

# Development of an Interactive Anatomical Three-Dimensional Eye Model

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The discrete anatomy of the eye's intricate oculomotor system is conceptually difficult for novice students to grasp. This is problematic given that this group of muscles represents one of the most common sites of clinical intervention in the treatment of ocular motility disorders and other eye disorders. This project was designed to develop a digital, interactive, three-dimensional (3D) model of the muscles and cranial nerves of the oculomotor system. Development of the 3D model utilized data from the Visible Human Project (VHP) dataset that was refined using multiple forms of 3D software. The model was then paired with a virtual user interface in order to create a novel 3D learning tool for the human oculomotor system. Development of the virtual eye model was done while attempting to adhere to the principles of cognitive load theory (CLT) and the reduction of extraneous load in particular. The detailed approach, digital tools employed, and the CLT guidelines are described herein. *Anat Sci Educ* 00: 000–000. © 2014 American Association of Anatomists.

**Key words:** gross anatomy education; medical education; undergraduate education; computer-assisted learning; three-dimensional modeling; cognitive load; eye virtual model; oculomotor system; animation; ophthalmology

## INTRODUCTION

The study of gross anatomy provides an unparalleled opportunity for students to form and model an individual three-dimensional (3D) understanding of the body and its functions (Marks, 2000). The education of future health care professionals involves both learning and applying three-dimensional (3D) knowledge to effectively care for their patients. For novice students in anatomy, learning is a process of development, affirmation, and reconstruction as they strive to master the intricacies and complexities of the materials. Students then apply their knowledge to understand the interrelations of anatomical structures and their functions in states of health and disease. Given the nature of the content, successful mas-

tery of the anatomical sciences may be dependent on one's ability to acquire, interpret, and conceptualize 3D spatial information (Silén, et al., 2008). Knowledge and skills obtained during anatomy training provide scaffolding on which future health care professionals will base their decisions for both diagnosis and therapeutic intervention (Marks, 2000; Aziz et al., 2002).

The survey conducted by Drake et al. found a 55% reduction in the number of gross anatomy course hours between 1955 and 2009, with the most drastic change occurring between 1955 and 1979 (Drake et al., 2009). The complementary use of web-based multimedia learning tools, such as 3D interactive models, in such courses may provide students with resources to improve and review their understanding of anatomy outside of the classroom. In response to another survey mailed to several postgraduate residencies, a majority of respondents indicated the gross anatomy was of very high importance, and ranked it as the most important basic science (Cottam, 1999). However, despite the perceived importance of anatomical competency, this study found a significant percentage of program directors reporting that residents need a refresher course in gross anatomy, while 14% of respondents report a serious lack in their residents' anatomy training.

Anatomical models utilizing a plethora of formats have been used in teaching human anatomy for over a thousand

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years (Vernon and Peckham, 2002). Continued advances in computer and interface technologies have spawned the generation of detailed anatomical models that enable users to visualize and manipulate anatomical structures through interaction with 3D digital models (Trelease, 2002; Vernon and Peckham, 2002). One of the most apparent benefits of 3D models is the opportunity to view spatial relationships from almost any desired angle. Such models provide 3D information that may be difficult to acquire by viewing traditional learning resources including textbook diagrams, photographs, or serial slice data contained in single magnetic resonance imaging (MRI) and computer tomography (CT) scans. All 2D images by nature, have fixed viewpoints, thus they present a limited amount of information, and in the case of MRI and CT serial scans, require a minimum level of expertise to interpret.

Debate regarding the efficacy and overall usefulness of 3D models in anatomical education continues. Previous studies have provided evidence in favor of the incorporation of 3D multimedia learning tools into anatomical education as based upon significant positive results on knowledge tests (Glittenberg and Binder, 2006; Nicholson et al., 2006; Venail et al., 2010), and performance in a clinical setting (Friedl et al., 2006); however the lack of consistent evidence may be preventing the widespread application of such tools. Studies that have measured the efficacy of computer-generated anatomical models, often find equivalent or negative results. A set of three studies conducted by Garg et al. evaluated the educational effects of an interactive 3D model of the carpal bones (Garg et al., 1999, 2001, 2002). Results from their first study found that multiple-view presentation of the carpal bones may offer a slight advantage to learners with high spatial ability, yet was found to be disadvantageous for students with lower spatial ability (Garg et al., 1999). The results may be explained by the theory suggesting multiple orientations may place a large burden on lower spatially able students' ability to mentally rotate the image to a familiar view (Shepard and Metzler, 1971). Garg and colleagues report on student strategy suggesting a large majority of students first rotated the images to a standard position, and then memorized the names. The approach was confirmed in their second study that found students spent most of their time studying anterior and posterior views (Garg et al., 2001). The results from this study did find an advantage for the students with multiple viewpoints, which the authors theorized may have been due to the superiority of active learning, or the ability of students to "wiggle," or deviate slightly around the key views to gain a sense of three dimensions. The third study from this group found that when spatial ability standardized among participants, no significant differences were observed between the key view and multiple view groups (Garg et al., 2002). From this series of studies, the authors concluded that dynamic 3D displays may provide some benefit to students with high spatial ability, but may hinder others with lower spatial abilities. An acknowledged limitation of this series of studies was that the nature of the stimulus utilized may not have been overtly spatially challenging, as the carpal bones naturally fall in two planes. Further research should examine whether similar results are found when the learning stimulus is more spatially complex. In a recent study by Khot et al. the relative efficacy of computer-based and traditional learning resources (in this case, plastic models of the pelvis with ligamentous structures intact) were compared (Khot et al., 2013). The two experimental groups used computer-based

resources. One group was defined as a key view group, and viewed a series of six photographs of a plastic model of the pelvis in a PowerPoint presentation. The second group, or virtual reality group, viewed a 3D color image of a pelvis reconstructed from a CT scan. Performance on post-test anatomy knowledge included both nominal and function-related test questions. Participants in the traditional model group scored significantly higher than either of the two computer-resource groups on nominal questions. Comparisons of function-related questions indicated no significant differences among groups (Khot et al., 2013). There were significant interactions between user sex, modality, and mental rotation ability indicating males performed better in the computer-based key view group, whereas females performed significantly better in the model group. This study highlights the importance of further studies to examine how providing a multi-modal curriculum may better support the better learning of all participants regardless of sex and spatial ability.

In some cases, the effectiveness of traditional teaching methods, including cadaveric dissection, may be decreased due to the size and complexities of the structures involved coupled with an inability of students to gain appropriate pre-knowledge prior to the dissection experience. The required dissection for exceptionally small, vacuous (Adams and Wilson, 2011), or complex areas, such as the orbital cavity, often requires advanced dissection skills, which many medical students lack (Nicholson et al., 2006). This renders some anatomical regions inaccessible to some curricula due to the aforementioned and seeming preferential reduction in laboratory time (Drake et al., 2009). Nicholson notes the usefulness of interactive computer models for such areas of discrete and hidden anatomy, based upon results that demonstrated their 3D learning tool of the inner ear had significant "educational effectiveness" in post-testing scores (Nicholson et al., 2006).

The eye may represent one of these areas of hidden anatomy where 3D digital models provide learning tools that may aid student spatial awareness of anatomical structure and function. There is growing interest in developing tools for teaching ocular anatomy in an effort to improve medical, and more specifically, ophthalmology training (Sagar et al., 1994; Glittenberg and Binder, 2006; Reeves et al. 2006, Perez et al., 2008; Lee and Park, 2009; Mustafa et al., 2011). The amount of medical knowledge is increasing rapidly. This increase in detailed information should be matched by innovative teaching methods that are efficient, and provide self-directed adult learning environments affording students more control over their own learning (Khalifa et al., 2006). Several cataract surgery simulators have been developed which are interactive and provide haptic feedback to improve the training of novice surgeons (Perez et al., 2008; Henderson et al., 2010). Evaluation of a Virtual Mentor cataract-training program found that the virtual learning tool had a positive impact on the learning outcomes of medical residents in ophthalmology. Participants in this study found the Virtual Mentor to be more engaging and "fun" (Henderson et al., 2010), which is beneficial considering that teaching tools are only effective if students use them. Participants who were given access to the Virtual Mentor also scored significantly higher on post-test scores when compared to those who practiced with traditional resources (Henderson et al., 2010). A different teaching tool has been developed using Blender and QuickTime software, to teach ocular ultrasonography, a procedure that is increasing in demand in routine ophthalmic practice (Mustafa et al., 2011). It is critical that

ophthalmologists have excellent depth perception and spatial awareness as they manipulate surgical instruments by small distances. This training tool is thought to be advantageous as it has the ability to display the image in a stereoscopic 3D format to assist students in their spatial awareness of minute structures, transferring those skills into clinical practice (Mustafa et al., 2011). Virtual simulators may also be created to assist students in developing laparoscopic skills. Such techniques require excellent depth perception in order to manipulate instruments in a 3D environment while viewing a 2D image. Previous studies using standardized tests indicated that virtual trainers were as effective as traditional box trainers, with no significant differences between the two groups before and after training at the novice level (Vitish-Sharma et al., 2011; Roach et al., 2014).

The 3D models may be used for other purposes. A recent study created a more accurate and realistic method of eye gaze tracking by utilizing a 3D model of the eye, with accurate measurements of the rotational radius of the human eye (Lee and Park, 2009). Improvements in gaze tracking could be beneficially applied to many fields such as medical education, rehabilitation, and interfaces for virtual simulations. The current work describes the process by which a interactive digital 3D model was created using serial sections of anatomical data combined to create a dynamic, interactive, user controlled learning environment to demonstrate the human oculomotor system, while adhering to the principles of cognitive load in multimedia design.

## METHODOLOGY

### Data Importation of Virtual Human Project Images

The initial step in any model construction process using scanned or photographed serial slices involves combining them into a volume. In the approach here, this involved the utilization of Amira software, version 5.2 (FEI Visualization Sciences Group, Burlington, MA) at the Corps for Research of Instructional and Perceptual Technologies (CRIPT) at the University of Western Ontario. One hundred twenty transverse cryosection images from the Visible Human Project (female) in png file format were isolated and aligned sequentially from the superior limit of the orbital roof to the inferior limit of the orbital floor to create the data set that served as the basis for model construction (Ackerman, 1991). In the female database each cryosection slice is 330  $\mu\text{m}$  thick. The images were converted from their original format to grayscale using Adobe Photoshop CS5 software (Adobe Systems Inc., San Jose, CA), in order to modify the color of the images such that they were compatible with Amira's importation protocol.

### Formation of 3D Anatomical Structures by Segmentation and Mesh Construction

The imported set of images represented data that may be modified and visualized in a variety of ways with the application of various viewers. The *Pool* viewer, in the Amira program, provided an interface for the management and organization of data objects and the visualization of the associated 3D representations. The process of manual segmentation was conducted to identify and construct 3D volumetric

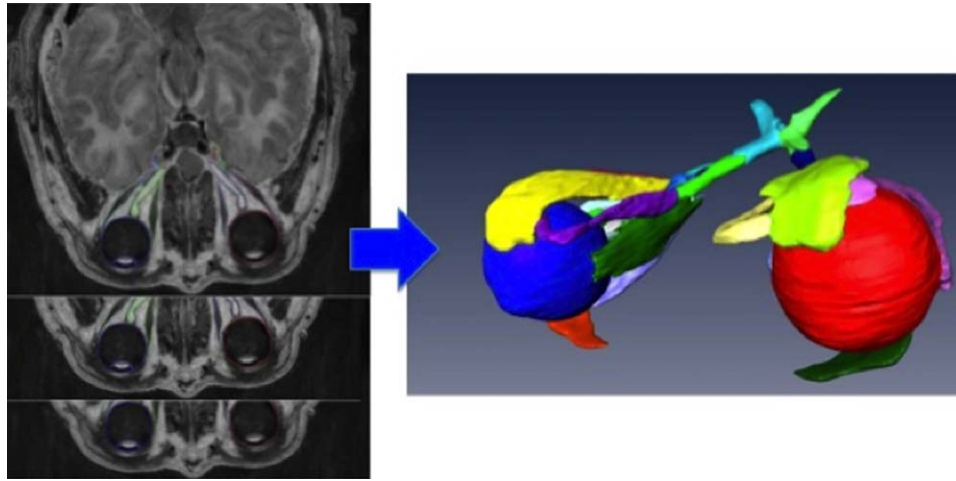
representations called meshes of selected anatomical structures present in the 2D serial image data (Nguyen and Wilson, 2009; Hu et al., 2010; Sergovich, et al., 2010; Adams and Wilson, 2011; Yeung et al., 2011; Brewer et al., 2012; Martin et al., 2013). The meshes are akin to digital wire frames of the anatomy in question. Here, the number of nodes and intersecting lines define an immense numbers of faces of each material. The number of faces influences the visual complexity of the mesh. This process was accomplished using a segmentation editor, which enables simultaneous viewing of a single serial image in any slice required by the user. Axial, coronal, and sagittal planes were all examined.

Interpretation of the cross-sectional data was guided by anatomical knowledge, aided by the use of images found in anatomy texts (Moore et al., 2010, 2011), and by making reference to the raw color photographs of the Visible Human corresponding to the slice in question. This process was undertaken to both identify and select the boundaries of particular structures using a software function called the *Brush* tool. The brush allows the user to select desired units, termed voxels, in 3D space. Once the boundaries of the desired structure were identified, the image voxels within the selected region in the image slice were assigned to a *material*. The repetition of said process on each slice of the serial sections enables the creation of a volume of user-defined voxels belonging to specific structures required for the 3D model, for example, medial rectus. The process of identification and voxel selection was repeated for each consecutive serial image for all the desired anatomical structures in order to construct a complete 3D representation, as illustrated in Figure 1.

The segmentation process was further aided within the Amira software by the Interpolation tool, which allowed the user to segment multiple individual images separated across intervals of images at the users preference. The interpolation enabled automatic segmentation of the images between those images that were manually completed. This technique approximates voxels in a linear fashion between the manually segmented images, accelerating the overall segmentation process. The structures that were segmented and appear in the completed 3D model were the globe, the seven extra-ocular muscles, and associated cranial nerves II, III, IV, and VI bilaterally (Moore et al., 2010, 2011). Once all anatomical structures were isolated to materials and their respective meshes were created, the next step in model construction was to enhance the visual esthetics of these meshes while maintaining the anatomical accuracy of the structures. This was accomplished through a multiple step process using freeware available online to the general public.

### Three-Dimensional (3D) Structural Refinements Using Mesh Lab Software

The first step incorporated the use of a 3D editing software called Mesh Lab, version 1.2.1, (Istituto di Scienza e Tecnologie dell'Informazione [ISTI] of Consiglio Nazionale delle Ricerche [CNR], Pisa, Italy). Three filters found in this program were sequentially applied to refine the appearance of each mesh, which ensured the topology and anatomical accuracy were maintained. The first filter applied was the *Re-orient all faces coherently* function, which assured that all the like faces of an individual mesh were directed outwards. This is an important step that enables meshes to later be imported



**Figure 1.**

Images on the left provide an overview of the segmentation process that was utilized to construct the structures (meshes) in Amira 5.2. Identification of appropriate anatomy in each VHP serial image, or slice, was assigned to that structure's material. This process was repeated for each serial image in which the structure was observed. Each structure was assigned a unique color to its material. The resulting 3D meshes produced for each material is seen in the image on the right.

into another program without the presence of visible holes or imperfections on the mesh surface. The second filter used was a tool for simplification of the meshes, known as Quadratic Edge Collapse Decimation. Simplification is a process that greatly reduced the number of faces within each mesh as compared to its original form exported from Amira, while maintaining the boundaries and overall shape of the mesh. This step was necessary to reduce unnecessary surface complexity of the structures, which greatly reduced digital size, thus facilitating the transfer and manipulation of the model components using other 3D software for eventual online use. The final step in Mesh Lab was to smooth the meshes, which was done in order to minimize any aberrant surface anomalies that were a product of the digital creation process within Amira and increase the realistic appearance of the meshes. The filter used to complete this process within Mesh Lab was Laplachian Smooth function, which completed the smoothing process in three consecutive steps.

**Addition of realistic textures to structures using Sculptiris software.** Virtual modeling of anatomy can produce detailed mesh models that give viewers information on the shape and proportion of the original structure, however these models become even more effective in conveying information when aspects such as shading, colors, and textures are included (Vernon and Peckham, 2002). Applying texture to the model increases the realism while creating significantly fewer faces, which enables more efficient rendering and viewing of the model (Sagar et al., 1994). For these reasons, the next step in the model formation was to apply an esthetically appealing texture to the meshes, thus providing a more realistic visual representation of the structures. To accomplish this goal, a 3D editing software called Sculptiris was utilized. Sculptiris further enabled modification of the 3D meshes through the application of user created texture to the meshes representing the ocular muscles (Sculptiris Alpha 6, Pixologic, Los Angeles, CA). The texture for the ocular muscle meshes

consisted of linear ridges and blended shades from the provided color palette. It was also possible to use a digital image as a texture, a feature employed to provide texture to the globe meshes.

**Enhancement of cranial nerves and bilateral eye movements using Blender software.** The subsequent 3D editing software that was employed in the model development was again a freeware software program, Blender, version 2.56b (Blender Foundation, Amsterdam, The Netherlands). Once the desired texture had been applied to each of the meshes in Sculptiris, they were imported into Blender 2.56b to collect individual meshes for each structure and assemble them into the complete model.

Blender 2.56b was also utilized to alter the appearance of the cranial nerves. One limitation encountered in Amira was the inability to visualize extremely small meshes. In the case of the oculomotor, trochlear, and abducens nerves, the meshes were not consistently visible when the accurate number of voxels had been segmented. Instead, these structures appeared fragmented, with "islands" of voxels appearing along the course of the nerves. In order to view a fully continuous mesh, the dimensions of the mesh had to be uniformly increased along all three axes. This caused the resulting meshes to be disproportionately large and inaccurate when incorporated into the model.

It was possible to alleviate the fragmented appearance generated in Amira by using a function within the Blender software known as a Bezier curve. The mesh for each of the three nerves was imported into Blender, and the path of a Bezier curve was modified to follow the course of the nerve that had been segmented in Amira. The benefits of this approach were that the magnitude of the Bezier curve could remain proportionately small, and the curve could be given a tapered appearance to approximate muscle innervation. In comparison with the mesh created from Amira segmentation, this process allowed for a more realistic (continuous), and

accurate representation of the nerves involved in the oculomotor system. The reconstructed cranial nerves are illustrated in Figure 2.

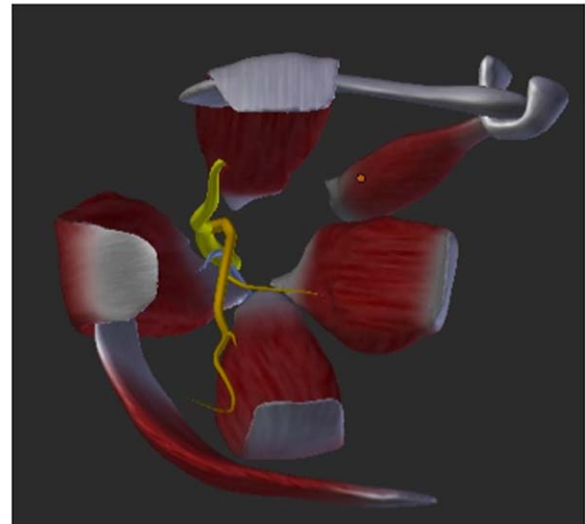
**Animation of the oculomotor system to demonstrate bilateral movement.** The subsequent steps involved creating animations for the eight bilateral eye movements. Starting from the primary position, at which point both eyes are centrally positioned and looking forward, these bilateral movements were up, down, left, right, up and right, up and left, down and right, and down and left (Moore et al., 2010). To enable the creation of the animations, an object data modifier called a Shape Key was applied to each of the extraocular muscles as well as the globe for each individual movement. Once this step was completed, the mesh was deformed in a continuous, fluid manner that was appropriate for the muscle's specified movement and a key frame was inserted. A key frame provided a defined starting and ending position for each smooth, continuous animation of the globe and musculature. A sequence of keyframes was made for each individual movement, and the sequences were arranged temporally to determine the order in which the animations would play in the Default viewer in Blender. The interval for animations correlating to a single gaze direction was 150 frames, with a separation of 50 frames between each set of animations. At the end of each animation for a bilateral movement, the direction of gaze returned to the primary position to establish a common position from which all animations originated and finished. This process was repeated for the primary muscle(s) involved in each eye movement, as well as the passive stretch or compression of each of the remaining muscles. This was necessary due to the interconnections among extraocular muscles as a result of their common attachments onto the sclera.

## Development and Construction of a User Interface for the 3D model

Development of the interactive learning module required construction of a virtual user interface that incorporated the animated Blender file. This procedure was accomplished using another freeware, Unity 3.4 software (Unity Technologies, San Francisco, CA) (Fig. 3).

Functions of the interface were designed using JavaScript programming code. An interactive menu was constructed to allow users to toggle the visibility of structures within the model on and off, in addition to displaying 3D visual information and animations corresponding to the selected structure or concept. Labels were inserted for each structure, and became visible for a structure when the position of the mouse was overlying the specified mesh. A zoom function, which had three consecutive settings of increased magnification controlled by the user, was also created. This function was created to facilitate viewing of smaller structures or specific structural details. Narration of information relevant to each structure and concept was also included within the 3D module interface and played when the user selected a structure or movement by clicking on the corresponding button found within the menu bar. Readers may navigate to the CRIPT website in order to download an Apple, or request a Windows-based, unity player including the interactive eye model for use in their own instructional environments (CRIPT, 2014).

Assumptions of cognitive load theory were considered in the creation of the 3D learning module (Mayer and Moreno,



**Figure 2.**

Reconstructed anterior view of right cranial nerves and oculomotor system in Blender 2.5b. Visible in this image are the inferior (orange) and superior (yellow) branches of the right oculomotor nerve, the right abducens nerve (blue), as well as the six extraocular muscles and levator palpebrae superioris.

2002, 2003). The format in which anatomical information was presented adhered to principles that enhance student learning through mediation of cognitive load—in particular, four specific approaches previously described by Mayer (2003) were utilized. First, the multimedia effect was applied by simultaneously using two of the learner's sensory modalities, auditory and visual channels, as the 3D model was accompanied by narration. Combining visuals with auditory stimuli follows the dual channel assumption suggesting cognitive load is reduced when information is presented in parallel verbal and non-verbal channels for information processing (Mayer, 2005). Second, visual and auditory details that were scrutinized as extraneous, containing what Mayer et al. describe as potentially seductive details, were excluded from the learning module (Mayer et al., 2001). This “detail pruning” procedure follows the coherence effect of cognitive load theory, which states that students' learning is enhanced when superfluous details are removed from lesson materials (Mayer, 2005). Information within the 3D module was divided into several smaller chunks of information. The presentation of smaller amounts of information at a given time aimed to improve students' learning by considering the limited capacity of working memory (Mayer, 2005). Third, labels for anatomical subcomponents were visible when users placed the mouse close to the structure, a computer term called a “mouse over” or “roll over.” Utilization of an interactive mouse over takes advantage of the spatial contiguity effect keeping labels close to the visual representation of the anatomy (Mayer, 2003). Finally, a unique feature of the model was the inclusion of narration in a personal and welcoming voice. This design method is termed the “personalization effect,” and has been shown to improve learning (Mayer, 2003).



**Figure 3.**

The completed 3D model was imported into an interactive user interface developed in Unity 3.4. This interface allows users to modify the visibility of structures by changing model orientation and removing selected structures. Users are also able to select which topic they would like to view information on by selecting one of the buttons located in the menu located on the left of the screen.

### Functionality-Based Changes in the Mesh Appearance

An additional interactive function incorporated into the 3D user interface was functional signaling indicated by a change in the color of the structures being demonstrated (Fig. 4).

Temporary change in the color of a structure was implemented to convey relevant functional information. This function was designed so that as muscle contractions for a specific movement are depicted in an animation, the meshes for complementary (yoke) muscles in both eyes turn green in contrast to the other structures. Concomitantly, the outlines of the antagonist muscles for both eyes during the muscle contraction were programmed to appear yellow. This use of contrasting colors was intended to visually alert the viewer of the structure that had been selected, as well as demonstrate the function of that structure. A legend of functionality relating to color-coding was positioned in the inferior aspect of the user interface

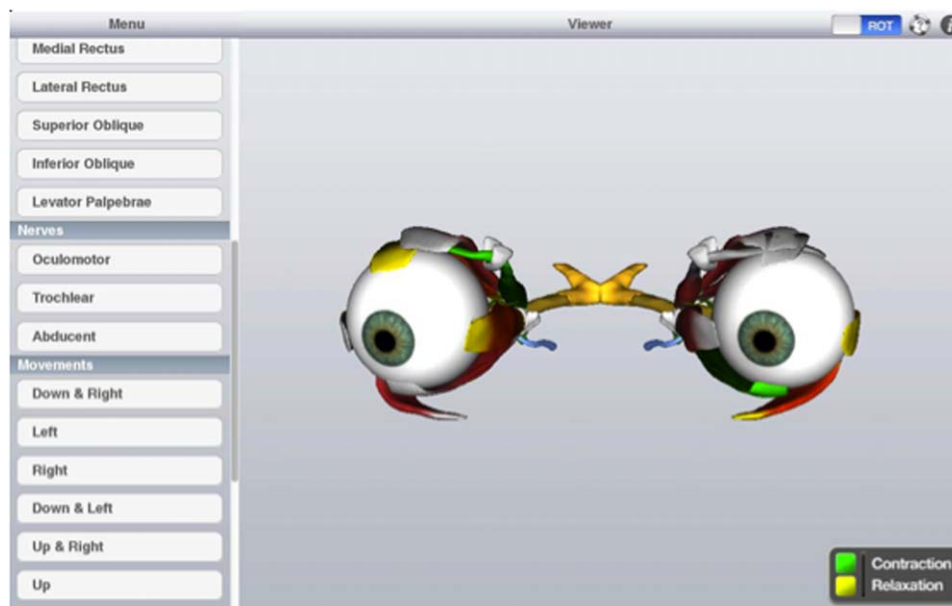
## DISCUSSION

There is increasing interest in developing virtual educational resources to improve students' understanding of ocular anatomy and movements, often with a focus on improved training for clinical procedures such as cataract surgery (Sagar et al., 1994; Glittenberg and Binder, 2006; Reeves et al., 2006; Perez et al., 2008; Lee and Park, 2009; Mustafa et al., 2011). There are existing models of the anatomy and movements of the eye that are available online for students to access, each with their own strengths and limitations. The UC Davis Eye Simulation Version 2.0 contains a very thorough explanation of the presentation, causes, case studies, and testing of nerve palsies affecting the oculomotor system (EyeSim, 2002). Individuals using this simulator are able to control the function of the

extraocular muscles, and see the resulting unilateral or bilateral change in the position of gaze, depending on which muscles have lost function. It is not possible however, for students to view the extraocular muscles and cranial nerves using this simulator; nor does this simulator describe which muscles are contracting or relaxing to produce a specific bilateral movement. The effectiveness of this simulator may be improved with the addition of options to view the muscles and nerves within the orbit, as well as having the ability to interact with the simulator to change the point of view.

Anatomia via Neuronotes is another simulator that has been created by the University of Toronto, and is an openly accessible online learning resource (Anatomia, 2009). The section demonstrating extraocular muscles has very good visual esthetics, and animations, with interactive controls that allow users to control and view the movements produced by the oblique and recti muscles. The Digital Dissection section also provides an alternative resource for students to view cadaveric images of an orbital dissection from superficial to progressively deeper levels. One limitation of this simulator is its unilateral nature, which prevents users from examining the yoke and antagonistic muscles that are responsible for producing a specific bilateral movement. The simulator is also missing the options to label the extraocular muscles, and manipulate the view of the structures. The only view available is the superior aspect of the orbit, which partially obscures some muscles from view, such as inferior rectus, inferior oblique, and superior rectus beneath levator palpebrae.

The Human Anatomy and Physiology Interactive Network (HAPIN) available for access through the University of Toledo also provides students with learning modules for ocular anatomy and physiology (HAPIN, 2005). The "Eye Muscles" module provides students with a video which shows the primary movements of the eye, as well as the insertions of the extraocular muscles. A second module, entitled "Eye Movements,"



**Figure 4.**

Colors were chosen to demonstrate functionality of agonist and antagonistic muscles involved in a specific eye movement. Contraction of agonists appeared green in color, as opposed to antagonistic muscles for the movement, which appeared yellow.

reviews the primary movements of the eye, and contains a very good explanation of how muscle position relative to axes of the eye causes a movement such as elevation and adduction in the case of superior rectus. There is, however, a limited level of interactivity, with videos that users can view, but no controls to change the view or select specific structures of interest.

The purpose of this project was to develop a novel, 3D exploratory model that may be paired with an electronic user interface to create an interactive learning module of the human eye. It is hypothesized that participants with access to the 3D learning module will show improved comprehension of the material presented, as measured by pre-test and post-test anatomy knowledge assessments, when compared with students who only have access to traditional 2D learning materials. The interactive interface allows students to fully rotate the model and adjust the level of magnification of view. There are also text labels and color highlighting to demonstrate functionality of individual muscles during specific movements. Since its development this online tool is being utilized to assist in the teaching of ocular anatomy and movements in both undergraduate and graduate human anatomy courses at Western University. The learning module is available both online and as an application that may be installed onto personal computers, to ensure that the material is highly accessible to students. Future research will look toward examining the possible effect this interactive learning module has on student learning outcomes as measured by an anatomy knowledge test following training with this educational tool.

## CONCLUSIONS

Advances in computer capability and interface technologies have enabled the generation of detailed anatomical models that allow users to visualize and manipulate anatomical

structures through interaction with 3D models (Trelease, 2002). One of the most apparent benefits of 3D models is the opportunity to view spatial relationships from any desired angle, in a manner that is accessible to students at their chosen time and location (Nguyen and Wilson, 2009). Students who accessed web-based virtual tools scored higher on assessments than did students who never accessed the online learning resources (McNulty et al., 2009). The aim of the work detailed here was to describe our innovative approach to interactive 3D learning module creations. As important as the technological steps is the incorporation of cognitive load reduction techniques. The implementation of multimedia design principles that reduce cognitive load is an emerging trend amongst anatomical educators (Issa et al., 2011) and it is an important step as educators endeavor to reach more students with significant effects on measures of learner understanding (Issa et al., 2013). The model applied several cognitive load reduction approaches from cognitive and educational psychology, namely the multimedia principle, coherence principle, spatial and temporal contiguity principle, signaling, and personalization effect to the underlying technical approach (Mayer and Moreno, 2002; Mayer 2003). The current 3D eye model provides users with a novel learning resource and is hypothesized to augment understanding of ocular movement in healthy and selected pathological states. In addition, we have improved upon existing approaches used in digital anatomical education through our addition of functionality and the effect of visual signaling for users of this tool. When incorporated into multimodal curricula, interactive virtual resources may assist in the creation of a user-controlled learning experience that can be personally tailored and self-paced to meet the unique learning requirements of each student. The next step to fully address the efficacy of the current model will be to field test this tool within a student

population. This testing will be conducted in order to validate and assess the potential benefits, and pitfalls, of this learning module as a novel resource in anatomical education in the area of gross anatomy and ophthalmology.

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