Journal of Interdisciplinary Science Topics

How Might the Force Work?

Leah Ashley, Rowan Reynolds & Robbie Roe
The Centre for Interdisciplinary Science, University of Leicester
14/03/2016

Abstract

This paper studies how Yoda's use of the Force (as depicted by the Star Wars series of films) may relate to the energy gained through biological processes. Using a power output of 19.2 kW when Yoda lifts an X-Wing and ignoring ATP recycling, it was found that the hydrolysis of all the ATP both initially present and able to be created in Yoda's body would not be sufficient to provide the energy for this feat. Therefore Yoda either draws on another form of energy storage in his body, or uses some unexplained aspect of the Force.

Introduction

In the Star Wars cinematic series 'the Force' is used in the universe to accomplish great feats of strength, agility and even telekinesis. The only explanation given for these abilities is that there are micro-organisms called 'midi-chlorians' living inside all living cells. No canon explanation is given to how midi-chlorians work, and what provides the energy to lift objects from a distance. We aim to calculate whether the standard energy production molecules of the body would be able to provide enough energy to produce a feat of Force strength such as that seen in the Star Wars series.

Which feat of Force strength?

The use of the Force in the films is wide and diverse. We decided to choose one Force usage moment in the series as a means of modelling this. In Episode V, Jedi Master Yoda lifts Luke Skywalker's X-Wing fighter from a swamp on Dagobah. A previous calculation for the amount of power produced by Yoda found that 19.2 kW was produced over a period of 3.6 seconds [1]. This amounts to 68.12 kJ in total. After reviewing the model and calculation, this power value seemed appropriate as the total power that is produced by Yoda.

Human energy sources

In the human body, different molecules are used to gain energy at different points during energy expenditure, based on the most efficient type of metabolism at that time. From Figure 1, the ATP stores in the muscle are initially used as they can immediately be hydrolysed to release energy. After approximately 1 second, this depletes and creatine phosphate becomes the next source of energy. Creatine phosphate is converted into creatine, which phosphorylates ADP to produce ATP molecules. When this is no longer sustainable, the glycolytic system takes over. This produces ATP from glycogen stores. Finally, the aerobic system produces ATP from glycolysis, the Krebs cycle and oxidative phosphorylation [3].

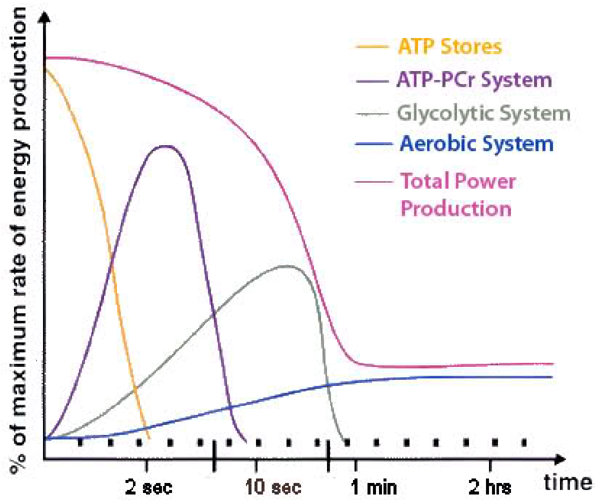

Figure 1) Energy sources used over time [2].

Finding the power output of biological molecules

We model Yoda as a scaled-down human, assuming that human Force users would have similar abilities to Yoda. Yoda, weighing 13 kg [4], would have 5.2 kg of muscle, based on an average muscle mass percentage of 40% in humans [5].

The human body contains 250g of ATP at any given time [6]. By assuming this is for a 70kg human, scaling down to Yoda's mass means he would have 46.4g ATP in his body [5]. Of this, a certain percentage would be usable in his muscles at any one time. Assuming this ATP is evenly distributed in the body, he would have 40% of this stored in his muscles (18.6g).

From this, the power produced by ATP hydrolysis could be found based on the standard free energy released from hydrolysing one mole of ATP (30.5 kJ mol^{-1} [3]), and the molar mass of ATP (507.18 g mol^{-1} [7]):

$$\frac{18.6\, g\ \times\ 30.5\, kJ\, mol^{-1}}{507.18\, g\, mol^{-1}\ \times\ 3.6\, s} = 0.311\, kW$$

This power output is very far from what was required to lift the X-Wing, and so the power from creatine phosphate was examined. We also consider the anaerobic and aerobic systems, as these are the next sources of energy a human will use when exercising over a longer period of time. The Force, or Yoda's alien qualities, may allow the sequential breakdown of these biological molecules to occur over a much quicker timescale than observed in reality. The maximal rate of ATP production calculated from these sources is summarised in Table 1.

The rate of ATP production from creatine phosphate in Yoda's muscles is calculated by first finding the rate of ATP production per minute per kilogram of muscle mass from the value above.

$$\frac{73.3\, mmol\, s^{-1}\ \times\ 5.2\, kg}{28\, kg}$$
$$= 13.6\, mmol\, s^{-1}$$

From this, the power produced from the extra ATP produced was found to be:

$$13.6\ \times\ 10^{-3}\, mol\, s^{-1}\ \times\ 30.5\, kJ\, mol^{-1}$$
$$= 0.415\, kW$$

The maximal rate of ATP production from glycogen in human muscles is 55.8 mmol s^{-1} [5]. The power produced from the extra ATP from glycogen was found by the method above to be 0.316 kW.

The rate of ATP production by mitochondria for an active human is given as 11 mmol per minute per kilogram of muscle mass [8]. The rate of ATP production by mitochondria in Yoda's muscles is calculated as follows:

$$\frac{11\, mmol\, min^{-1}\, kg^{-1} \times\ 5.2\, kg}{60\, s}$$
$$= 0.953\, mmol\, s^{-1}$$

This gives a power output of 0.0291 kW. Therefore from these fuels combined, Yoda would be able to generate 1.07 kW. For comparison, a very fit human can produce 1 kW for a period less than a second, but this drops to 0.2 kW over 10 seconds [9] – Yoda's power output is much higher than feats seen in human life on Earth.

Fuel Source	Human ATP synthesis rate (mmol s^{-1})	Yoda's ATP synthesis rate (mmol s^{-1})	Power produced (kW)
ATP-PCr	73.3	13.6	0.415
Glycolytic system	55.8	10.4	0.316
Aerobic system	5.13	0.953	0.0291

Table 1) ATP synthesis rates in humans [5, 9], converted to Yoda's scale, and the subsequent power produced from these sources.

Conclusion

We have shown that by using all the energy sources available to humans, Yoda would only be able to produce 5.58% of the power he is calculated to expend in the film. Therefore the energy he draws on must come from another source. This paper concludes that the energy channelled by the Force does not come from the user alone.

References

[1] Finnie, R. (2015). *Yoda*. [online] what if?. Available at: https://what-if.xkcd.com/3/ [Accessed 21/02/2016].

[2] Beattie, D. (n.d.). *Energy Systems*. [online] Dale Beattie's PDHPE. Available at: http://dalebeattie.weebly.com/energy-systems.html [Accessed 28/02/2016].

[3] Reece, J., Urry, L., Cain, M., Wasserman, S., Minorsky, P. & Jackson R. (2011). *Campbell Biology*. 9th ed. San Francisco: Pearson, Benjamin Cummings, p.196, 209-229.

[4] Wookieepedia, (2016). *Yoda*. [online] Available at: http://starwars.wikia.com/wiki/Yoda [Accessed 21/02/2016].

[5] Berg, J., Tymoczko, J. & Stryer, L. (2002). *Biochemistry*. 5th ed. New York: W. H. Freeman. Available at: http://www.ncbi.nlm.nih.gov/books/NBK22417/ [Accessed 28/02/2016].

[6] University of Leeds, (2010). *'Nature's batteries' may have helped power early lifeforms*. [online] ScienceDaily. Available at: https://www.sciencedaily.com/releases/2010/05/100525094906.htm [Accessed 21/02/2016].

[7] Raval, A. & Ray, A. (2013). *Introduction to biological networks*. Boca Raton: CRC Press, p.117.

[8] Wibom, R. & Hultman, E. (1990). *ATP production rate in mitochondria isolated from microsamples of human muscle*. American Journal of Physiology - Endocrinology and Metabolism, 259(2).

[9] McCloy, D. & Harris, D. (1986). *Robotics: An Introduction*. Springer Science, p.2.