Vitale, J. M., Jyung, R. W., & Black, J. B. (2017). Direct manipulation is better than passive viewing for learning anatomy in a three-dimensional virtual reality environment. *Computers and Education*, *106*, 150–165. https://doi.org/10.1016/j.compedu.2016.12.009

Maresky, H. S., Oikonomou, A. , Ali, I. , Ditkofsky, N. , Pakkal, M. and Ballyk, B. (2019), Virtual reality and cardiac anatomy: Exploring immersive three-dimensional cardiac imaging, a pilot study in undergraduate medical anatomy education. Clin Anat. https://doi.org/10.1002/ca.23292

McCloy, Rory. "Virtual Reality in Surgery." National Center for Biotechnology Information, U.S. National Library of Medicine, 21 Oct. 2001, www.ncbi.nlm.nih.gov/pmc/articles/PMC1121442/.

Fairén, M, and Farrés, M, and Moyés, J, and Insa, E. "Virtual Reality to Teach Anatomy." EUROGRAPHICS 2017.

Codd, Anthony M, and Bipasha Choudhurt. "Virtual Reality Anatomy: Is It Comparable with Traditional Methods in the Teaching of Human Forearm Musculoskeletal Anatomy?" Anatomical Sciences Education, 4 3, 2011, pp. 119–25.

Hoffman, Helene, and Vu, Dzung. "Virtual Reality: Teaching Tool of the Twenty-First Century? ." Academic Medicine, vol. 72, no. 12, 1997, pp. 1076–1081.

Heise, Natascha, Hall A. Heather, Brendan A. Garbe, Chad M. Eitel, and Todd R. Clapp. "A Virtual Learning Modality for Neuroanatomical Education." The FASEB Journal, April 20, 2018.

Seunghwan Lee, Ri Yu, Jungnam Park, Mridul Aanjaneya, Eftychios Sifakis, and Jehee Lee. 2018. Dexterous Manipulation and Control with Volumetric Muscles . ACM Trans. Graph. 37, 4, Article 57 (August 2018), 13 pages. https://doi.org/10.1145/3197517.3201330

Kesim, M., & Ozarslan, Y. (2012). Augmented Reality in Education: Current Technologies and the Potential for Education. Procedia - Social and Behavioral Sciences, 47(222), 297–302. https://doi.org/10.1016/j.sbspro.2012.06.654

Jamali, S. S., Shiratuddin, M. F., Wong, K. W., & Oskam, C. L. (2015). Utilising Mobile-Augmented Reality for Learning Human Anatomy. Procedia - Social and Behavioral Sciences, 197(February), 659–668. https://doi.org/10.1016/j.sbspro.2015.07.054

CREATIVE ARTIFACT

Video

Description

Video playthrough of InNervateVR as a user moves through its learning modules.

Filename

InNervateVR_Playthrough.mov