Play it by Ear: An Immersive Ear Anatomy Tutorial

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Abstract

The anatomy of the ear and the bones surrounding it are intricate yet critical for medical professionals to know. Current best practices teach ear anatomy through two-dimensional representations, which poorly characterize the three-dimensional (3D), spatial nature of the anatomy and make it difficult to learn and visualize. In this work, we describe an immersive, stereoscopic visualization tool for the anatomy of the ear based on real patient data. We describe the interface and its construction. And we compare how well medical students learn ear anatomy in the simulation compared with more traditional learning methods. Our preliminary results suggest that virtual reality may be an effective tool for anatomy education in this context.

Keywords: virtual reality, medical imaging, visualization, spatial perception

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality; J.4 [Computer Applications]: Social and Behavioral Sciences—Psychology

1 Introduction

Medical professionals must have a comprehensive understanding of the human body in order to interact with patients. Ear anatomy is especially challenging as it consists of many small, complex structures. Virtual reality (VR) may be useful for learning this anatomy since it provides stereoscopic viewing of three-dimensional (3D) virtual objects. Ear anatomy is also encased in bone, which presents a challenge for visualization even with human cadavers. VR may allow developers to graphically manipulate data so that anatomy-of-interest is more visible for observation.

However, for this technology to be used in practice, we must confirm that it is more effective than traditional learning methods. Textbooks with 2D representations are still the most commonly disseminated education materials. To date, several VR anatomy simulations have been developed for education, but many of these simulations were evaluated subjectively by experts [1], instead of rigorously by learners.

For the current study, we wanted to better quantify learning effects in virtual reality. A large number of VR studies for anatomy education have used paper tests to evaluate learning, as they're easy to administer [2]. However, cadavers represent a gold standard for understanding ear anatomy. We wanted to directly test users' spatial understanding of the relationships between these anatomical structures. Therefore, we evaluated participant understanding of ear anatomy by having them localize individual structures on an actual ear cadaver.

Specifically, we ran an A/B test to compare two learning tutorials against each other–one with 3D representations in VR and one with standard 2D representations. Participants located ear anatomy on a cadaver after learning in either the virtual reality or standard learning conditions. We hypothesized that the participants who used VR would perform better. And we conducted a preliminary analysis with medical students of comparable skill levels to balance between groups.

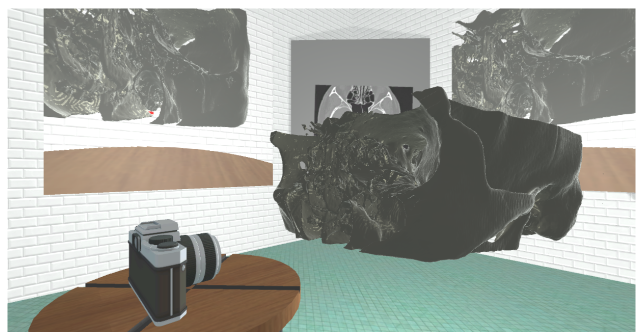

Figure 1: The immersive virtual environment

2 Simulation

Our virtual reality simulation uses automatic techniques, such as graph-based path finding, to segment anatomical structures-of-interest from cone-beam CT images of a human head [3]. The simulation is then rendered by the Oculus Rift CV1 head-mounted display. The system is networked to allow multiple users to interact with anatomy data synchronously.

The immersive virtual environment, which includes the segmented skull and ear structures, can be seen in Figure 1. Within the environment, users may freely translate, rotate, and scale the skull (Figure 2). Next to the skull is a camera, which enables users to capture still images of the data from various angles. The camera serves as a metaphor for an endoscope–an optical instrument used by medical professionals for viewing interior anatomy.

The screens along the walls capture both the camera feed and selected CT scans, which are displayed using a cutting plane that intersects with the 3D model. The cutting plane can be translated and rotated to select specific, triaxial CT scans. The simulation also contains several different visualization modes. The skull may be rendered with translucency (Figure 3), allowing users to see the position of the ear structures otherwise hidden by a bony outer casing. And a mastoidectomy can be iteratively simulated so that the outer casing of bone is removed to reveal middle and inner ear anatomy.

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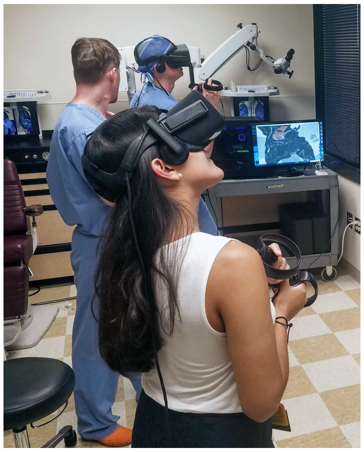

Figure 2: Multiple users interact with the system

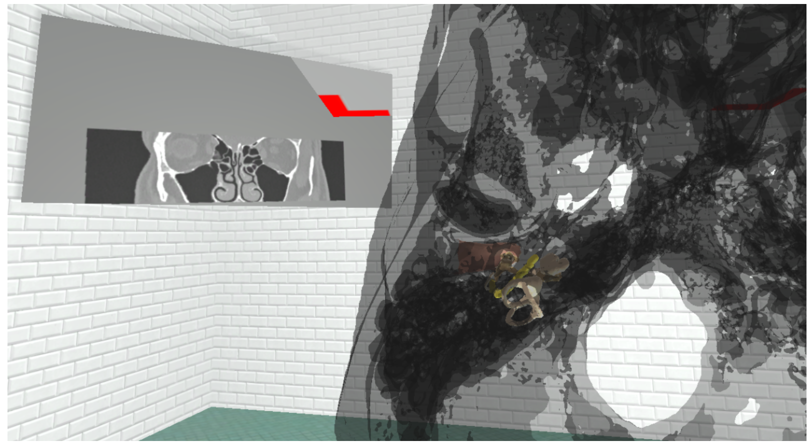

Figure 3: A user peers at the ear structures through a translucent skull model

3 Experiment

Ten medical students were recruited to evaluate learning effects between ’standard’ and ’virtual reality’ learning conditions in a between subjects design. The VR learning group was read aloud a script, which was determined a priori, while they explored and manipulated the virtual anatomy. The standard learning group was provided a written script that incorporated 2D representations of anatomy. The verbal content of both groups’ scripts was kept as identical as possible. The standard learning group was also provided two chapters from the House temporal bone dissection guide.

Prior to entering the learning phase, the VR group underwent a separate tutorial for 3 minutes to familiarize participants with the equipment. This tutorial did not include any information relevant to the posttest. Then, participants in each group were allotted 17 minutes to learn anatomy. Participants’ understanding of anatomy was then tested on a pre-drilled cadaveric temporal bone. An experienced ENT asked participants to locate certain anatomical structures, such as the chorda tympani and facial nerve. A single point was given to participants for each structure correctly identified. Fifteen structures were tested using binocular microscopy on a post-auricular, transmastoid view and seven structures were tested via transcanal endoscopy. Both vantage points are often used in surgical operation and training. After the testing phase, participants completed a post-test survey. This included the System Usability Scale (SUS), which is a reliable, technology agnostic evaluation tool for usability.

4 Results

Five participants, ranging from medical student year two to four, were randomized to each group. For identification of transmastoid structures, the VR group answered 60% (M=9, SD=3.54) of the structures correct compared with 37% (M=5.6, SD=4.16) in the standard learning group. For the endoscopic structures, the virtual training group answered 60% correct (M=4.2, SD=1.10) compared with 40% (M=2.8, SD=1.79) in the standard learning group. See Figure 4 for a plot of the means and standard deviations. Post-test survey showed the VR system was easy to use, useful, and enjoyable. The SUS showed a significant (p=0.006) difference between the VR system (M=67, SD=10.1) and the standard learning arm (M=43, SD=10.2).

5 Discussion

Although preliminary, our results reveal a trend in which the VR group outperforms the standard learning group. These results are promising and encourage further development of the system. In future work, a complete evaluation of the system will be necessary

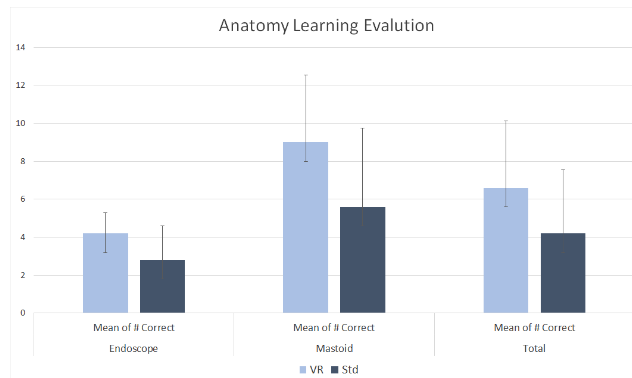

Figure 4: Mean number of correctly identified anatomical structures for VR and standard learning groups

to determine if there is truly a significant effect of learning condition. As the learning environment matures, next iterations of the system may provide beneficial learning functionalities like repeated practice, error correction, and feedback within the immersive tutorial.

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References

[1] H. Adams, J. Shinn, W. G. Morrel, J. Noble, and B. Bodenheimer. Development and evaluation of an immersive virtual reality system for medical imaging of the ear. In *SPIE Medical Imaging: Image-Guided Procedures, Robotic Interventions, and Modeling*, vol. 10951, 2019. doi: 10.1117/12.2506178

[2] D. T. Nicholson, C. Chalk, W. R. J. Funnell, and S. J. Daniel. 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, 2006. doi: 10.1111/j.1365-2929.2006.02611.x

[3] J. H. Noble and B. M. Dawant. An atlas-navigated optimal medial axis and deformable model algorithm (nomad) for the segmentation of the optic nerves and chiasm in mr and ct images. *Medical Image Analysis*, 15(6):877 – 884, 2011. doi: 10.1016/j.media.2011.05.001