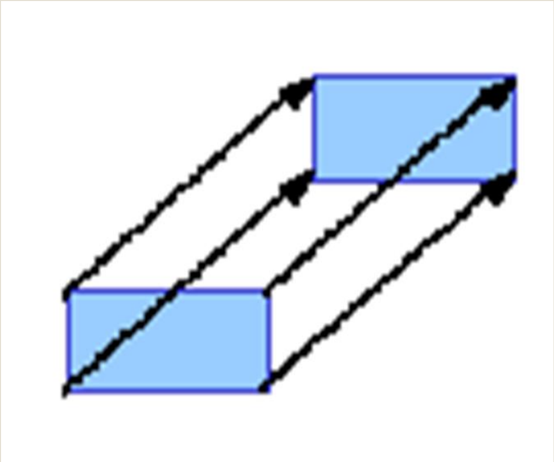
BIOMECHANICS LECTURE-1

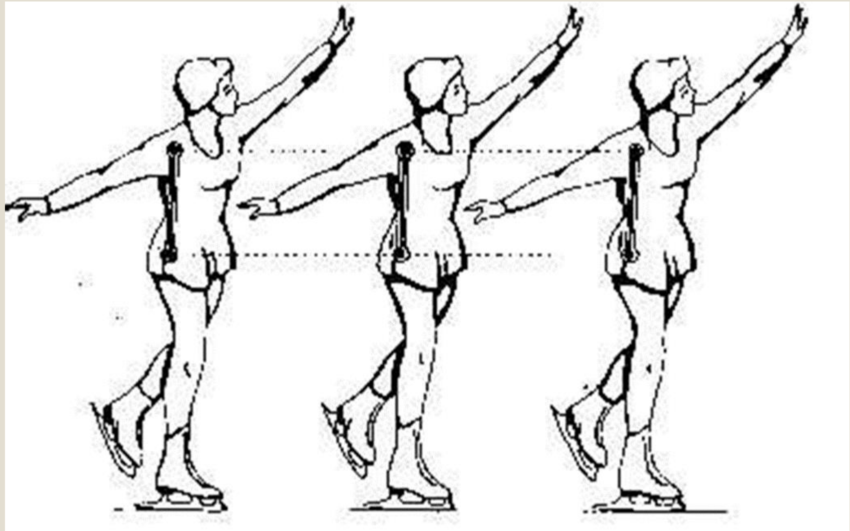
MOTION

Linear motion

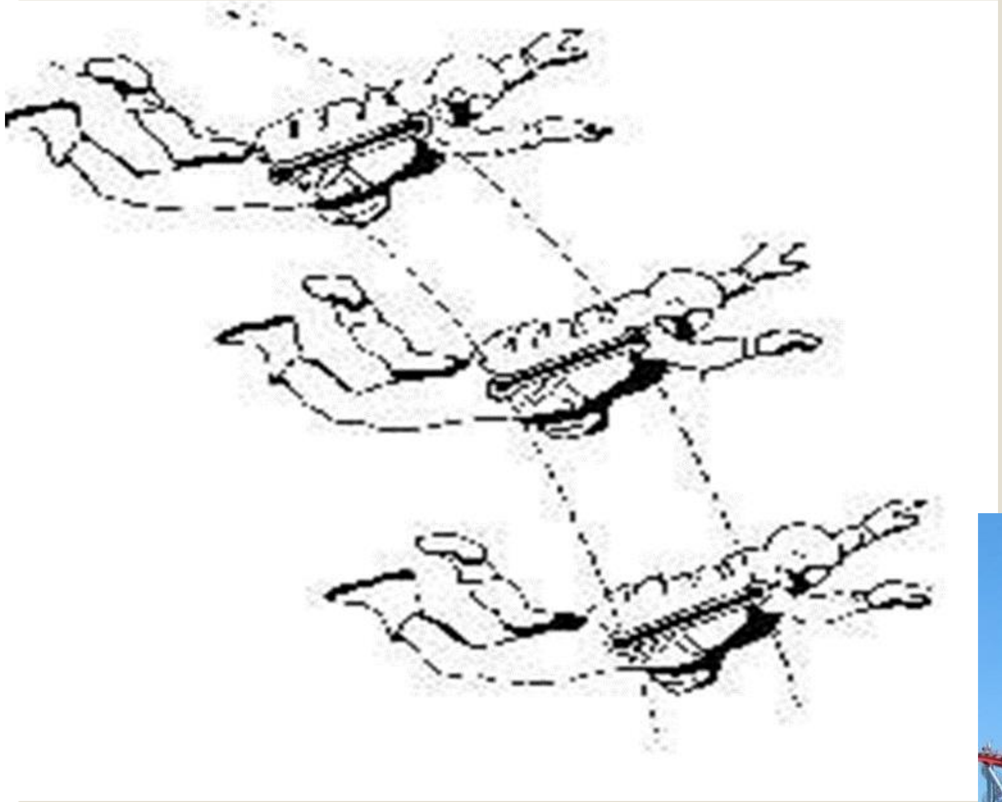
- Linear motion (Translation): motion in which a straight line drawn between 2 or more points on the body maintain the same speed and direction during the movement. All points along the line will move along the parallel paths

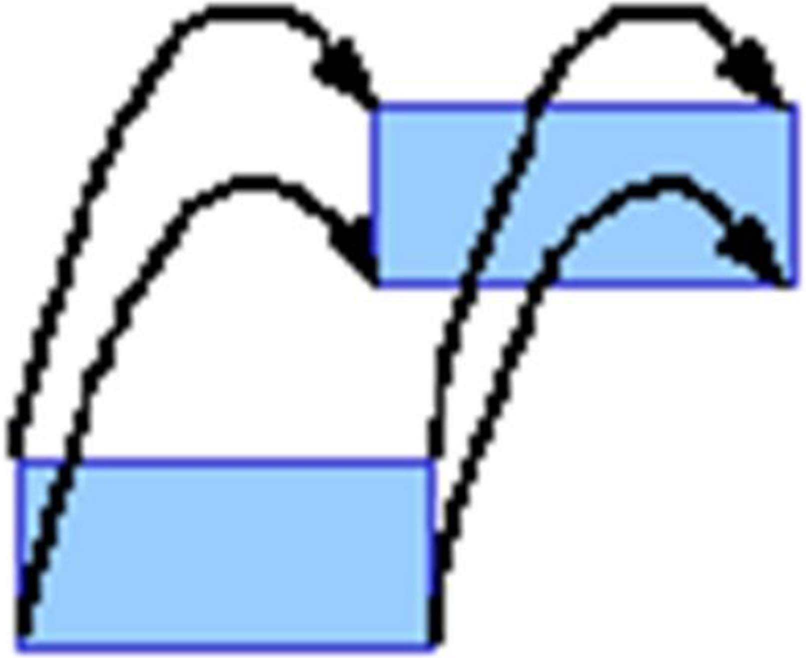
Straight paths ➡ rectilinear motion



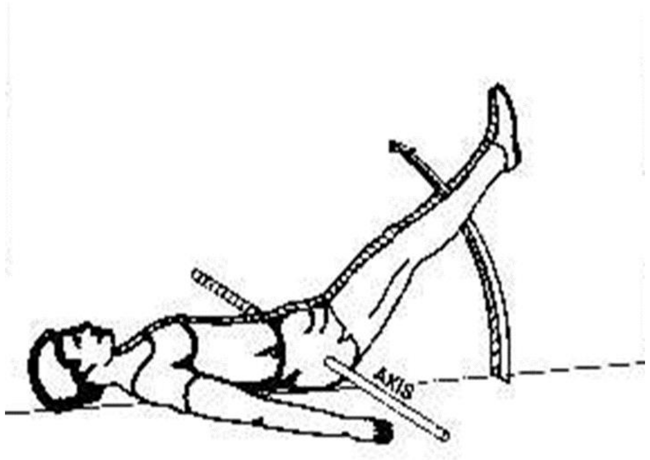


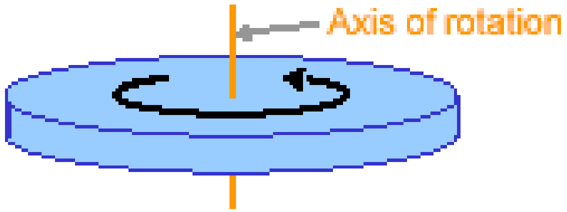
Curved paths → curvilinear motion



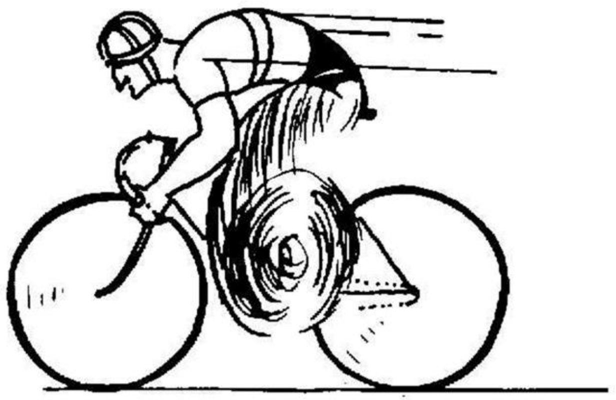


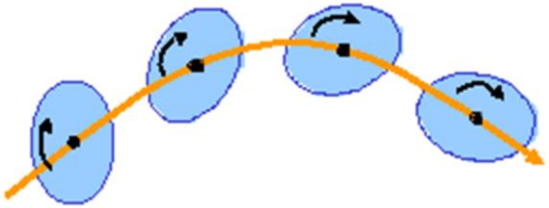
Angular motion (Rotation)





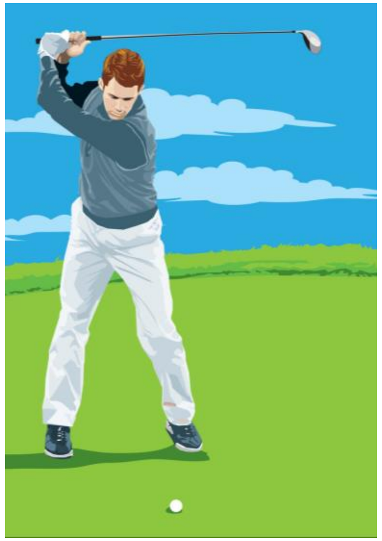
- rotation around a fixed axis has all points on a rigid segment moving in parallel planes along circular paths about the axis. Moved around a fixed point or axis.



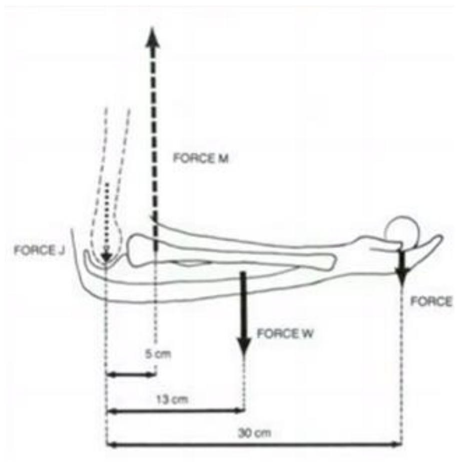


GENERAL MOTION- COMBINATION OF LINEAR MOTION + ANGULAR MOTION


Angle of Release




GETTY IMAGES


FORCE M
FORCE J
FORCE
FORCE W
5 cm
13 cm
30 cm


3:55, 3:56, 3:57,...
192 bpm
6.8 m/s

FORCE

Force

- \- a push or pull that that alters or tends to alter the state of motion of a body. If the body changes its direction or speed then a force has been applied

"A force is that which alters or tends to alter a body's state of rest or of uniform motion in a straight line."

Force

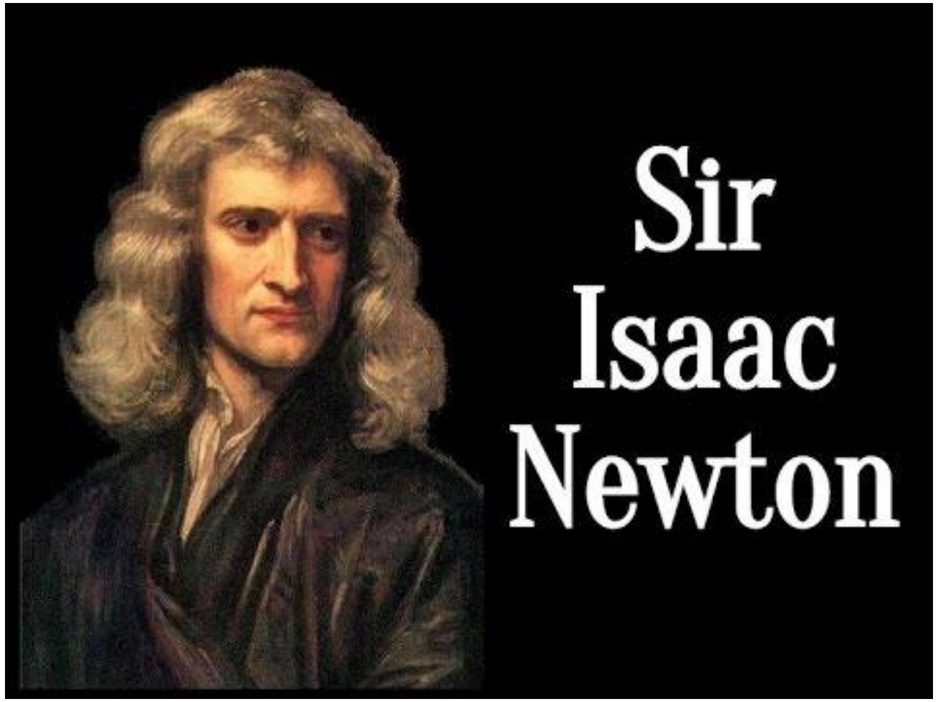
- Can cause a body at rest to move
- Cause a moving body to change direction, accelerate or deaccelerate
- Change a body shape

- Look at this example and see where you can work out the F force, and what effect it has.

- Two factors that will significantly affect the outcome of the force being applied on the body or objects?
- Size of the force
- Direction of the force

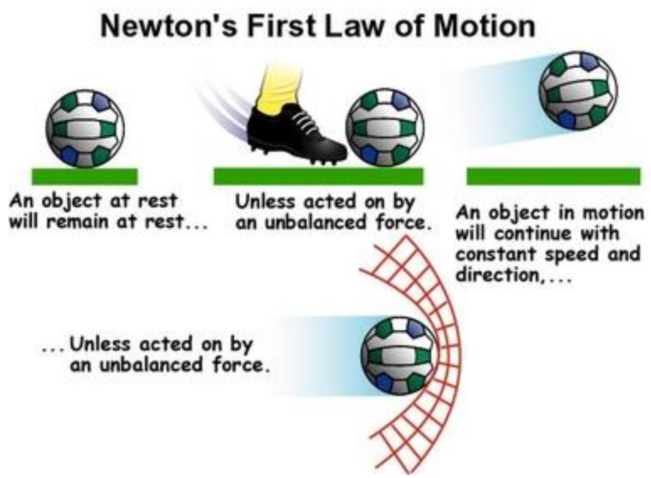
The link between Force and Motion?

- Without forces being applied, there will be no change in motion.
- Whether still of moving



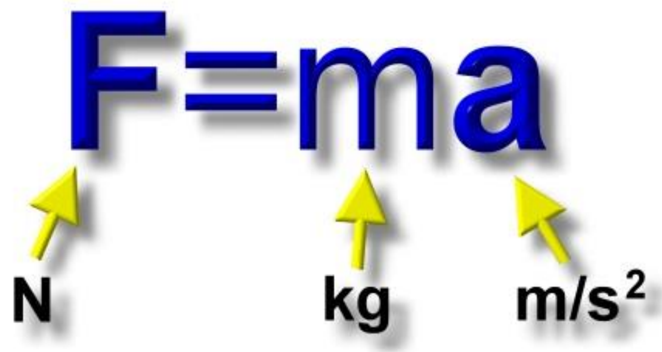
Laws of motion

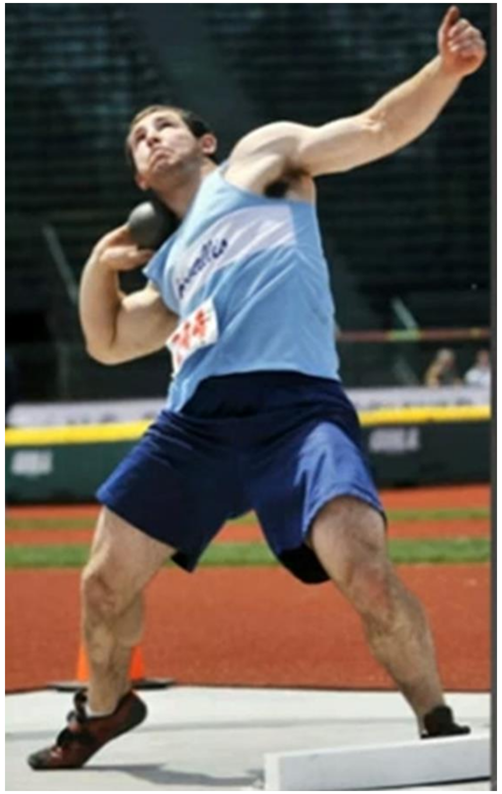
- Three laws of motion
  - Law of inertia
  - Law of Acceleration
  - Law of action and reaction



Law of Inertia

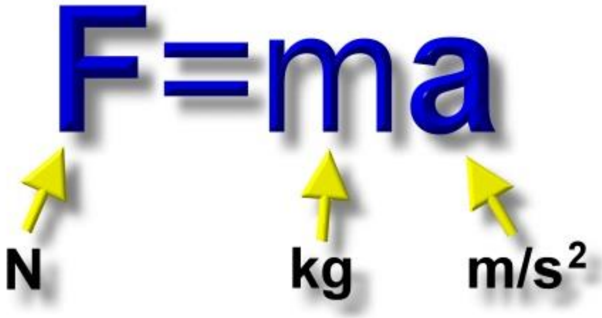
- Newton's First Law states that an object will remain at rest or in uniform motion in a straight line unless acted upon by an external force. It may be seen as a statement about inertia, that objects will remain in their state of motion unless a force acts to change the motion



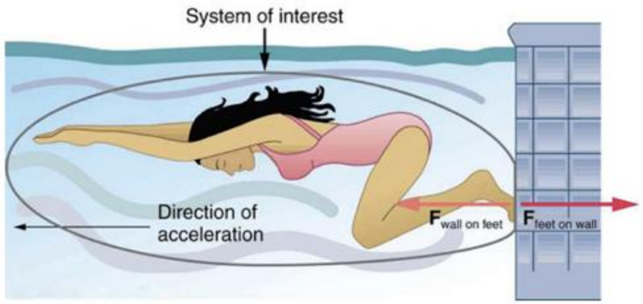


Newton's second law of motion

- The second law states that the acceleration of an object is dependent upon two variables - the net force acting upon the object and the mass of the object.
- The acceleration of an object depends directly upon the net force acting upon the object, and inversely upon the mass of the object.
- As the force acting upon an object is increased, the acceleration of the object is increased. As the mass of an object is increased, the acceleration of the object is decreased.



- Greater the mass of an object, greater the force required to give the same amount of acceleration and also the greater the force applied the greater the acceleration.

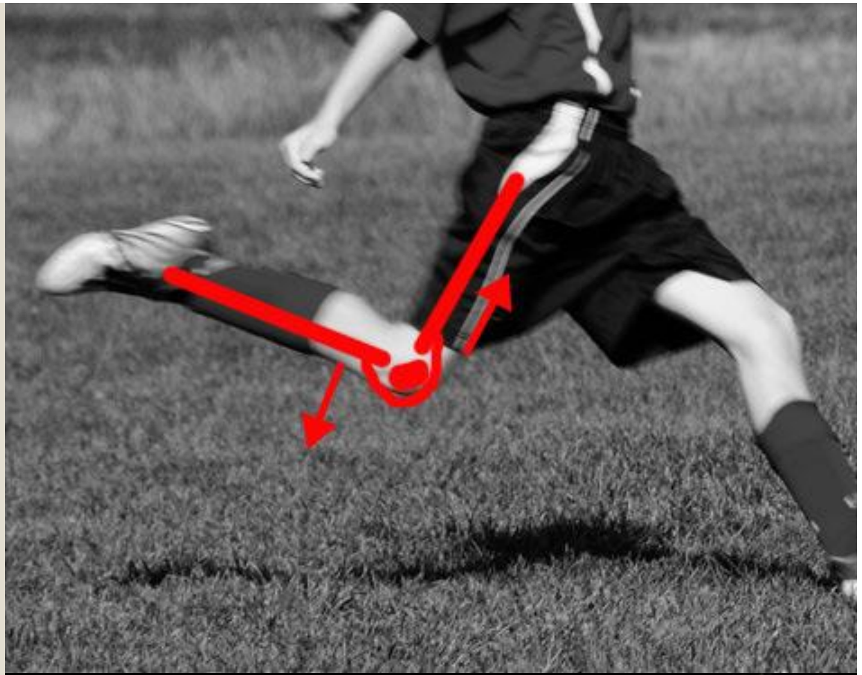


Law of action and reaction

- The third law states that all forces between two objects exist in equal magnitude and opposite direction: if one object A exerts a force FA on a second object B, then B simultaneously exerts a force FB on A, and the two forces are equal in magnitude and opposite in direction: FA = −FB.

Types of machines found in the body

- A machine is a device which enables work to be done more easily and or more quickly by applying forces.
- Musculoskeletal system arrangement provides for 3 types of machines in producing movement
  - – Levers (most common)
  - – Wheel-axles
  - – Pulleys
- Machine types not found in the body
  - – Inclined plane
  - – Screw
  - – Wedge



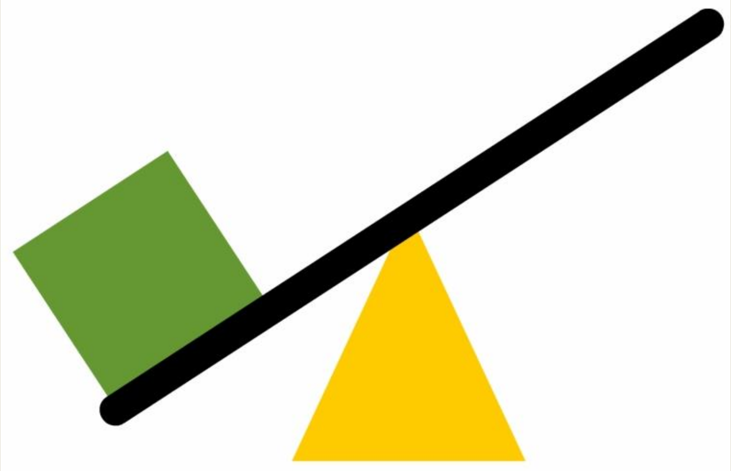
Types of machines found in the body

- Machines function in four ways
  - –balance multiple forces
  - – enhance force in an attempt to reduce total force needed to overcome a resistance
  - – enhance range of motion & speed of movement so that resistance may be moved further or faster than applied force
  - – alter resulting direction of the applied force

Levers

It is a **rigid bar** or mass which rotate around a **fulcrum** on an axis perpendicular to the **plane of motion.** The rotation is caused by a **force** applied to this bar. If the force is used to **overcome a resistance** it is called **effort**, and all parts of the lever between the axis & the point of application of this force is called the **effort arm**

- In anatomical lever, the rigid bar is the bone (it does not necessarily resemble bars), the fulcrum is the joint axis, the effort is applied by the muscle & its point of application is at the insertion of the muscle.
- The resistance is the gravitational force alone or plus any outside force & its point of application is at the COG of the segment or the combined COG of both masses.
- In the anatomic levers with few exceptions, the effort arm is shorter than the resistance arm, so it tends to favor speed & range in expense of effort.



Mechanical advantage (M.A.) of a lever :

- It is a measure of the efficiency of the lever in terms of stating the "output" of this machine relative to its "input" . It is the ratio between the effort applied to the lever & the resistance overcome by the lever. So,
- $$\text{M.A.} = \frac{E}{R}$$ or $$\text{Mechanical advantage} = \frac{\text{Length of force arm}}{\text{Length of resistance arm}}$$

Problem 1

- You are a passenger in a truck that gets stuck in mud. You and the driver use a tree branch as a lever to lift up the truck. You apply an effort force of 600 N to the branch. The back of the truck weighs 2400 N. What is the mechanical advantage of the branch-lever?

Problem 2

- Suppose that you are riding a bicycle. You exert an effort force of 697 N downward as you push on the pedals. The resulting load force that causes the bicycle to move forward is 93 N. What is the mechanical advantage of the bicycle?

Problem 3

- Two people use a ramp to move a heavy box onto a truck. The box weighs 750 N. The mechanical advantage of using the ramp is 4. How much effort is required to move the box?

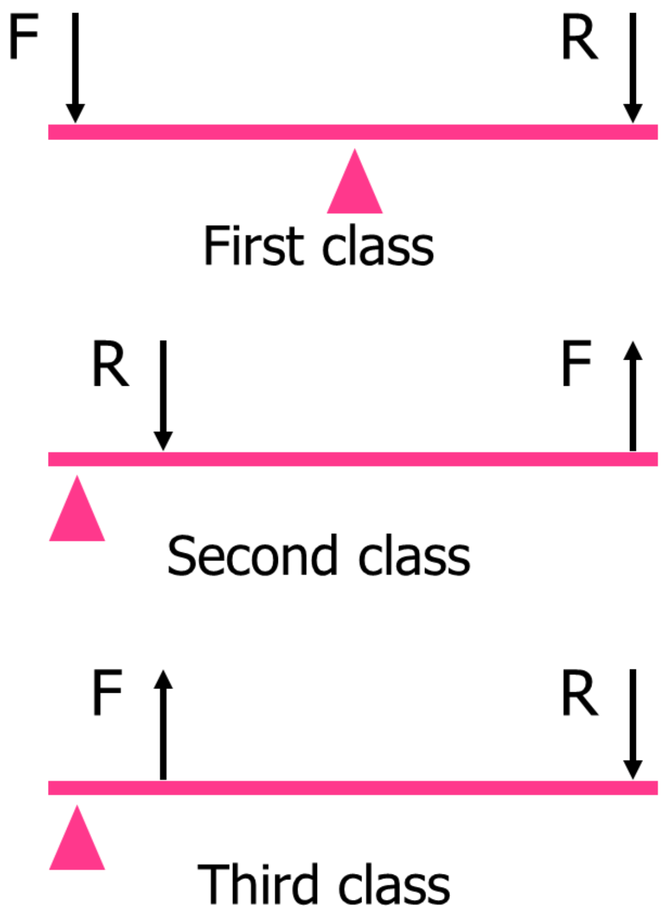
Problem 4

- A pulley is used to raise a bucket that weighs 60 N. How much effort is required if the mechanical advantage is 1?

LEVERS

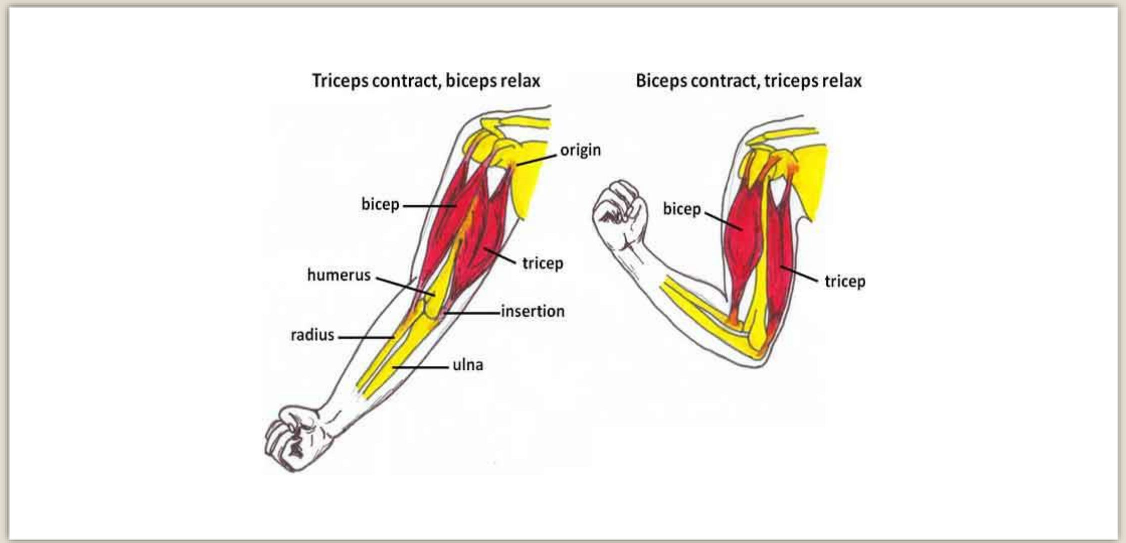
Types of Levers

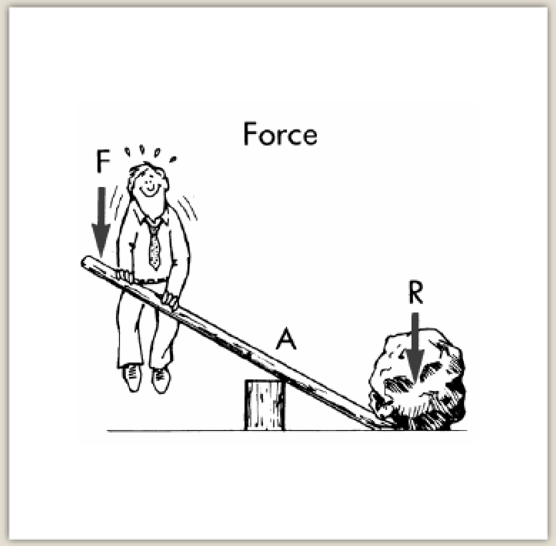
- Three points determine type of lever & for which kind of motion it is best suited
- – Axis *(A)*- fulcrum - the point of rotation
- – Point *(F)* of force application (usually muscle insertion) - effort
- – Point *(R)* of resistance application (centre of gravity of lever) or (location of an external resistance)
- 1st class lever – axis *(A)* between force *(F)* & resistance *(R)*
- 2nd class lever – resistance *(R)* between axis *(A)* & force *(F)*
- 3rd class lever – force *(F)* between axis *(A)* & resistance *(R)*

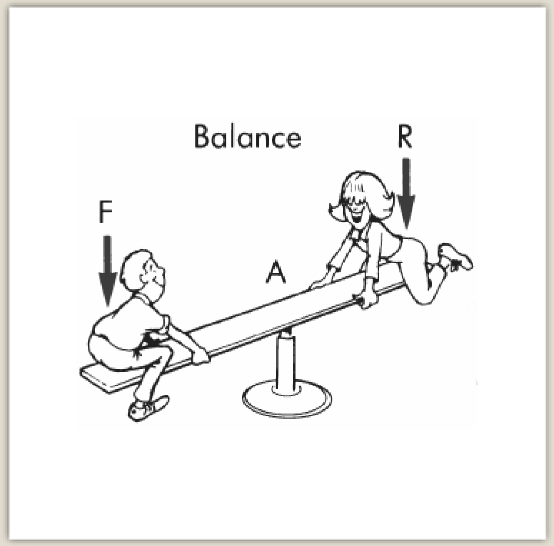


Class 1 levers

- In this arrangement, the fulcrum is located between the effort and the resistance.
- Depending upon the relative distance of the effort and resistance arms, it may take a small effort to lift a large resistance or the effort may act at a small distance to move the resistance a greater distance.
- Its mechanical advantage **can be either greater or less than one.**
- The direction of the effort and resistance is always opposite to each other e.g. the triceps muscle when extending the elbow against gravity

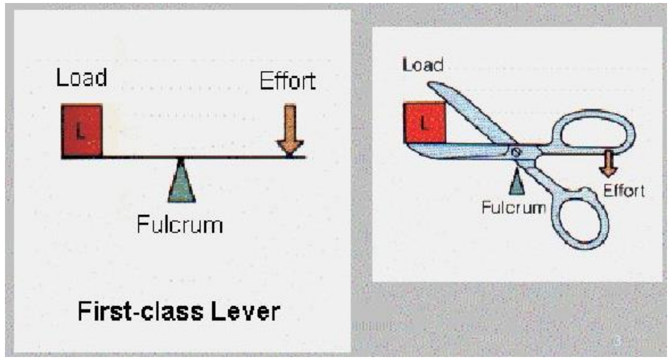


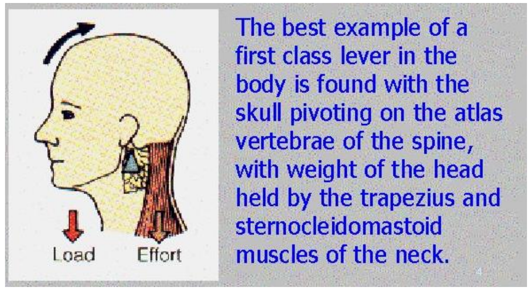


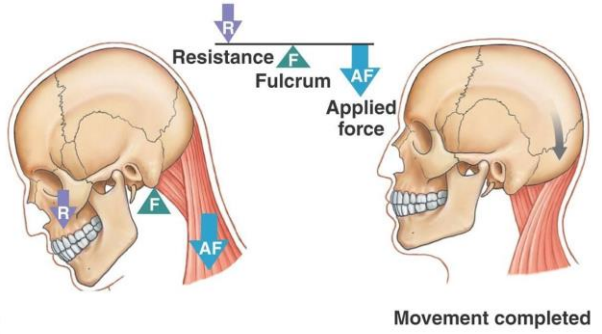


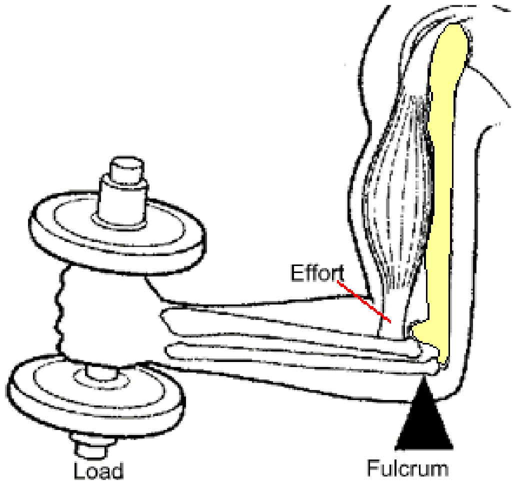
Advantages

- Produce balanced movements when axis is midway between force & resistance
- Produce speed & range of motion when axis is close to force,
- Produce force motion when axis is close to resistance



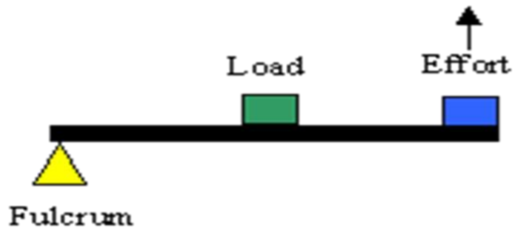


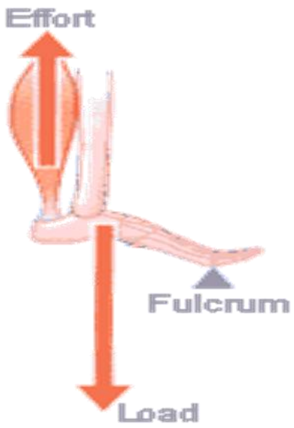




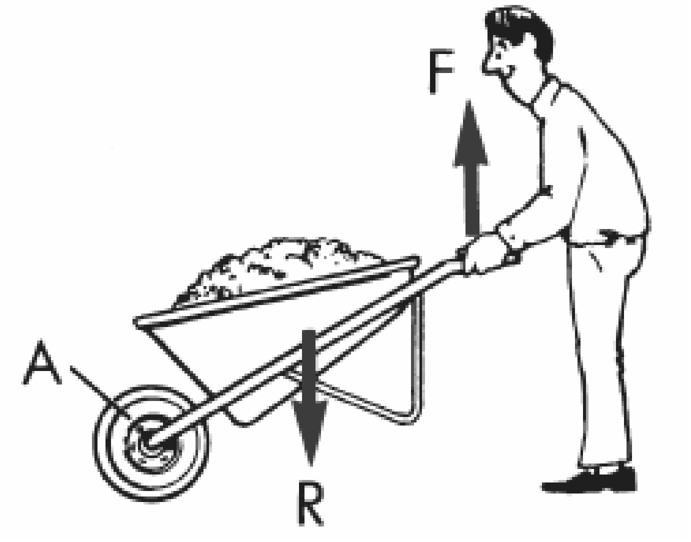
CLASS 1 LEVERS

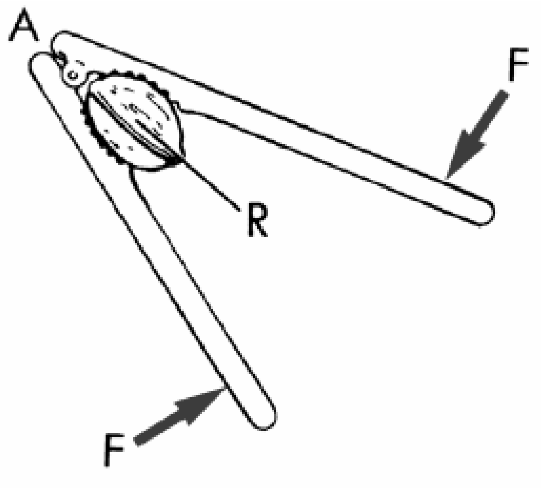
Class 2 Levers





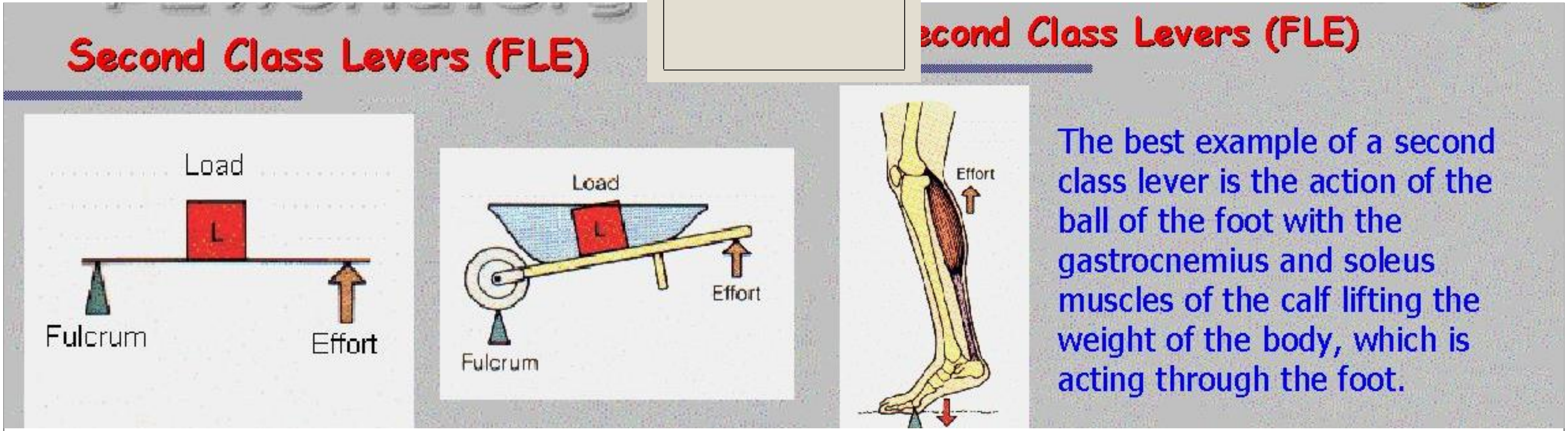
- In this arrangement the resistance is located between the effort and the fulcrum.
- Its mechanical advantage is **<u>always greater than one</u>** because the effort arm is always greater than the resistance arm.
- The effort will be less than the resistance and will always move a greater distance than the resistance. The direction of movement of effort and resistance will be the same.
- It is doubtful that this class of lever may be found in the human body.
- Because of this arrangement, this class of levers magnifies force at the expense of range and speed.





Advantages

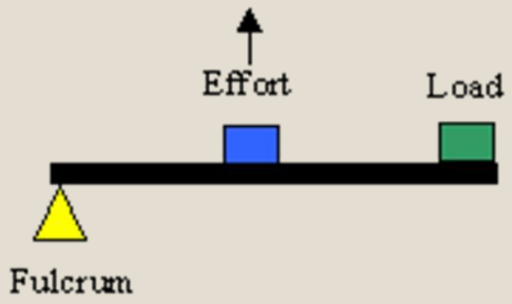
- Produces force movements, since a large resistance can be moved by a relatively small force
- Relatively few 2nd class levers in body

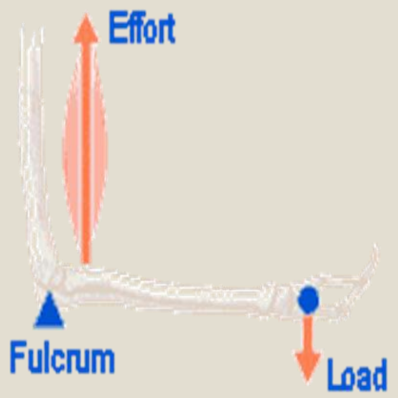


CLASS 2 LEVERS

Class 3 Levers

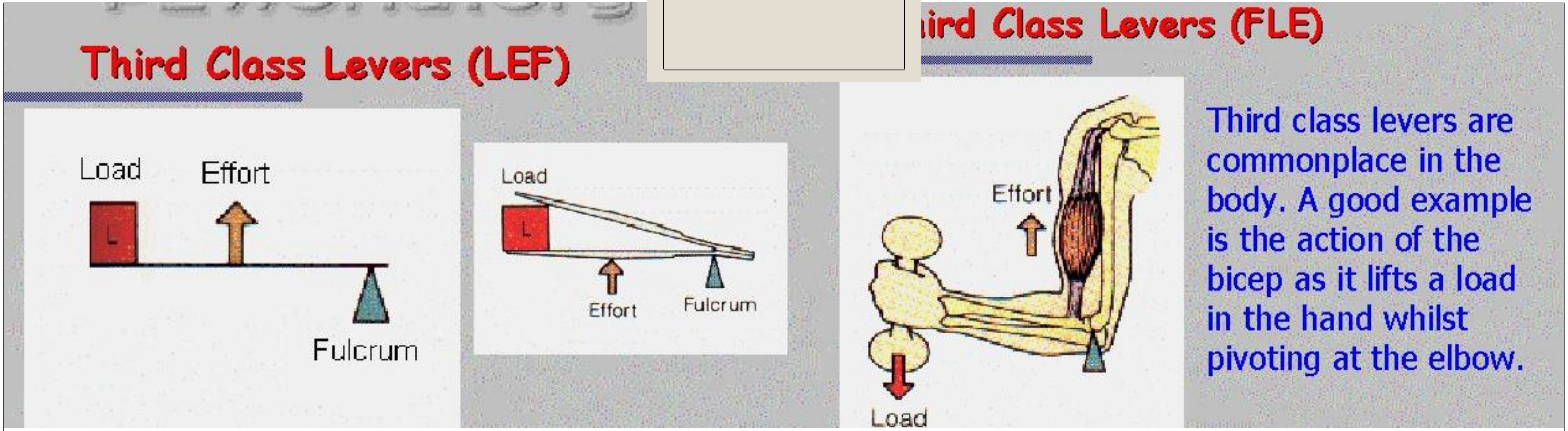
- In this arrangement, the effort is located between the fulcrum and the resistance.
- The effort arm is always less than the resistance arm.
- To support the resistance, the effort must be of greater magnitude than the resistance, but the effort moves less distance than the resistance.
- So, there is a loss of effort but a gain in distance and speed.
- The direction of movement of the effort and resistance will be the same.
- Anatomical example is the biceps muscle acting on a flexed forearm.
- In general most of the anatomic levers are of this class.



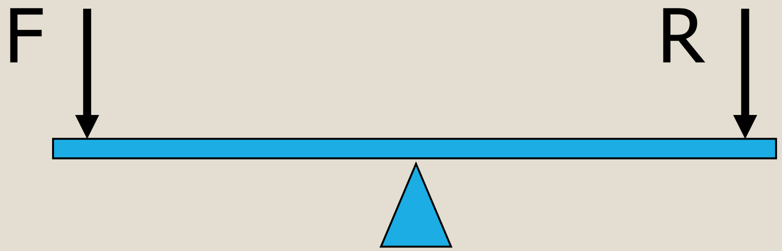


Advantages

- Produce speed & range-of-motion movements
- Most common in human body
- Requires a great deal of force to move even a small resistance

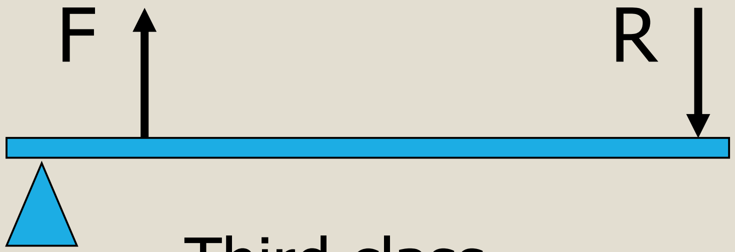


CLASS 3 LEVERS

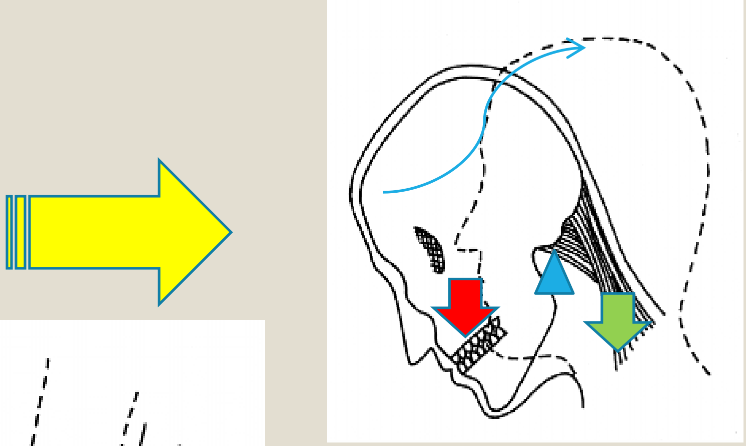


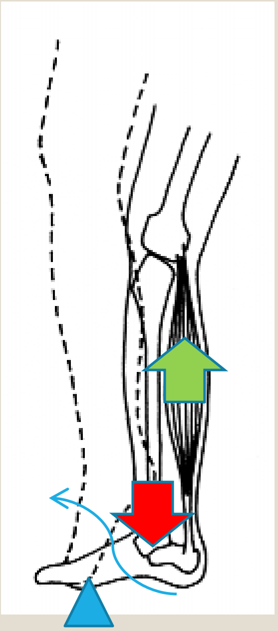
First class

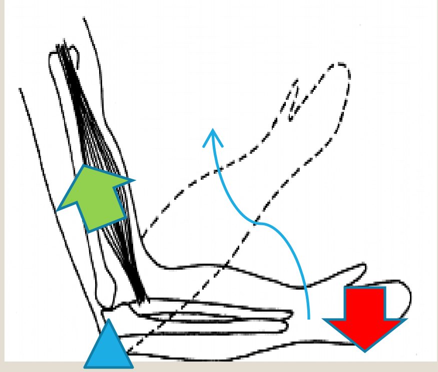
Second class



Third class



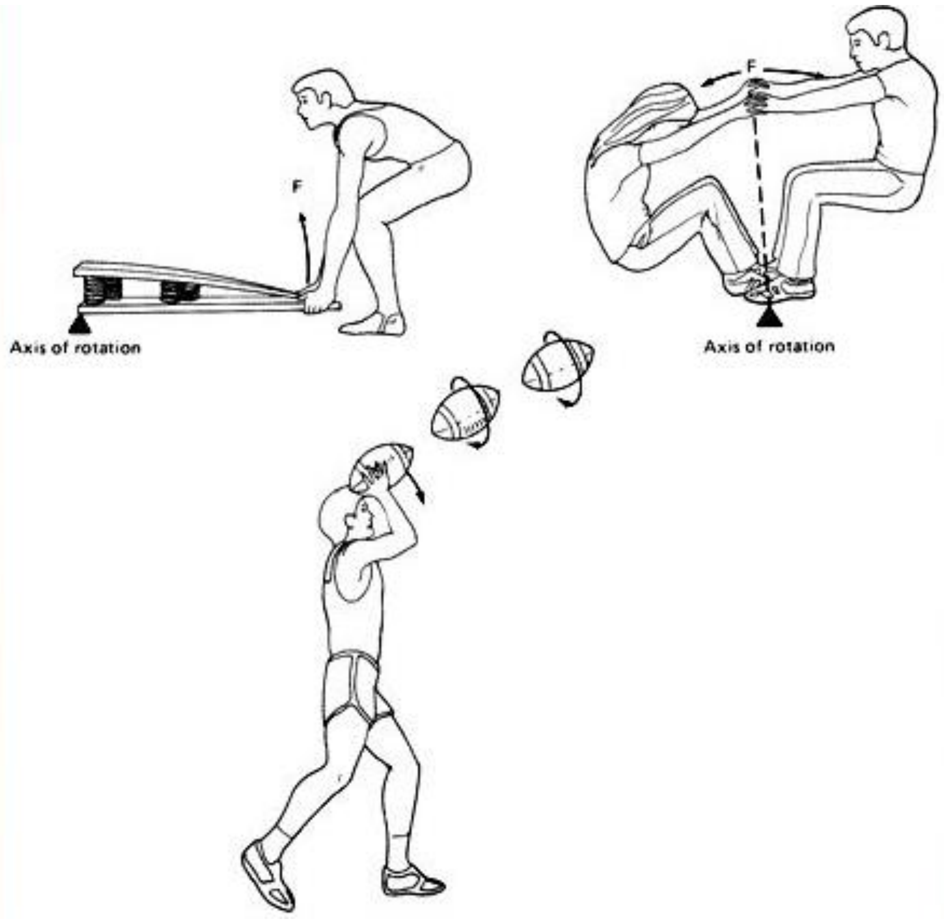




Fulcrum　Resistance　Effort

Factors in use of anatomical levers

- Anatomical leverage system can be used to gain a mechanical advantage
  - Improve simple or complex physical movements
  - Some habitually use human levers properly
  - Some develop habits of improperly using human levers



Torque and length of lever arms

- *Torque* – (moment of force) the turning effect of an eccentric force
- *Eccentric force* - force applied in a direction not in line with the center of rotation of an object with a fixed axis
- A **force** that does not pass through the centre of gravity of the body on which it acts or through a point at which the body is fixed. Such a **force** produces translation and rotation. Its rotatory effect is known as torque.
- In objects without a fixed axis it is an applied force that is not in line with object's center of gravity
- For rotation to occur an eccentric force smust be applied

Torque and length of lever arms

- In humans, contracting muscle applies an eccentric force (not to be confused with eccentric contraction) to bone upon which it attaches & causes the bone to rotate about an axis at the joint
- Amount of torque is determined by multiplying amount of force (*force magnitude*) by *force arm.*
- Force arm - perpendicular distance between location of force application & axis moment arm or torque arm
  - shortest distance from axis of rotation to the line of action of the force
  - the greater the distance of force arm, the more torque produced by the force.
- *Resistance arm* - distance between the axis and the point of resistance application

Torque and length of lever arms

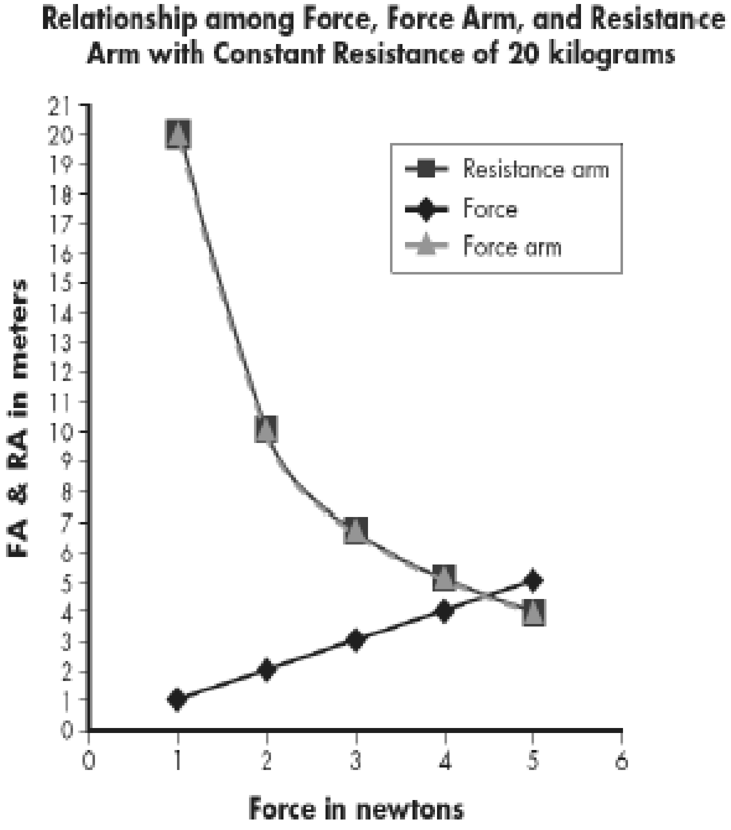
- Inverse relationship between length of the two lever arms
- – Between force & force arm
- – Between resistance & resistance arm
- – The longer the force arm, the less force required to move the lever if the resistance & resistance arm remain constant
- – Shortening the resistance arm allows a greater resistance to be moved if force & force arm remain constant

Torque and length of lever arms

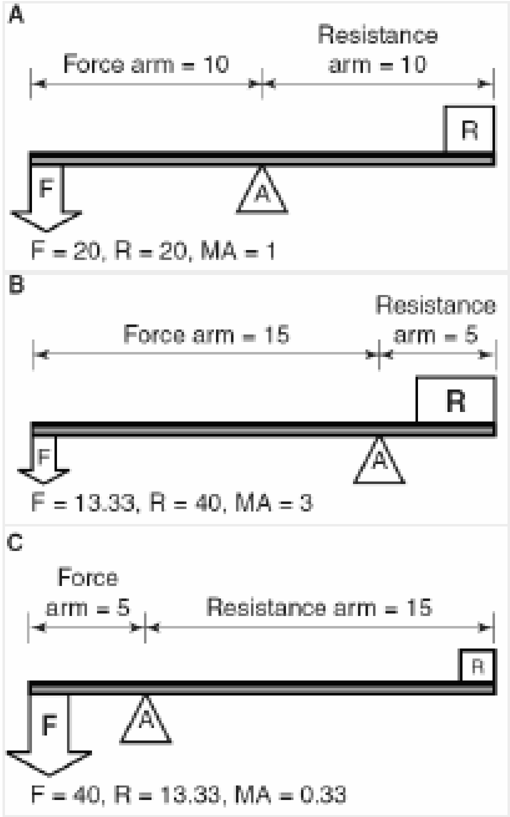
- Proportional relationship between force components & resistance components
- – If either of the resistance components increase, there must be an increase in one or both of force components
- – Greater resistance or resistance arm requires greater force or longer force arm
- – Greater force or force arm allows a greater amount of resistance to be moved

Torque and length of lever arms

- Even slight variations in the location of the force and resistance are important in determining the effective force of the muscle



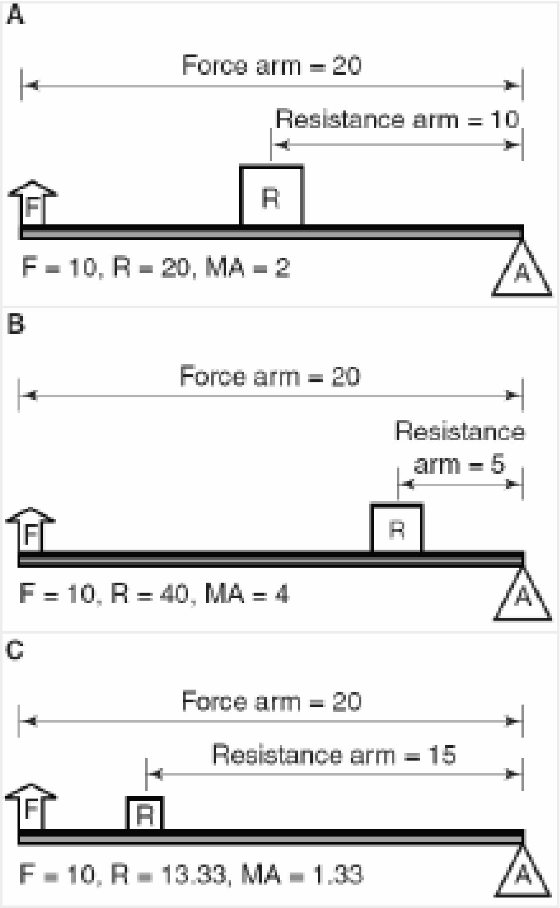
Torque and length of lever arms



First class levers

A, If the force arm & resistance arm are equal in length, a force equal to the resistance is required to balance it;
B, As the force arm becomes longer, a decreasing amount of force is required to move a relatively larger resistance;
C, As the force arm becomes shorter, an increasing amount of force is required to move a relatively smaller resistance

Torque and length of lever arms



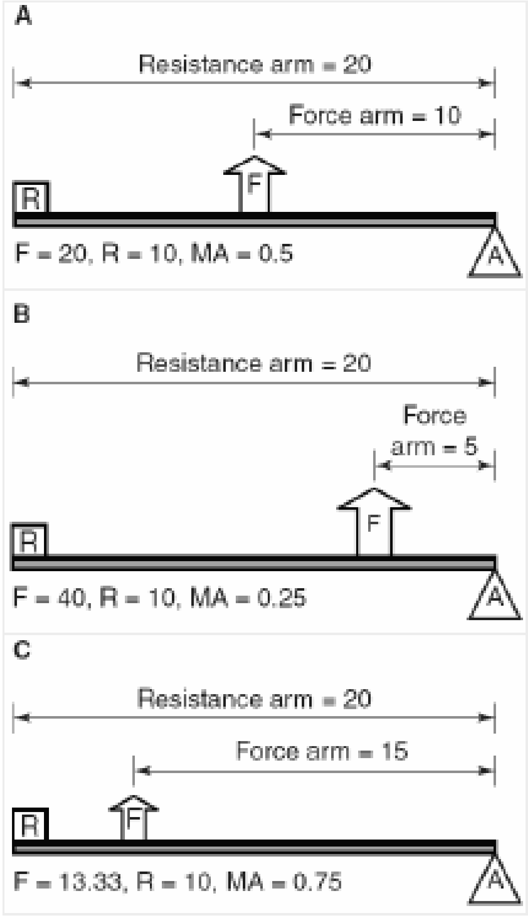
Second class levers

A, Placing the resistance halfway between the axis & the point of force application provides a MA of 2;

B, Moving the resistance closer to the axis increases the MA, but decreases the distance that the resistance is moved;

C, the closer the resistance is positioned to the point of force application the less of a MA, but the greater the distance it is moved

Torque and length of lever arms



Third class levers

A, a force greater than the resistance, regardless of the point of force application, is required due to the resistance arm always being longer;

B, Moving the point of force application closer to the axis increases the range of motion & speed;

C, Moving the point of force application closer to the resistance decreases the force needed

Torque and length of lever arms

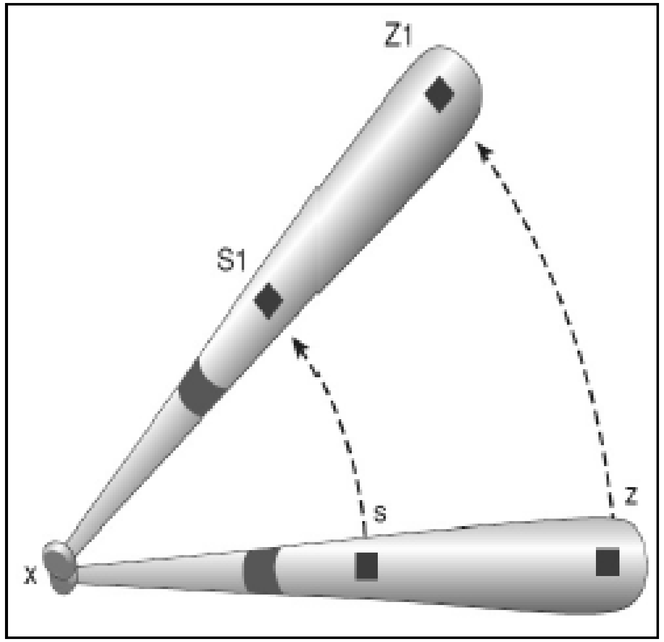
- Human leverage system is built for speed & range of movement at expense of force
- Short force arms & long resistance arms require great muscular strength to produce movement
- Ex. biceps & triceps attachments
  - biceps force arm is 1 to 2 inches
  - triceps force arm less than 1 inch

Torque and length of lever arms

- Human leverage for sport skills requires several levers
  - throwing a ball involves levers at shoulder, elbow & wrist joints
- The longer the lever, the more effective it is in imparting velocity
  - A tennis player can hit a tennis ball harder with a straight-arm drive than with a bent elbow because the lever (including the racket) is longer & moves at a faster speed

Torque and length of lever arms

- Long levers produce more linear force and thus better performance in some sports such as baseball, hockey, golf, field hockey, etc.

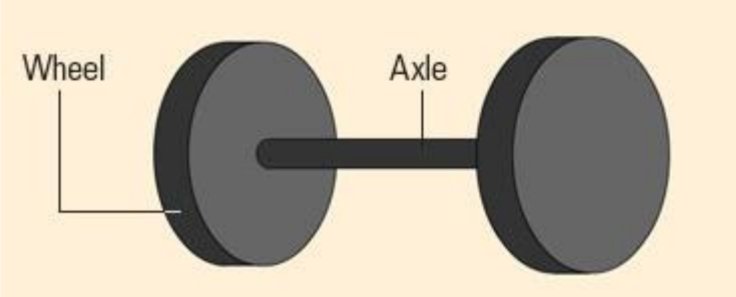


Torque and length of lever arms

- For quickness, it is desirable to have a short lever arm
  - baseball catcher brings his hand back to his ear to secure a quick throw
  - sprinter shortens his knee lever through flexion that he almost catches his spikes in his gluteal muscles

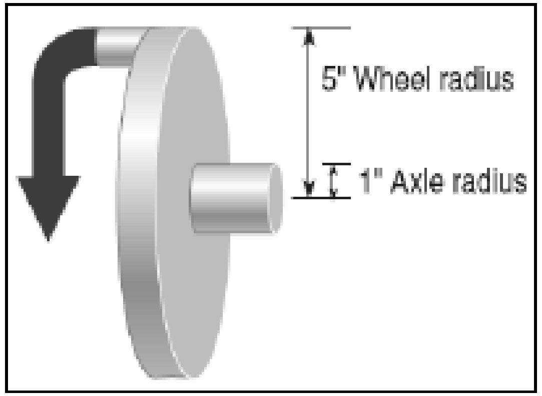
Wheels and axles

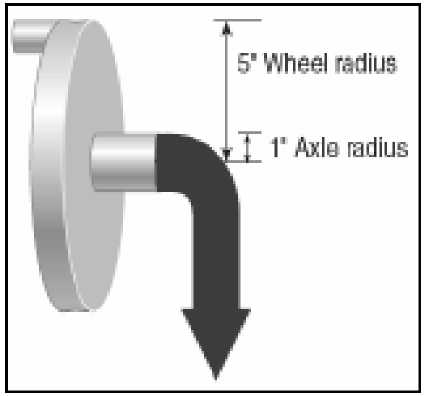
- Used primarily to enhance range of motion & speed of movement in the musculoskeletal system
  - function essentially as a form of a lever
- When either the wheel or axle turn, the other must turn as well
  - Both complete one turn at the same time

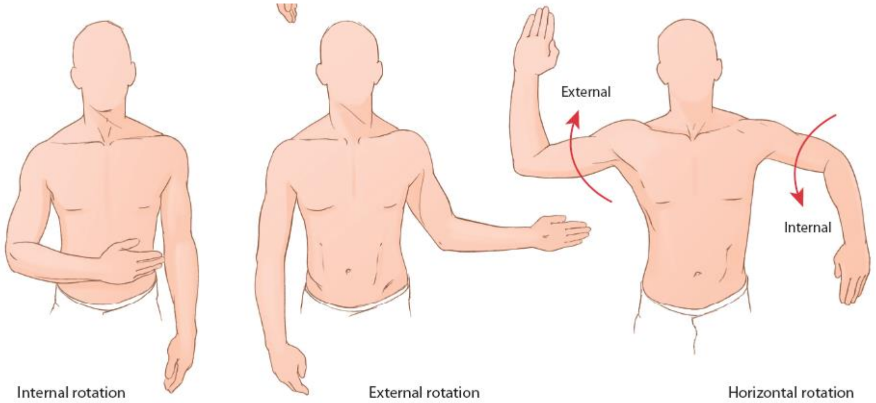


Wheels and axles

- Center of the wheel & the axle both correspond to the fulcrum
- Both the radius of the wheel & the radius of the axle correspond to the force arms







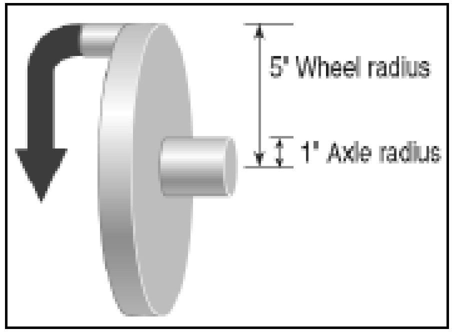
Wheels and axles

- If the wheel radius is greater than the radius of the axle, then, due to the longer force arm, the wheel has a mechanical advantage over the axle
  - a relatively smaller force may be applied to the wheel to move a relatively greater resistance applied to the axle
  - if the radius of the wheel is 5 times the radius of the axle, then the wheel has a 5 to 1 mechanical advantage over the axle

Wheels and axles

– calculate mechanical advantage of a wheel & axle by considering the radius of the wheel over the axle

$$\text{Mechanical advantage} = \frac{\text{radius of the wheel}}{\text{radius of the axle}}$$



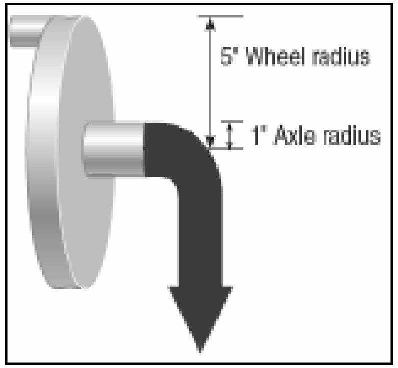
Wheels and axles

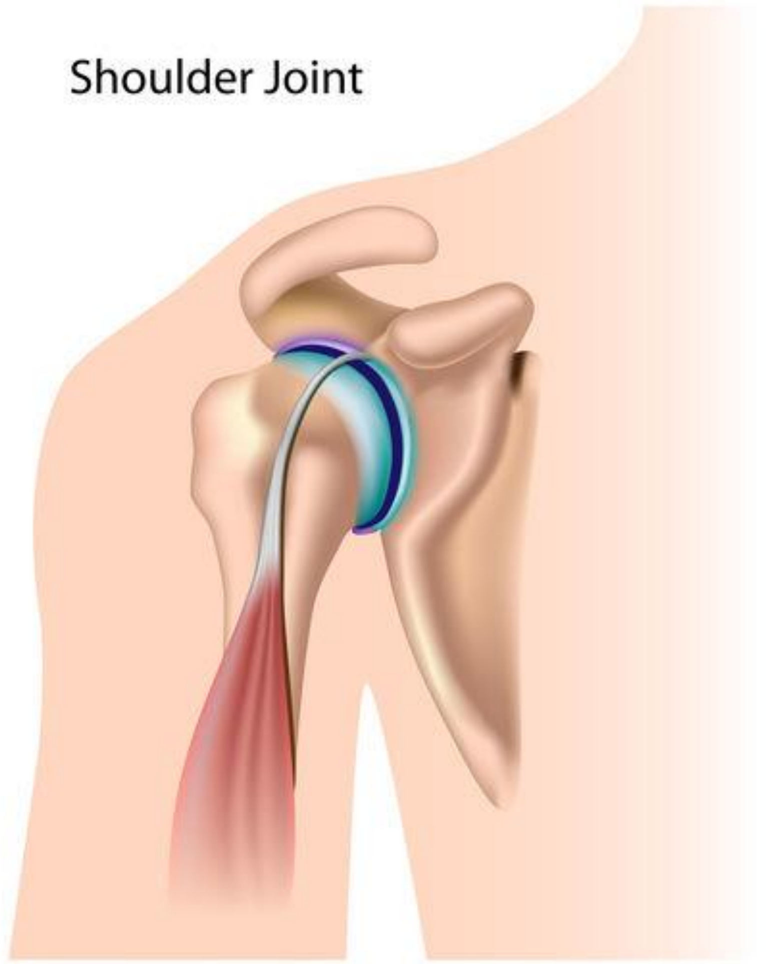
- If application of force is reversed and applied to the axle, then the mechanical advantage results from the wheel turning a greater distance & speed
  - if the radius of the wheel is 5 times the radius of the axle, then outside of the wheel will turn at a speed 5 times that of the axle
  - the distance that the outside of the wheel turns will be 5 times that of the outside of the axle

Wheels and axles

– Calculate the mechanical advantage for this example by considering the radius of the wheel over the axle

$$\text{Mechanical advantage} = \frac{\text{radius of the axle}}{\text{radius of the wheel}}$$





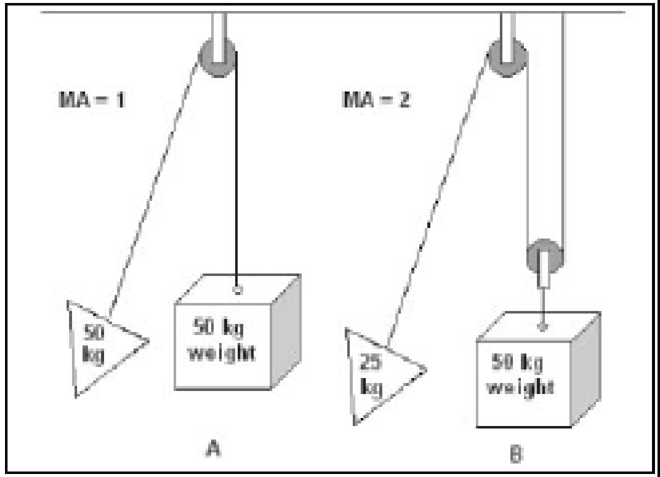
Wheels and axles

- Ex. resulting in greater range of motion & speed is with upper extremity in internal rotators attaching to humerus

  - humerus acts as the axle
  - hand & wrist are located at the outside of the wheel when elbow is flexed 90 degrees
  - with minimal humerus rotation, the hand & wrist travel a great distance
  - allows us significantly increase the speed at which we can throw objects

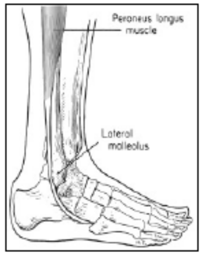
Pulleys

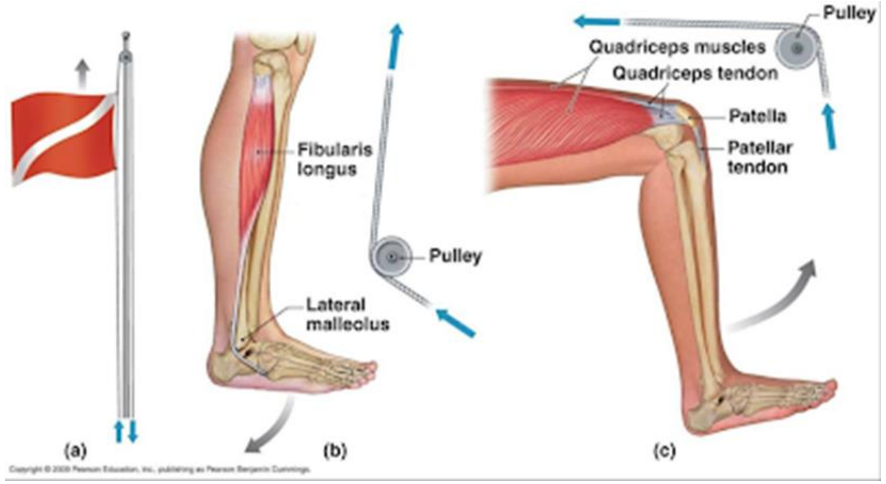
- Single pulleys function to change effective direction of force application
  - Mechanical advantage = 1
- Pulleys may be combined to form compound pulleys to increase mechanical advantage
  - Each additional rope increases mechanical advantage by 1



Pulleys

- Ex. lateral malleolus acting as a pulley around which tendon of peroneus longus runs
  - As peroneus longus contracts, it pulls toward it belly (toward the knee)
  - Using the lateral malleolus as a pulley, force is transmitted to plantar aspect of foot resulting in eversion/plantarflexion



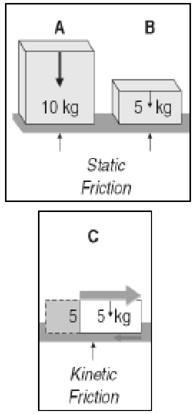


Friction

- *Friction* - force that results from the resistance between surfaces of two objects from moving upon one another
  - Depending increased or decreased friction may be desired
  - To run, we depend upon friction forces between our feet & the ground so that we may exert force against the ground & propel ourselves forward

Friction

- Static friction or kinetic friction
  - *Static friction* - the amount of friction between two objects that have not yet begun to move
  - *Kinetic friction* - friction occurring between two objects that are sliding upon one another



Friction

- With slick ground or shoe surface friction is reduced & we are more likely to slip
- In skating, we desire decreased friction so that we may slide across the ice with less resistance

Friction

- To determine the amount of friction forces consider both forces pressing the two objects together & the *coefficient of friction*
  - depends upon the hardness & roughness of the surface textures
- Coefficient of friction - ratio between force needed to overcome the friction over the force holding the surfaces together

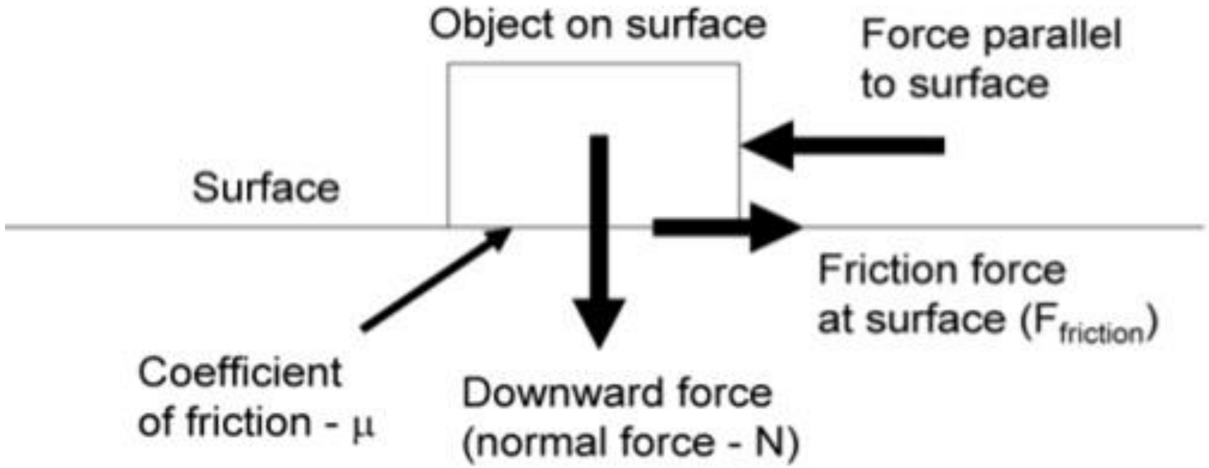
The coefficient of kinetic friction is the force between two objects when one object is moving, or if two objects are moving against one another. The coefficient of friction is dimensionless, meaning it does not have any units. A value of 1 means the frictional force is equal to the normal force.

Coefficient of friction

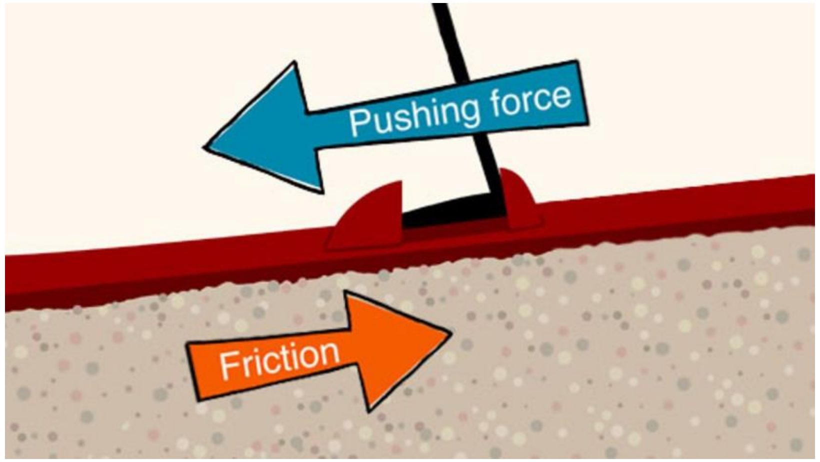
The coefficient of friction (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction. Coefficients of friction range from near zero to greater than one.

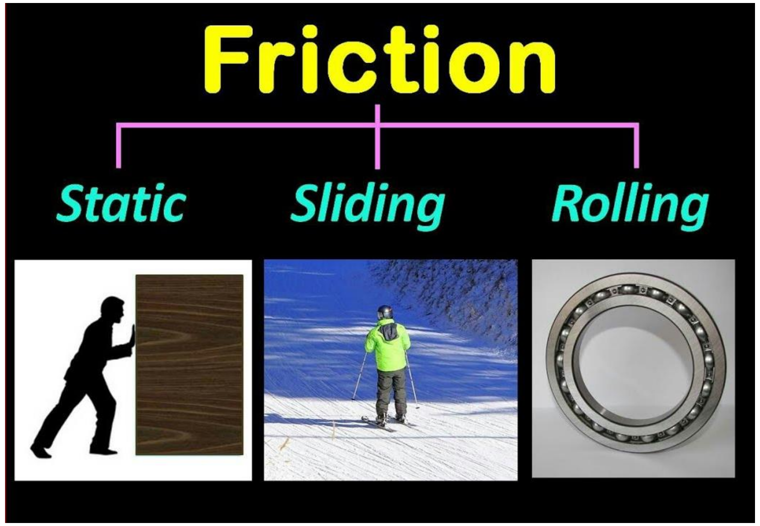
Coefficient of static friction μ_s

Coefficient of kinetic friction μ_k



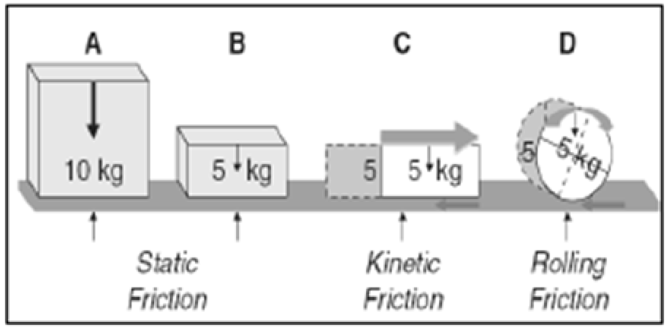
$F_{friction} = \mu N$





Friction

- *Rolling friction* - resistance to an object rolling across a surface such as a ball rolling across a court or a tire rolling across the ground
  - Rolling friction is always much less than static or kinetic friction



Balance, equilibrium, & stability

- *Balance* - ability to control equilibrium, either static or dynamic
- *Equilibrium* - state of zero acceleration where there is no change in the speed or direction of the body
  - – static or dynamic
- *Static equilibrium* - body is at rest or completely motionless

Dynamic equilibrium

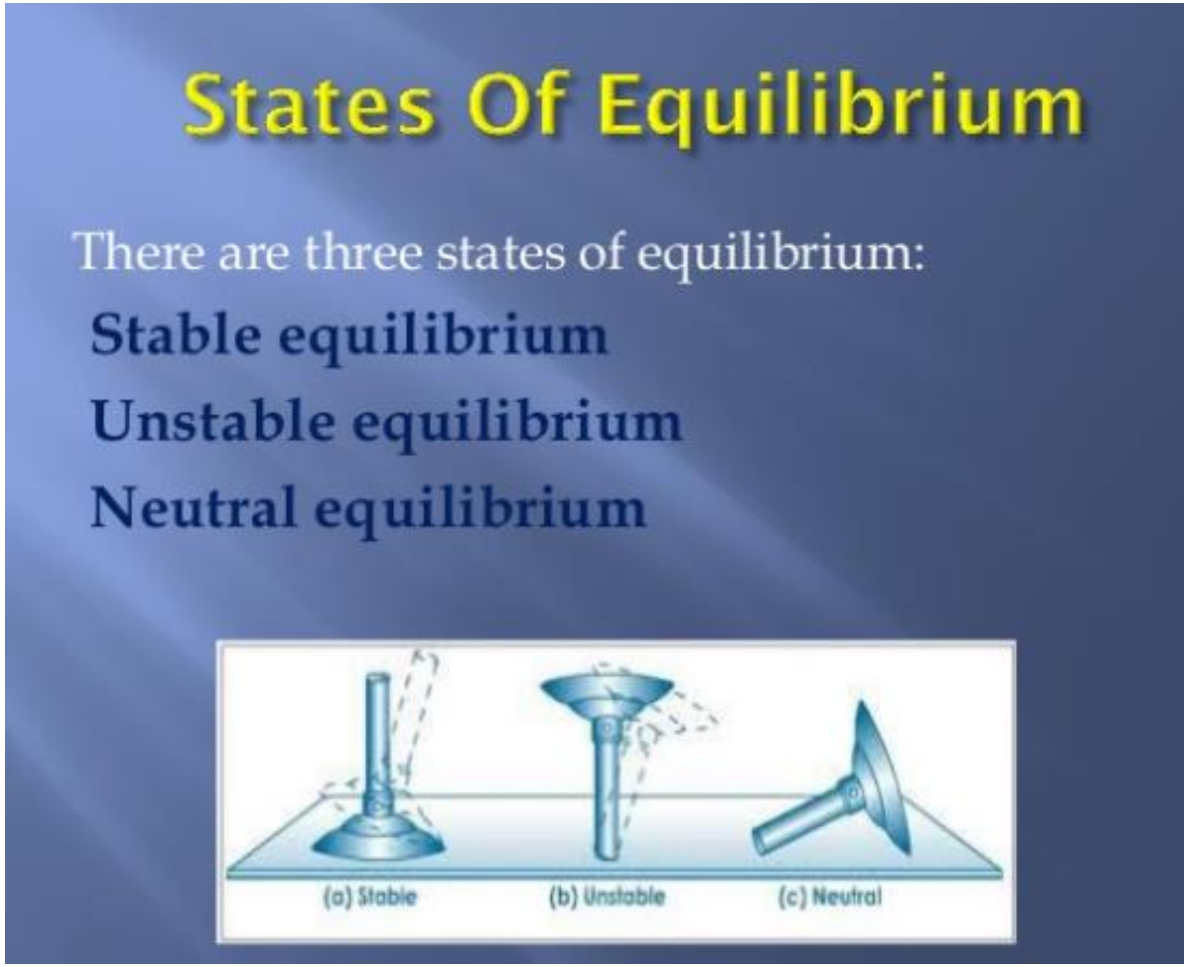
when a body is in state of uniform motion and the resultant of all the forces acting upon it is zero then it is said to be in **dynamic equilibrium.**

For example: Jump by using parachute.

Static equilibrium

If the combined effect of all the forces acting on a body is zero and the body is in the state of rest then its equilibrium is termed as **static equilibrium.**

For example: All stationary bodies


States Of Equilibrium
There are three states of equilibrium:
Stable equilibrium
Unstable equilibrium
Neutral equilibrium
(a) Stable
(b) Unstable
(c) Neutral

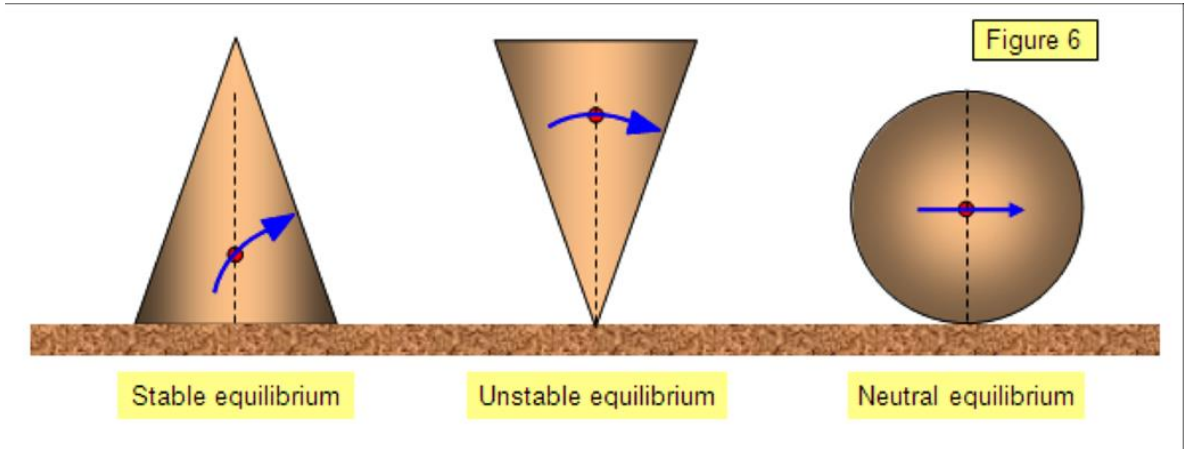


Figure 6
Stable equilibrium
Unstable equilibrium
Neutral equilibrium

Stable equilibrium

A body is said to be in stable equilibrium if it comes back to its original position when it is slightly displaced.

When a body which is in stable equilibrium is disturbed its centre of gravity is raised.

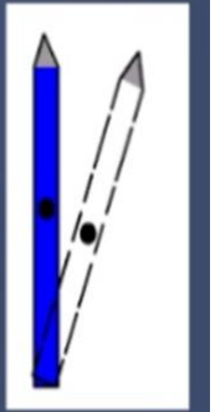
For example a book lying on a table is in stable equilibrium.

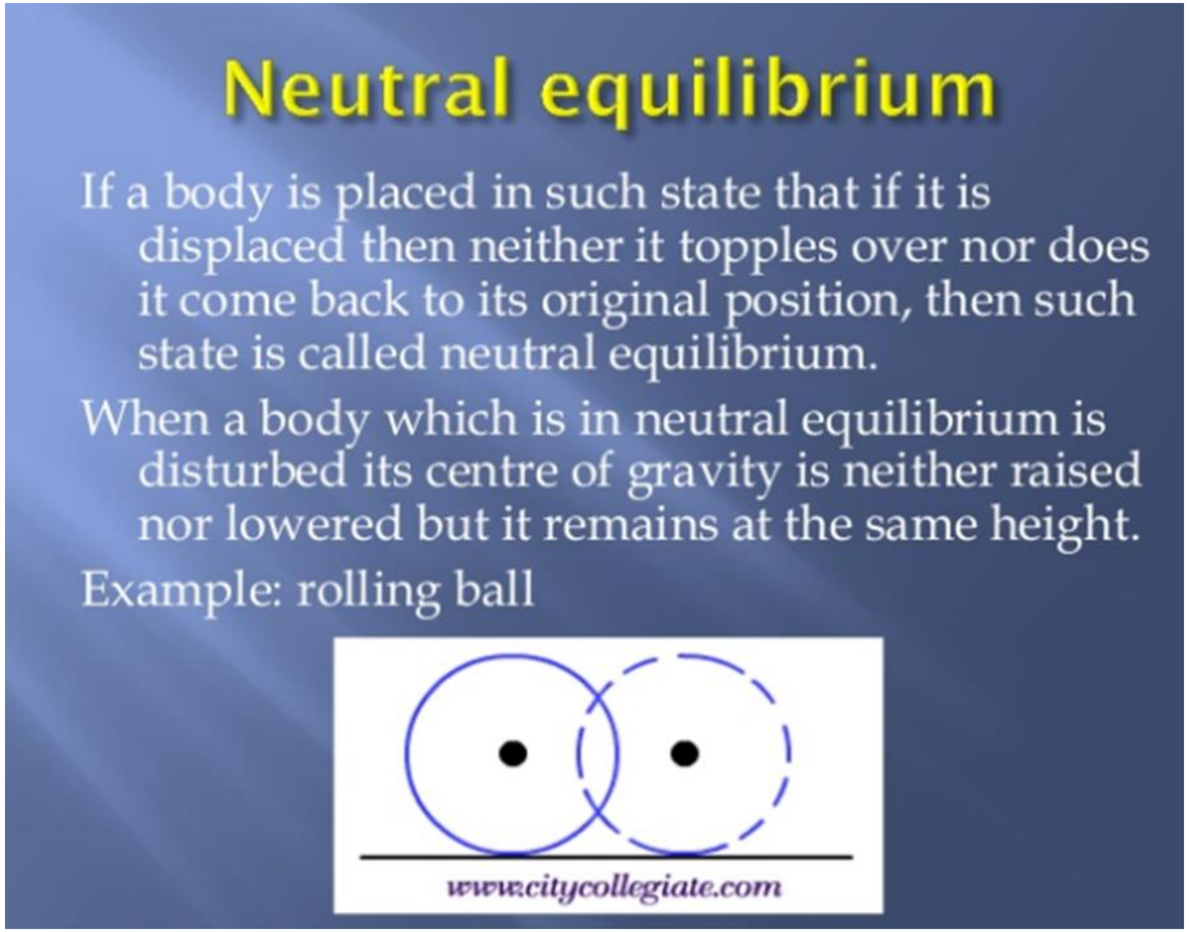
UNSTABLE EQUILIBRIUM

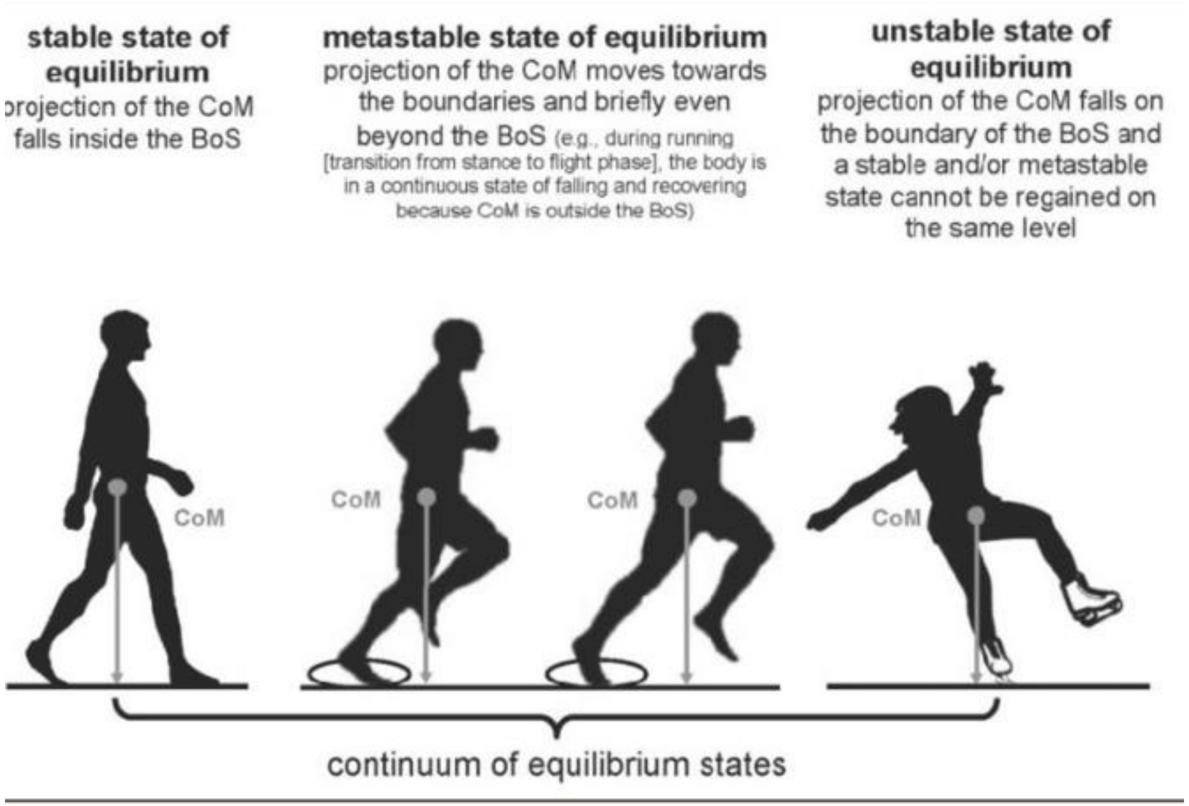
A body is said to be in unstable equilibrium if it does not come back to its original position when it is slightly displaced

When a body which is in unstable equilibrium is disturbed its centre of gravity is lowered

Example: pencil standing on its point or a stick in vertically standing position




Neutral equilibrium
If a body is placed in such state that if it is displaced then neither it topples over nor does it come back to its original position, then such state is called neutral equilibrium.
When a body which is in neutral equilibrium is disturbed its centre of gravity is neither raised nor lowered but it remains at the same height.
Example: rolling ball
www.citycollegiate.com


stable state of equilibrium
rojection of the CoM falls inside the BoS
metastable state of equilibrium
projection of the CoM moves towards the boundaries and briefly even beyond the BoS (e.g., during running [transition from stance to flight phase], the body is in a continuous state of falling and recovering because CoM is outside the BoS)
unstable state of equilibrium
projection of the CoM falls on the boundary of the BoS and a stable and/or metastable state cannot be regained on the same level
CoM
CoM
CoM
CoM
continuum of equilibrium states

- **EQUILIBRIUM**

  Equilibrium is a state of balance in which all forces are equal

- **STABILITY**

  Stability is the resistance to disruption of equilibrium

- **BALANCE**

  Balance is the ability to control equilibrium during changing body's position

Balance and Stability

"How balanced are you?"

Skilled athletes are able to employ certain tactics to increase their stability under oncoming forces, practically bracing themselves to be immovable.

Chris Judd and Jimmy Bartel

Young athletes learning a skill:

2

As soon as the athlete loses balance, he or she loses the contest. The following sports fall into that category:

Cycling
Speed skating

Judo
Figure skating

Diving
Weightlifting

Skiing
Gymnastics

Types of stability

1. **Linear Stability**

   is the resistance of an athlete or object against being moved in a certain direction

   Sport dependent

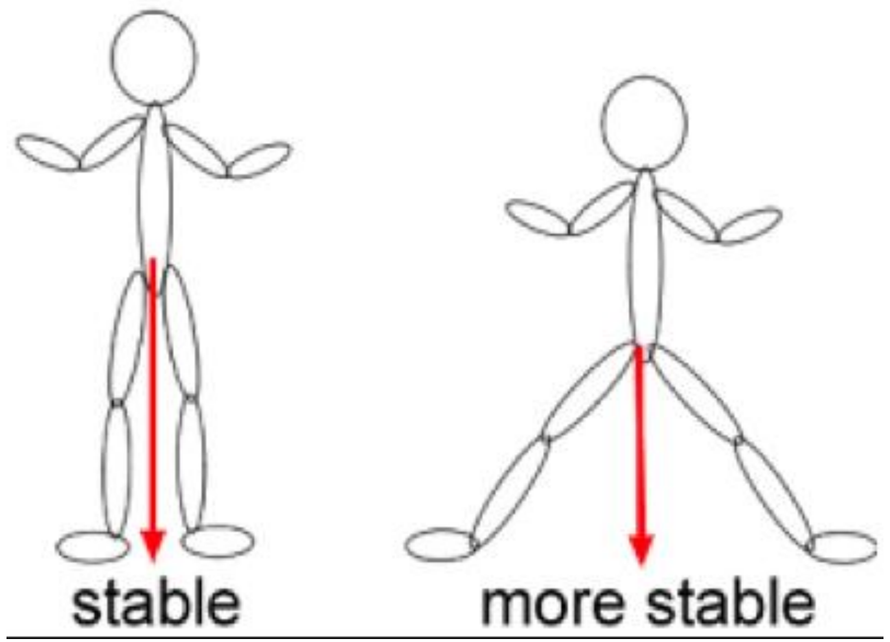
   Football

   Baseball Catcher

2. **Rotary Stability**

   is the resistance of an athlete or object against being tilted, tipped over, up ended or spun around in a circle.

5

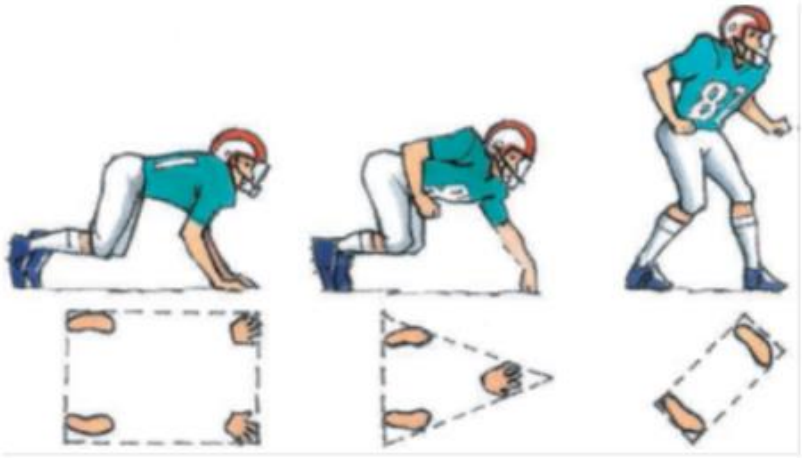


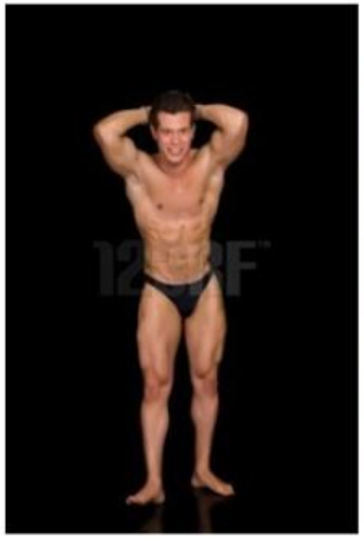
Factors which affect balance and stability

- The size of the base of support
- The position of the line of the COG relative to the base of support
- The height of the COG
- The mass of the body

The Size of the Base of support

A person is more stable when standing on two feet than does a person standing on one





LINE OF GRAVITY

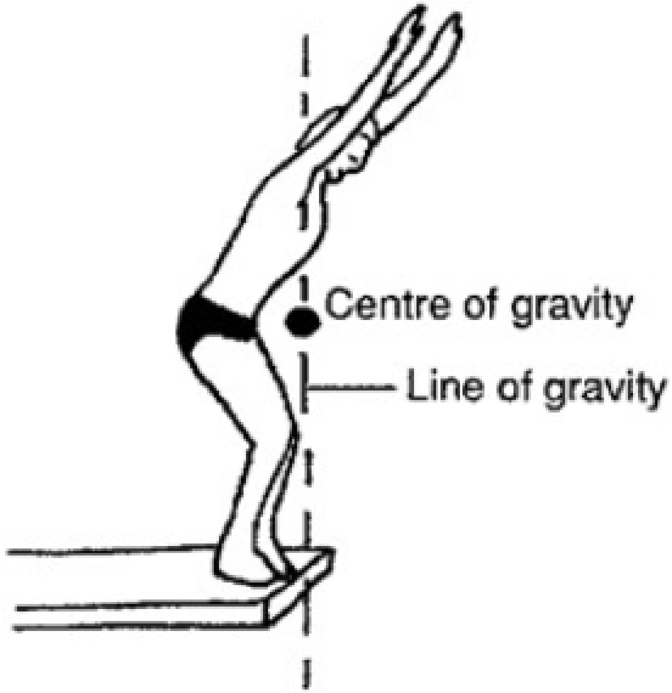
A vertical line which passes through the centre of mass to the ground.

The position of the line of the COG relative to the base of support

The closer the line of the COG is to being directly over the base of support ->

The closer the line of the COG is to being at the edge of the base of support ->

This is required by many sports: ie: diving, sprint start



The position of the line of the COG relative to the base of support

11

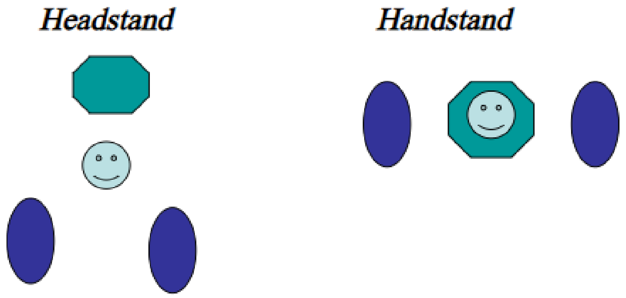
The height of the COG

The mass of the body

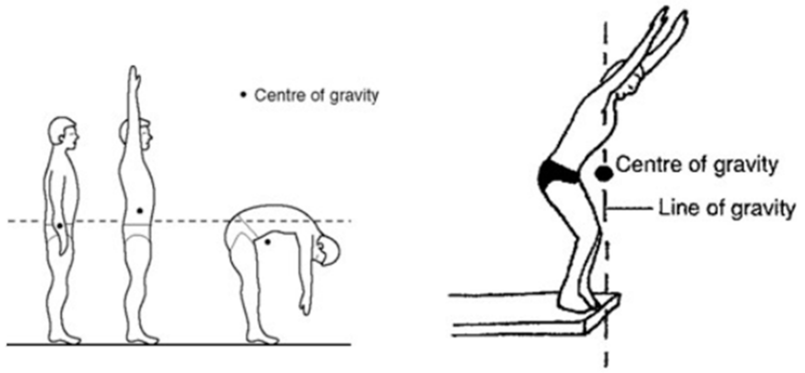
Centre of Gravity, Stability & Balance

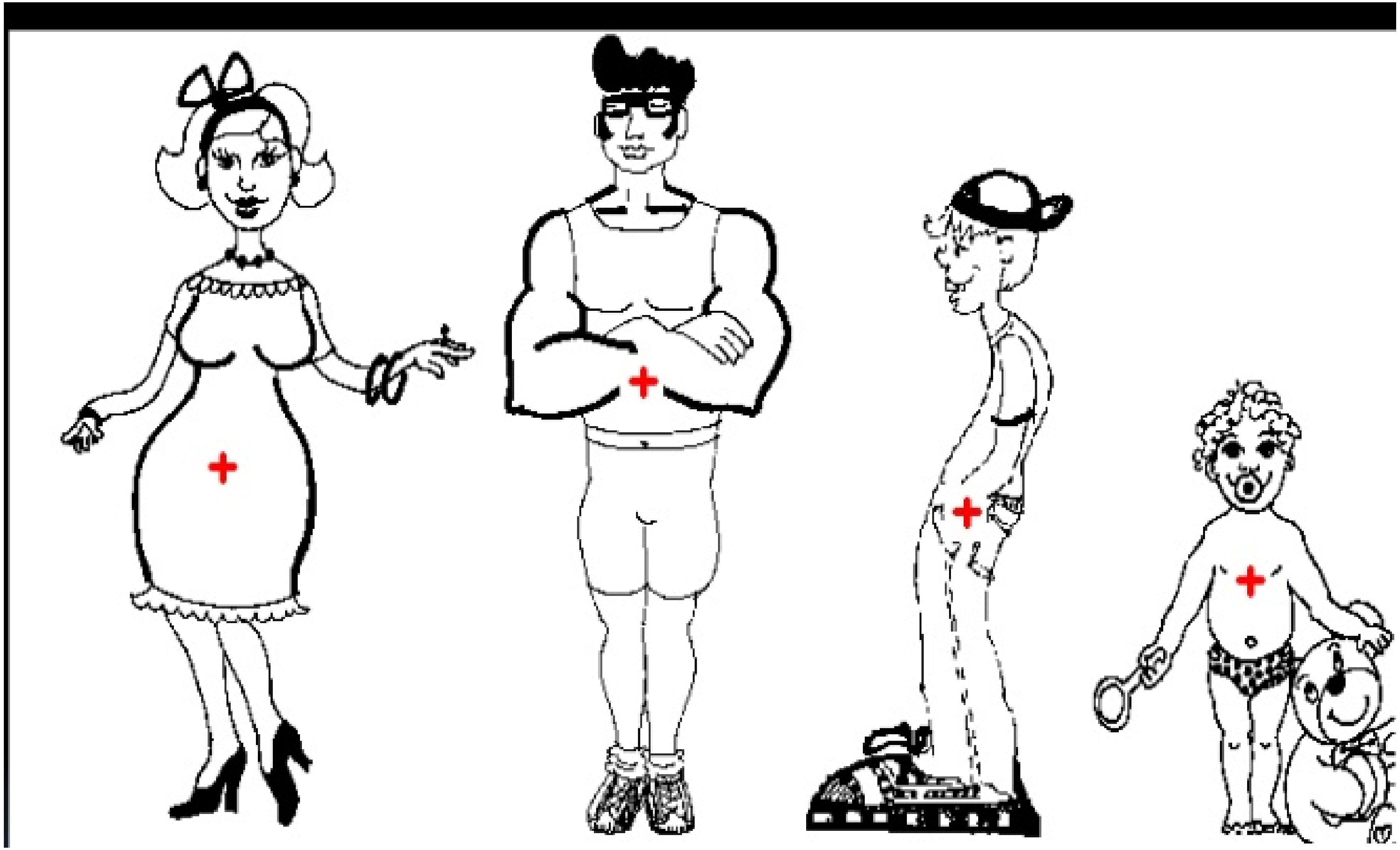
Stability and balance will be easier if:

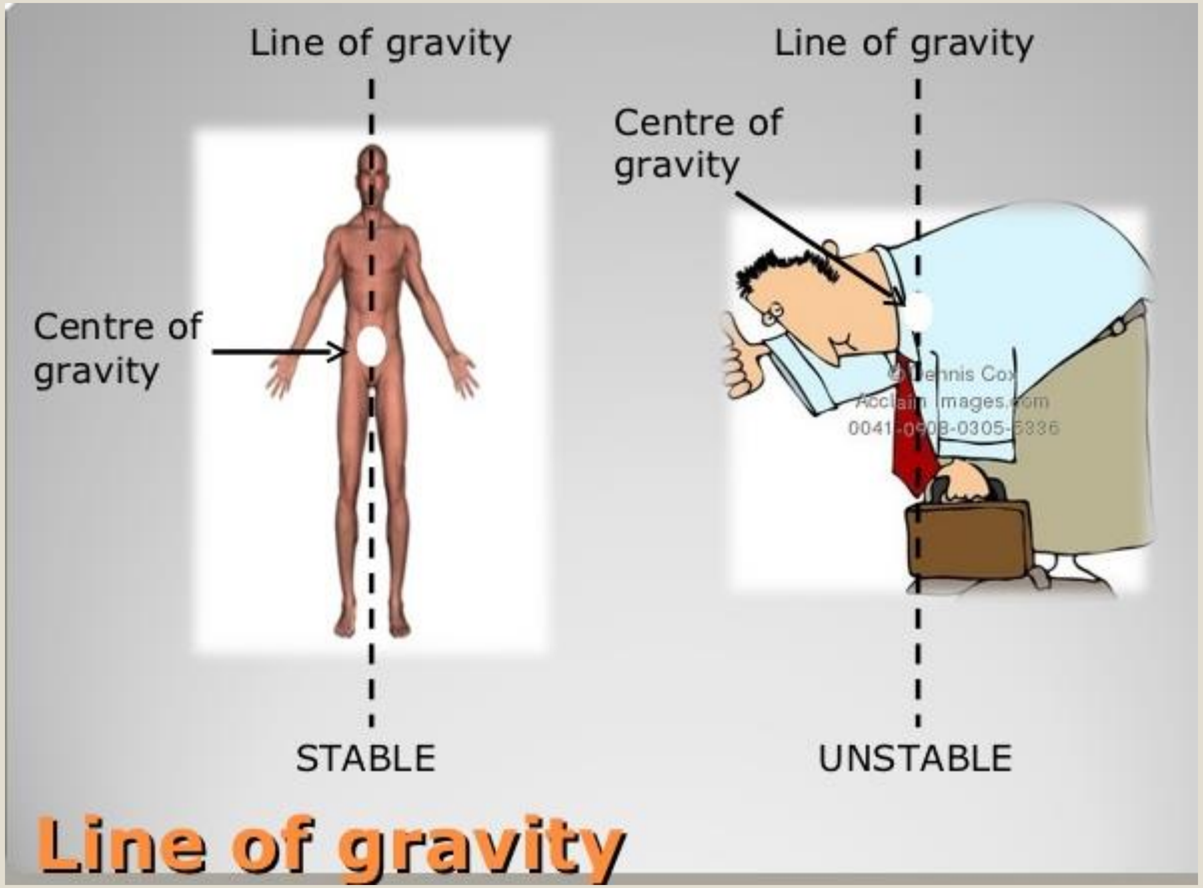
- The mass is large
- The base is large
- The centre of gravity is low
- The centre of gravity is located over the base

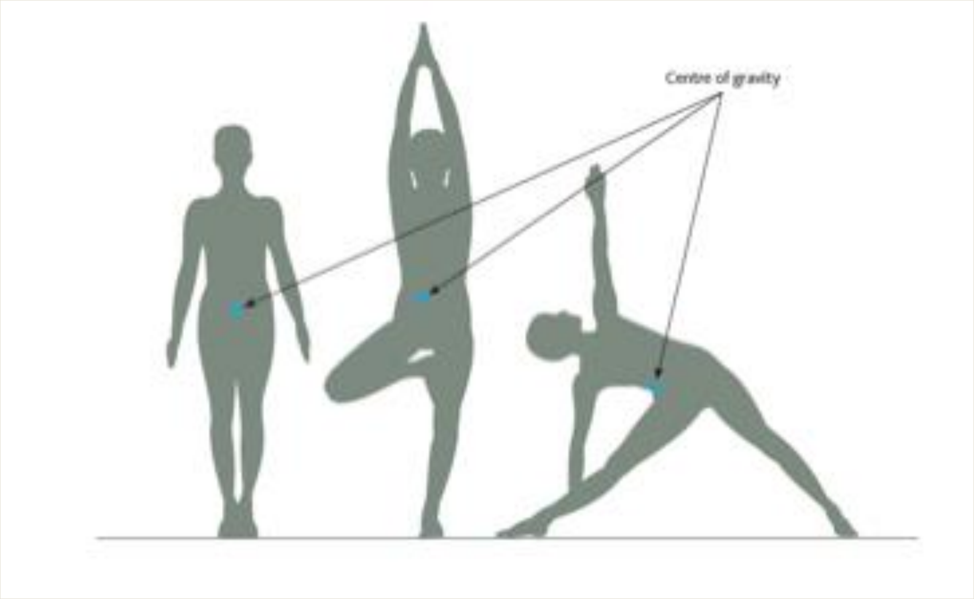


Centre of Gravity

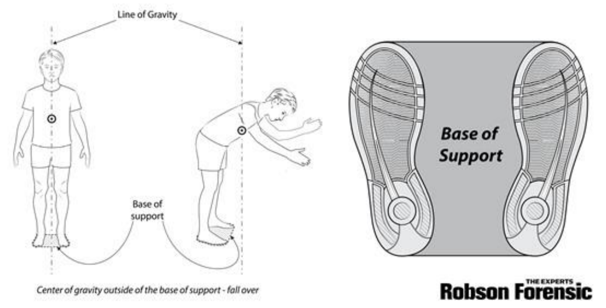


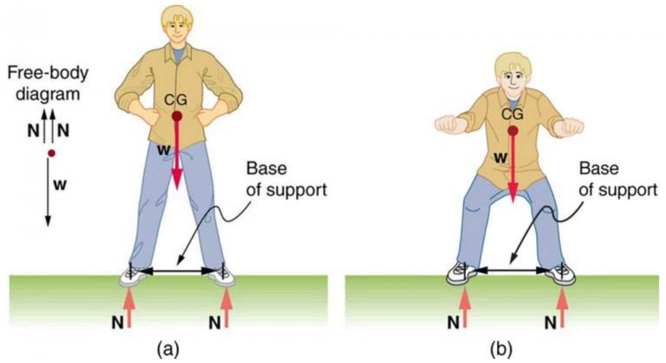






Stability is the resistance to a change in the body's acceleration or, more appropriately, the resistance to a disturbance of the body's equilibrium





Balance, equilibrium, & stability

- Stability is enhanced by determining body's *center of gravity* & appropriately changing it
- Center of gravity - point at which all of body's mass & weight are equally balanced or equally distributed in all directions
- Balance - important in resting & moving bodies

Balance, equilibrium, & stability

- *Dynamic equilibrium* - all applied & inertial forces acting on the moving body are in balance, resulting in movement with unchanging speed or direction
- To control equilibrium & achieve balance, *stability* needs to be maximized
- Stability is the resistance to a
  - change in the body's acceleration
  - disturbance of the body's equilibrium

Balance, equilibrium, & stability

General factors applicable to enhancing equilibrium, maximizing stability, & ultimately achieving balance:

- A person has balance when the center of gravity falls within the base of support
- A person has balance in the direct proportion to the size of the base
    - The larger the base of support, the more balance
- A person has balance depending on the weight (mass)
    - The greater the weight, the more balance
- A person has balance, depending on the height of the center of gravity
    - The lower the center of gravity, the more balance
- A person has balance, depending on where the center of gravity is in relation to the base of support
    - Balance is less if the center of gravity is near the edge of the base
    - When anticipating an oncoming force, stability may be improved by placing the center of gravity nearer the side of the base of support expected to receive the force
- In anticipation of an oncoming force, stability may be increased by enlarging the size of the base of support in the direction of the anticipated force
- Equilibrium may be enhanced by increasing the friction between the body & the surfaces it contacts.

- Rotation about an axis aids balance . A moving bike is easier to balance than a stationary bike
- Kinesthetic physiological functions contribute to balance
  - The semicircular canals of the inner ear, vision, touch (pressure) & kinesthetic sense all provide balance information to the performer
- Balance and its components of equilibrium and stability are essential in all movements and are all affected by the constant force of gravity as well as by inertia