Journal of Physics Special Topics
An undergraduate physics journal

A5_3 Spinning around!

K. Crutcher, L. Carvalho, S. Hughes, S. Taper

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

December 4, 2019

Abstract

Regan MacNeil survived turning her head a full rotation in 9 seconds in the film 'The Exorcist'. We investigated the forces Regan applies to her neck during the rotation by modelling her motion as Newtons second law of rotation and discovered that by the rotational forces alone, her neck would undergo 5.88×10^{-6} N while breakage for her weight would require 1005.6 N.

Introduction

'The Exorcist' is a 1973 classic piece of film which is often cited as one of the greatest horror movies of all time. The film was directed by a pair of documentarians, doing as much practically and as true to life as possible. One of the most shocking moments within the film involves a twelve-year-old girl Regan MacNeil, the victim of a demonic possession, twisting her head through 360°. We explored the forces applied to Regan's neck as she performs the motion assuming the force would not kill her. In tackling this problem, Regan is assumed to be the average twelve-year-old girl and ignores all other internal biology barring the structure of the spinal column. Much of the central nervous system also resides in the spine, the damage to this in extreme rotation is also being ignored. To find the torque exerted on Regan we used Newtons second law of rotation (1).

$$\tau_{ext} = \sum \tau_{ext} = I\alpha \tag{1}$$

Where τ_{ext} is the external net torque, I is the inertia and α is the angular acceleration. We found the acceleration by using the equations of motion (2).

$$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta \tag{2}$$

Where ω is the angular velocity, ω_0 is the initial angular velocity, α is the angular acceleration and θ is the angle travelled through. Using a clip of the head twist scene [1] we recorded the timestamps at the beginning and end of the motion. A full rotation took nine seconds to complete. We assume constant angular velocity throughout the scene for simplicity, as we are unable to track to adequate precision. This gave us a figure of 6.67 revolutions per minute, which was converted and calculated at 0.70 rad/s. This gave a rotational acceleration of 6.8×10^{-4} rad/s^2. Inertia was found using (3).

$$I = \int dI = \int_0^m r^2 dm \tag{3}$$

Modelling the spine as a solid cylinder with a uniform mass distribution within gave an inertia of the spine to be (4) where R is the radius of the neck and M is the neck mass.

$$I = \frac{MR^2}{2} \tag{4}$$

Using the average mass of vertebral segments, the mass was calculated as 0.29 kg [2] and the radius of an extra-extra-small neck [3], we calculated the inertia of Regan's spine. Using the inertia (4) to find the torque (1), the force applied to Regan's neck is found by relation (5).

$$F = \frac{\tau_{ext}}{R \times \sin(\theta_a)} \tag{5}$$

Where F is the force applied to the neck and $\sin(\theta_a)$ is the angle at which the force is applied. The force is assumed to be constantly applied perpendicular to the neck.

Discussion

Using a procedural document for military executions [4] we were able to identify the force required to break Regan's spine. As detailed in the introduction, Regan is an average female child weighing 41.5 kg [5]. If she were to be hung and her neck snap on the drop, she would have to fall 2.47 m. The force on her spine would need to be a minimum of 1005.6 N to ensure a break. Regan applies 5.88×10^{-6} N of force to her neck in the spin. This is tiny, applying as much force as some of NASA's experimental ion drives [6]. This shows that Regan's neck would not snap under the force of her neck completing a full rotation.

Conclusion

Our value obtained for the rotational forces applied to Regan's neck shows that her neck would in fact remain intact, even if the damage to her nervous system may kill her. This however is due only to the model we have applied to her, by modelling the neck as a solid body object and head as independent from the spine. This as we know, is not true in real life. The spinal column is a curved, geometrically varying structure [7] that when rotated would apply frictional forces of the individual vertebrae and tension from the muscle holding the spine in place. Further studies could investigate the forces that arise from friction between the vertebrae and the tension that muscles apply during movement.

Data on the weight of a human spine across multiple age ranges is understandably scarce and so the spinal weight found in [2] are likely to be too heavy, however due to the low weights in the source it wouldn't vastly change the findings. Furthermore our force was low as the model effectively treats the neck as a car axle spinning on it's axis, if Regan's neck snapped purely due to rotational forces then the entire fundamentals to how transportation works would be undermined. The greatest influence on Regan's low applied force is the acceleration her neck undergoes. Her neck as seen in the clip [1] slowly rotates through two radians. In professional sports in which brain injuries are a potential such as the NFL, it is found that fractures occur due to linear acceleration, but brain injury is applied through rotational acceleration [8]. Our model is purely looking at fractures and so rotational accelerations would need to be far higher to compensate for this. Regan's rotational acceleration was 6.8×10^{-4} rad/s^2 while injuries in American football occur at rotational accelerations of 6383 rad/s^2 [8]. This acceleration is associated with rotational velocities of 28.3 rad/s [8]. This difference in magnitude of the acceleration is 10^8, which is a similar magnitude difference needed for a spinal break to occur, with the 10^2 difference in magnitude being due to the weight of the spine compared to the weight of a full body. So if the demon that possessed Regan rotated her head faster on its axis then Regan's neck would have sheared in two.

References

[1] `https://bit.ly/381SnBz`[Accessed 16 Oct. 2019]

[2] `https://bit.ly/2PdkqFu` [Accessed 20 Nov. 2019]

[3] `https://bit.ly/2LlWWgd` [Accessed 16 Oct. 2019]

[4] `https://bit.ly/35UfQ5I` (Pg.9) [Accessed 16 Oct. 2019]

[5] `https://bit.ly/2Rujm2T` [Accessed 16 Oct. 2019]

[6] `https://bit.ly/2Lnoa5Z` [Accessed 16 Oct. 2019]

[7] `https://bit.ly/387Xsbe` [Accessed 16 Oct. 2019]

[8] `https://bit.ly/2DN2RGM` [Accessed 16 Oct. 2019]