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MECHANICS AND THE HUMAN BODY: HANDS ON AND SIMULATION APPROACH TO MEASURE DELTOID FORCE

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Abstract

We report the combined use of hands-on activities and the effective use of simulations in physics education. The importance of this work is more significant than other research done in the past as this is focused on mechanics and the human body, a less explored field in college-level physics courses. While physics and mechanics typically find more prominent applications in well-established areas like engineering, they play a crucial role in elucidating the physics governing human body motion. Nevertheless, interactive physical models of the human body that help in physics education are not widely available. Our long-term goal is to create less sophisticated, more accessible demonstrations and dynamic animations to fill this gap in pedagogical tools relating to the human body. This study focused on forces applied to the deltoid muscle when lifting a load. We examined these forces in static equilibrium by combining animations and a life-sized model arm. The model was printed out mainly using PLA in a 3D printer. Given the intricate nature of the human arm, we made necessary approximations to understand the associated torque and rotational dynamics around the shoulder joint. Our study involved measuring the response force of the deltoid muscle as a function of the load force. In order to validate our experimental data, we created an animation using GeoGebra. The link to the animation was shared with the students, and they were encouraged to explore the simulation by changing the parameters: length of the arm, the weight of the person, and the weight of the lifting load. In a two-semester study with control groups, we evaluated the effectiveness of the physical arm model and the animation on students' understanding of torque. Positive user feedback and successful results were obtained from classes where both tools were tested.

Keywords: *Physics education, pedagogy, mechanics and human body, deltoid force.*

1. Introduction

In physics education, exploring effective instructional methodologies has always been a driving force for educators and researchers alike. As we navigate the complexities of disseminating knowledge in physics, it becomes increasingly evident that a multifaceted approach - including hands-on activities, in-class demonstrations, integrating other pedagogical tools like interactive simulations and animations - is necessary to unlock more a profound understanding and engagement among students. In this paper, we briefly discuss the critical role played by these educational strategies and try to fix the disparities in their accessibility, particularly in diverse areas in physics.

Hands-on activities provide students with a tangible and experiential understanding of abstract concepts, fostering a connection between theory and the physical world. In-class demonstrations, on the other hand, serve as powerful visual aids, allowing students to witness complex phenomena in real-time and enhance their comprehension and retention of subject matter. Not limited to physics, integrating interactive simulations and animations as discussed in [Price et al. (2019); Perkins (2020); Adams et al. (2008)] to any field of study amplifies the learning experience. They provide a virtual laboratory experience for students to explore concepts that may be challenging to replicate in real-life settings. We note that they were immensely beneficial during, and immediately after, the COVID era.

However, the availability of these pedagogical resources is not uniform across all branches of physics. Engineering physics often enjoys a plethora of hands-on tools and simulations (Mohottala et al., 2023; Phet, 2008; Ophysics, 2002) that cater to the specific needs of their curriculum. In contrast, areas like medical physics, face unique challenges. The lack of resources - both physical and digital - tailored to these specialized fields hinders the ability of educators to equip students with comprehensive and immersive learning experiences.

In this paper, we examine one of the problems we discuss, related to the deltoid force, in a Mechanics and Human Body course. We highlight the significance of bridging gaps and ensuring that every student, regardless of their chosen field within physics, can benefit from the rich tapestry of educational resources available. The role of technology in enhancing learning is emphasized, and we discuss its potential advantages. However, we approach its integration cautiously. Despite the positive advantages, we are mindful of the potential drawbacks, such as the risk of becoming a costly distraction or obstructing effective education. Our experience so far has been to take a hybrid approach, and this study is an extension of it.

2. Background

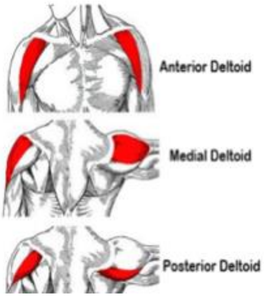
The primary objective of this paper is to enhance students' comprehension of the connection between the force applied to the deltoid muscle during object lifting and the equilibrium dynamics of the human arm. While the human arm constitutes a complex system, our emphasis, as physics instructors concentrating on the mechanical aspects, does not extend to delving into intricate anatomical details. Nevertheless, we offer a brief overview of the human arm's structure to facilitate a broader readership understanding.

2.1. Deltoid muscle structure and function

The deltoid muscle is the superficial muscle of the shoulder, which gives its characteristic shape and contour. It is called the deltoid muscle because of its triangular shape that resembles the upside-down capital Greek letter Delta. The deltoid muscle is divided into three parts based on their origin: the anterior (clavicular) fibers, the lateral (acromial) fibers, and the posterior (spinal) fibers, as shown in *Figure 1*. The deltoid's anterior fibers (anterior head) originate from the superior aspect of the lateral third of the clavicle. The medial fibers (medial head) originate from the acromion process of the scapula, while the posterior fibers (posterior head) originate from the inferior edge of the spine of the scapula. All deltoid fibers converge (join), forming a short tendon that inserts at the deltoid tuberosity of the lateral aspect of the humeral bone.

The anterior fibers cause shoulder flexion and medial rotation of the humerus, whose fibers work synergistically with the pectoralis major muscle in arm flexion during walking. The posterior fibers cause the arm's extension and the humerus's external rotation; they work together with the latissimus dorsi in arm extension when walking. The deltoid muscle does not initiate the shoulder abduction due to the pulling force being parallel to the humeral axis; the supraspinatus muscle initiates that movement. The medial fibers of the deltoid muscles arising from the acromion are powerful abductors and assist in shoulder abduction from angles measured from the vertical ranging15° to 100° in the counterclockwise direction (Elzanie, & Varacallo, 2023). In this study we focused on the force of deltoid medial fibers.

Figure 1. The deltoid muscle is divided into three parts, based on their origin: the anterior (clavicular) fibers, the lateral (acromial) fibers, and the posterior (spinal) fiber (Socratic Q&A, 2023).



2.2. Physics equations

The Figure 2 shows the arm making an angle of θ with respect to the vertical as shown in the diagram. The forces, F_d, F_a and F_o represent the force on the deltoid muscle, weight of the arm and the weight of the lifting object. The F_h and F_v are the horizontal and vertical force components acting on the rotating cuff of the shoulder.

At a given angle θ, where $15° < \theta < 90°$, we consider the static equilibrium of the arm, where net force and torque are zero. That is, $\Sigma F = 0$ and $\Sigma \tau = 0$. The angle of the deltoid force with the arm is taken as α.

$$\Sigma F = 0 \text{ and } \Sigma \tau = 0$$

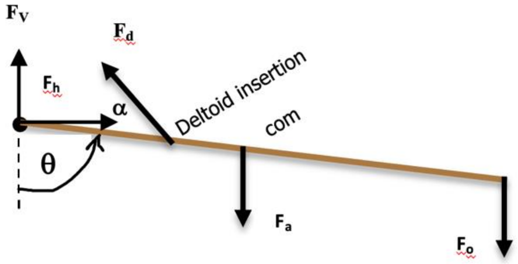
$$\Sigma F_x = 0 \text{ (by taking the arm as the x axis)}$$

$$F_h \cos(90-\theta) - F_d \cos(\alpha) + F_a \cos(\theta) + F_o \cos(\theta) = 0$$

$$F_h sin\theta - F_d \cos(\alpha) + F_a \cos(\theta) + F_o \cos(\theta) = 0$$

$$F_h = \frac{F_d \cos(\alpha) - F_a \cos(\theta) - F_o \cos(\theta)}{sin\theta} \qquad \text{———— (1)}$$

Figure 2. shows the force diagram of the arm at equilibrium.
The angle θ is measured with the vertical and for this study, it was set at 90^0.



Also,

$$\Sigma F_y = 0$$

$$F_v - F_a - F_o + F_d \sin(90 - \theta + \alpha)$$

$$F_v = F_a + F_o - F_d \sin(90 - \theta + \alpha) \qquad \text{———— (2)}$$

Considering the rotational motion, with static equilibrium conditions.

$$\Sigma \tau = 0$$

Here we consider the shoulder cuff as the axis of rotation.

$$\Sigma \tau = \tau_{Fh} + \tau_{Fv} + \tau_{Fd} + \tau_{Fa} + \tau_{Fo}$$

As both F_h and F_v pass through the axis of rotation they do not contribute to the net torque, leaving us with the rest of the forces. Note: Clockwise torques are taken as negative and the Counterclockwise torques are taken positive.

$$\Sigma \tau = + F_d r_d \sin(\alpha) - r_a F_a \sin(\theta) - r_o F_o \sin(\theta)$$

Where, r_d, r_a, and r_o are the distances from the axis of rotation to deltoid muscle (insertion), center of mass of the arm, and the fist (where the lifting weight, F_O, is held), respectively.

Considering the equilibrium, $F_d r_d \sin(\alpha) - r_a F_a \sin(\theta) - r_o F_o \sin(\theta) = 0$

$$\frac{r_a F_a \sin(\theta) + r_o F_o \sin(\theta)}{r_d \sin(\alpha)} = F_d$$

$$F_d = \frac{r_o F_o \sin\theta}{r_d \sin(\alpha)} + \frac{r_a F_a \sin\theta}{r_d \sin(\alpha)} \qquad \text{———— (3)}$$

Given that F_o is the independent variable, and the F_d is the dependent variable, for a given angle θ, The above equation follows $y = mx + c$ type linear behavior.

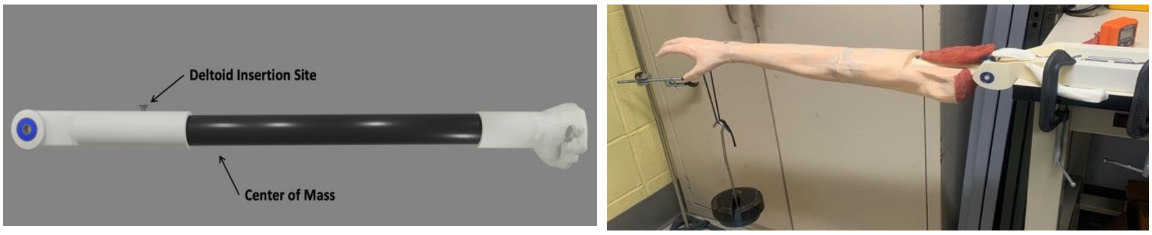
2. Design: 3D model and animation

The focus of this study is to teach the torque and equilibrium of a given system and help students become comfortable with applying linear and rotational Newton's Laws to a closed system. Given the absence of readily available demonstrations of the forces at the deltoid muscle, we opted to employ a hands-on approach. We developed a simulation, allowing students to conduct virtual experiments and thoroughly comprehend the forces at play and the associated calculations. We used 3D printing to craft an anatomically accurate arm model, subjecting it to different weights for practical testing. Figure 3 shows a picture of the 3D model we printed out *using the PLA material.*

Life size skeleton model bones of a scapula and a humerus were obtained and measured, and the relative locations of the deltoid tuberosity and the acromion insertion point were recorded. Using

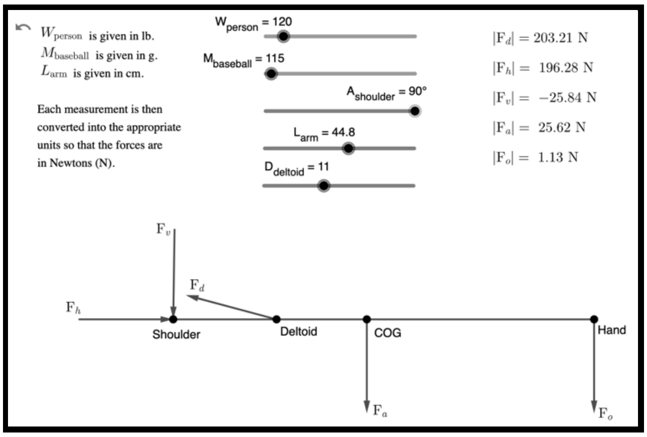
Embodi3D web application, an “stl” file representing the scapula and humerus were downloaded. These models were then scaled to the measurements taken from the life-sized bones. The Visible Body Suite web application was used to determine the correct orientation between the scapula and humerus, as well as the space and angle of orientation between these bones. Using these measurements and the Fusion 360 program, a 3D printed model was generated. The three pieces of this model included the acromion, humerus, and a fixation piece. A Newton meter was attached to measure the tension of the deltoid muscle, between the deltoid tuberosity and the acromion insertion point. We used a series of masses on the hand and recorded the corresponding force, F_d, using the Newton meter.

Figure 3. The first figure (left) shows the first arm model, and the second diagram (Right) shows the completed version of the 3D-printed arm. We used a metal rod to add weight to the arm.



The Interactive Arm simulation was created using GeoGebra [https://www.geogebra.org/calculator/qbu43e9j]. It is a dynamic visual representation of an arm that displays various forces acting on the arm, and their magnitudes, for example, when lifting an object. The users are given the weblink of the simulation, along with the access to all the equations used to calculate the deltoid force. There the user starts by inputting the following parameters: the weight of the person, the mass of the baseball (in grams), the angle that the arm makes from the side or vertical (in degrees), the angle that the deltoid makes at the point of insertion, and the length of the subject’s arm (in centimeters). As discussed in (Goldick, 2010), et al, the weight of the arm is 4.8% of the total body weight. Figure. 4 shows the interface of the animation. We used the length of the arm to be 0.52 m and changed the mass of the object from 10 g to 1000 g. The F_d was recorded as a function of the weight of the hanging object, F_o.

Figure 4. The interface of the GeoGebra simulation. There we used five sliders to input the weight of the person, mass of the lifting object, angle of the arm, angle between arm and deltoid, and the length of the arm.



W_{person} is given in lb.
M_{baseball} is given in g.
L_{arm} is given in cm.

Each measurement is then converted into the appropriate units so that the forces are in Newtons (N).

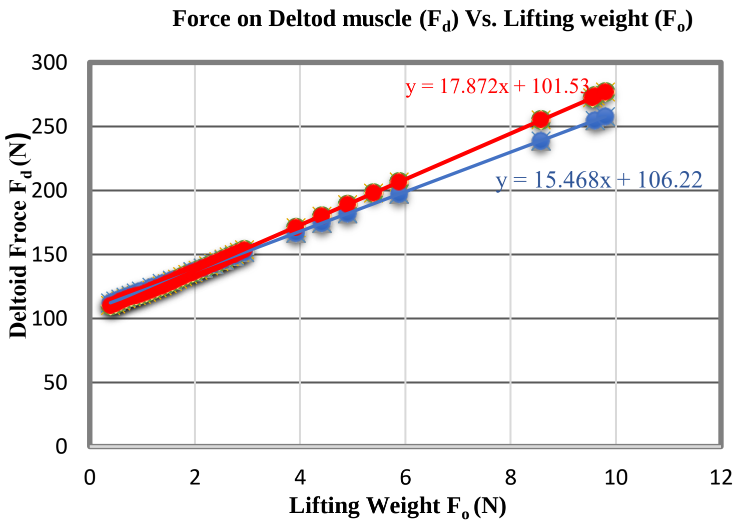
$W_{\text{person}} = 120$
$M_{\text{baseball}} = 115$
$A_{\text{shoulder}} = 90°$
$L_{\text{arm}} = 44.8$
$D_{\text{deltoid}} = 11$

$|F_d| = 203.21$ N
$|F_h| = 196.28$ N
$|F_v| = -25.84$ N
$|F_a| = 25.62$ N
$|F_o| = 1.13$ N

3. Results and discussion

Using the data retrieved from the physical model and the animation, we plotted a graph of F_d vs. F_o. *Fig. 5* shows the linear relationship, $y = mx + c$ type, between F_d and F_o. This linear behavior agrees with the expectations as shown in our calculations, equation (3). The angle that the deltoid force made with the arm was taken as 5° as stated in (Goldick, 2010). The prototype data follow a linear trend throughout the range of data collected and are in perfect agreement with theory (data retrieved from the animation). The data points from both models align consistently up to 4 N, with a slight deviation observed thereafter. We suspect this deviation may be attributed to an issue around the shoulder cuff of the prototype. Currently, we are actively addressing these issues. Additionally, we plan to repeat the experiment by varying the arm angle and then compare this new data with the animation results.

Figure. 5 shows the graph of F_d vs. F_o obtained from the physical prototype (blue data points) and the animation (red data points).



4. Conclusion

We utilized the animation and the physical prototype in two course sections (*Mechanics and Human body*), with one controlled group, and compared the results obtained for problems relating to rotational motion. Students exposed to both the prototype and animation performed significantly better than those without exposure to either. At the end of the semester, students particularly appreciated the opportunity to work with the simulation, manipulate variables, and confirm solutions on the web platform. In conclusion, we successfully completed the initial phase of our experiment, and we plan to improve the prototype to illustrate various angles for better student comprehension, integrating NASA's mission on space suits.

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References

Adams, W. K., Reid, S., LeMaster, R., McKagan, S. B., Perkins, K. K., Dubson, M., & Wieman, C. E. (2008). A study of educational simulations part I - Engagement and learning. *Journal of Interactive Learning Research, 19*(3), 397-419.

Elzanie, A., & Varacallo, M. (2024). Anatomy, Shoulder and Upper Limb, Deltoid Muscle. *StatPearls [Internet]*. Treasure Island (FL): StatPearls Publishing. Available from: https://www.ncbi.nlm.nih.gov/books/NBK537056/

Goldick, H. D. (2010). *Mechanics, Heat, and the Human Body: An Introduction to Physics*. Pearson.

Mohottala, H., Althani, B., & Higgins, B. (2023). Human body and physics: combined use of simulations and hands-on experiments to explain the quadricep muscle exercise. *Physics Education, 58*(6), 065001.

OpenStax (2012). *College physics 2e*. Available at: https://openstax.org/details/books/college-physics

Perkins, K. (2020). Transforming STEM Learning at Scale: PhET Interactive Simulations. *Childhood Education, 96*(4), 42-49. https://doi.org/10.1080/00094056.2020.1796451

Price, A., Wieman, C., & Perkins, K. (2019). Teaching with simulations: Teachers use simulations for student motivation, content learning, and engagement in science practices. *The Science Teacher, 86*(7), 46-52.

Socratic Questions (2023). What is the action of the deltoid muscle? *Anatomy & Physiology*. Available at https://socratic.org/questions/what-is-the-action-of-the-deltoid-muscle

University of Colorado at Boulder (2002). *Interactive simulations for science and math*. Available at https://phet.colorado.edu

Walsh, T. (2002). *Interactive Physics Simulations 2002*. Available at: http://ophysics.com/index.html