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The Viability of Throwing Giant Tortoises onto Mines

Yannic Chen and David McDonagh
The Centre for Interdisciplinary Science, University of Leicester
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Abstract
Due to Mario's comparatively small stature in relation to Bowser, the hero of The Mushroom Kingdom must come up with novel ways to defeat his powerful nemesis to restore order to the land. One particular method in Super Mario 64 involves throwing Bowser onto explosive mines via grabbing his tail and spinning to generate angular momentum. The viability of this technique is investigated and found to be well beyond the limits achieved by Olympic athletes.

Introduction

For decades now the popular Nintendo franchise Super Mario has been based upon the unassuming Italian plumber Mario fighting to rescue Princess Peach from The King of the Koopas and terroriser of The Mushroom Kingdom, Bowser. Although varying significantly in size throughout the series, in Super Mario 64, Bowser appears approximately three times the height of Mario, where the tortoise-like creature is grabbed by the tail and spun until enough angular velocity is generated to throw Bowser onto conveniently placed, explosive mines. Through making some basic assumptions and modelling this technique akin to the Olympic hammer throw, the viability of a human being achieving this with such a creature can be investigated.

Generating Angular Velocity

In treating Bowser as a sphere with his tail acting as a rope, the distance over which Bowser can be thrown can be represented as a projectile motion problem, where the x and y components of the displacement can be written as

$$x = v_0 \cos(\theta)\, t$$

$$y = v_0 \sin(\theta) - \frac{1}{2} g t^2,$$

where v_0 is the initial velocity upon release, θ is the angle upon realise, g is the gravitational force acting downward and t is time.

Rearranging the first equation for time and substituting into the second gives

$$y = \sin(\theta) \frac{x}{\cos(\theta)} - \frac{1}{2} g \frac{x}{v_0 \cos(\theta)}.$$

In taking the initial and final y values to be zero, corresponding to the height of Mario's chest and the height of the mine, this can be rearranged for velocity to give

$$\tan(\theta)\, x = \frac{1}{2} \frac{g x^2}{v_0^2 \cos^2 \theta}$$

$$v_0 = \sqrt{\frac{g x}{2 \tan(\theta) \cos^2(\theta)}}.$$

From a still image of the boss battle[1], the size of the arena is taken to be 30m, giving an x value of 15m if Mario is standing in the centre. Although the gravitational force of The Mushroom Kingdom is not known, this is taken to be the same as on Earth. Finally, assuming the ideal launch angle of $45°$and air resistance to be negligible in the arena, this gives a required velocity of

$$v_0 = \sqrt{\frac{9.81 m s^{-2} \times 15 m}{2 \tan(45) \times \cos^2(45)}}$$

$$v_0 = 12.13 m s^{-1}$$

To achieve this Mario rotates Bowser in a circle to gain angular momentum. The speed at which Mario has to rotate can be calculated by considering the angular velocity

$$v = \omega r,$$

where v is the angular velocity, ω is the angular frequency and r is the radius between Mario's centre of gravity and Bowser's. The radius r is taken to be approximately the sum of Mario's arm length and half of Bowser's height when fully extended, taken to be 0.75m and 2.25m respectively, estimated from a still image[1]. Substituting this with the calculated velocity gives

$$12.13m\,s^{-1} = \omega(3m),$$

hence

$$\omega = 4.04\,s^{-1}.$$

The angular frequency can then be converted to revolutions per second, meaning the rate Mario will need to turn equates to:

$$2\pi f = 4.04s^{-1}$$

$$f = 0.64\,s^{-1}.$$

This means that Mario needs to rotate roughly once every 1.38 seconds to gain enough velocity to throw Bowser 15m.

Centripetal Force

Throughout this motion, centrifugal force experienced by Mario can be calculated from the centripetal acceleration, given by

$$a = \frac{v^2}{r} = 49.05ms^{-2}.$$

Due to the ambiguous evolutionary origin of Bowser, his mass is estimated from scaling up the mass of a giant tortoise, which based on three giant tortoises to give a similar size gives a mass of 645kg[2]. From Newton's second law, this results in a centrifugal force of

$$F = ma$$

$$F = 645kg\ \times 49.05ms^{-2} = 31634.43N$$

pulling outward from the axis of rotation, assuming all of Bowser's mass included into the centrifugal force. Even without considering the pulling force required to accelerate Bowser to the required velocity, to counteract the centrifugal force Mario must apply an equal centripetal force to keep Bowser moving in a circle. The magnitude calculated reaches over eleven times that calculated for Olympic hammer throwers[3], which, due to Mario's comparative fitness, makes it unlikely Mario could achieve this.

Discussion and Conclusion

Despite the low frequency of rotation required to throw Bowser onto a nearby mine, such a feat would require a centripetal force beyond that of top athletes at 15m, due Bowser's mass. Decreasing this distance is not found to lower the required centripetal force to within those of hammer throwers until within the circle outlined by spinning Bowser, putting Mario himself in danger. Furthermore, the mass of Bowser means merely lifting him into a position where he could then be accelerated to the required velocity would require almost three times the current limit for what human beings can lift[4]. From this, it can be seen that it is unlikely that this method would be an efficient way of saving The Mushroom Kingdom.

References

[1] Mitjitsu, 2007, *Mario 64 beaten with 0 stars in 5:47,* Youtube, available at: http://www.youtube.com/watch?v=DTzs9bcNgMQ&t=5m22s

[2] National Geographic, 2014, *Galapagos Tortoise*, National Geography, available at: http://animals.nationalgeographic.com/animals/reptiles/galapagos-tortoise/

[3] Enoka, R.M, 2008, *Neuromechanics of Human Movement,* Sheridan Books

[4] Marshall J, 2010, *Maxed out: How much can a human lift?,* New Scientist