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TECHNICAL REPORT
Using a Model to Understand the Symptoms of Ophthalmoplegia

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When the term muscular paralysis is used, most people will think of large muscle groups such as the upper and lower limbs or life-dependent muscles such as the diaphragm. However, the extrinsic extraocular muscles can also succumb to paralysis (whether partial or otherwise). Ophthalmoplegia can arise from a number of neural conditions, and in conjunction with the complex anatomy of the ocular orbit, it can be difficult to teach such syndromes.

The range of existing physical models for the eye are limited in their functional ability, prohibiting the understanding of the structure and its function especially with regards to muscles. Only one eye model has been developed which is tangible and functional by design in relation to rotational movements (Williams, 1965). The aim of this study was to ultimately build a modern version of Williams' model and via means of a Likert-type, cross-sectional questionnaire, determine the model's capacity to assist students in learning the function and anatomy of the extrinsic muscles of the eye. This foundational knowledge could then be transferred to better understand the internal causes of the visible symptoms of ophthalmoparesis and ophthalmoplegia.

In much the same way that different diagnostic scans are used to observe different bodily materials, functional models may not necessarily replace the range of anatomical resources which exist, but it is hoped that models such as this will instead provide insight into an alternative aspect of anatomical learning which is yet to be considered.

Key words: ophthalmoplegia; functional model; anatomy; education; resources; extraocular muscles

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Ophthalmoplegia is a condition characterized with paralysis of the extraocular muscles. Most often, the disease is caused by multiple sclerosis or cerebral infarction, but can in some cases be caused by trauma, infection or the presence of tumors (Keane, 2005; Hossain et al., 2018; Roper-Hall, 2018). Symptoms of the condition can vary from complete inability of eye movement to inhibited movement in a particular direction depending on the number of muscles affected and in which combination (Keane, 2005; Hossain et al., 2018; Roper-Hall, 2018). Since these symptoms are clear in their appearance and their detection does not need any specialized equipment, it was concluded that ophthalmoplegia would be a good example to teach the anatomy of the ocular orbit and the surrounding structures (McDaniel and Daday, 2017; Stokes and Grosofsky, 2017).

One unit at Western Sydney University in which the anatomy and physiology of each of the extraocular muscles is taught, as well as a range of related conditions including ophthalmoplegia, is the Anatomy of the Head and Neck unit in the Spring semester. The unit is structured so that students learn in weekly two-hour lectures and weekly two-hour practicals. In previous years, students were taught the ocular orbit and surrounding structures through a combination of still images, diagrams, animations and models. Based on the nature of the orbit, it is very difficult to use cadaveric specimens to teach such content (Adams et al., 2015), and although the use of physical models allows the anatomy of the orbit to be successfully learnt (Fredieu et al., 2015), the models used are not functional by nature, and so, the respective movements created by each muscle cannot be effectively illustrated.

In fact, only one model of the eye has been developed which is tangible and functional by design in relation to rotational movement (Williams, 1965). This model consists of a hardwood ball as the eyeball with elastic and string for the rectus and oblique muscles respectively. Users of the model are able to pull on the various lengths of material to "activate" the corresponding eye muscle, causing the hardwood ball to rotate accordingly. In order to teach the anatomy and physiology of the extrinsic eye muscles, in addition to diseased conditions such as ophthalmoplegia, we developed a functional model using the Williams model as a template (our model is hence called "the Functional Eye Model").

CLASSROOM MANAGEMENT OVERVIEW

In keeping with the self-guided approach to learning, our new model was placed in the laboratory all semester in amongst the other eye models (Keeler et al., 2008) for the duration of each of the two-hour practicals. Students had the opportunity to use our model at their own discretion. Students used our model (without any instructions) while having the other commercial eye models, textbooks and posters in close proximity to allow for comparison. Two academic members rove around the lab to assist students in their learning and in this case to answer any questions about our model.

LEARNING OBJECTIVES

At the end of their study, students were able to:

- Identify the six (four recti and two oblique) extraocular muscles
- Identify the resulting position of the eye after activating each extraocular muscle
- Identify which muscles need to be activated to position the eye in a particular direction
- Explain what ophthalmoplegia is and the effect this condition has on eye movement

- Discuss the difference in resulting eye position between a single and multiple extraocular muscles affected by clinical conditions like ophthalmoplegia

THE FUNCTIONAL EYE MODEL

The Functional Eye Model of the left eye is shown from three different perspectives in Figures 1-3 (anterior and medial view, superior view and posterior view), and the Supplementary Material demonstrates the eye movements produced in the model in a short video. The model has been designed to accentuate each of the extraocular muscles and their function with respect to the eye. Consequently, the length and belly diameter of each muscle was ignored in creating the final product, with focus instead on the insertion point of each muscle on the eyeball as well as the angle at which each muscle pulls on the eyeball. In keeping with anatomical accuracy, the superior oblique and inferior oblique muscles project anteromedially at an angle of 51° to the anterior/posterior axis, whilst each of the rectus muscles and the section of superior oblique muscle between the trochlea and common fibrous ring project posteromedially at an angle of 22.5° to the same anterior/posterior axis (Standring et al., 2005).

To allow users to see each muscle's movement as well as origin and insertion points, it has been necessary to omit the vasculature and innervation of each of the extraocular muscles, as well as the surrounding fat and fascia, ligaments and tendons, lacrimal gland, optic nerve and bony orbit. Although the lack of surrounding tissue makes it difficult to understand the spatial configuration of the muscles in the orbit, ignoring these components of the visual system does not affect understanding of how each muscle independently moves the eyeball, and so their removal does not significantly impair the overall aesthetics.

Consideration has also been given to the fact that the binding passes through wood in the Functional Eye Model compared to existing in fatty tissue, which is the case in the human body.

To this end, the model has been designed in such a way that the lengths of binding pass almost parallel to one another, thus allowing fluid and independent movement without the risk of the fabric tearing against the wood. Further, the four recti muscles still converge at a common origin (Standring et al., 2005) similarly to the common fibrous ring, ensuring the agonistic/antagonistic relationship of opposing muscles can still be observed.

Finally, changes such as the replacement of the hardwood ball (Williams, 1965) with a rubber ball were also made in order to minimize costs and simplify the production process. A complete description of the Materials and Methods to build our eye model is found in the Appendix.

FUNCTIONAL EYE MODEL EVALUATION

Student feedback

To determine the efficacy of the developed model, a student evaluation survey (Artino et al., 2014) was developed with approval from the Human Research Ethics Committee (Approval No.: H12437) at Western Sydney University. Students enrolled in the unit in Spring 2017 were asked to provide feedback on their use of the Functional Eye Model by completing a Likert-style questionnaire. The survey consisted of eleven 3-point Likert-scale questions (disagree, neutral and agree [Table 1]) as well as two open-ended questions relating to the positive and negative aspects of the model.

For ease of analysis, the categorical data of the Likert-scale questions were converted to ordinal data (i.e., agree=3, neutral=2 and disagree=1) and a mean response

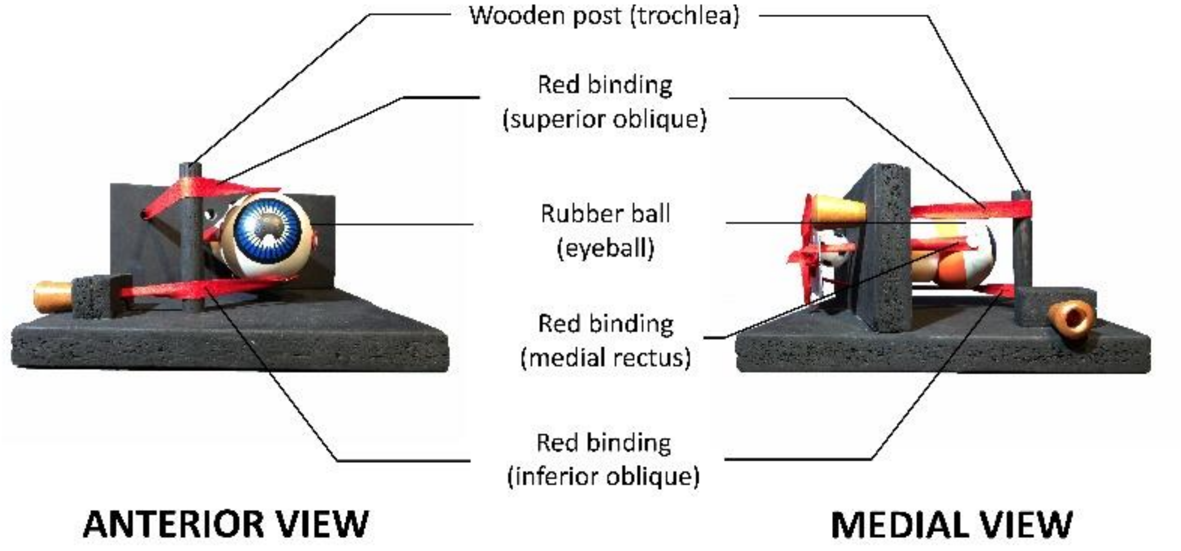


Figure 1. An anterior and medial view of the Functional Eye Model. The red binding represents the extraocular muscles of the eye.

was calculated (Boone and Boone, 2012). A subsequent chi-squared analysis found nine of the eleven Likert-scale questions to be statistically significant (assuming a random distribution to be an equal number of responses for each preference, and $p < 0.05$ to be statistically significant) (Table 1).

Of the 72 students enrolled in the unit, 54 responded to the questionnaire (75% return rate). The two questions that were not statistically significant were concerned with the fragility of the model and the process of learning anatomy from cadaveric material. Of the five negatively worded questions (6, 7, 8, 9 & 11), only question 11 had a mean value close to 3 (agree), meaning that the students agreed the model was valuable but needed some improvement.

Overall, the results from the evaluations indicated that the students thought the model was a good learning tool to understand the movements of the eye and agreed that the model provided a 3D perspective of the structures which helped to deepen their learning. Students were neutral about the fragility of the model with a mean score of 2.02, however, the students who strongly agreed with this statement added a comment in the "needs improving" open-ended question as seen below.

Other themes that emerged from the "need improving" question include the details in the models, with a number of students wanting to see additional structures such as blood vessels and nerves. Selected examples of student comments in the open-ended questions are shown below.

<u>*What were the best aspects of the Functional Eye Model?*</u>

- *"Being able to see exactly how each muscle would move the eye."*
- *"Provided life like structure and was easy to identify landmarks, increasing understanding."*
- *"It shows the function of the various muscles in more depth by showing them in action."*
- *"The mechanics of the eye were well thought out. I was very impressed with how well it worked and it helped me to understand what movements were associated with which muscle/s."*

<u>*What aspects of the Functional Eye Model need improving?*</u>

- *"It does not currently move fluidly and it feels a bit fragile when moving the muscles."*
- *"Make it more sturdy so more carefree students have a harder time breaking the model."*
- *"More detail…maybe add the nerves or vessels."*

Comparison to Other Teaching Resources

In considering ophthalmoplegia, each length of binding in our model can independently or in combination with the other representative muscles be detached from the eyeball to prevent concentric movement, thus simulating the pathology of the disease. This pathological symptom cannot be reproduced using the model by Williams (1965), nor any other disease characterized with an inhibition of certain eye muscles to contract, such as congenital fibrosis of the extraocular muscles or CFEOM (Cooymans et al., 2010).

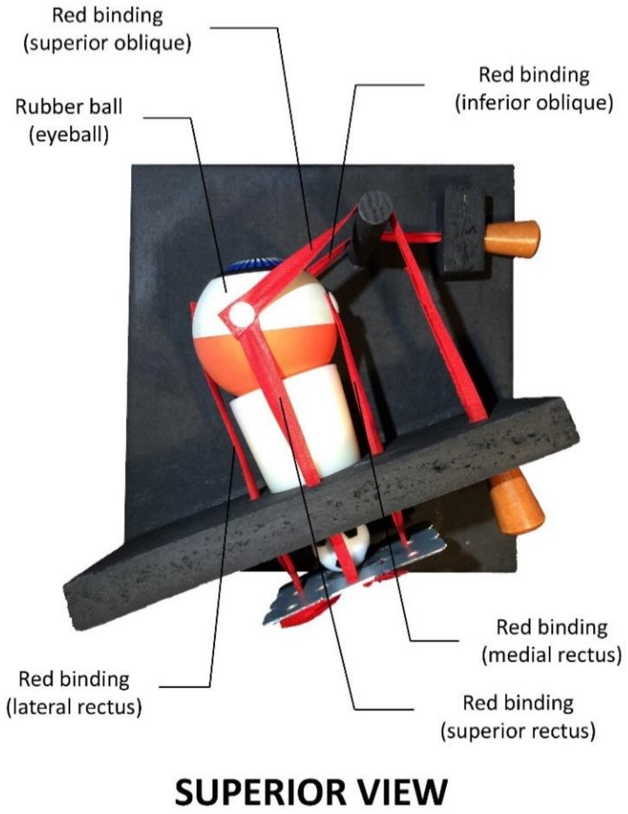


Figure 2. A superior view of the Functional Eye Model. The red binding represents the extraocular muscles of the eye.

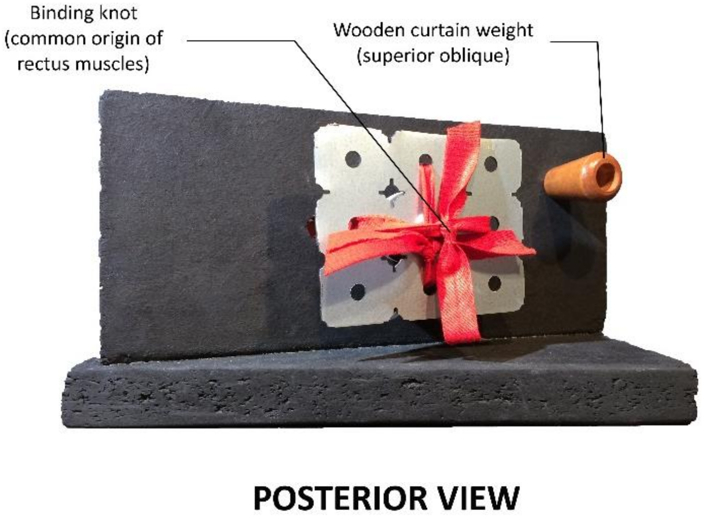
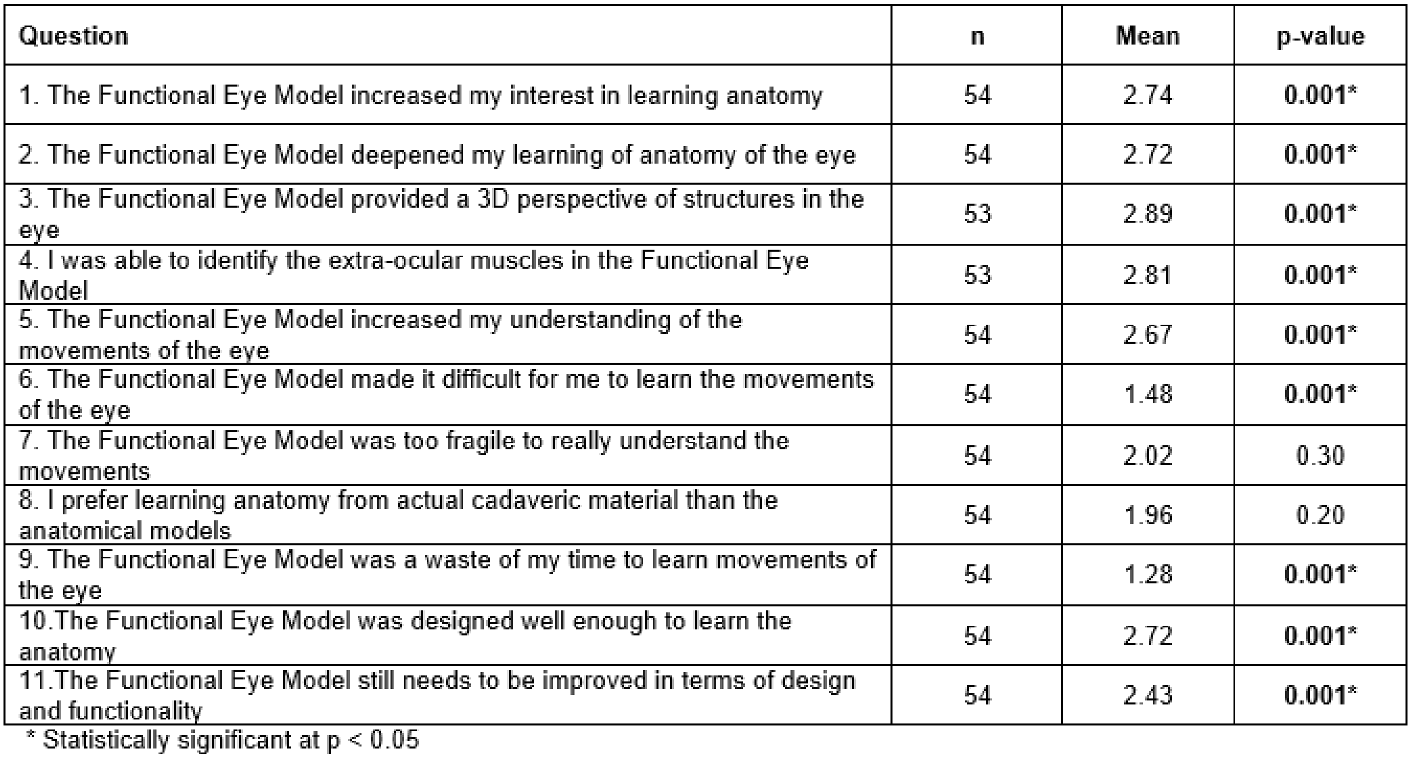


Figure 3. A posterior view of the Functional Eye Model. The red binding represents the extraocular muscles of the eye.

Table 1. Mean Likert scores indicating those that disagree (1), are neutral (2) or agree (3).



Question	n	Mean	p-value
1. The Functional Eye Model increased my interest in learning anatomy	54	2.74	**0.001***
2. The Functional Eye Model deepened my learning of anatomy of the eye	54	2.72	**0.001***
3. The Functional Eye Model provided a 3D perspective of structures in the eye	53	2.89	**0.001***
4. I was able to identify the extra-ocular muscles in the Functional Eye Model	53	2.81	**0.001***
5. The Functional Eye Model increased my understanding of the movements of the eye	54	2.67	**0.001***
6. The Functional Eye Model made it difficult for me to learn the movements of the eye	54	1.48	**0.001***
7. The Functional Eye Model was too fragile to really understand the movements	54	2.02	0.30
8. I prefer learning anatomy from actual cadaveric material than the anatomical models	54	1.96	0.20
9. The Functional Eye Model was a waste of my time to learn movements of the eye	54	1.28	**0.001***
10.The Functional Eye Model was designed well enough to learn the anatomy	54	2.72	**0.001***
11.The Functional Eye Model still needs to be improved in terms of design and functionality	54	2.43	**0.001***

* Statistically significant at $p < 0.05$

The situation is similar when comparing the Functional Eye Model to that of a computer-generated model. Taking the model developed by Allen et al. (2015) as an example, movement of the eyeball due to contraction of the extraocular muscles is limited to a series of pre-programmed simulations.

After clicking a button relating to the movement of choice in Allen et al.'s (2015) computer eye model, the activated muscles are illuminated, and the eyeball moves accordingly. However, this model is limited to the eight bilateral movements mentioned previously and is therefore a representation of an individual with normal functioning eyes only. In a study of an individual with ophthalmoplegia, the user cannot determine the pathology of the disease using this model as there is no simulation or option to prevent any of the muscles from contracting.

Our Functional Eye Model is also a significantly more versatile learning model when compared with clinically-oriented anatomy models that are commercially-available. A number of companies stock a large range of anatomical models and charts in Australia, but the only eye model available which has the capacity to provide anatomical information in a clinical situation is a cataract eye model. Considering the symptomology of ophthalmoplegia, the lack of movement of any of the eye models listed inhibits understanding of the disease in relation to eye movement, and thus our Functional Eye Model can assist anatomy students in understanding the functional rotational movements of the eye and any variations that could occur.

LIMITATIONS

In the process of accentuating the mobility of the Functional Eye Model, anatomical accuracy was made a secondary goal. Thus, a number of components have been modified or exaggerated to improve the fluidity of movements such as an increase in muscle length. The materials used are also less durable than the plastics used in most non-functional eye models, which may affect functionality in the long term. Finally, since each eye orbit is a mirror-image of the other along the anterior-posterior axis, some confusion may arise when considering the bilateral movements of the eye.

SUMMARY AND FUTURE DIRECTIONS

The model developed as part of this study is unique in both its appearance and function. It is also a great tool for teaching the anatomy of the ocular orbit and related conditions such as ophthalmoplegia. Nevertheless, the model still has room for improvement, particularly with its design and usability.

After testing the model in the anatomy laboratories, we developed a set of potential instructions (Appendix 2) that could accompany the model to provide direction to students on how to use it. A number of other ideas have also been suggested to increase the model's anatomical accuracy whilst maintaining functionality, as well as a list of alternative materials of greater durability. Further, in order to overcome any confusion about ocular movement of the left and right eyes, a second model representing the right eye may be developed to be used in accordance with the original model of the left eye.

Even in light of this, students still rated our model very highly as a teaching tool to learn the mechanisms of eye movement. Its future use is ultimately promising, especially after implementing the aforementioned improvements.

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APPENDIX 1 – Complete list of materials and methods

The following materials and equipment were used in the development of the Functional Eye Model:

- 17 mm x 190 mm x 200 mm piece of particle board
- 17 mm x 80 mm x 190 mm piece of particle board
- 17 mm x 17 mm x 38 mm piece of particle board
- 4 x 65 mm wood screws
- 4 x 33 mm wood screws
- 1 x 10 mm wood screw
- 6 x white thumbtacks
- 1 x 60 mm diameter rubber ball with eyeball design
- 1 x 45 mm diameter Teflon cylinder (40mm length)
- 1 x 12 mm diameter dowel rod (83 mm length)
- 1x 25 mm diameter plastic ball
- 1 x packet of 1 m length x 10 mm width red binding
- 1 x 80 mm x 200 mm x 1 mm mending plate
- 2 x wooden curtain weights
- Wood glue
- Black paint and foam paint brush
- Drill, drill bits and counter-sync drill bit
- Protractor and ruler
- Graphite pencil
- Screwdriver
- Saw
- Metal lathe

Method

1. Obtain three pieces of particle board (dimensions below) and paint with one coat of black paint:
   a. Piece 1: 17 mm x 190 mm x 200 mm (model base)
   b. Piece 2: 17 mm x 80 mm x 190 mm
   c. Piece 3: 17 mm x 17 mm x 38 mm
2. Using Wood glue, adhere the 17 mm x 190 mm side of Piece 2 particle board to the 190 mm x 200 mm side of Piece 1 particle board at an angle of 22.5° to the long axis of Piece 1. Piece 2 should be orientated so that the 80 mm x 190 mm side faces forward and to the left so that the corners of Piece 2 touch the back and right sides of Piece 1 (refer to Fig. 2).
3. To ensure complete stability, insert four 65 mm long wood screws equidistant into the underside of Piece 1 and continue to screw into Piece 2.
4. Glue the 17 mm x 38 mm side of Piece 3 to Piece 1 on the same side that Piece 2 has been adhered. Ensure that Piece 3 is positioned so it’s long axis is parallel to the long axis of piece 1 and is 20mm from both the forward and right sides of Piece 1 (again refer to Fig. 2).
5. Insert two 33 mm long wood screws into the underside of Piece 1 equidistant and continue into Piece 3 to provide additional support.
6. Using a compass, draw a circle of 55 mm diameter at the very centre of Piece 2. Drill 4 holes along the circumference at each of the four points of the cardinal bearings 8 mm in diameter (Fig. 4).

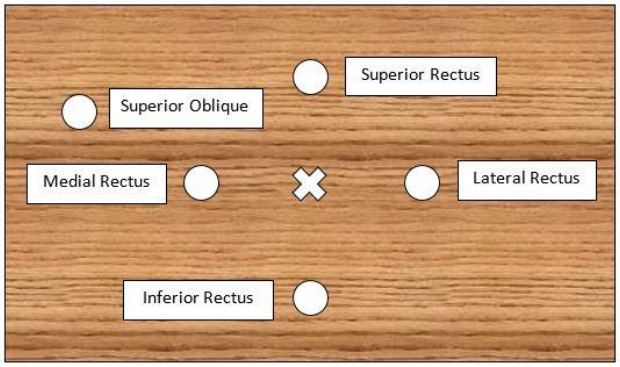

Figure 4. Positioning of the holes for each length of elastic when viewing Piece 2 from the front.

Drill a fifth hole also of 8 mm diameter into Piece 2 particle board 22 mm from the top and 27 mm from the left when looking at its front-facing surface.

7. Drill a sixth hole through the very centre of Piece 3 which is also 8 mm in diameter.
8. Using a metal lathe, carve a hole into the centre of the Teflon cylinder of 37 mm diameter and 20 mm depth.
9. At the very base and centre of the hole in the Teflon cylinder, pre-drill a hole of 3 mm diameter through the remaining Teflon as well as a hole in the very centre of Piece 2 of equivalent diameter
10. Using a counter-sync drill bit, carve a 15 mm diameter hole into the back-facing side of Piece 2.
11. Screw a 33 mm wood screw into the hole produced in step 11 and through Piece 2 into the Teflon cylinder, keeping the two objects together.
12. Cut the 10 mm width binding into six different lengths as listed below. These will act as the extraocular muscles;
    a. Superior rectus: 155 mm
    b. Inferior rectus: 155 mm
    c. Lateral rectus: 160 mm
    d. Medial rectus: 150 mm
    e. Superior oblique: 190 mm
    f. Inferior oblique: 170 mm
13. Using the white thumbtacks, fasten each of the elastic lengths to the rubber ball in accordance with their anatomical position (refer to Fig. 4).
14. Drill a 12 mm diameter hole into Piece 1 approximately 3 mm deep. This will be positioned 45 mm from the short side and 75 mm from the long side of Piece 2 in the top right corner when Piece 2 is closest to you
15. Coat one end of the dowel rod with wood glue and insert it into the hole in Piece 1 ensuring it remains vertical whilst drying.
16. Once dry, screw the remaining 33 mm wood screw into the underside of Piece 1 and into the dowel rod for further stability
17. Subsequently apply 2 layers of black paint to the dowel rod and another coat to the rest of the model.
18. Feed each of the lengths of binding representing the four rectus muscles into their respective holes (Fig. 4) and place the rubber ball against Teflon cylinder.
19. Loop the length of binding representing the superior oblique muscle around the dowel rod inserted into Piece 1 and feed it through the respective hole in Piece 2, ensuring the material remains horizontal. The length of binding which represents the inferior oblique muscle should be wound around the same dowel rod before being fed through the hole in Piece 3, again making sure it remains horizontal.
20. Once through the respective holes, continue to pass each length of binding through a wooden curtain weights. Make a knot at the end of each length to ensure the binding does not pass back through the weights.
21. Using the 10 mm wood screw, screw the plastic ball together with the mending plate by passing the screw through the center hole.
22. Pass the four lengths of binding representing the rectus muscles through the respective cardinal bearings of the mending plate and tie the opposite lengths of material together (i.e., superior rectus is tied to inferior rectus and lateral rectus is tied to medial rectus). Whilst doing so, ensure the rubber ball is held against the Teflon cylinder at significant tension, as well as ensuring the line of sight of the eyeball is parallel to the long axis of the model's base (i.e., primary position).

Appendix 2: Instructions for the Functional Eye Model

Use this model to understand the movements of the eyeball produced by each of the extra-ocular muscles.

1. This is a model of the left eye. Each of the red bands represent the extra-ocular muscles of the orbit. Can you name and identify the six muscles on the model?
2. For each of these muscles name the origin and insertion (this gives you a clue to the main action).
3. Now to understand the main actions of each of these muscles, pull gently on the bands using the mending plate for the recti muscles and the curtain weights for the oblique muscles.
4. Use the following table to record what happens to the eyeball when you activate each of the muscles (note that some muscles may have more than one main action).

Muscle	Main Action (adduction/abduction, elevation/depression, medial/lateral rotation)
Superior rectus	
Inferior rectus	
Lateral rectus	
Medial rectus	
Superior oblique	
Inferior oblique	

5. In clinical situations such as ophthalmoplegia, the extraocular muscles can become paralysed and fail to work. Observe what the resulting presentation of the eye will look like when this is the case.

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