InNervate Immersion: Case Study of Dynamic Simulations in AR/VR Environments for Learning Muscular Innervation

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ABSTRACT

We present a collaborative immersive technology effort, InNervate AR and InNervate VR. These applications meet the need to expand on existing anatomy education platforms by implementing a more dynamic and interactive user interface. This user interface allows for exploration of the complex relationship between motor nerve deficits and their effects upon the canine anatomy's ability to produce movement. Preliminary AR user studies provided us with positive feedback in the quality of learning. The studies show that the dynamic touch interactions in AR definitely benefit students' critical reasoning and spatial visualization in learning motor nerve and muscle relationships. However, users seek a more immersive VR-based learning environment, without the distractions that an AR experience may offer. Based on this feedback, a VR version of this learning experience was created. Preliminary responses show that users are satisfied with this VR environment which allows them to manipulate and control the anatomical content with full-body interactions.

CCS CONCEPTS

• **Human-centered computing → Ubiquitous and mobile computing design and evaluation methods**; • **Applied computing → Interactive learning environments**.

KEYWORDS

Immersive Technology, Virtual Reality, Augmented Reality, Anatomy Education

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1 INTRODUCTION & BACKGROUND

Augmented reality (AR) and virtual reality (VR) are immersive technologies which have both been studied for their effectiveness as anatomy education tools. They are powerful educational tools because they offer improvements in academic content knowledge, engagement, efficiency, and attitude towards learning [Suh and Prophet 2018]. However, the existing AR/VR anatomy applications' interactions are still limited to identifying and labeling of the anatomical structures [Lee 2012]. It is important that AR/VR technologies support dynamic 3D interactions and personalized learning in anatomy education. AR and VR technologies have their own advantages and disadvantages, and the literature does not have definitive answers about whether AR or VR is the better platform for learning through 3D object manipulation [Suh and Prophet 2018] [Hoffman and Dzung 1997] [Krichenbaue et al. 2018] [Kücük et al. 2016]. Because of their own characteristics, users choose Mobile AR for accessibility of individual users and wearable VR for dynamic manipulation and embodied learning with full-body immersion. With this in mind, we developed *InNervate AR* and *InNervate VR* applications to explore how users can benefit from different interactions of AR/VR, while exploring the theme of deficits to canine muscle movement, in response to damage of the motor nerves which provide innervation to the muscles. These applications have two learning modules for the user to explore. The first is designed to give the same baseline labelling and identification that other anatomy education applications offer. The second module allows the user to become more actively engaged and to explore the relationship between motor nerves and the muscles through the use of interactive animation simulations.

1.1 Critical Reasoning of Muscular Innervation

The concept of motor nerve deficits is dynamic because it explores the relationship between muscles and the nerves which allow them to move. The concept of motor innervation deficits is difficult for these 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. To answer an exam question of this nature, the student must have a working knowledge of the spatial relationship between all of the muscles and nerves of the limb, the actions that the muscles perform to move the skeleton, and the nerves which provide innervation to each muscle. We explored how medium-dependent dynamic interactions in both AR/VR environments support critical reasoning in learning motor nerve and muscle relationships.

2 DESIGN OF AR/VR APPLICATIONS

InNervate AR and *VR* were designed to give students a learning platform to support spatial visualization and clinical reasoning. Both applications cover the radial nerve and related muscles on the canine thoracic limb. For the learning module involving the relationship between muscles and nerves, the radial nerve was singled out as the only nerve with user interactions. In the simulation module, the user is able to interact with a photo-realistic canine thoracic limb, and play animations of a healthy canine limb's range of movement. They can then create "damage" to different areas of the nerves of the limb, and be educated on what deficits exist. The resulting muscle action deficits were displayed with before and after animations of the muscles' ability (or inability) to move.

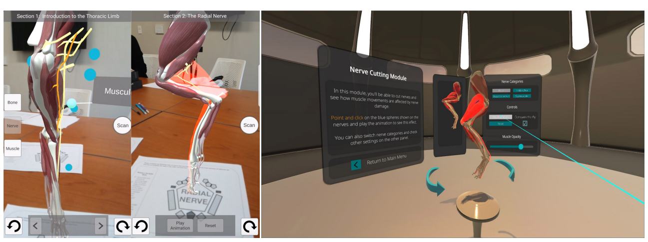

Figure 1: The views of *InNervate AR* participant left) and the view of the *InNervate VR* participant (Right).

In the development of the 3D anatomical content, we focused on intuitive user interface and the quality of the learning experience. To provide an effective learning experience, we created anatomically correct 3D models and simulations. One of the guiding design principles of the applications was that the muscles needed to appear to be driving the bones' movements. In many other anatomy applications, the bones are moving on their own, while the muscles ride along and contract/relax to appear as though they are working with the bones. *InNervate AR* was developed first because there was a high-demand need for a classroom setting. Based on the preliminary user studies using Mobile AR, we learned that Mobile AR allowed students to actively view 3D structures and dynamically manipulate anatomical content. However, users easily became distracted by the camera view and constrained by limited degree of interactions. Therefore, we developed *InNervate VR*. *InNervate VR* pushes the dynamic concepts of *InNervate AR* further by giving us control over design choices in the user's entire environment so that we can better direct the user's attention on their interaction with the canine limb. Since the VR environment provided fully body interaction, users can freely walk around the canine limb and view from different perspectives. We were also able to add three additional nerve scenarios for interaction in InNervateVR: the suprascapular nerve, median and ulnar nerves, and musculocutaneous nerve.

2.1 Preliminary User Studies

To evaluate *InNervate AR* as an educational intervention, a formal user study was conducted. This user study involved a pre- and post-anatomy knowledge test, and a test to measure the participants' existing critical thinking skills. The results of this study showed positive quantitative improvement (77 percent) in anatomy knowledge performance. In addition, we were given positive qualitative user experience results, which showed that the participants appreciated visualizing the actions of muscles with animations. Finally, the results of the study showed us where the user interface of this immersive technology could be improved in VR.

Preliminary responses to *InNervate VR* have included extremely positive feedback towards more dynamic interaction and immersive experience. We focused on refining and innovating our thoracic limb asset for *InNervate VR*, as the model would be physically larger in the VR application as compared to the AR app. All anatomy experts and students who tested the VR application responded well towards the new user interface, and provided them with the ability to better observe the spatial relationship between the nerves and the muscles which they innervate.

3 CONCLUSION & FUTURE WORKS

We have seen positive quantitative and qualitative responses to this innovative method of approaching anatomy education, by expanding the user interface to be more dynamic in both an AR and VR settings. Our preliminary studies show that the dynamic interactions in AR definitely benefit students' critical reasoning in learning motor nerve and muscle relationships. However users want more immersive learning through direct manipulations and controls of anatomical contents. Future works will involve evaluating these educational interventions in a large classroom of a higher education setting.

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