STUDYING EFFECTS OF MUSCLE REPRESENTATIONS AND LEVELS OF INTERACTIVITY IN A VIRTUAL REALITY CANINE THORACIC LIMB APPLICATION

An Undergraduate Research Scholars Thesis

by

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ABSTRACT

Studying Effects of Muscle Representations and Levels of Interactivity in a Virtual Reality Canine Thoracic Limb Application

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Virtual Reality, or VR, is at the forefront of modern technology; revolutionizing current methods for conducting activities such as gaming, training simulations, business meetings, and even teaching. When considering anatomy education specifically, students must learn form, function, and movement of various bones, muscles, muscle tendons, ligaments, and joints within the body. Cadaver dissection is believed to be the most optimal form of study, but it is not always the most accessible form of study. We propose a VR canine thoracic limb application that allows students to learn about musculoskeletal movements while also enhancing spatial visualization abilities in the hope of increasing memory retention in a more fun, engaging way. In our study, three major factors were considered: (1) spatial visualization ability of learners, (2) visualization styles of muscles, and (3) interactivity of the application. Participants of differing spatial abilities (high and low) will study a virtual thoracic limb in one of two visual conditions (realistic muscles or symbolic muscles) and one of two interactive conditions (interactive manipulation or non-interactive viewing). We plan to test these against each other to determine which method of muscle representation holds the most effective form of memory retention, and what role interactivity plays in this retention. Before the experiment, we will gather data

pertaining to student's spatial visualization ability via a mental rotation test to create a baseline. After the experiment, we will interview the participant to gather qualitative data about the application's effectiveness and usability. Our results should show overall, based on our hypothesis, that the more realistic and interactive the application is, the more retention there should be. Both the quantitative data from the experiment, and the qualitative data from the post experiment should support this hypothesis. Regardless of which condition shows to be more successful, we hope to revolutionize teaching methods, practices, and even test taking applications for anatomy students with this virtual reality teaching application.

ACKNOWLEDGEMENTS

We would like to thank our research advisor, Dr. Jinsil Hwaryoung Seo, and all the other members of our research team including Dr. Michelle Pine, Dr. Zhikun Bai, Brian Smith, Erica Malone, Megan Cook, Steven Leal, and Erin Schulte for their contributions to our overall goal as we plan to continue onward with the teaching application. We would also like to thank the Department of Visualization for providing us with the equipment necessary to conduct our study.

NOMENCLATURE

VR	Virtual Reality
Vz	Spatial Visualization
SR	Spatial Relation Ability
PSVT:R	Purdue Spatial Visualization Test: Rotation
RI	Realistic Interactive
RNI	Realistic Non-Interactive
SI	Symbolic Interactive
SNI	Symbolic Non-Interactive

SECTION I

INTRODUCTION

1. Importance and Limitations of Anatomy Education

Anatomy education is fundamental in life science and health education as well as visual studies and dance science. In traditional anatomy education, it has been believed that cadaver dissection is the optimal teaching and learning method (Winkelmann, Hendrix, & Kiessling, 2007). Cadaver dissection provides tangible knowledge of the shape and size of the organs, bones, and muscles. Beyond this, students use many visual study aids including diagrams, illustrations, animations, and 3D graphics (Albanese, 2010). We believe that the current learning tools for anatomy can be improved upon though. Students are rarely able to use [current methods] to accurately demonstrate movement that results from specific muscle contraction (Cake, 2006; Smith & Brennan, 2013) or to understand the spatial relationships between structures. They often have difficulties on mentally visualizing the three-dimensional (3D) body from inside out (i.e. bone to skin) and on how individual body parts are positioned relative to the rest of the body.

2. The Role Virtual Reality Could Play in Anatomy Education

Our focus is on developing a virtual reality application of a musculoskeletal thoracic limb model to support students' understanding of movements. Since we are testing the role of interactivity in the study, some students will be able to manipulate the pre-assembled model and simulate muscle group movements in VR. While the other group will simply watch the model perform with similar interactions without the option for manipulating these movements. We think that without such an enabling environment, any visual learning aids will continue to be impractical due to the lack of immersion into the subject material. The basic idea of virtual reality is to use computer technology to create a simulated, three-dimensional world that a user can manipulate and explore while feeling as if they were in that world (Strickland, 2016). Using virtual reality, in turn, would create a much more captivating learning environment while also trying to be as realistic as possible. It’s already being used to enhance learning experiences in many disciplines. The use of virtual reality has already proven to be effective in the anatomical world by providing a revolutionary step that extends the perceptions of our five senses beyond the real state of things involving immersion, navigation, and interaction (Marescaux et al., 2016). The practical applicability of virtual reality in eLearning is a hotly discussed topic right now. For now, potential applications in the fields of physics and medicine show the most promise (Treser, 2016).

3. Building Off Our Research Advisor’s Previous Work

Our research advisor, Dr. Jinsil Hwaryoung Seo, has integrated virtual reality and augmented reality techniques in anatomy education applications: ARnatomy and Anatomy Builder VR. ARnatomy aims to integrate a tangible user interface and augmented reality by using dog bones to control the display of information on a mobile device such as a smartphone or tablet (Seo et al., 2014). Anatomy Builder VR is an ongoing project that examines how a virtual reality system can support embodied learning in anatomy education. The backbone of the project is to pursue an alternative constructivist pedagogic model for learning canine anatomy. Direct manipulations in the program allow learners to interact with either individual bones or groups of bones, to determine their viewing orientation and to control the pace of the content manipulation.

The Anatomy Builder VR program utilizes the HTC Vive virtual reality platform. Building on top of her previous work, we hope to combine the knowledge and technology from these projects and merge them into our new project.

4. Problem

Which variables allow for the most effective way to teach an anatomy student about the canine thoracic limb in a virtual environment? The following experiment plans to study the effect of muscle representations and levels of interactivity on memory retention. In our study, three major factors were considered: (1) spatial visualization ability of learners, (2) visualization styles of muscles, and (3) interactivity of the application.

To address these questions, we created a virtual reality application that a participant must use to learn various anatomical aspects of the canine thoracic limb. The lesson taught in accordance with the application covers anatomical views, localized muscle contractions of the bicep and triceps, and identifying position and rotation of the shoulder and elbow joint due to these contractions. The major factors were assessed through a post-study anatomy test covering the topics listed above. The use of one’s spatial visualization ability can assist with all 3 tasks while muscle representation and level of interactivity are cross-referenced in this study to find out how these variables can further aid student’s memory retention. Below we will discuss each of the major factors in more depth.

Spatial Visualization, or Vz, is the ability to apprehend, encode, and manipulate mental representations. We are using dynamic visualizations in our application to help engage spatial visualization. A dynamic visualization is a way to represent material that involves rotational movement and analysis for a more in depth study. To learn the information represented in the teaching module, students must be able to mentally visualize the canine thoracic limb. Anatomical views, and various positions of the limb during various states of muscle contraction can be learned by simply changing the mental representation to fit a specific view, position, or contraction. This ability is called Spatial Relation Ability, or SR. SR refers to rapidly and accurately rotating 2D and 3D information. Some students have a lower SR than others, but the use of dynamic visualizations help low SR students by compensating for their spatial weakness, and even allow them to do almost as well as their high SR counterparts.

The representation of the muscles can be seen in our study through either realistic or symbolic means. The realistic version (fig. 1) contains muscles that attempt to mimic the actual muscles that can be found in the canine thoracic limb. The shape, texture, and deformation during contraction were all considered.

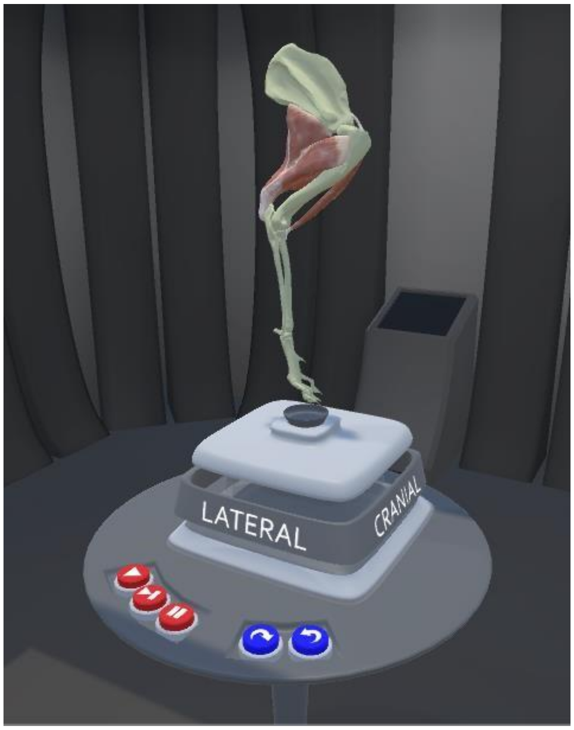

Figure 1: Realistic Interactive App.

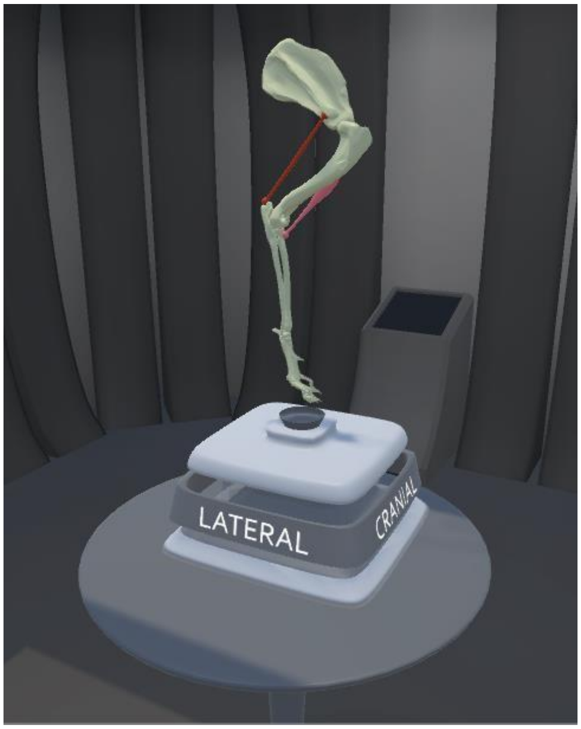

Figure 2: Symbolic Non-Interactive App.

The symbolic muscles (fig. 2), however, are made up of cylindrical tubes that expand in the center, kind of like a balloon, during contraction. We created two representations of the muscles to examine which allows for better results on the post-study anatomy test, and which is preferred by the students.

The interactivity of the module also becomes a big factor in student's memory retention. We have two models of varying interactivity. The interactive version (fig. 1) has 5 buttons the user can push with an HTC Vive hand controller to manipulate the thoracic limb during learning. The red buttons control the speed of the walk cycle, and the blue buttons control the rotation of the model and base that displays labels of the anatomical views. The non-interactive version (fig. 2), however, doesn't have any buttons and must be controlled by the teacher using the keyboard. Virtual reality is already an immersive technology, but we aim to test how added interactivity can affect learning potential and engagement.

5. Hypothesis

There is a strong spatial component to the way anatomical information is mentally represented. Based on research we did prior to the creation of the application, we found various hypotheses from previous research and, following along with their findings, we have formulated 3 hypotheses of our own. In terms of Vz, we hope that students with low SR will be able to perform as well as high SR students through the dynamic visualization learning that we are providing. We also believe that the best way to understand the form, function, and movement of the canine thoracic limb is through more realism and interactivity. We believe that the realistic representation of muscles will be more favorable to the symbolic representation just as the interactive version should show better results than the non-interactive version.

Spatial Visualization is essentially the ability to mentally manipulate an object in multiple dimensions. It was examined in a recent study concerning the effectiveness in methods of problem-solving strategies, and was shown to be the strongest indicator in visuospatial anatomy comprehension, or in other words, visualizing the movement of the canine thoracic limb in VR enhances memory retention (Nguyen et al., 2016).

Both muscle representations offer the same movement and function, but we believe the form is going to be the deciding factor on memory retention. In a study on representations of the virtual hand, it was found that there is a direct correlation between the sense of ownership, or sense that one's own body is the source of sensations, and the virtual representation of the virtual hand where there was an increase in ownership as the model more closely resembled its actual form (Argelaguet et al., 2016).

The level of interactivity in the application changes the experience more than anything else. The interactive version utilizes HTC Vive hand controllers while the non-interactive version does not. The participants were not able to perform the same actions, but still had to learn the information in almost the same exact way. A similar study done on interactivity and conceptual learning in virtual reality found that the interactive VR experience aided children in problem solving, but the non-interactive version seemed to support greater indications of conceptual change (Roussou et al., 2006)

SECTION II

METHODS

1. Virtual Reality Application

1.1 Creation of Virtual Models

The final applications required one set of hyper realistic dog bones from the thoracic limb, two different representations of the biceps/triceps, a functional model stand that could include interactive buttons, and a lab setting to help immerse the participants. We planned to 3D scan real bones to have realistic virtual models. In terms of creating the bones, each bone went through a process that included laser scanning, 3D sculpting, retopology, and texturing. The realistic muscle models went through a similar process, but 1-on-1 sculpting sessions with our anatomy experts replaced laser scanning. Symbolic muscles were created through muscle effects in Autodesk Maya (a 3D, digital art program). The same program was used to create the model stand and lab environment. Rigging and animating had to be done on both thoracic limbs so they could complete a walk cycle and show muscle contractions accordingly. Programming in Unity was also required to set up the VR equipment, and interactive actions, to run with the application.

1.2 Creation of the Bones

1.2.1 Photogrammetry

The process of photogrammetry entails the use of photography to 3D map objects based on their distance. Our experimentation with photogrammetry resulted in poor quality scans that we were unable to use. This process did not allow us to achieve the level of anatomical accuracy that we desired.

1.2.2 Laser Scanning

Laser scanning was found to be the most effective way for us to initially create the bones models, and we used the “XYZ Scan Handy” laser scanner. The scanner has a sensor built in and once the object is recognized and in focus it produces an OBJ file (a 3D digital model file). However, after the scan is complete and the model is created, there is still a touch-up process involved.

1.2.3 Sculpting/Retopologizing Bones

We used a 3D software called “Sculptris” (fig. 3) that let us control and fix any problems with the topology of each bone. The topology refers to the 3D grid or mesh consisting of vertices, faces, and edges that shapes the object. We went through each of the five bones on the thoracic limb (the scapula, radius, ulna, humerus, and carpal bones) and assured there were no errors in the topology to avoid texture complications. For the scapula and carpal bones, we were forced to bring them into another application before Sculptris, called Autodesk Maya to repair holes in the mesh from the laser-scans.

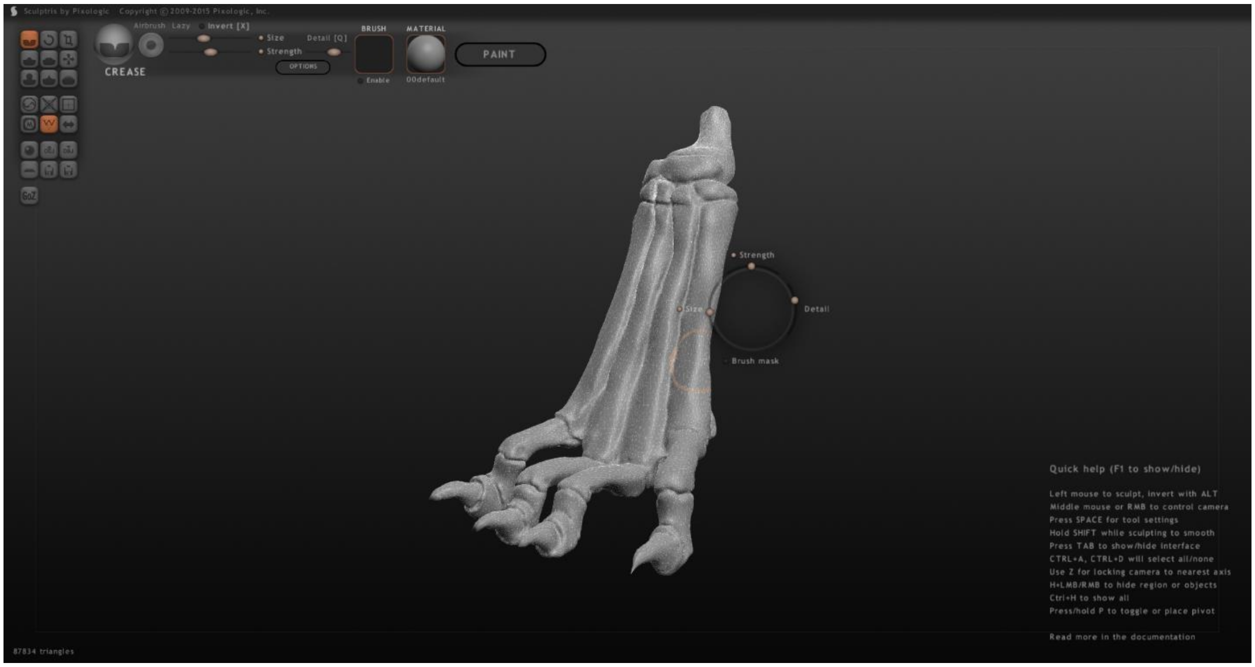

Figure 3: Demonstration of Sculpting Software

1.3 Creation of the Muscles

1.3.1 Studying Muscle Reference

The final application involved the creation of realistic anatomical muscles, which meant that it was vital that we had guidance through the process. We worked with anatomists from the Veterinary College, and they checked the accuracy of the model at every step of the process. They also provided us with various anatomy books that we could use for reference. This reference combined with the anatomist's reviews proved to be effective for us to create realistic models.

1.3.2 Sculpting/Retopologizing Muscles

We initially decided to have the muscle sculpted in clay and it was scanned just like the bones and exported to a 3D model. Because the scans never turned out well, we decided to take another route and utilize the members of our research team to help us sculpt the muscles from scratch in real time. As we would sculpt the muscle in Sculptris, one of the anatomists would guide us in the creation of the muscles. With partial tweaks to the muscles for anatomical accuracy, the model was essentially finished, and just needed to be optimized for the VR application. Using Autodesk Maya, we retopologized the muscles using the quad draw tool. This method lowered the polygon count of the models to more than half the original value, and also optimized their UV's for texturing purposes. The lattice tool was also used to reposition the lateral and medial heads on the triceps brachii by moving them in closer and closing the gap that originally existed between the heads.

1.3.3 Texturing

Texturing was the final step to have finished muscle assets that could be rigged and animated. We strived to create a texture that would look like real muscles. Using software called Substance Painter, we created multiple layers to influence the texture of the models. This allowed us to get a two-toned, red/orange texture showing striations similar to a real muscle. (fig. 4).

Figure 4: Final realistic module muscle texture

1.4 Rigging and Animating the Walk Cycle

1.4.1 Bone Inverse Kinematics

After we finished modeling and texturing the muscles and bones, the next step was to animate an anatomically accurate walk cycle. We began by implementing an inverse kinematic, or IK, rig on the bones that we created (fig. 5). The IK rig we built also had additional ankle and knee controls to mimic the real canine walk cycle. We used reference videos and keyed each pose to make sure the movements were anatomically correct.

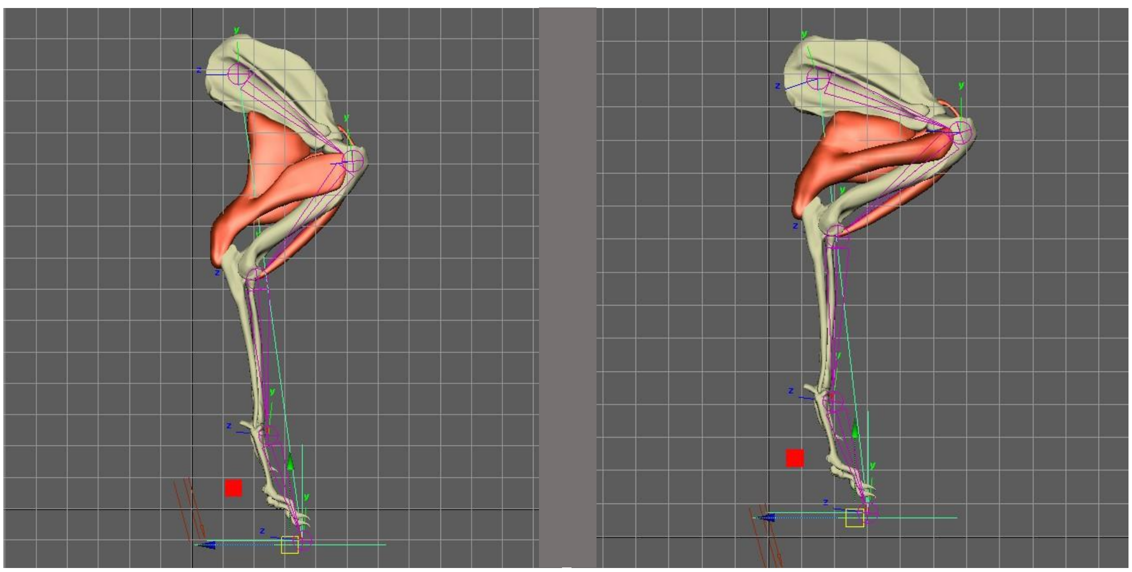

Figure 5: Representation of rig control

1.4.2 Muscle Deformations

After creating the fluid bone animation, it was time to incorporate the muscles and their correct contractions. We had two sets of muscles, one realistic, and one symbolic, and they each contracted the same way. We started with the realistic muscle mesh and binded it to the bones and the rig in Maya. Maya automatically guesses how objects will deform based on the joint locations that are binded to the mesh. Because we wanted a realistic deformation in the muscle during contraction, we had to manually deform and animate them. The blend shape deformer tool in Maya allowed us to pause the animation in the middle of the walk cycle and sculpt the muscle to the form of contraction pertaining to the symbolic and realistic versions.

1.5 Virtual Reality Application in Unity 3D

1.5.1 Combining Assets in Unity Game Engine

After both versions were animated, we converted them into FBX files, which retain the texture and animation information associated with each model. We also created an environment for the application that consisted of the lab along with two different tables in respect to which module was in use.

1.5.2 Creating 4 Unique Conditions for Experimentation

Four unique versions of the application can be created from the pieces that have been produced so far. The four different versions are realistic interactive, realistic non-interactive, symbolic interactive, and symbolic non-interactive. The interactive versions of our application had buttons that enabled the user to control the thoracic limb. We programmed the interactive application to control the animation speed of the walk cycle, and the rotation of the thoracic limb and base. The rotation ability allows us to not only rotate the thoracic limb, but also teach the user four different anatomical views (lateral, medial, cranial, and caudal). When the model rotates, part of the base rotates at the same rate to display the corresponding view. Playing and pausing the animation teaches the user about the reciprocal relationship between the bicep and tricep. By pointing the Vive hand-controller laser at a specific button, the user can press the trigger on the back of the controller to activate the function of that button.

The non-interactive versions of our application consisted of no buttons, and the user did not receive a controller. Muscle representation is the only difference between the realistic and symbolic versions of our application. In the symbolic version emphasizes muscle contractions more easily, but the realistic version provides a realistic contraction.

2. User Studies

2.1 Study Procedure

The user studies were conducted to give us a better understanding of how effective the different methods will be on musculoskeletal movement retention and anatomical identification. We recruited 24 participants who had never studied a university level anatomy course before, and randomly assigned them 1 of 4 versions based on their Vz scores.

Before the experiment, participants' spatial visualization abilities were assessed using the *Revised Purdue Spatial Visualization Test*. In addition, students' comprehension of anatomical information was assessed using a post-test involving anatomical views, joint locations, and muscle contractions. We finished the study by asking questions to the participants (table 1) about their experiences they had during the study.

Table 1: Interview questions asked post-study.

Post-Study Interview Questions
1. Is this your first time using VR? If so, how did you like it? If not, how did it compare to the other times you have used VR?
2. How did you learn the anatomy information today? Was it different from your past experiences with anything biology or science related?
3. Do you remember the representation of muscles in VR? What do you remember about them?
4. Do you think that the representation of muscles was more beneficial or detrimental to your learning? Why do you think that?
5. How did you learn about movements of the skeleton in VR today? How did you like it? Do you have any suggestions?
6. How did you learn about different anatomical views in VR today? How did you like it? Do you have any suggestions?
7. Do you think walking around the model is more effective than having the model rotate? Why is that?
8. Would you be willing to learn some of the subjects that you currently are studying in a VR environment like this and what was your favorite part of this experience?

2.2 Data Collection

In this study, we will collect data through quantitative and qualitative means along with recording the user experience to fully analyze the experiment. In the quantitative data (fig. 6) the main analyzations revolved around comparing the post-test scores. We also compared the users' MRT scores that determined if they had high or low Vz abilities. After that we compared the effectiveness of each of the applications by sorting the results respectfully. The qualitative data we received came from the post-study interview we performed at the very end of the study.

fx Data Analysis

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	Data Analysis																					
2																						
3	VR Scenes																					
4	ID Card			Mental Rotat		Pre-Experim		VR Sc	Test Questions													
5									Views					Joints			Views/Contractions					
6	Partic	Gend	Major	Score	Sz	Famili	Familiar with		Q1	Q2	Q3	Q4	View	Q5	Q6	Joints	Q7	Q8	Q9	Q10	Views/Contractions	Final
7	Real Muscles Vs. Symbolic Muscles																					
8	4	[redacted]	[redacted]	19	L	No	No	RI	1	1	1	1	4	1	0	1	1	1	1	1	4	90
9	8	[redacted]	[redacted]	29	H	No	No	RI	1	1	1	1	4	1	1	2	0	1	1	0	2	80
10	11	[redacted]	[redacted]	21	H	No	Yes	RI	1	1	1	1	4	1	0	1	0	0	1	0	1	60
11	18	[redacted]	[redacted]	27	H	No	No	RI	1	1	1	1	4	1	1	2	0	1	1	0	2	80
12	23	[redacted]	[redacted]	26	H	No	Yes	RI	1	1	1	1	4	1	1	2	0	0	0	1	1	70
13	24	[redacted]	[redacted]	9	L	No	No	RI	1	1	1	1	4	1	1	2	1	1	1	1	4	100
14	5	[redacted]	[redacted]	23	H	No	Yes	RNI	1	1	1	1	4	1	1	2	1	1	1	1	4	100
15	9	[redacted]	[redacted]	15	L	Yes	Yes	RNI	1	1	1	1	4	1	1	2	1	0	1	1	3	90
16	15	[redacted]	[redacted]	24	H	Yes	No	RNI	1	1	1	1	4	1	1	2	1	1	1	1	4	100
17	19	[redacted]	[redacted]	27	H	No	Yes	RNI	1	1	1	1	4	1	1	2	1	1	1	1	4	100
18	21	[redacted]	[redacted]	19	L	No	No	RNI	1	1	1	1	4	0	1	1	1	1	0	1	3	80
19	25	[redacted]	[redacted]	25	H	No	No	RNI	1	1	1	1	4	1	0	1	1	1	1	1	4	90
20	12 To	[redacted]	[redacted]	22	8/4	2/12	5/12		12	12	12	12	48/48 100%	11	9	20/24	8	9	10	9	36/48	86.67

Figure 6: Quantitative Data Analysis

SECTION III

RESULTS

1. Spatial Visualization

Observing Spatial Visualization across all 4 VR conditions, we see that 15 participants scored high on the revised PSVT:R, and 9 participants scored low. Individual scores (fig. 7) show a confusing distribution across the spectrum. It looks like the high Vz did better overall, but it has to be remembered that there was an uneven number of participants. Looking at the averages between high and low Vz,(table 2) we can observe that the **high Vz** scored (Mean = **78.67**, SD = **24.73**) on the post-study anatomy test, whereas the **low Vz** scored (Mean = **71.11**, SD = **33.48**).

Table 2: Test Score Averages for High Vz vs. Low Vz

Test Score Averages for High Vz vs. Low Vz		
	Mean	Standard Deviation
High Spatial Visualization	78.67	24.73
Low Spatial Visualization	71.11	33.48

The results seem insignificant to show the enhancer hypothesis, so we conclude that the compensating hypothesis is in effect here (Berney et al).

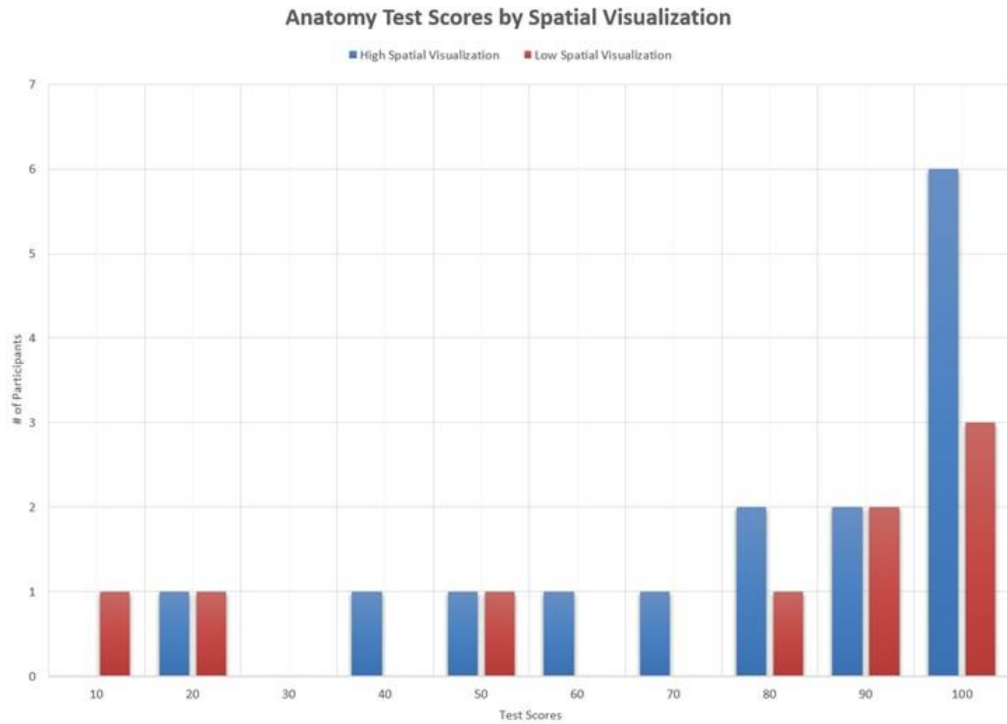

Figure 7: Anatomy Test Scores by Spatial Visualization

2. Muscle Representation

The realistic and symbolic muscle representations are the only difference that can be seen in the thoracic limb across all 4 VR conditions. Participants were tasked with identifying anatomical views, muscles, and memorizing muscle movements. The distribution of individual participant's test scores (fig. 8) shows a high concentration of realistic muscles towards passing grades. Comparing realistic and symbolic muscle representation, we can see that overall **realistic** scored (Mean = **86.67**, SD = **12.47**) and **symbolic** scored (Mean = **65**, SD = **35.24**) (table 3).

Table 3: Test Score Averages for Realistic Muscles vs. Symbolic Muscles

Test Score Averages for Realistic Muscles vs. Symbolic Muscles		
	Mean	Standard Deviation
Realistic Muscles	86.67	12.47
Symbolic Muscles	65	35.24

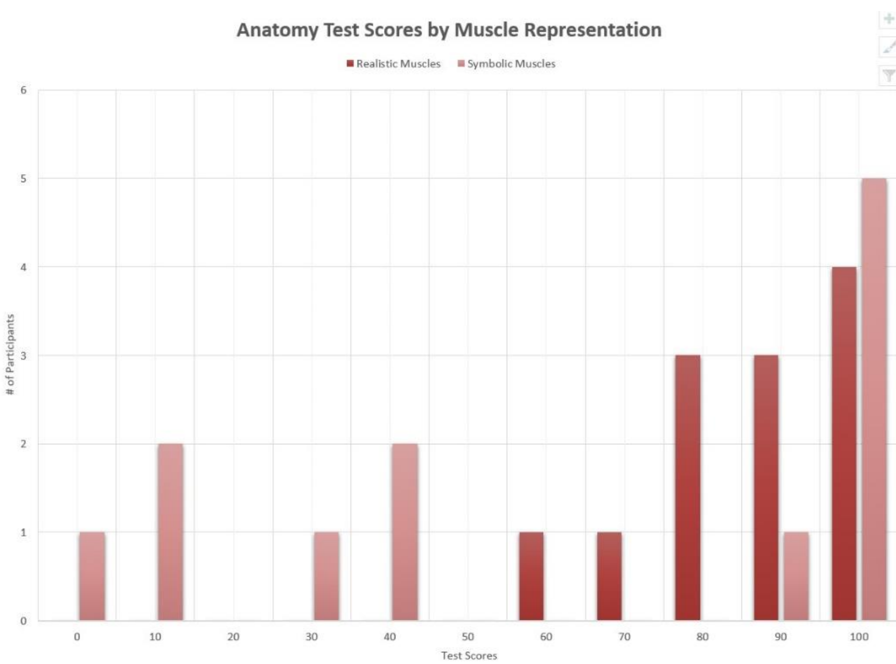

Figure 8: Anatomy Test Scores by Muscle Representation

There were 10 questions in the post-study anatomy test that were divided into sections based on what participants learned in the application. The first 4 questions focused on identifying views where **realistic** scored (Mean = **100**, SD = **0**) and **symbolic** scored (Mean = **70.83**, SD = **39.65**). We see that the more realistic muscles helped participants identify anatomical views way more efficiently than symbolic muscles. The next 2 questions focused on joint location, which is an extension of learning muscle contractions. **Realistic muscles** scored (Mean = **80.33**, SD = **24.62**) and **symbolic** scored (Mean = **70.83**, SD = **39.65**). More realistic muscles aided the participants in memorizing muscle contractions visualized through joint location. Finally, the last

4 questions analyzed the combination of anatomical view and muscle contraction, testing to see how well the students could piece all the information they learned together. **Realistic muscles** scored (Mean = **75**, SD = **30.15**) while **symbolic** muscles scored (Mean = **50**, SD = **46.47**) (table 4).

Table 4: The breakdown of the post-study anatomy test by sections that test different material learned from the VR application. The information in this table is organized by muscle representation user groups.

Anatomy Test Question Breakdown for Realistic vs. Symbolic Muscle Representation						
	Anatomical Views Questions		Joint Location Questions		Anatomical View/Muscle Contraction Questions	
	Mean	SD	Mean	SD	Mean	SD
Realistic Muscles	100	0	80.33	24.62	75	30.15
Symbolic Muscles	70.83	39.65	70.83	39.65	50	46.47

The question to be asked is whether the problem lies in identifying anatomical views, or muscles and their contractions. Based on the results from just the views section of the test, we see that muscles were the recurring problem among participants who did not score a 100. The more realistic muscle condition has proven to do better on our anatomy test in all areas with significant results supporting this.

3. Interactivity

The interactivity of the system defined the rest of the VR conditions, being either interactive or non-interactive. The interactive condition had 5 buttons that controlled the thoracic limb's walk cycle animation speed and rotation on the y (vertical) axis. The non-interactive version had no interactive elements. The participants were read slightly different scripts during the application to account for this change. Overall, the interactive version scored (Mean = 60.83%, SD = 30.13) the non-interactive version scored (Mean = 90.83%, SD = 16.83). (table 5)

Table 5: Test Score Averages for Interactive System vs. Non-Interactive System

Test Score Averages for Interactive System vs. Non-Interactive System		
	Mean	Standard Deviation
Interactive System	60.83	30.13
Non-Interactive System	90.83	16.83

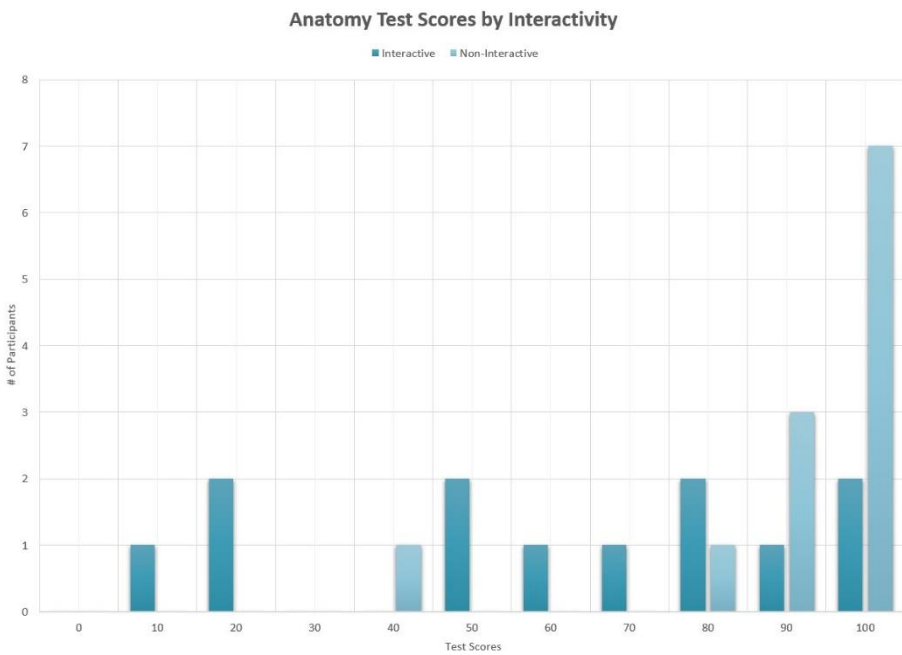

Figure 9: Anatomy Test Scores by Interactivity

Individually, based on distribution, it's clear to see that the non-interactive version performed better because of the overwhelming amount of 100's (fig. 9). Also, based off the sections in the anatomy test mentioned above in the *Muscle Representation* section, we saw in the first 4 questions that **interactive** scored (Mean = **70.83%**, SD = **39.65**) while the **non-interactive** scored (Mean = **100%**, SD = **0**). The non-interactive version allowed the participants to pay more attention to the lesson, and they learned the views more efficiently. Questions 5 and

6 show the **interactive** scored (Mean = **75%**, SD = **33.71**) while the **non-interactive** scored (Mean = **79.16**, SD = **33.43**). Surprisingly, there is not much of a difference here despite the 30-point difference in the overall score. When we look at the last 4 questions that combine the knowledge from anatomical views and muscle contractions, we see that interactive scored (Mean = **43.75%**, SD = **38.62**) while non-interactive scored (Mean = **87.5%**, SD = **29.19**). (table 6)

Table 6: The breakdown of the post-study anatomy test by sections that test different material learned from the VR application. The information in this table is organized by level of interactivity in user groups.

Anatomy Test Question Breakdown for Interactive vs. Non-Interactive System						
	Anatomical Views Questions		Joint Location Questions		Anatomical View/Muscle Contraction Questions	
	Mean	SD	Mean	SD	Mean	SD
Interactive System	70.83	39.65	75	33.71	43.75	38.62
Non-Interactive System	100	0	79.16	33.43	87.50	29.19

The average score for the non-interactive version is more than double the average from the interactive version. Looking at why the non-interactive versions did so much better in this section of the test, we see that several participants who mixed up their anatomical views from the first 4 questions of the test also did on this section for the same reason. In each section of our anatomy test, non-interactive learning had the best memory retention.

4. Discussion and Limitations

Overall, we saw varying results from each VR condition that are worth noting. The realistic non-interactive scene scored best with (Mean = 93.33%, SD = 8.16). Had it not been for an outlier in the symbolic non-interactive scene that made the score (Mean = 88.33%, SD = 24.01), then it would've scored higher. The score without the outlier was (Mean = 98%, SD = 4.47). The non-interactive scenes had better scores than the interactive scenes, and the realistic versions scored better than the symbolic versions for both levels of interactivity. The realistic interactive version scored (Mean = 80%, SD = 14.14) because participants struggled to understand bicep/triceps contractions as effectively. The shocking, seemingly coincidental result is the symbolic interactive version with a score (Mean = 41.67%, SD = 33.12). The specific scores in that section were (100, 50, 50, 20, 20, 10), and aside from the outlier in the symbolic non-interactive scene, all the worst scores on the test happen to emerge from this VR condition. Analyzing each test individually, we see participants primarily chose opposite anatomical views, but bicep/triceps contraction also caused problems, and sometimes both were switched.

Because of the results from the SI version, any data analysis will be skewed in favor of the group that does not contain the SI participants, in part or in whole. We see this in the analysis of muscle representations where realistic muscle versions scored 20 points higher on average, and in the levels of interactivity where the non-interactive versions scored 30 points higher on average. Based on previous research and some of our hypotheses, the results show what is to be expected, but the way in which they have come to be is quite questionable. A larger scale study would be beneficial in determining more accurate numbers, and definitively proving the results we found from this study.

Another limitation from the study was the design of the anatomy test. The way we worded the questions did not allow for partial knowledge gain. We can see from most participant's results who did not do well that they simply flipped anatomical views or bicep/tricep contractions. A student who switches the side views (lateral/medial) and the front/back views (cranial/caudal) could score a 20 on the anatomy test because the questions rely heavily on knowing this material.

Additionally, we noticed in a few sessions that the participants preferred walking around the model in VR than rotating the model, but others preferred rotation. The interactivity of the application had some influence here because non-interactive conditions required students to walk around the model to review anatomical views, and see muscle contractions from different angles if they were inclined to.

SECTION IV

CONCLUSION

This experiment utilizes virtual reality technology to assess varying teaching methods of canine anatomy using dynamic visualizations. Spatial visualization, muscle representations, and levels of interactivity were tested as independent variables in our user studies to determine which conditions would promote the most effective form of memory retention. We observed through 24 user studies that low spatial visualization users gained an advantage through dynamic visualization learning to almost perform as well as their high spatial visualization counterparts. Realistic muscles assisted participants with identifying anatomical views more efficiently, and therefore had a significantly better average compared to the symbolic representation. Despite the symbolic muscle representation’s simplistic contractions, first-time anatomy learners still performed better in the realistic version. The non-interactive system proved to be less distracting based on test scores, but also from the qualitative information gathered during the post-study interview. Users could focus more on learning the anatomy information because there was nothing else presented in the application to draw attention away from the user. Because of the small sample size, additional user studies should be done with this experiment for more accurate results, but the conclusion should be expected to show similar findings.

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