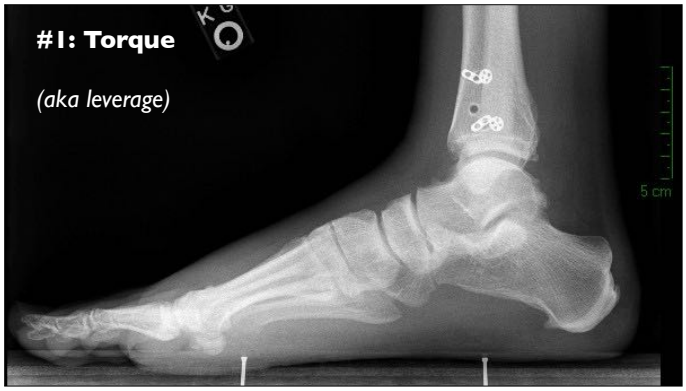
Form and Function

Three topics:

1. Torque (Leverage)
2. Oscillations (Pendulums)
3. Fluids (Size Matters)

#1: Torque

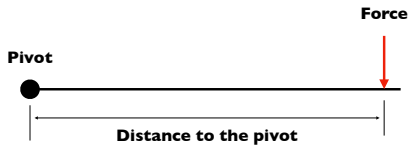
(aka leverage)



Forces make things move.

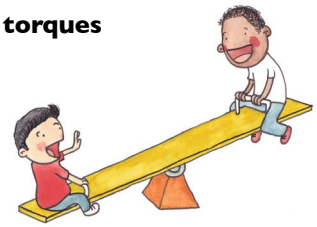
Torques make things rotate.

Torque



Torque = Force x Distance to the pivot

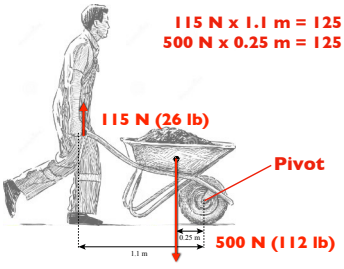
Balancing torques



Who needs to sit closer to the pivot, the person with the larger mass or the person with the smaller mass?

What's the point of the wheelbarrow?

A man is carrying a 51 kg (112 lb) load in a wheelbarrow. What upward force must his hands provide?



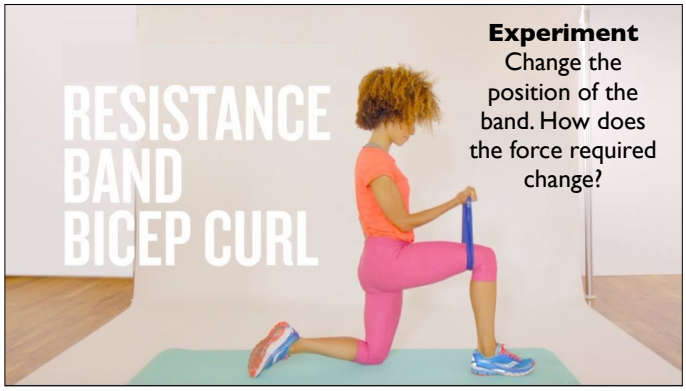
Mechanical Advantage

The force on the garlic clove is 5x the force exerted by the hand.

Mechanical Advantage

Question
What are other tools in the kitchen or the workshop that use this principle?

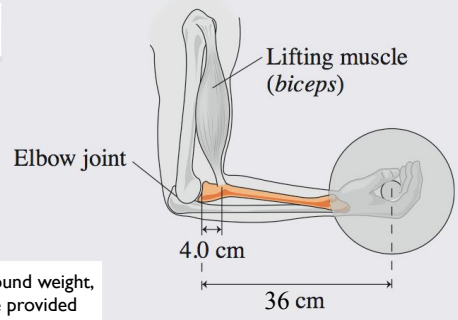
Internal forces from muscles vs. externally applied forces



Experiment
Change the position of the band. How does the force required change?

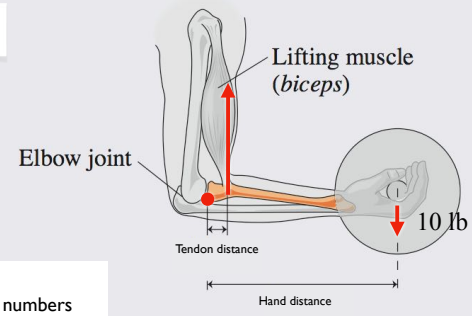
Negative Mechanical Advantage
The force provided by *each* quadriceps for this stance is more than 5x the person's weight

The Curl



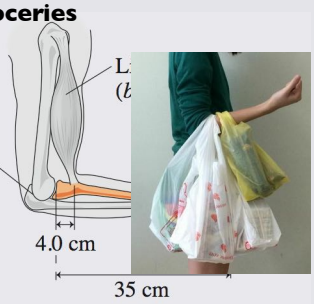
If you lift a 10 pound weight, what is the force provided by your biceps?

The Curl

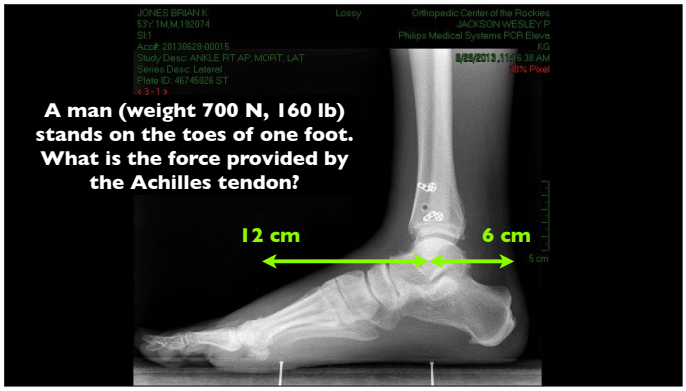


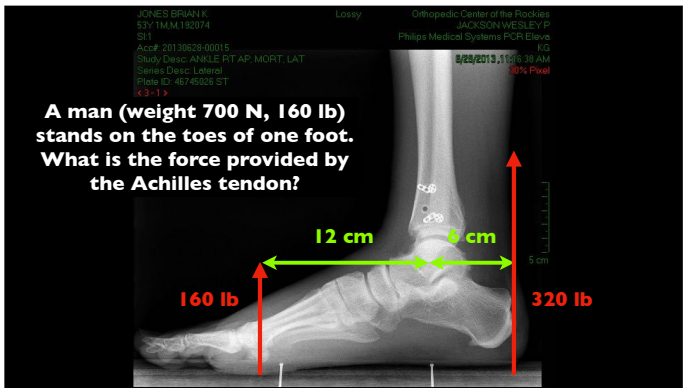
Experiment
What are these numbers for your body?

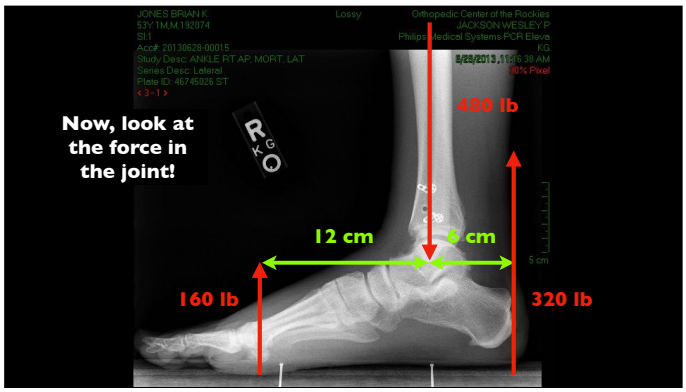
Carrying Groceries



Question
How does looping the bag over the arm close to the elbow help?



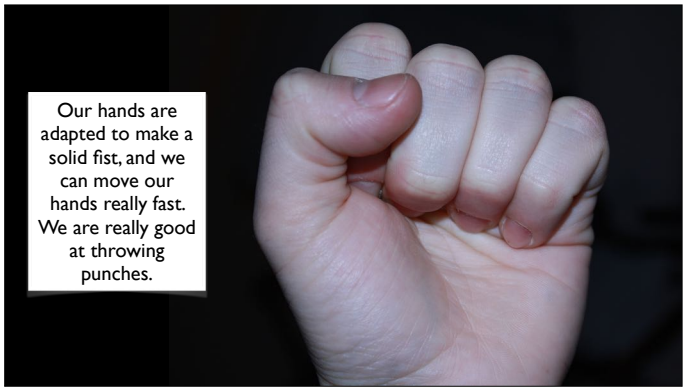




Question
Every joint in your body has negative mechanical advantage.
Are there any beneficial tradeoffs?

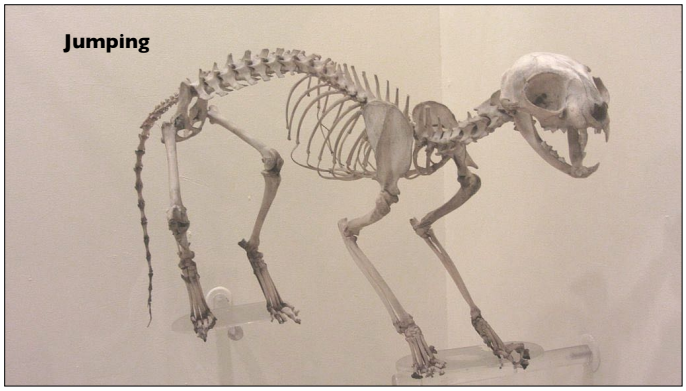
Range of Motion & Speed

Our hands are adapted to make a solid fist, and we can move our hands really fast. We are really good at throwing punches.



Which one is a digger, which one is a jumper?

Jumping



Digging

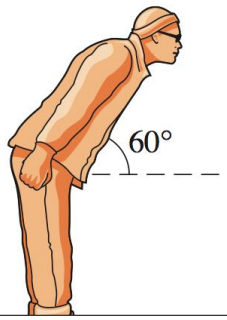
Pronghorn

Mole

Question
What's the most problematic part of the human skeleton?

Torques in the Spine

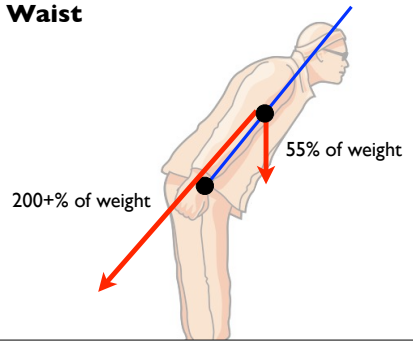
Bending at the Waist



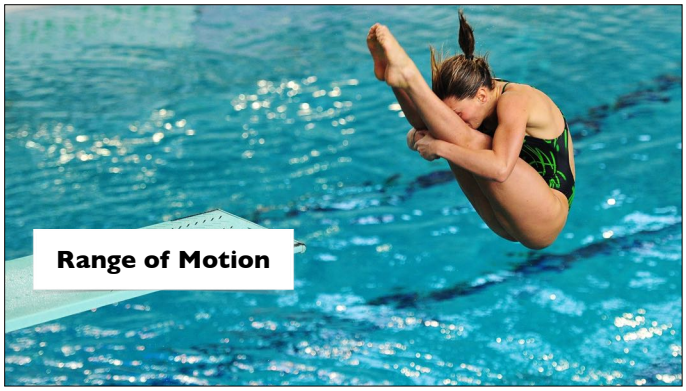
A 70 kg man bends forward at the waist; the gravitational torque is balanced by muscles along the back.

If you assume that 55% of his weight is in his torso, and the center of gravity of his torso is 43 cm from his hips, and the moment arm for his spinal muscles is 0.060 m, what is the force provided by the muscles?

Bending at the Waist



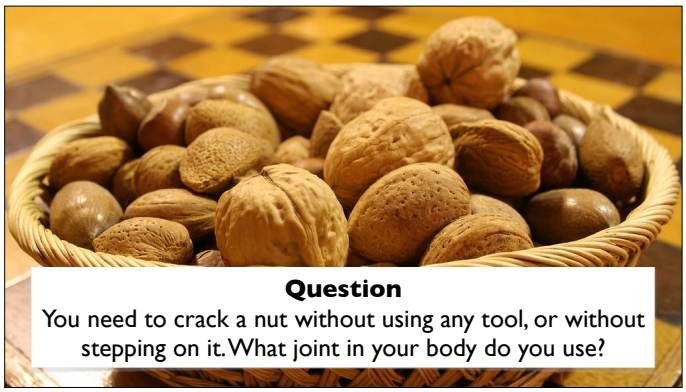
Man's weight:
690 N (150 lb)
Muscle force:
1370 N (310 lb)



Range of Motion

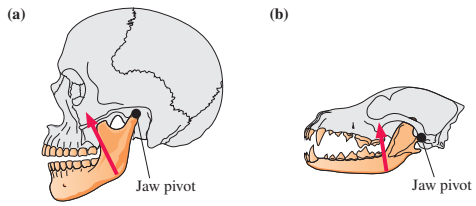
Human

Question
What does the length of the extension on the buffalo vertebra tell you about strength and range of motion?

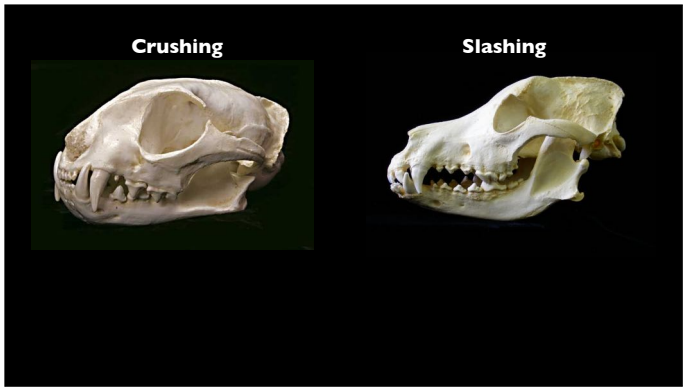


Question
You need to crack a nut without using any tool, or without stepping on it. What joint in your body do you use?

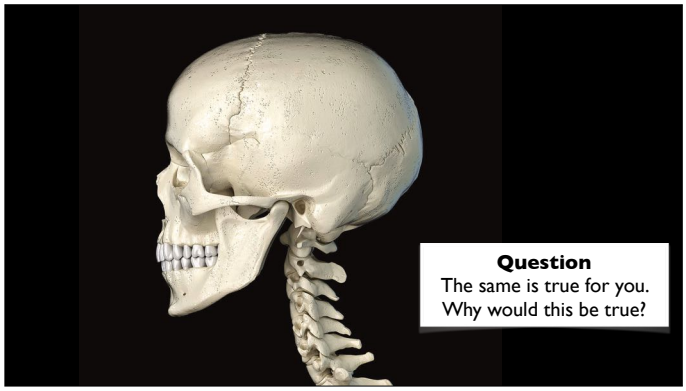
Bite force



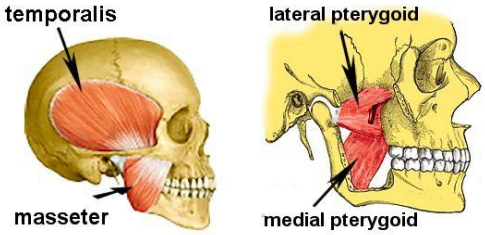
Why do dogs have long snouts while cats do not?



Very strong bite force, but small force to open jaws.



Question
The same is true for you.
Why would this be true?



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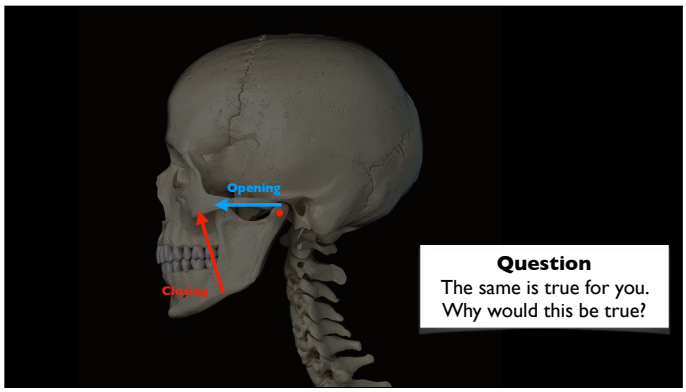

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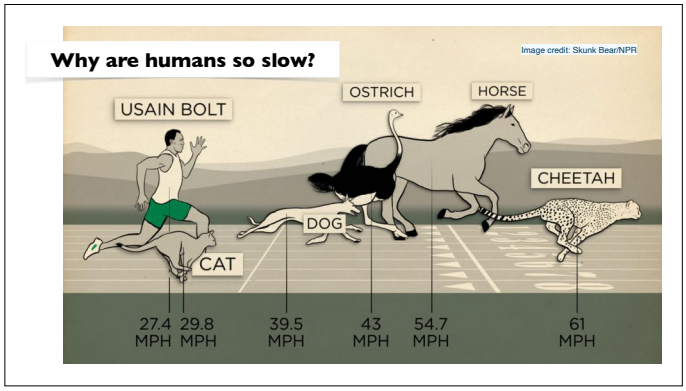
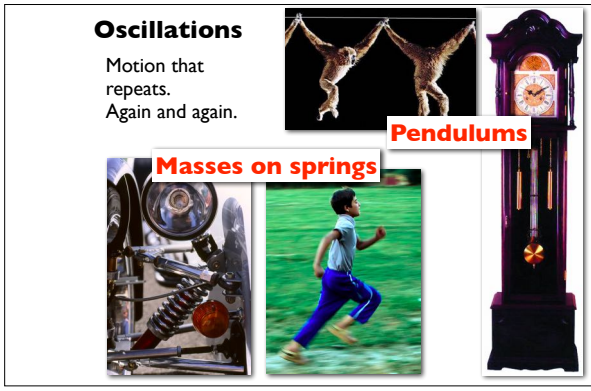
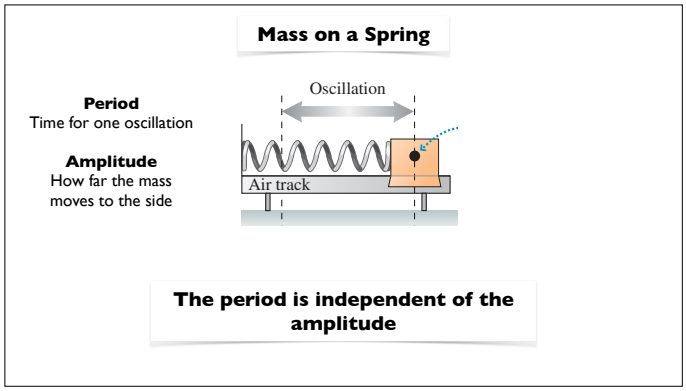
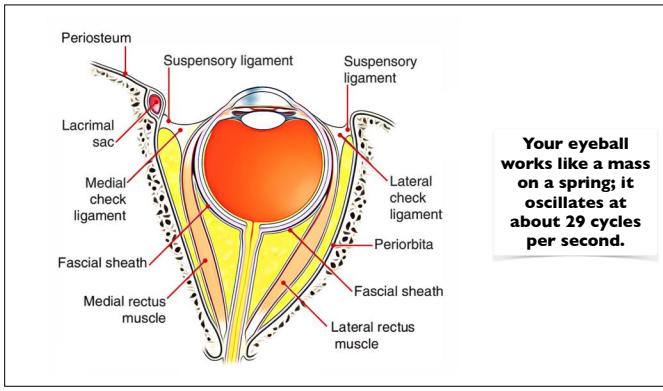
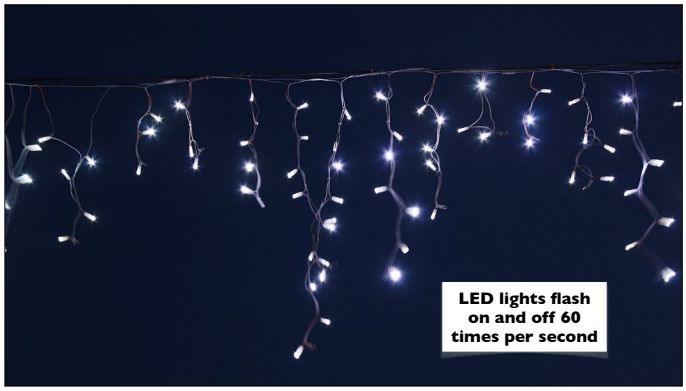








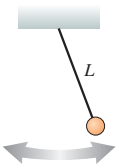


LED lights flash on and off 60 times per second

The pendulum

Period
Time for one swing

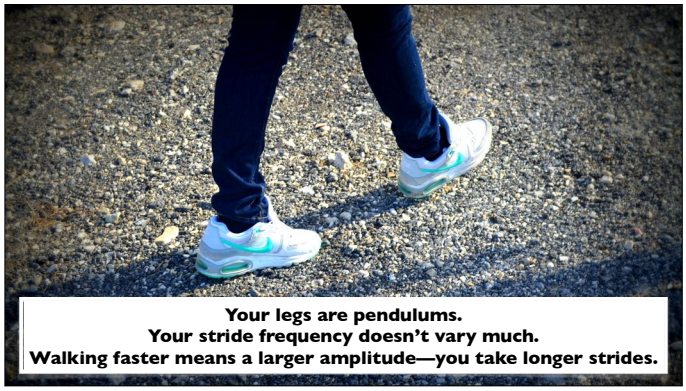
Amplitude
How far the pendulum swings to the side



Experiment
How does the length of the pendulum affect the period?
How does the amplitude of the pendulum affect the period?

Timekeeping.

Swinging Arms And Legs Are Pendulums



Your legs are pendulums.
Your stride frequency doesn't vary much.
Walking faster means a larger amplitude—you take longer strides.

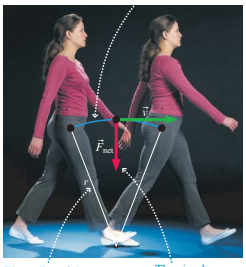
How does adding weight to your ankles change the natural period of your legs?

Why are we so slow?

Blame our big feet.

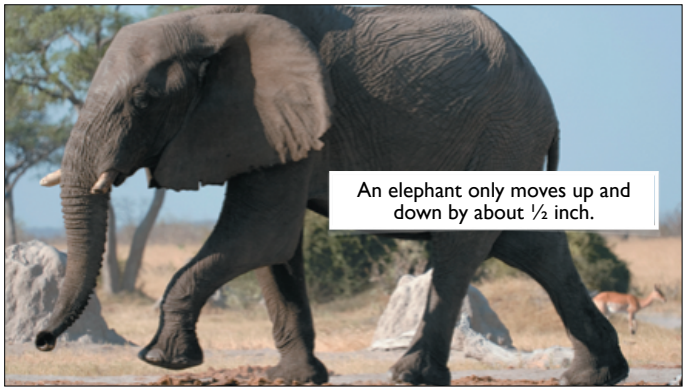
Energetics of Locomotion

As you walk, your body moves up and down through a total distance of about 4 inches.



The radius of the circular motion is the length of the leg from the foot to the hip.

The circular motion requires a force directed toward the center of the circle.

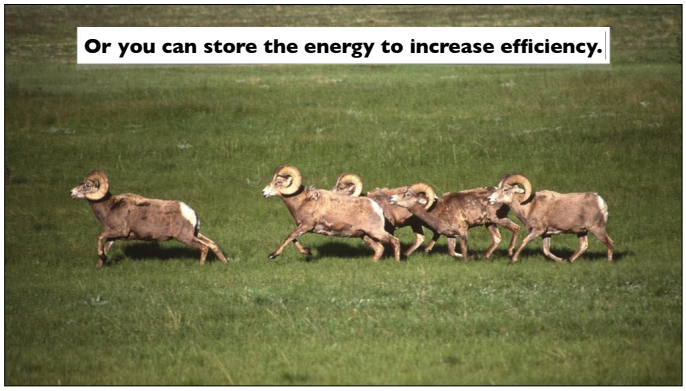


An elephant only moves up and down by about ½ inch.

This makes elephants very efficient walkers.

During a diagnostic test.

Horses are bobbleheads.
This makes them more efficient.

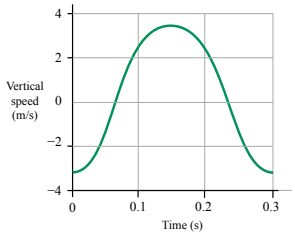


Or you can store the energy to increase efficiency.

Sheep are bouncy.

Wild sheep have very elastic tendons in their legs that provide energy return as they trot, dramatically increasing their efficiency. This graph shows a segment of a velocity-versus-time graph for an 81 kg ram's torso while trotting. As you can see, the motion is approximately simple harmonic motion.

- At what approximate time does the ram's torso reach its highest point? Its lowest point?
- What is the total vertical displacement of the ram, from the lowest point to the highest point, during the period shown?
- What is the spring constant of the ram's leg system?

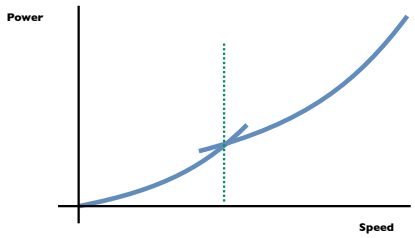


Energetics of locomotion

It was much easier to take a walk with Pumba than it is with Milo.

Why?

Transition

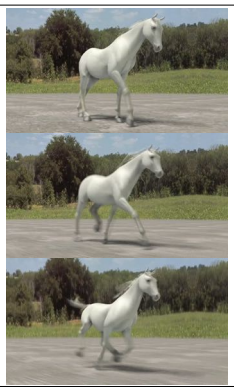


Four legs, three gaits.

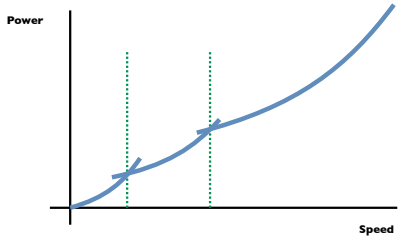
Walk

Trot

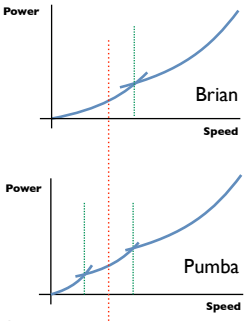
Gallop / Canter



Transitions

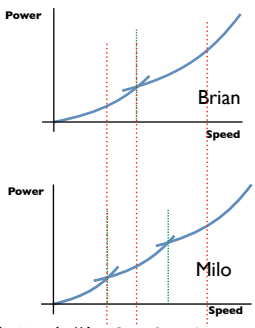


Pumbalation



Brian walking, Pumba trotting.

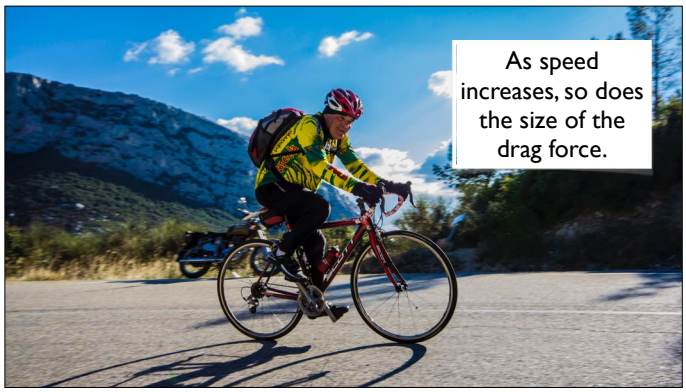
Milocomotion



Mismatch #1 Mismatch #2 Run for it!

The stickiness of water matters more and more at smaller and smaller scales.

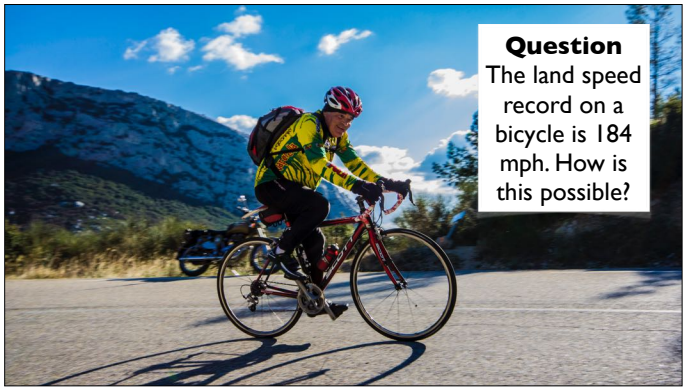
Air isn't sticky at all. Drag is simply a matter of pushing air out of the way as you move.



As speed increases, so does the size of the drag force.

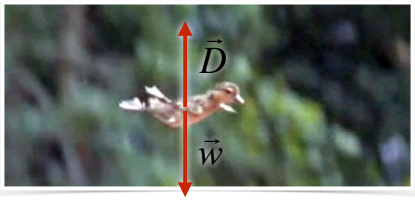
Going 2x as fast means 4x the force and 8x the power

The fastest speed recorded on a regular bike is about 50 mph.



Question
The land speed record on a bicycle is 184 mph. How is this possible?

Terminal Speed



After a certain point, speed is constant.

Scaling

$\frac{1}{4}\rho A v^2 = mg$

$v \propto \sqrt{\frac{m}{A}}$

$m \propto l^3$

$A \propto l^2$

$v \propto \sqrt{l}$

Skydiving, Man & Mouse

A man jumps from an airplane and falls with his body horizontal. He holds his arms and legs tight to his body as he falls. What is his terminal velocity? Assume the 75 kg skydiver's body has dimensions 1.8 m long, 0.40 m wide.

Now, repeat the calculation for a mouse. Assume the mouse has a mass of 20 g and is 7 cm long and 3 cm wide.

100 mph

25 mph

16 times the energy

More robust skeleton

This doesn't end well for a human, but the mouse is fine.

HAILSTONE SIZE COMPARISON

Hailstone Diameter (inches)	0.5"	0.75"	1"	1.25"	1.5"	1.75"	2"	2.5"
Terminal Velocity (mph)	35	43	50	56	61	66	72	80
90° Impact Energy (joules)	0.12	0.59	1.39	5.42	10.85	18.96	29.8	71.9
Size Description NWS	moth ball	dime	quarter	half dollar	ping pong ball	golf ball	hen's egg	tennis ball
Energy Comparison	0.02	0.11	0.25	1.00	2.00	3.50	5.50	13.27
% of Hailstones With This Maximum Size	58%	24%	10%	4%	2%	0.8%	0.3%	0.06%