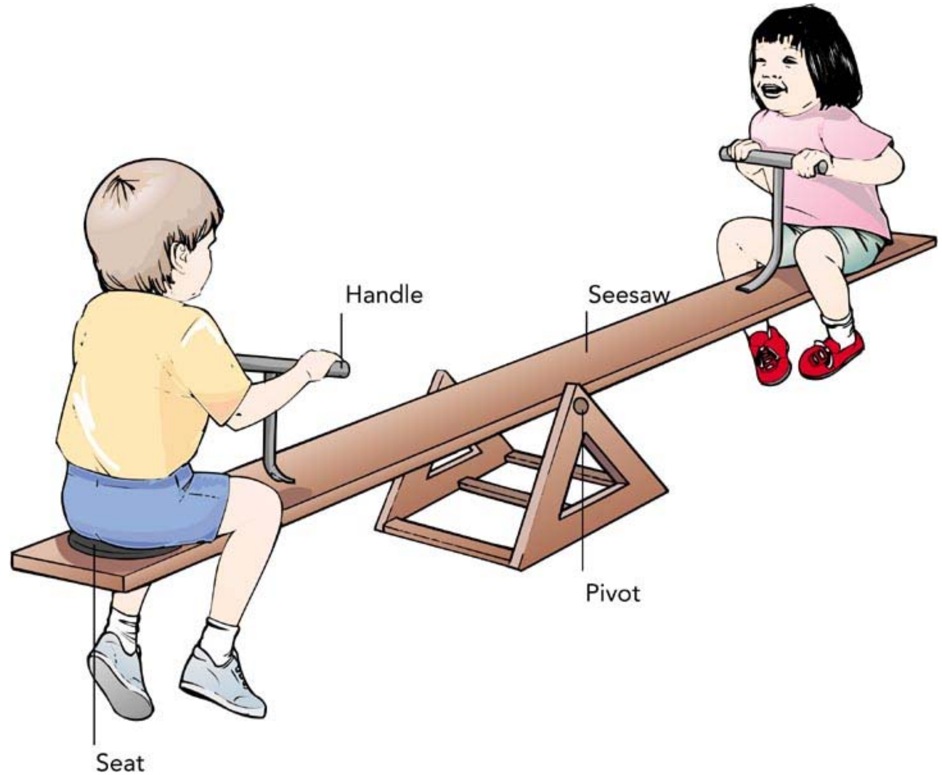
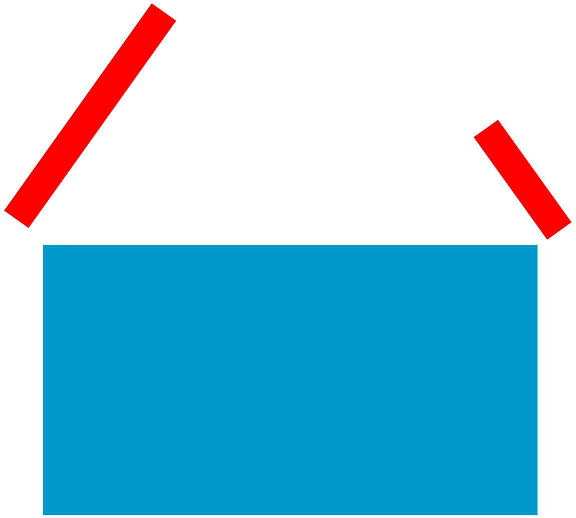



# Seesaws

# Introductory Question

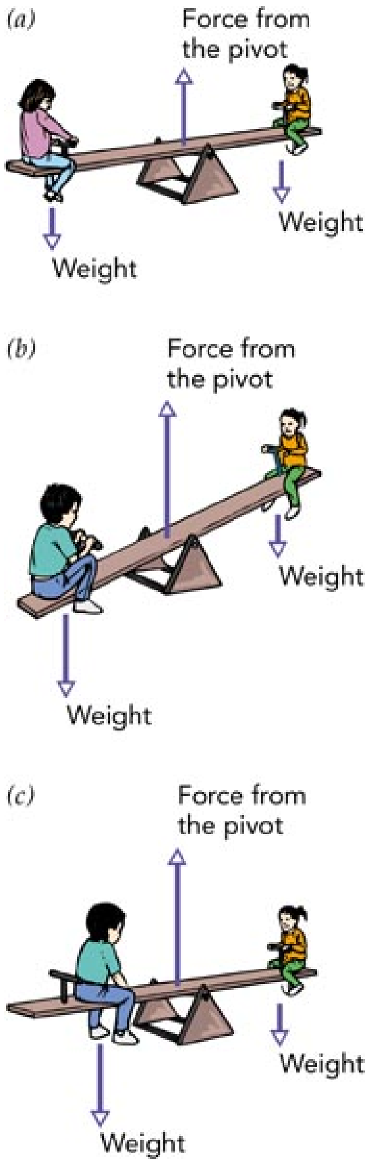
- You and a child half your height lean out over the edge of a pool at the same angle. If you both let go simultaneously, who will tip over faster and hit the water first?

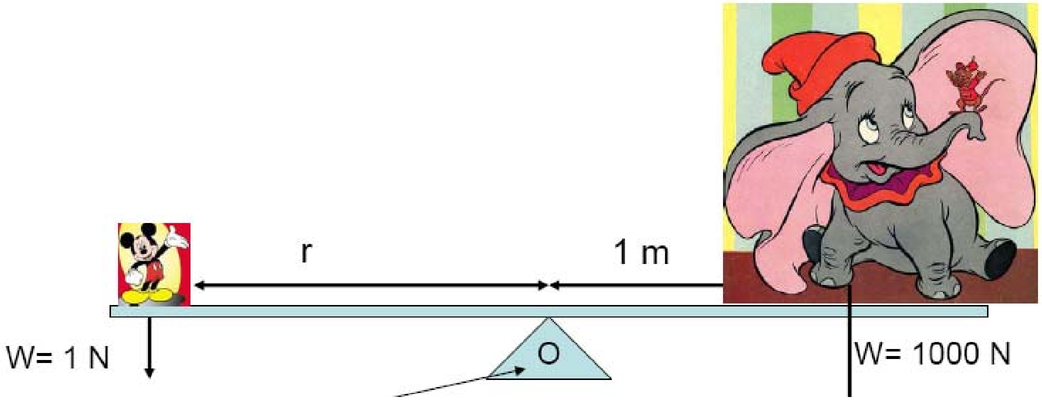
A. You
B. The small child



# Observations about Seesaws

- A balanced seesaw rocks back and forth easily
- Equal-weight children balance a seesaw
- Unequal-weight children don't normally balance
- Moving heavier child inward restores balance
- Sitting closer to the pivot speeds up the motion



# 5 Questions about Seesaws

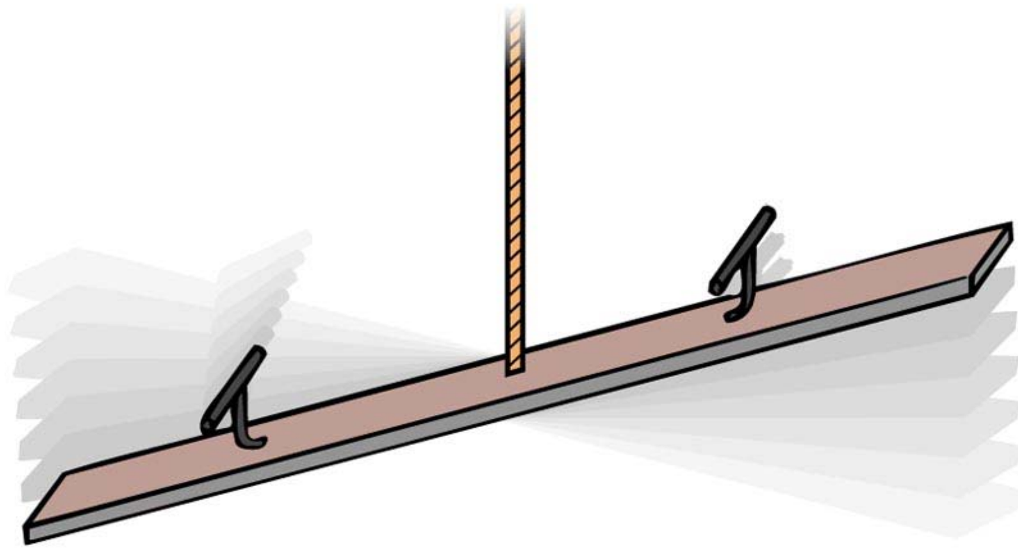
- How exactly does a balanced seesaw behave?
- Why does the seesaw need a pivot?
- Why does a lone rider plummet to the ground?
- Why do the riders' weights and positions matter?
- Why does distance from the pivot affect speed?

# Question 1

- How exactly does a balanced seesaw behave?
  - Is a balanced seesaw horizontal?
  - Is a horizontal seesaw balanced?

# Physics Concept

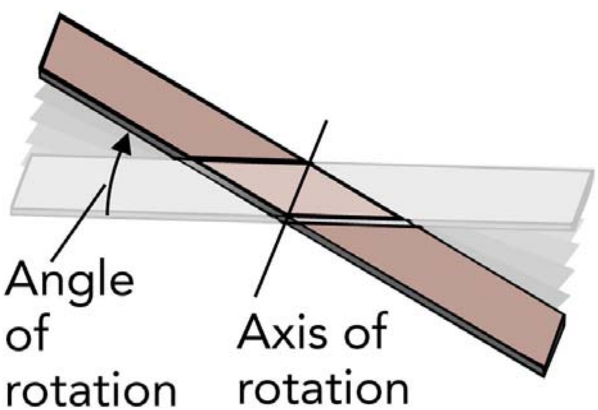
- Translational motion – overall movement from one place to another
- Rotational motion – motion around the fixed point
- Rotational Inertia
  - A body at rest tends to remain at rest
  - A body that's rotating tends to keep rotating

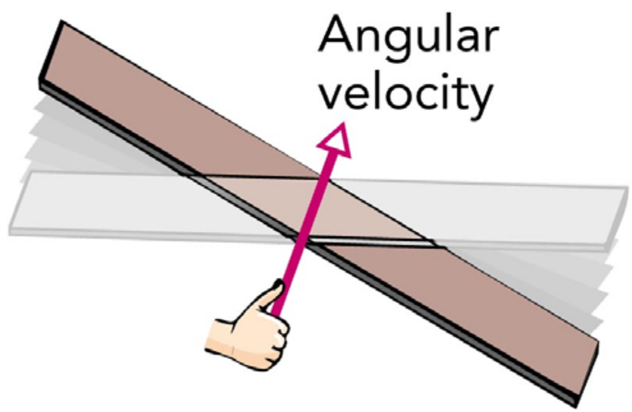


# Physical Quantities

- Ang. Position – an object's orientation[radian]
  - $2\pi$ radians = full circle = 360°
- Ang. Velocity – change in ang. pos. with time

  $\omega$[rad/s]=[1/s]
- Torque – a twist or spin [Nm]




$\omega$

# Newton's First Law of Rotational Motion

- A rigid object that's not wobbling and that is free of outside torques rotates at a constant angular velocity.

# Balanced Seesaw
# Example of the Newton’s I Law of Rotational Motion

- A balanced seesaw
  - experiences zero torque
  - has constant angular velocity
- It’s angular velocity is constant when it is
  - motionless and horizontal
  - motionless and tilted
  - turning steadily in any direction

# Question 2

- Why does the seesaw need a pivot?
  - How would a pivotless seesaw move?

# Center of Mass

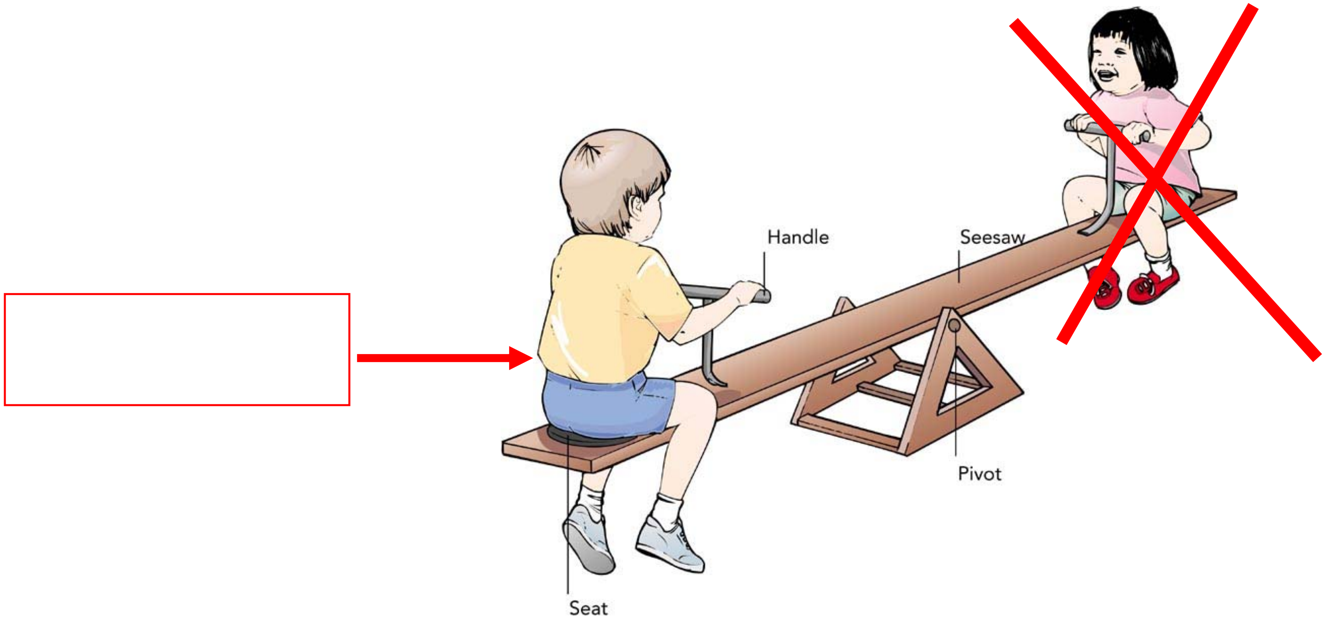
- Point about which object's mass balances
- A free object rotates about its center of mass while its center of mass follows the path of a falling object
  - When a diver does a rigid, open somersault off a high diving board, his motion appears quite complicated. Can this motion be described simply?
  - The center of mass moves if the object has an overall translational velocity.

# Seesaw's Pivot

- The seesaw needs a pivot to
  - support the total weight of the seesaw and riders
  - prevent the seesaw from falling
  - permit the seesaw to rotate but not translate

# Question 3

- Why does a lone rider plummet to the ground?
  - How does a torque affect a seesaw?
  - Why does a rider exert a torque on the seesaw?
  - What if the rider sits on the pivot?



# Physical Quantities

- Ang. Position – an object's orientation
- Ang. Velocity – change in ang. position w/ time
- Torque – a twist or spin T[N·m]
- Ang. Accel. – change in ang. velocity with time
  - $\alpha[1/s^2]$
- Rotational Mass – measure of rotational inertia
  - Depends on how far the mass is from he axis of rotation I[kg $m^2$]

# Newton's Second Law of Rotational Motion

- An object's angular acceleration is equal to the torque exerted on it divided by its rotational mass. The angular acceleration is in the same direction as the torque.

angular acceleration = torque/rotational mass

$$\alpha = T / I$$

torque = rotational mass · angular acceleration

# Forces and Torques

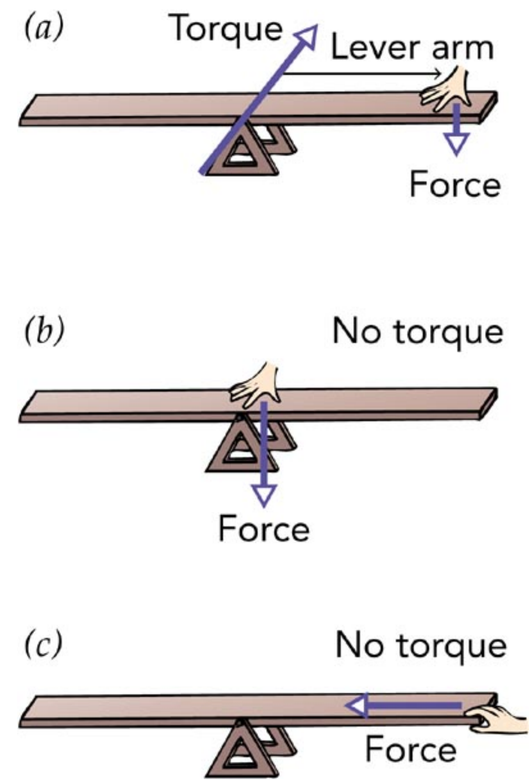
- A force can produce a torque
- A torque can produce a force

torque = lever arm · force

$T = r \cdot F_{\perp}$

(where the lever arm is perpendicular to the force!)

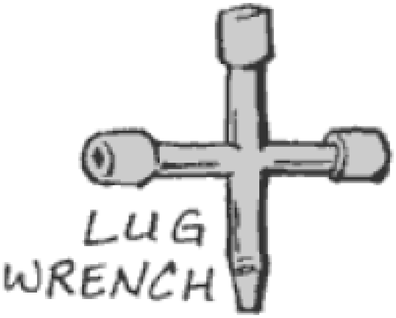
For the same force you get more torque by extending the arm!



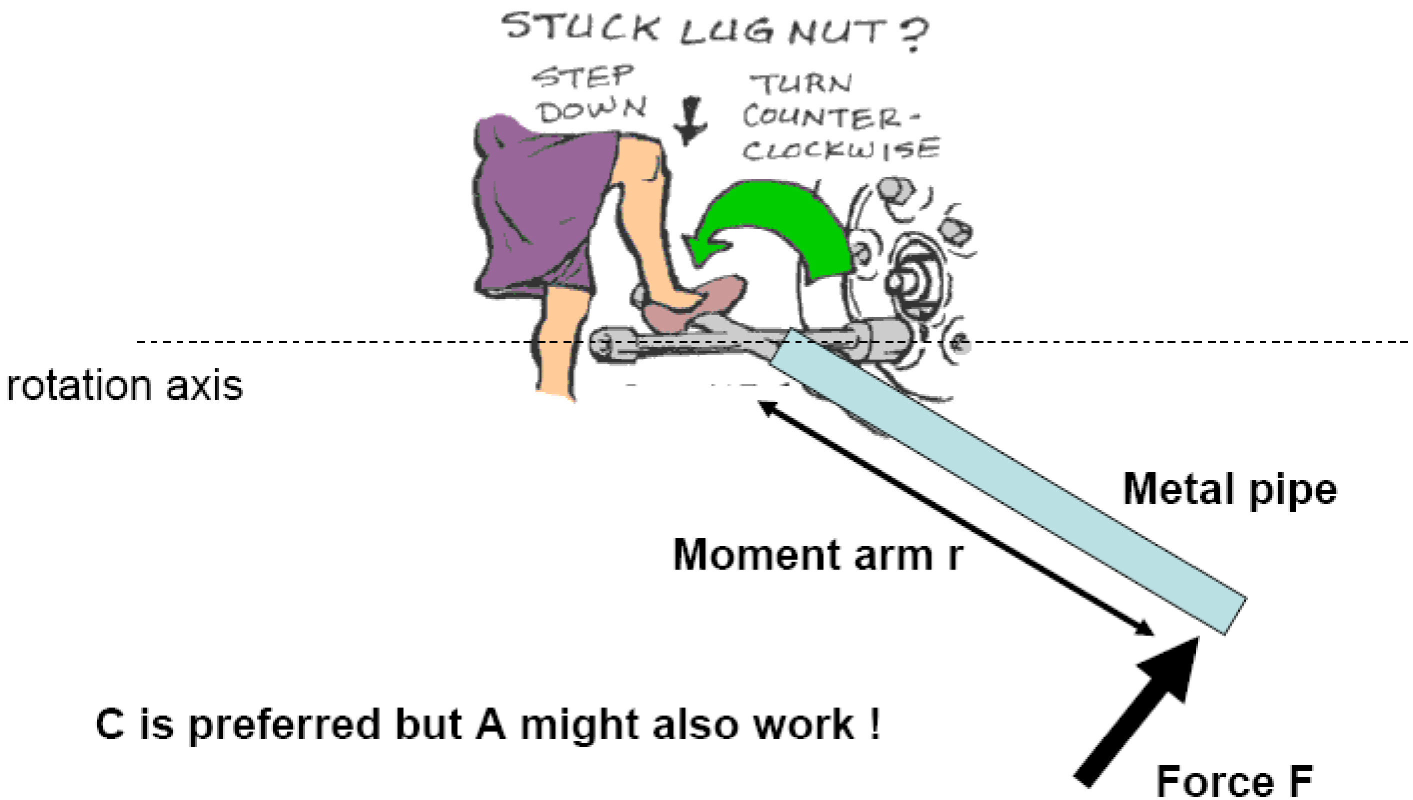
## A more real-world problem.

**Question:**

Your car has a flat tire and you need to unscrew the bolts with a lug wrench. Unfortunately, the bolts are really tough to turn and you are physically weak because you forgot to eat lunch and breakfast. What is the best thing to do ?




A. Jump on one of the wrench's arm to turn it.
B. Tap on the bolts. They sometimes just get "stuck".
C. Use a strong metal tube to lengthen one of the wrench's rotating arm.
D. Call 911




**C is preferred but A might also work !**

Moment or Lever Arm = distance between the line of action of force F to the axis of rotation

**By using a longer moment arm, you can with increase the Torque produced by a reasonable amount of force. This produces a mechanical advantage.**

$$T = r \times F$$

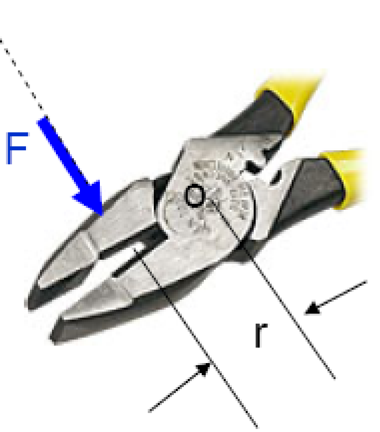
# There are **many** everyday applications of Torque/Rotation

(You can find these in your garage or toolbox)

To cut a wire, where do you put the wire ?  Away from or close to axis O ?

Line of action of

Cutting Force F




Torque T = r x F

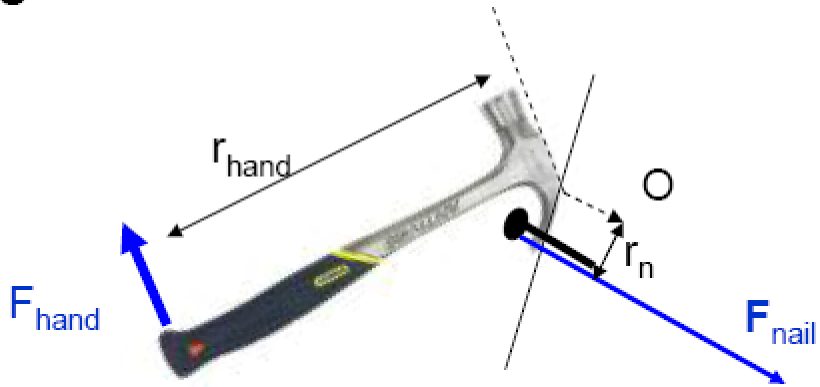
o – axis of rotation

A Pair of Pliers

moment arm r

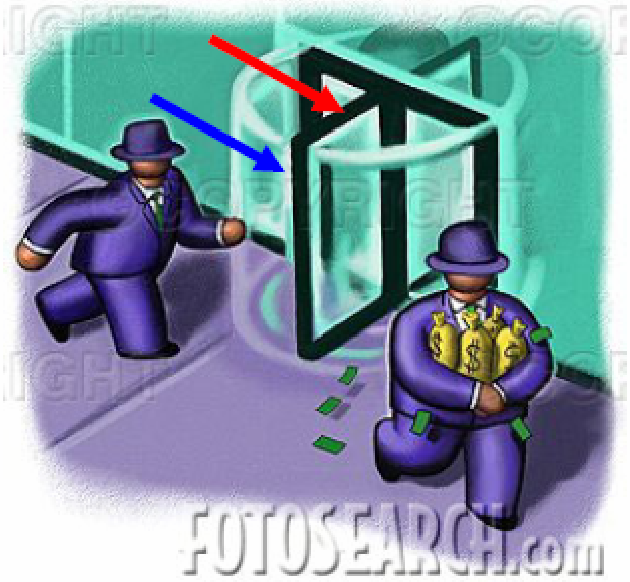
*For the same Torque T: a small r* → *Large Cutting Force F*

## Prying off a nail with a hammer




Required Torque = $F_{hand} \times r_{hand}$

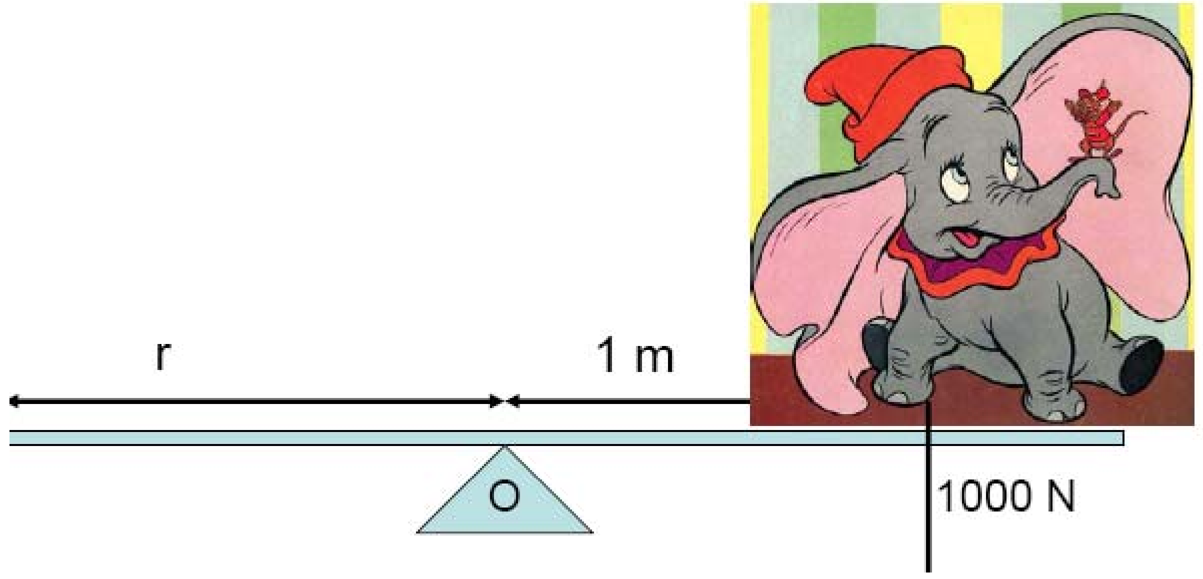
**Pushing a revolving door or turnstile**



Why are the door handles at the rim of doors ?

# The Lone Rider's Descent

- Rider's weight produces a torque on the seesaw
- Seesaw undergoes angular acceleration
- Seesaw's angular velocity increases rapidly
- Rider's side of seesaw soon hits the ground

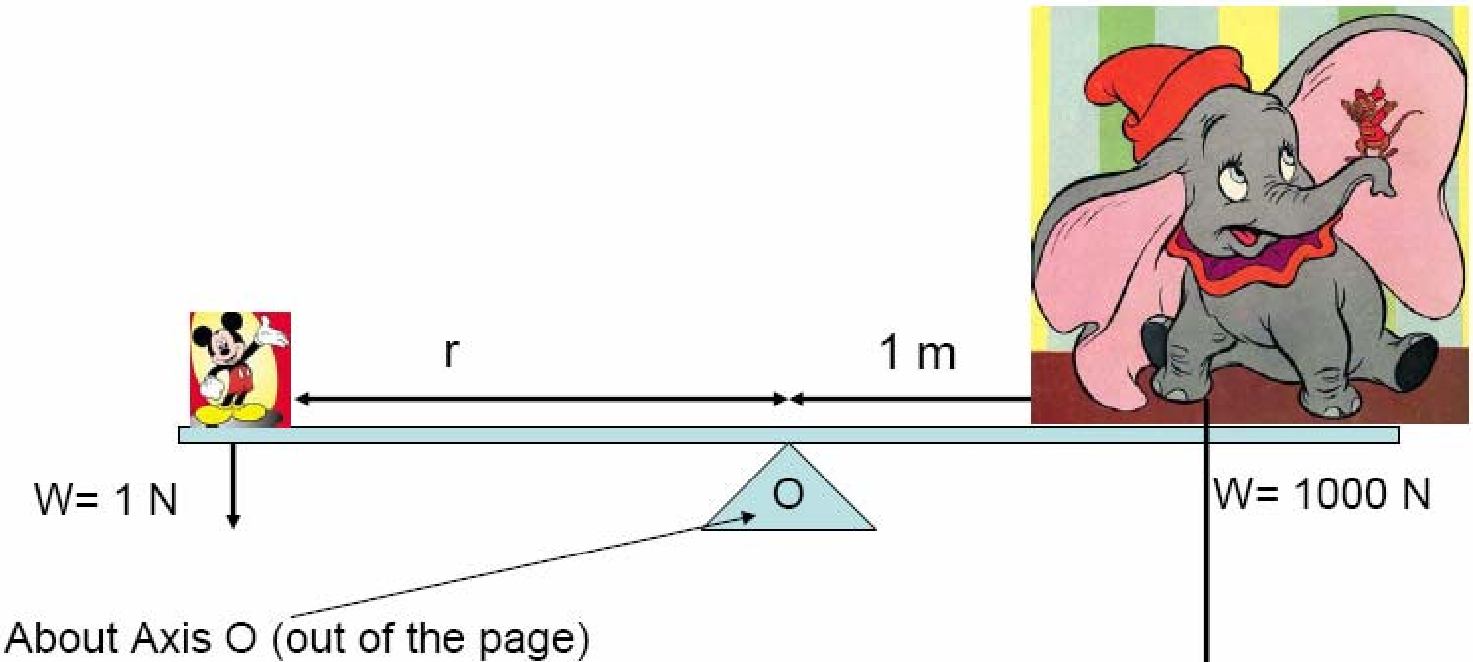


# Question 4

- Why do the riders' weights and positions matter?

# Net Torque

- The net torque on the seesaw is
  - the sum of all torques on that seesaw
  - responsible for the seesaw's angular acceleration



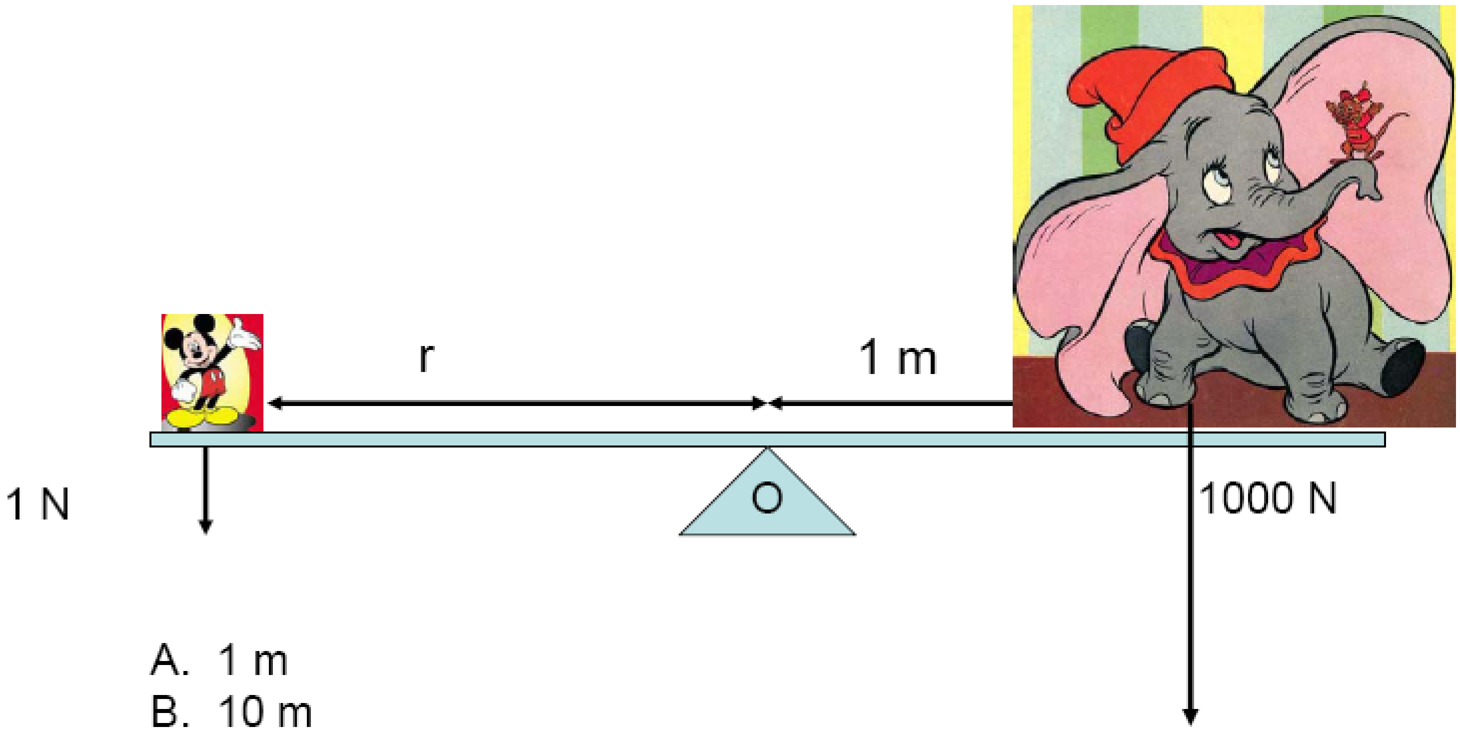

Dumbo's weight : a torque T tending to rotate seasaw ***clockwise***. T = (1m)(1000N)

Mickey's weight : a torque T tending to rotate seasaw ***counter-clockwise***.

T = r (1 N)

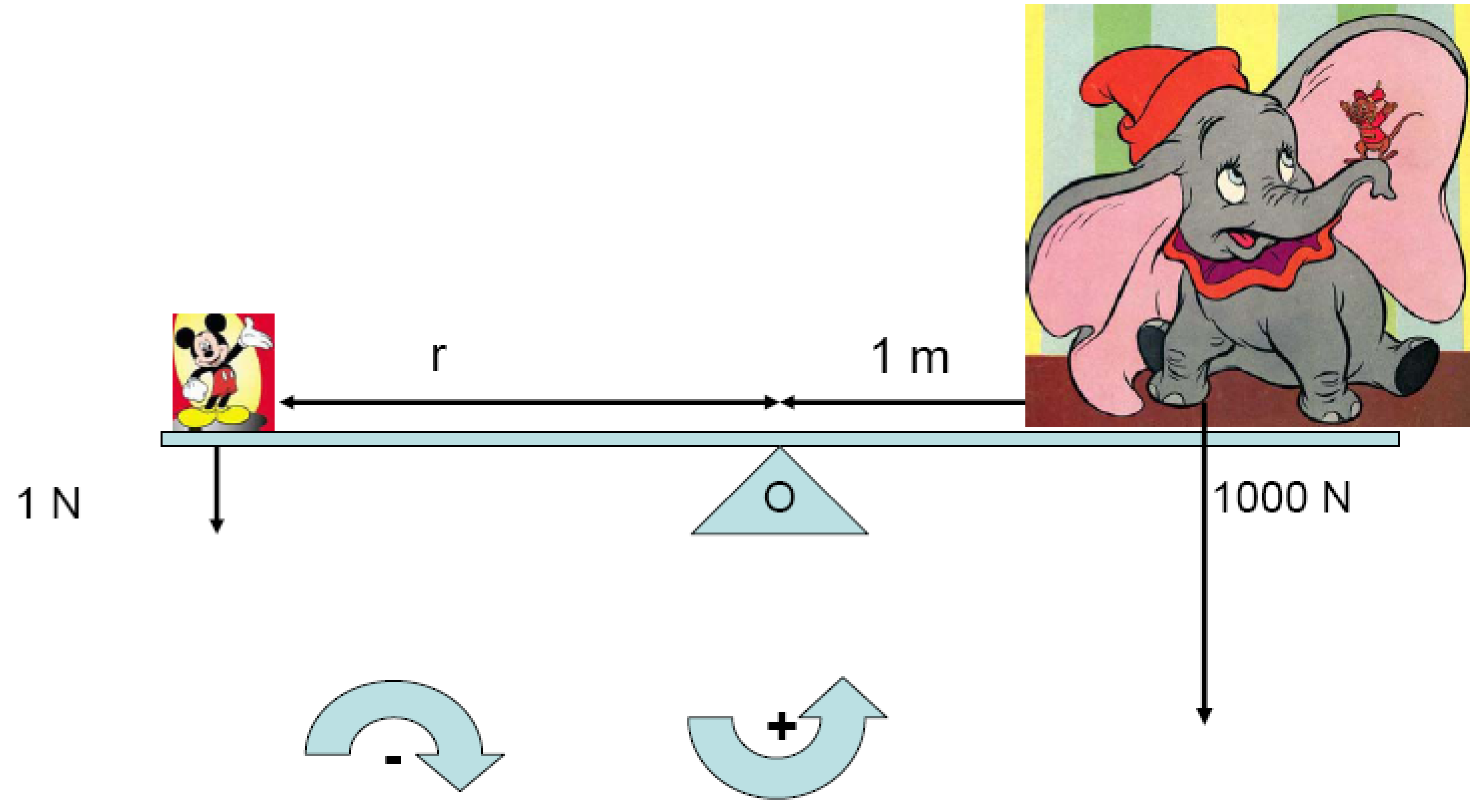

$\sum \text{Torques}_O = -\,1000\ \text{N-m} \quad + \quad (1\text{N})\ (r) = 0$ (if in equilibrium)

## How long should the seasaw be for Mickey to balance Dumbo ?




A. 1 m
B. 10 m
C. 100 m
D. 1000 m

Answer: D. 1000 m




$\sum \text{Torques}_O = -\,1000\ \text{N-m} \quad + \quad (1\text{N})\,(r) = 0$ (at equilibrium)

$r = 1000\ \text{m}$

# Balancing the Riders

- Each rider exerts a torque
  - Left rider produces ccw torque (weight · lever arm)
  - Right rider produces cw torque (weight · lever arm)
- If those torques sum to zero, seesaw is balanced

# Question 5

- Why does distance from the pivot affect speed?
- How does lever arm affect torque?
- How does lever arm affect rotational mass?

# Mass and Rotational Mass

- Rider's part of rotational mass is proportional to
  - the rider's mass
  - the square of rider's lever arm
  - $I \sim m \cdot r^2$ [$kg \cdot m^2$ ]
- Moving away from pivot dramatically increases the seesaw's overall rotational mass!

# Seesaw and Rider-Distance

- When riders move away from pivot,
  - the torque increases in proportion to lever arm
  - the rotational mass in proportion to lever arm$^2$
- Angular accelerations decrease!
- Motions are slower!

# Introductory Question (revisited)

- You and a child half your height lean out over the edge of a pool at the same angle. If you both let go simultaneously, who will tip over faster and hit the water first?

A. You

B. The small child

# Summary about Seesaws

- A balanced seesaw
  - experiences zero net torque
  - moves at constant angular velocity
  - requires all the individual torques to cancel
- Force and lever arm both contribute to torque
  - Heavier children produce more torque
  - Sitting close to the pivot reduces torque

# Angular Momentum

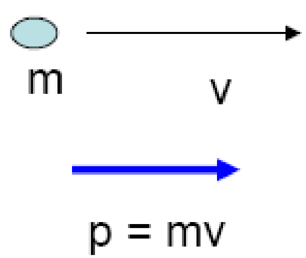
If the external agent provides a torque, what kind of momentum will change ?

## Linear Case

Force $F = \Delta p / \Delta t$

Linear Momentum $p = mv$

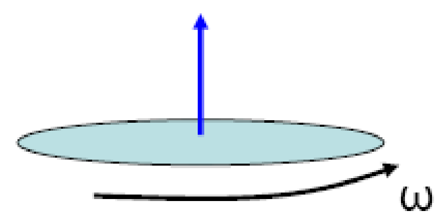
Picture




## Rotational Case

Torque $T = \Delta L / \Delta t$

Angular Momentum $L = I\omega$




$I$ = "moment of inertia"

# Conservation of the angular momentum

**When is Angular Momentum Conserved ?**

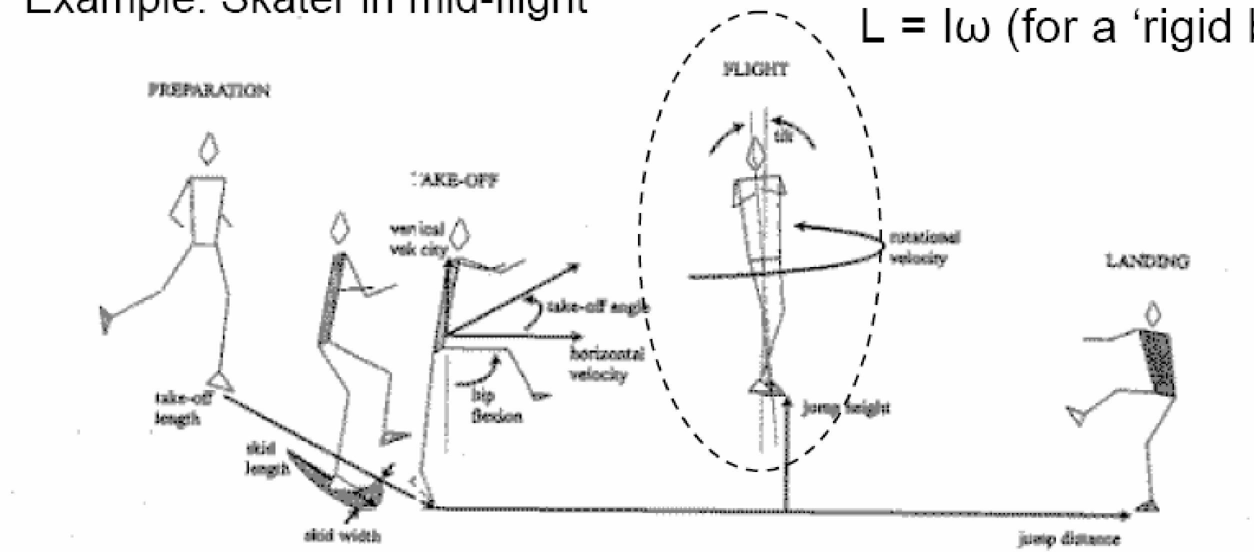
$$\sum \mathbf{T}_{ext} = \Delta \mathbf{L}/\Delta t$$

No or negligible net external torques
$\sum T_{ext} = 0$ ⇒ **0** = d**L**/dt

***L is conserved***

Example: Skater in mid-flight

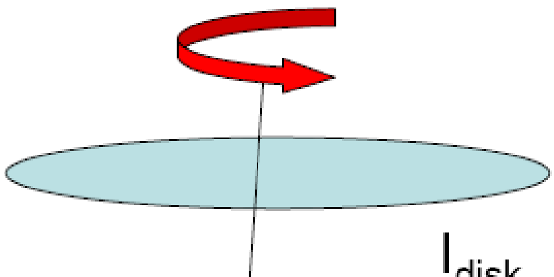
L = Iω (for a 'rigid body)

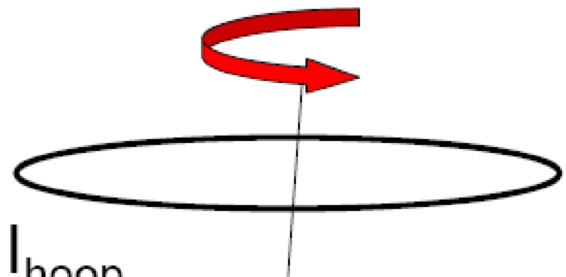


the further out the mass from the axis of rotation,

the larger the moment of inertia I (the measure of resistance

to a change in rotational motion





$I_{disk} < I_{hoop}$

$I_{skater,folded} < I_{skater,\ extended}$

# Can a change in Moment of Inertia result in faster spins ?

Arms extended vs Arms Withdrawn

$$L_i = L_f$$

$$I_i\omega_i = I_f\omega_f$$

Slow rotation        Fast Rotation

By drawing arms inwards, the spinning skater *reduces her moment of inertia I*. If angular momentum L is conserved, This *results in a larger ω*, thus resulting in a faster spin.

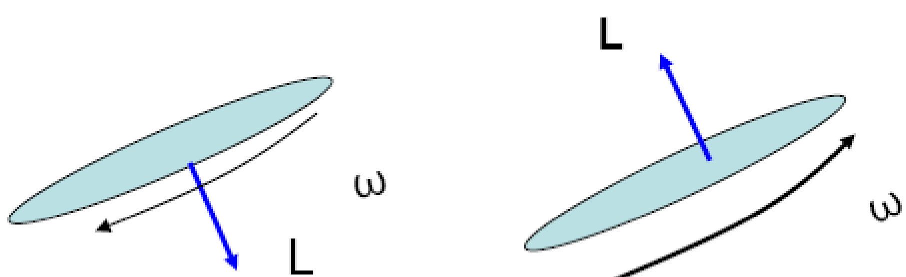
The FRISBEE - illustrates stability due to large **angular momentum L** = Iω

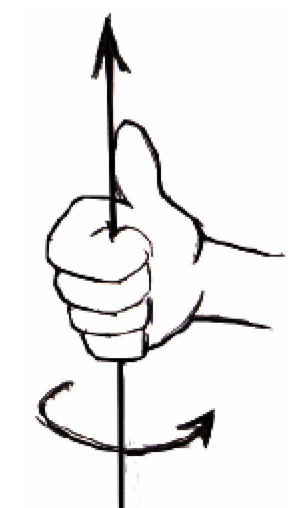
I = "moment of inertia"
*(how mass is distributed)*

ω = angular speed
*(how fast it is rotating)*


How do we get the direction of L ?

Use the "right-hand rule" (Curl fingers along
The sense of rotation and the thumb's direction
gives L's direction.



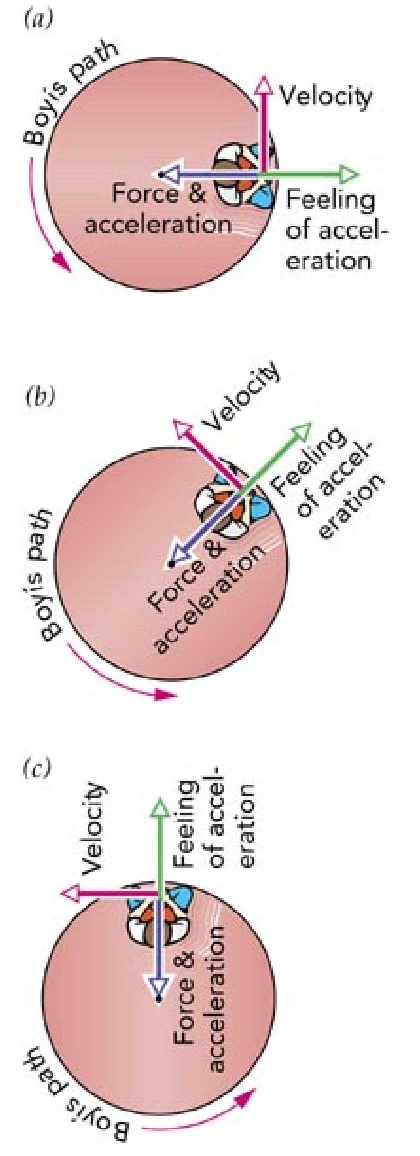



# Carousels and Roller Coasters

# Introductory Question

- You are a passenger in a car that is turning left and you find yourself thrown against the door to your right. Is there a force pushing you toward the door?

A. Yes
B. No



# Observations about Carousels and Roller Coasters

- You can feel your motion with your eyes closed
- You feel pulled in unusual directions
- You sometimes feel weightless
- You can become inverted without feeling it

# 5 Questions about Carousels and Roller Coasters

- What aspects of motion do you feel?
- Why do you feel flung outward on a carousel?
- Why do you feel light on a roller coaster's dives?
- Why do you feel heavy on a roller coaster's dips?
- How do you stay in seated on a loop-the-loop?

# Question 1

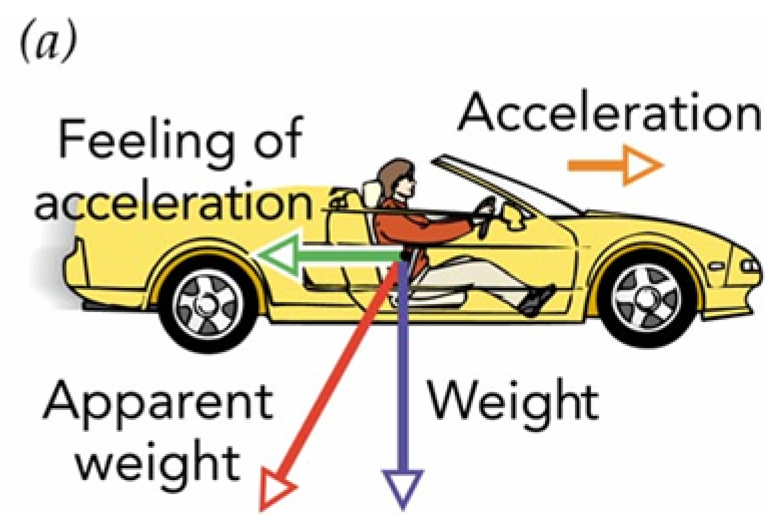
- What aspects of motion do you feel?
  - Can you feel position?
  - Can you feel velocity?
  - Can you feel acceleration?

# The Feeling of Weight

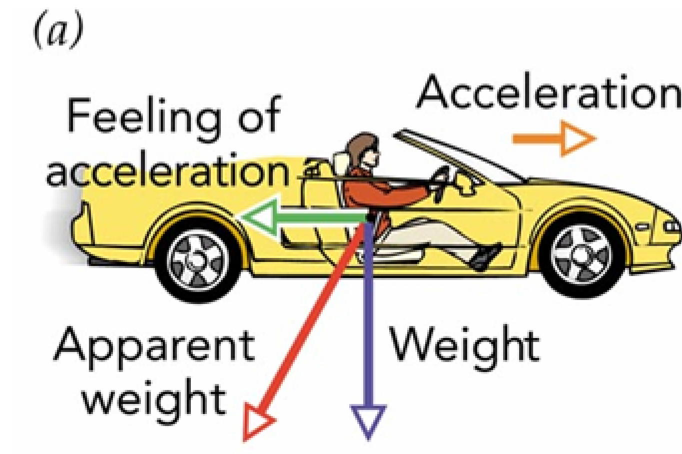
- When you are at equilibrium,
  - a support force balances your weight
  - and that support force acts on your lower surface,
  - while your weight is spread throughout your body
- You feel internal supporting stresses
- You identify these stresses as weight

# The Feeling of Acceleration

- When you are accelerating,
  - a support force causes your acceleration
  - and that support force acts on your surface,
  - while your mass is spread throughout your body
- You feel internal supporting stresses
- You misidentify these stresses as weight



# Acceleration and Weight




- This "feeling of acceleration" is
  - not a real force
  - just a feeling caused by your body's inertia
  - directed opposite your acceleration
  - proportional to that acceleration
- You feel an overall "apparent weight"
  - feeling of real weight plus "feeling of acceleration"