An investigation into how changing gears on a bike affects the force generated and transmitted to the back wheel

How does changing the gear of a bicycle affect the force value transmitted to the back wheel from the biker, when the force provided by the biker remains constant?

Introduction

The purpose of my work was to find out how changing gears on a bicycle affects the torque produced by the rider. I was interested in this because I naturally noticed that changing to a higher gear increases the amount of force required to pedal at the same speed. When I took a closer look at how this happened, I saw that the gear shifted the chain of the bicycle either closer or further away from the center of the back wheel. After my studies in physics, I realized that the difference in the difficulty of pedaling is because changing the radius changes the torque produced by the biker. I decided to investigate the physical principles as to why this happens and identify a trend scientifically.

Figure: Some relevant parts of a bike [3][4]

Table: Key to Figure above

Number	Name
1	Rear hub (Center of back wheel)
2	Bike chain
3	Bottom bracket (Center of pedal)
4	Crankset
5	Crank-arm
6	Sprockets
7	Teeth

Method

The main issue I faced with the method was ensuring that the torque produced stayed constant for a long enough period of time, so that I could get reliable readings. If the pedal and the wheel moved, both the input and the output torques would continuously vary, resulting in an inconclusive investigation. Therefore, I designed a system where all the parts would stay stationary by turning my bike upside down.

First, a force meter was hung from the pedal using string. The other end of the force meter was connected to a large weight on the ground, also using string. This large weight is needed to keep the system stationary. Then, the pedal was moved so the strings were pulled taut. This provided a reading on the force meter, therefore it was reset so that the force between the ground and the pedal would not be measured. A smaller weight was then added at the edge of the back tire, providing a force to the pedal and moving it upwards. However, the large weight attached to the force meter and the pedal would pull the pedal downwards and keep the system stationary, and therefore keep the torques the same. This force is picked up by the force meter, and is the force provided by the smaller weight through the powertrain of the bicycle. The image below shows the set-up.

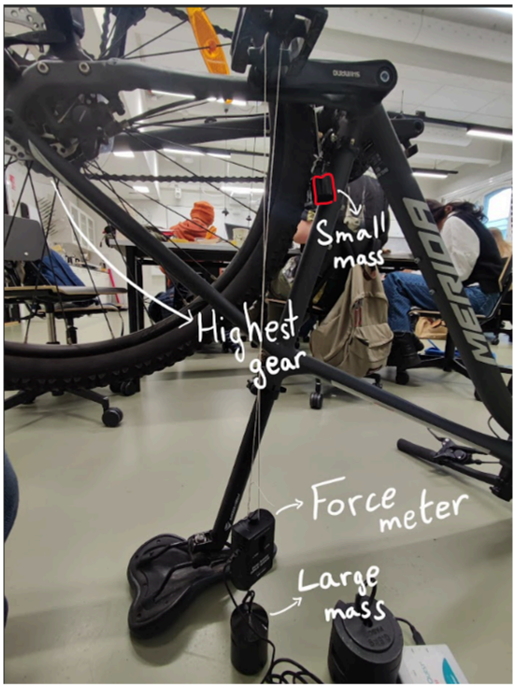

Figure: Set-up of the experiment

Gear radii were also measured, since the gears (numbered 1-7) did not increase in their radii linearly, so a graph of Force vs Gear number would not produce useful results.

Results

Three trials were conducted, and the average of these was used in calculations to improve accuracy. These, along with the gear radii are shown in the table below.

Table: Radius and force of each gear

Gear number	Gear radius (cm)	Reciprocal of gear radius (1/cm)	Force (N)
1	2.25	0.44	7.55
2	2.65	0.38	6.75
3	3.05	0.33	5.53
4	3.46	0.29	4.69
5	3.86	0.26	3.73
6	4.26	0.23	3.16
7	4.86	0.21	2.65

A graph was created out of this, with 1/gear radius used instead of gear radius. Using gear radius would have provided a curve with asymptotes at x and y axes. Using 1/gear radius would provide a line theoretically going through the origin, and would be easier to analyze and make conclusions from. The graph is shown below.

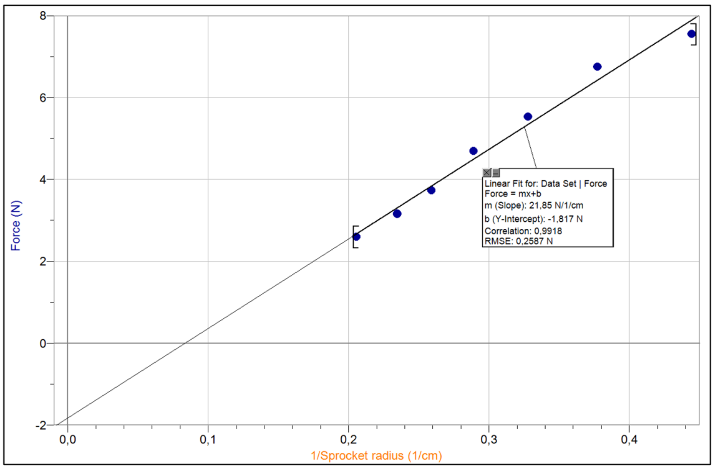

Figure: Force vs 1/Sprocket radius, with line of best fit

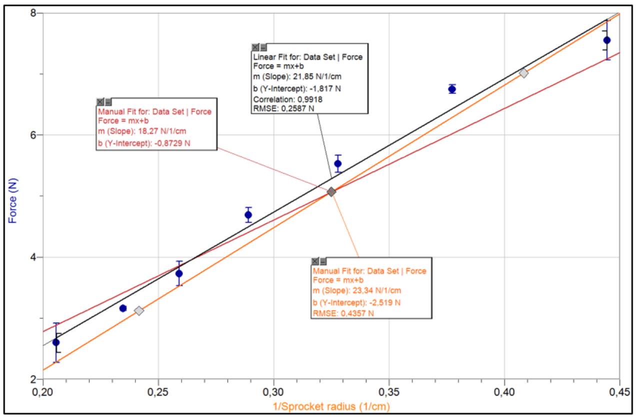

Figure: Force vs 1/Sprocket radius, with line of best fit and minimum and maximum slope lines

Method for theoretical calculations

Since torque is conserved through the system, the equation $F_1 r_1 = F_2 r_2$, where F and r are force and radius respectively, was used to find the theoretical output torque with the torque input I had used. The following table can be obtained.

Table: Ideal output force and experimentally obtained output force.

Gear number	**Gear radius (cm)**	**Ideal output force (N)**	**Experimental output force (N)**	$\frac{Experimental\ force}{Ideal\ force}$
1	2.25	14.22	7.55	0.53
2	2.65	12.08	6.73	0.56
3	3.05	10.50	5.53	0.53
4	3.46	9.28	4.69	0.51
5	3.86	8.31	3.73	0.45
6	4.26	7.52	3.16	0.42
7	4.86	6.59	2.65	0.40

When compared with theoretical values, it seemed like around 50% of the energy in the system had dissipated. While this includes a frictional component, reasons for such massive energy dissipation could include the weight of the force meter affecting calculations, as well as other forces such as stiction. Further research would be needed to be conclusive in this regard.

Conclusion

The aim of the experiment was to answer the research question, "*How does changing the gear of a bicycle affect the force value transmitted to the back wheel from the biker, when the force provided by the biker remains constant?*" The expected result was that changing to a lower gear (which would mean a larger gear radius) would result in less force at the pedal being needed to keep the 0.2kg mass on the back wheel in place, i.e., when the force input is the same, a lower gear rather than a higher gear would result in a greater force output at the back wheel. This would mean that switching to a lower gear helps the biker pedal at the same speed using less force on the same terrain. The experimental data supported this with a clear linear correlation between reciprocal of the gear radius and force output. The y-intercept of the calculated graph was not 0, and this indicates the presence of outside forces in the system. The theoretical calculated slope was also not achieved with the experimental data, but this is not a problem since the theoretical slope assumes no friction. Overall, the experiment was successful in answering the research question, with a positive correlation observed.