BIOMECHANICS

Ianc Dorina

Introduction to biomechanics:

- **What is biomechanics:**

=> Applying laws of mechanics to biology

or as defined by ***Y. C. Young in 1993,***

=> biomechanics studies the "mechanical properties of living tissues".

Introduction to biomechanics:

Basic concept:

- **Mechanics**
  - a branch of physics
  - the study of the action of forces on particles and mechanical systems.

- **System**
  - an object or group of interacting objects

- **Biomechanics**
  - application of the principles of mechanics to the study of living organisms (e.g. the human body and its parts)

MECHANICS

STATICS

- branch of mechanics dealing with systems in a constant state of motion

DYNAMICS

- branch of mechanics dealing with systems subject to acceleration

Sub-branches of Mechanics

- **Statics**
  - *branch of mechanics dealing with systems in a constant state of motion*;
  - includes systems that are:
    - at rest (i.e. not moving)
    - moving with a constant velocity

- **Dynamics**
  - *branch of mechanics dealing with systems in which acceleration is present* (i.e. where velocity is not constant)
  - is the study of forces and motion; or more formally, the branch of mechanics that deals with the effect that forces have on the motion of objects.

MECHANICS

KINEMATICS

it is the study of the motion of a body without considering the cause of motion;

KINETICS

study of the action of forces

Sub-branches of Mechanics

- **Kinematics**

- study of the description of motion, including considerations of space and time
- describes the motion of a body without regard to the forces that produce the motion
- the kinematics of an exercise or a sport skill execution is also known, more commonly, as form or technique.

- **Kinetics**

- examines the forces acting on the body during movement and the motion with respect to time and forces
- study of the relationship between the forces acting on a system and the motion of the system.

BIOMECHANICS

KINEMATICS

- *Time*
- *Trajectory*
- *Distance*
- *Position*
- *Angle*
- *Speed*
- *Acceleration*

DYNAMICS

- *Forces*
- *Impulse*
- *Work*
- *Energy*

STATICS

- *Equilibrium*
- *……*

Biomechanics:

- deals with the study of movements in terms of the laws of mechanics;
- deals with the study of the forms of movement, the forces that produce the movement, the interaction between these forces and the opposing forces.

Biomechanics: is the science that deals with the study

of the repercussions of the mechanical forces on human's functional structure

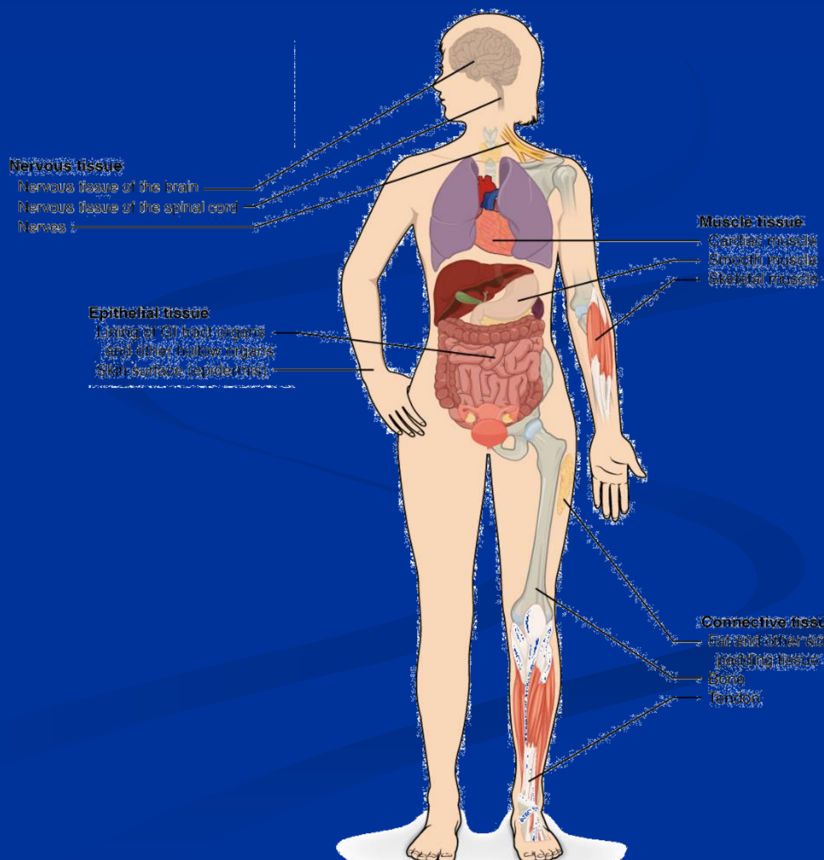
with regard to

the architecture of the bones, joints and muscles, as the determinants factors of the movement.

(Gowaertes)

Biomechanics

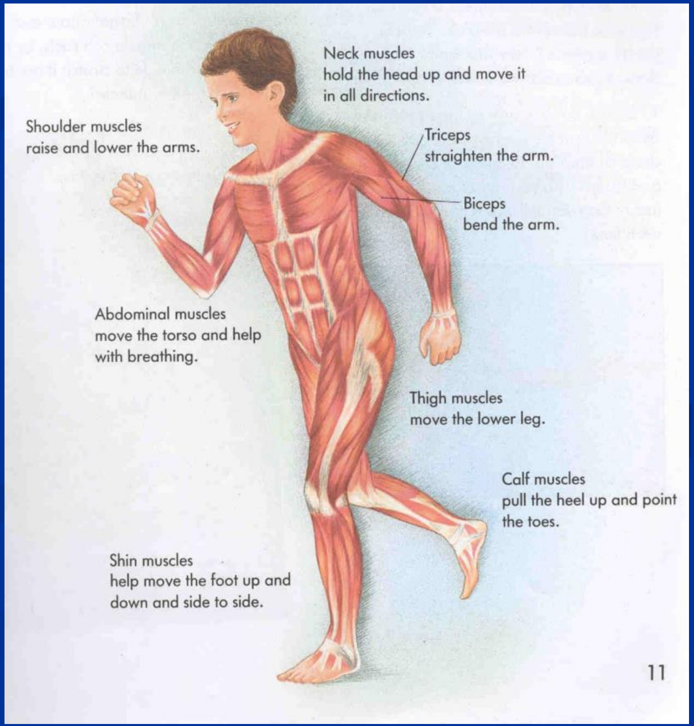
deals with both mechanical analysis of <u>movements</u>, as well as their effects on the structure of the organs <u>conducting the movement</u>.



In the field of biology, "mechanics"

- shows us the movement of living systems;
- teaches us their normal function as well as the modifications involving to the alteration of these systems;
- directs us on the necessary interventions to correct these alterations.

- It is important to study biomechanics because it helps to identify the best techniques to perform an action



- It allows a skill to be broken down into its sub skills.

Who Uses Biomechanics?

- Phys. Ed. Teachers
- Coaches
- Athletic Trainers
- Physicians
- Physical Therapists
- Engineers
- Researchers

What is Biomechanics Used For?

Improving Sports Performance

(MLB)

technique

(Viking)

equipment
(*e.g.* klapskates)

Improving Sports Performance

Factors affecting athletic performance:

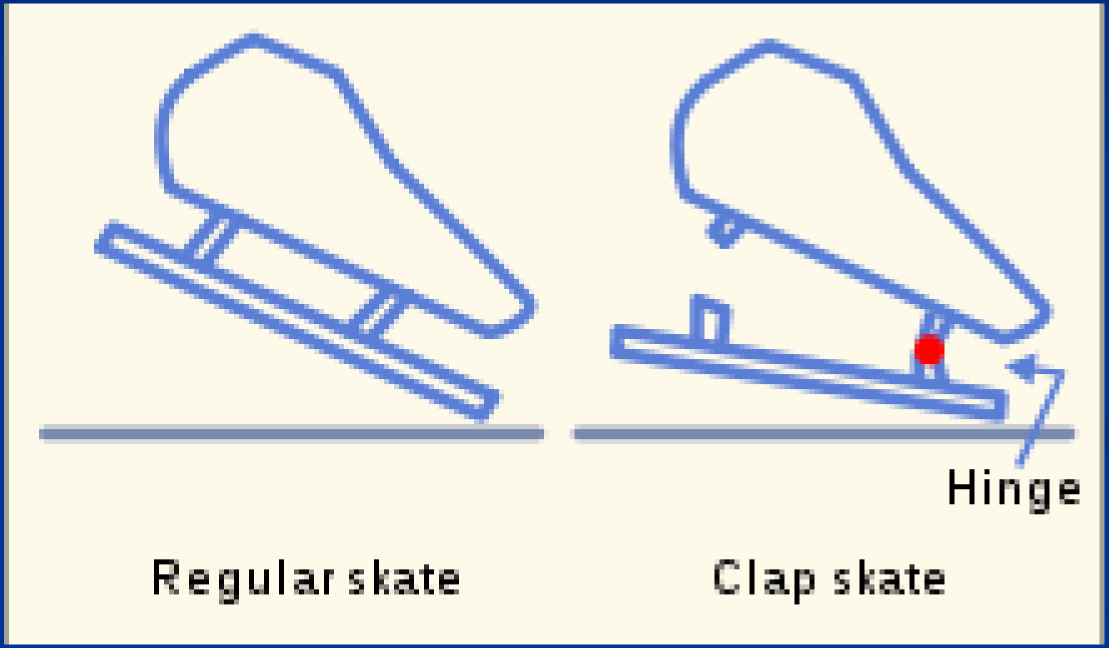
- Technique
- Physical Structure
- Physiological Capacity
- Equipment
- Coach-athlete relationship
- Nutrition
- …..

Biomechanics is most useful in improving performance in sports or activities where *technique* is the dominant factor rather than physical structure or physiological capacity.

Biomechanists have also contributed to performance improvements in sports through the design of innovative *equipment*.

What is Biomechanics used for?

Improving Sports Performance



hinge = balama

Klapskate = the speed skate equipped with a hinge near the toes that allows the skater to plantar flex at the ankle during push-off, resulting in up to 5% higher skating velocities than were obtainable with traditional skates.

- Other concerns of sport biomechanists relate to minimizing sport injuries through both identifying dangerous practices and designing safe equipment and apparel.

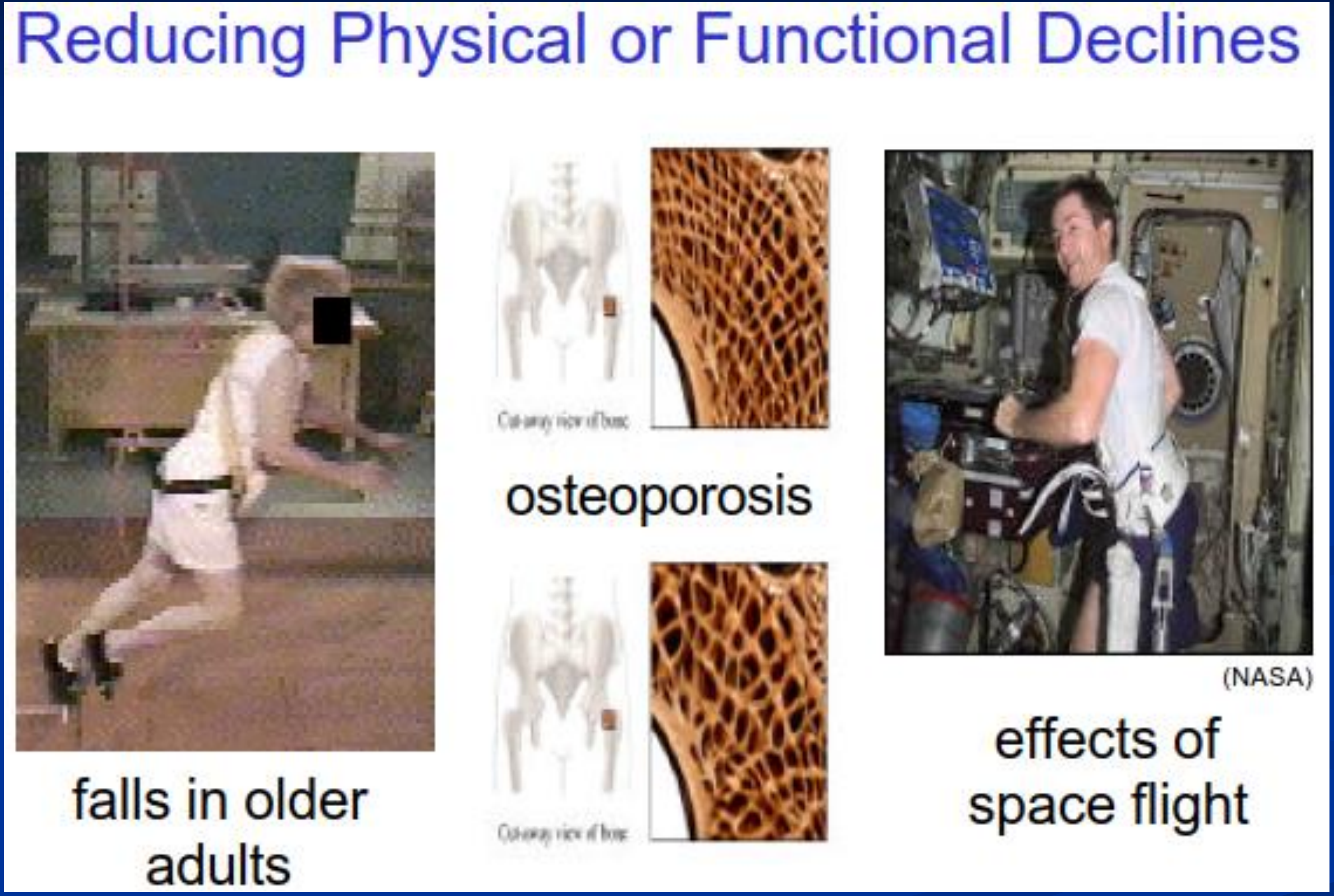
- Occupational biomechanics is a field that focuses on the prevention of work-related injuries and the improvement of working conditions and worker performance.

Occupational biomechanics

- Researchers in this field have learned that workrelated low back pain can derive not only from the handling of heavy materials but from unnatural postures, sudden and unexpected motions, and the characteristics of the individual worker.

- Sophisticated biomechanical models of the trunk are now being used in the design of materials-handling tasks in industry to enable minimizing potentially injurious stresses to the low back.

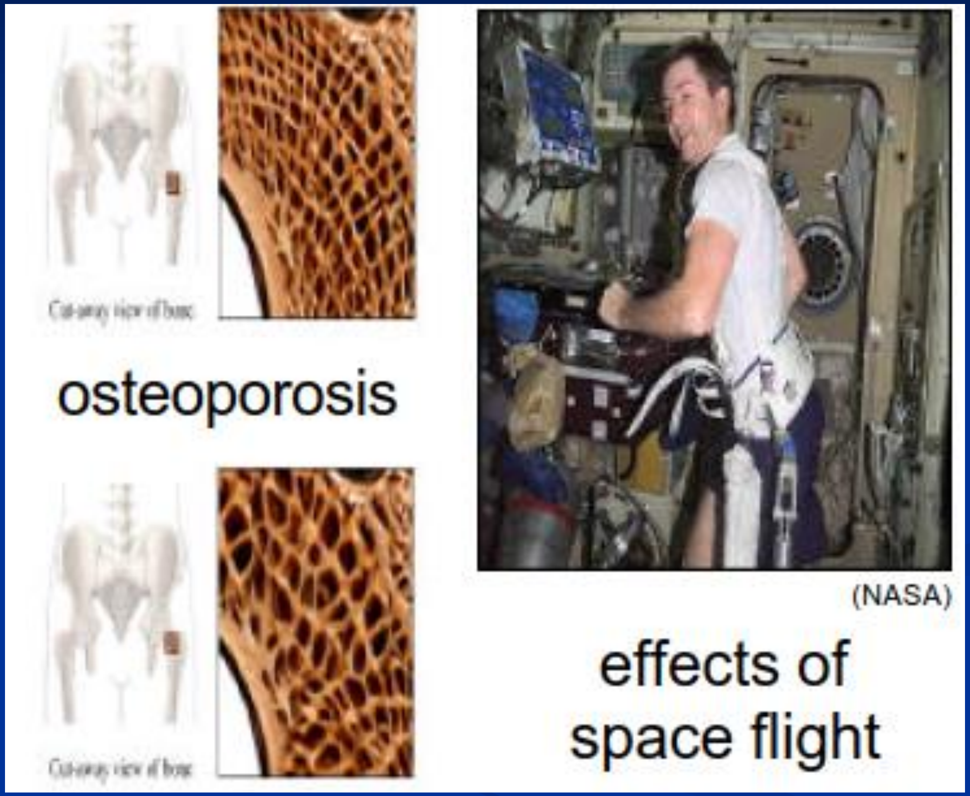
What is Biomechanics used for?



- Osteoporosis is a disease that occurs with advancing age, but it also occurs in people going into space due to the non-existence of gravity.

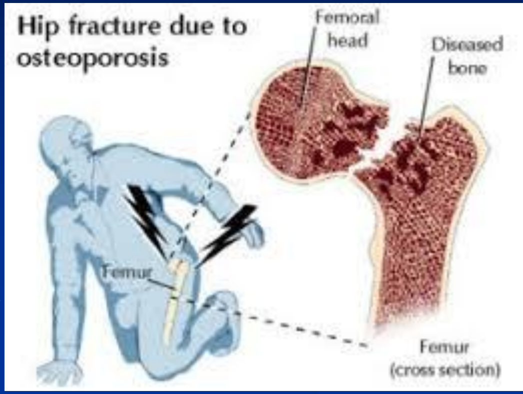
Reducing Physical or Functional Declines

- NASA sponsors an multidisciplinary line of biomechanics research to promote understanding of the effects of microgravity on the human musculoskeletal system.



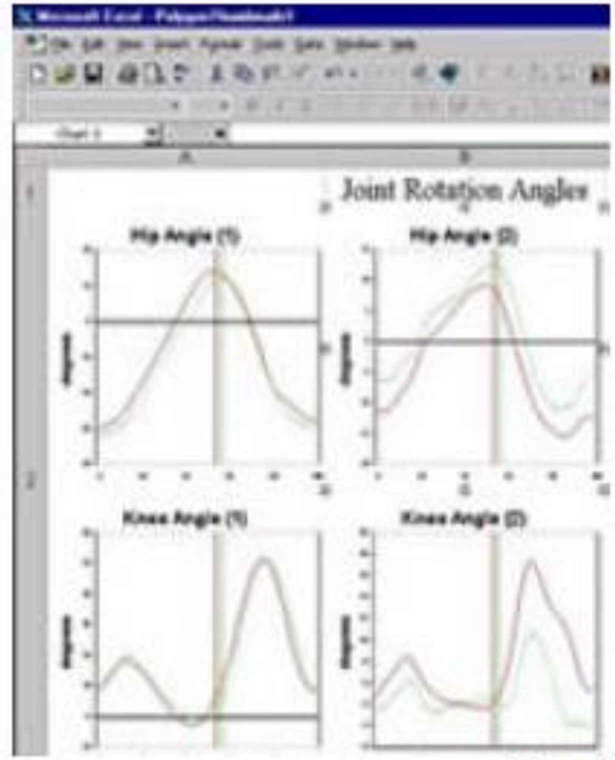
- The astronauts who have been out of the earth's gravitational field for just a few days have returned with muscle atrophy, cardiovascular and immune system changes, and reduced bone density, mineralization, and strength, especially in the lower extremities .

Reducing Physical or Functional Declines



- Another problem area challenging biomechanists who study the elderly is ***mobility impairment***.
- Age is associated with decreased ability to balance.
- Falls, and particularly fall-related hip fractures, are extremely serious, common, and costly medical problems among the elderly.
- Biomechanical research teams are investigating:
  - the biomechanical factors that enable individuals to avoid falling,
  - the characteristics of safe landings from falls,
  - the forces sustained by different parts of the body during falls,
  - and the ability of protective clothing to prevent falling injuries.

Improving Mobility



(Vicon)

surgery planning in cerebral palsy

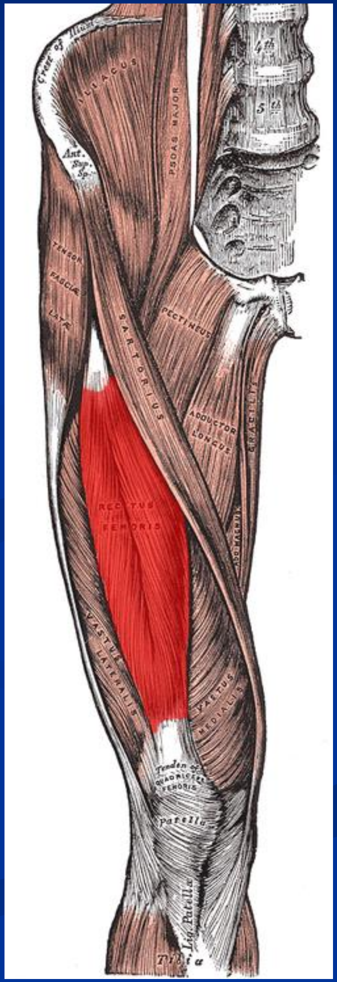
Improving mobility - improved gait among children with cerebral palsy, a condition involving high levels of muscle tension and spasticity.

- The gait of the cerebral palsy individual is characterized by excessive knee flexion during stance.

- This problem is treated by surgical lengthening of the hamstring tendons to improve knee extension during stance.

- In some patients, however, the procedure also diminishes knee flexion during the swing phase of gait, resulting in dragging of the foot.

Improving mobility - improved gait among children with cerebral palsy, a condition involving high levels of muscle tension and spasticity.



After research showed that patients with this problem exhibited significant co-contraction of the rectus femoris with the hamstrings during the swing phase, orthopedists began treating the problem by surgically attaching the rectus femoris to the sartorius insertion.

- This creative, biomechanics research–based approach has enabled a major step toward gait normalization for children with cerebral palsy.

Product Design

athletic shoes

(Össur)

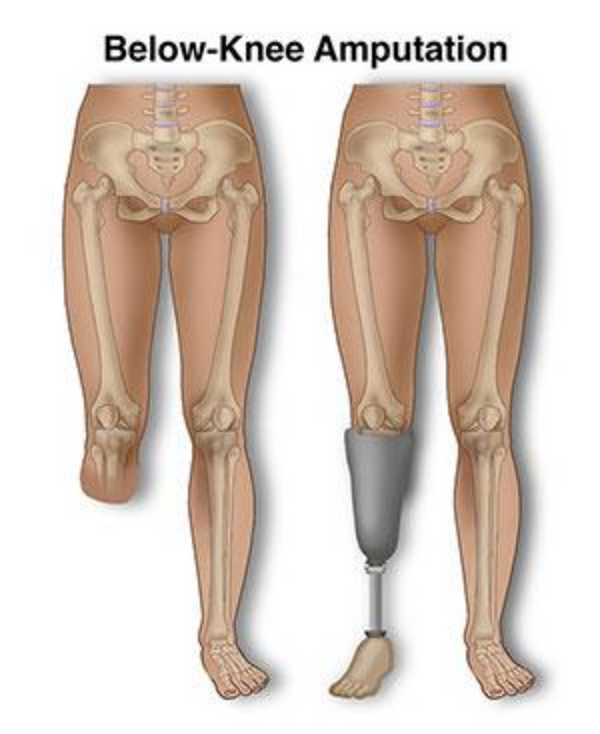
Flex-foot

artificial hip

Improving gait for children and adults with below-knee amputations.

- Researchers have developed an array of lower-limb and foot prostheses that store and return mechanical energy during gait, thereby reducing the metabolic cost of locomotion.

- Studies have shown that the more compliant prostheses are better suited for active and fast walkers, whereas prostheses that provide a more stable base of support are generally preferred for the elderly population.



- Researchers are currently developing a new class of "bionic" prosthetic feet that are designed to better imitate normal gait.

Why Study Biomechanics?

- Biomechanics:
  - has many and wide-ranging applications within health and sport sciences
  - is used by professionals throughout health and sport sciences

Why Study Biomechanics?

- This course will provide a foundation for:
  - understanding the mechanical principles underlying human movement
  - applying these principles to the analysis of human movement
- Understanding biomechanics will make you a more competent professional !

BIOMECHANICS
= bios (viaţă) + mehane (maşină) (greacă)

Fundamental biomechanics

Forces
Movement
Levers
……

Anatomical biomechanics

Joints
Muscles
Origins, Inserţtions
……

Biomecanics of great functions

Breath
Walking
……

Objectives of BIOMECHANICS in kinetology:

- to present the reports that are established between the kinematics and the kinetics of a joint;
- to analyze the pressures developed in the joint in statics and dynamic;
- analyze forces by assessing muscle torque (moment of force) and strength reports between muscle groups;
- to specify the neutral positions, the functional amplitudes for ADLs;
- to study biomechanical aspects in various musculo-articular pathological conditions.

The Motion

Motion - in the most general sense, is the mode of existence of matter

- in physics, motion is change with time of the position or orientation of a body, in an **chosen reference frame**.

reference frame = a system of objects that are not moving with respect to one another.

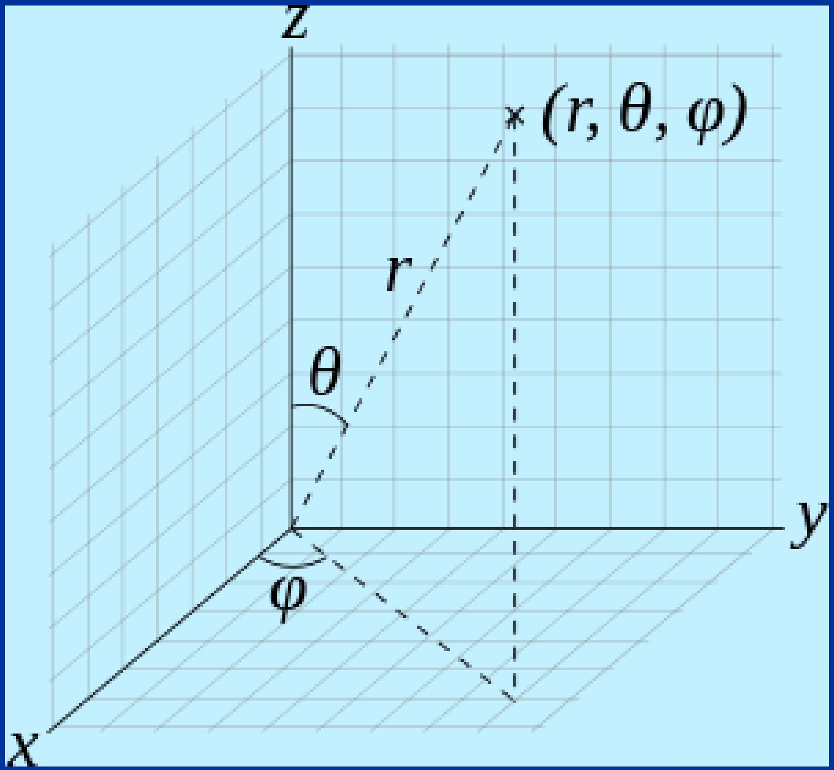
Relative motion = Movement in relation to a frame of reference.

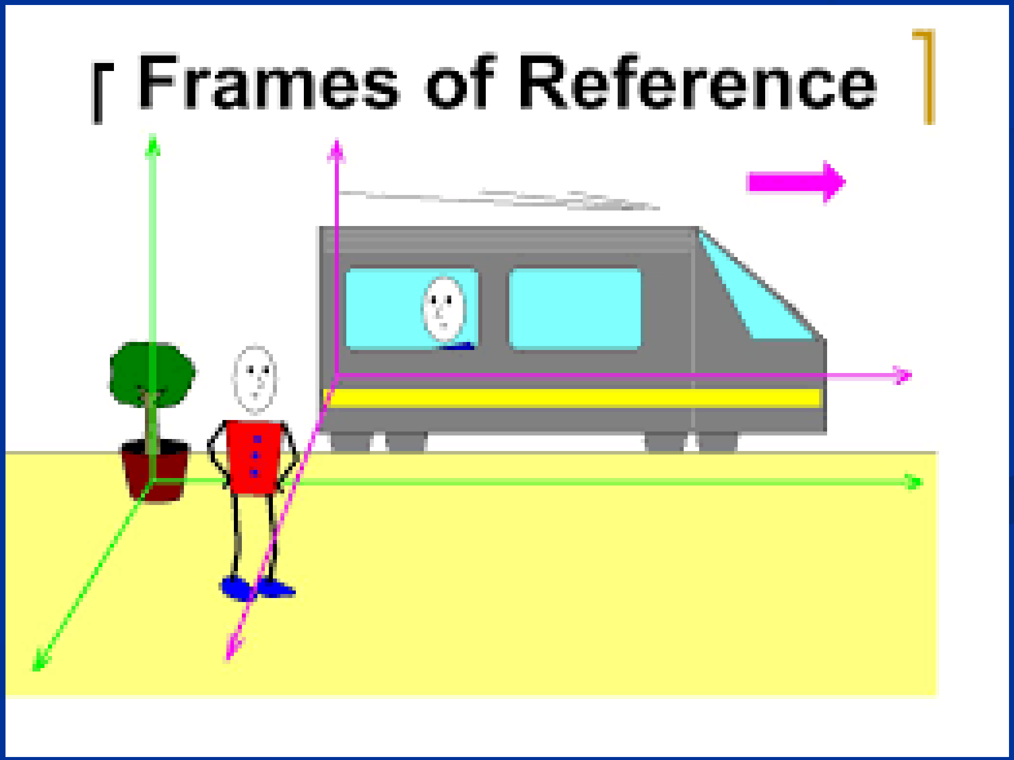
Exemple: Does a person sitting on a moving train have motion?
– it all depends on the frame of reference.

The Motion

Reference frame

The reference frames used in dynamics are known as coordinate systems with axes (lines) emanating from a point known as the origin.





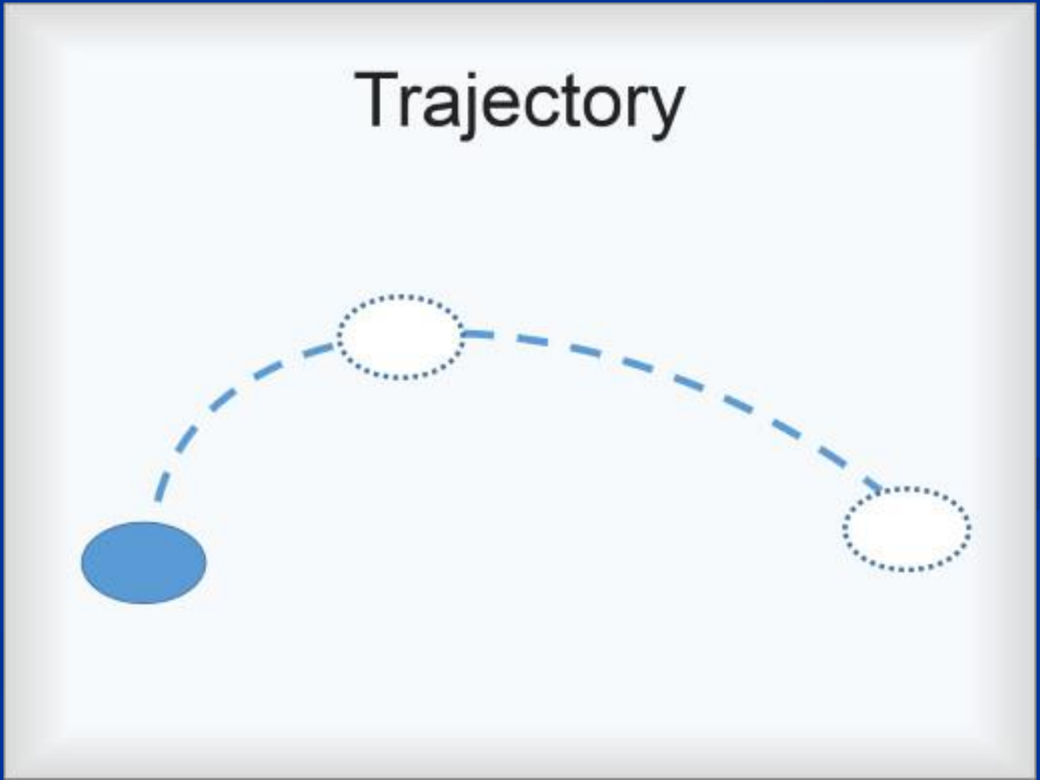
The Motion

Motion is a change in position over a period of time.

The movement is characterized by trajectory and speed parameters.

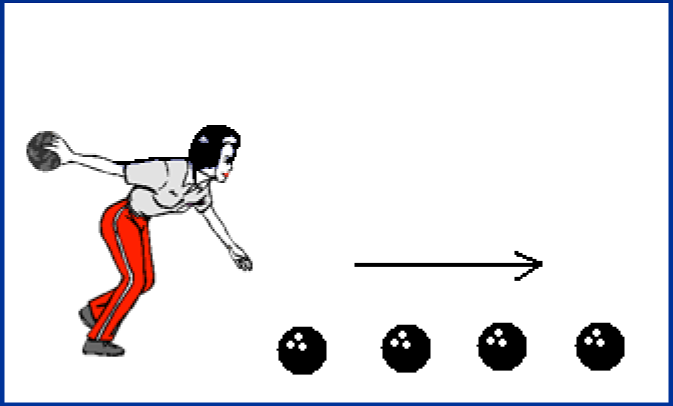
Trajectory

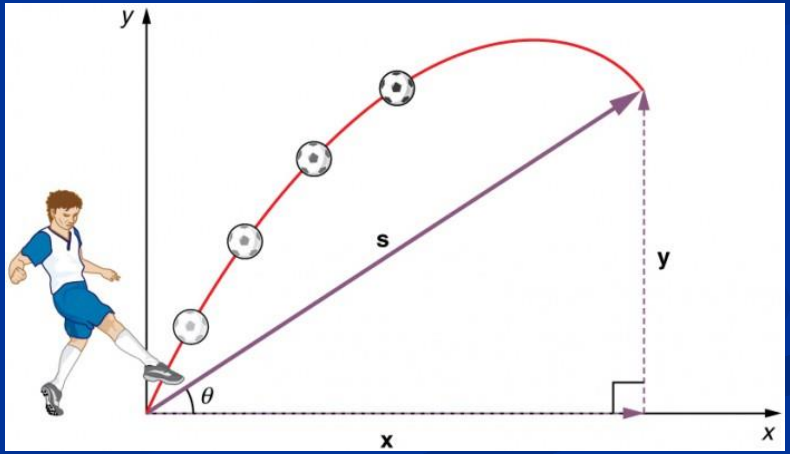
- represents the geometric location of the successive positions occupied by the material point in space; is the curve described by a body during its movement.



The Trajectory:

- can be rectilinear or curvilinear





The Trajectory:

- can be done in a plane (circular motion) or in a space (movement of a peripheral point of a screw).

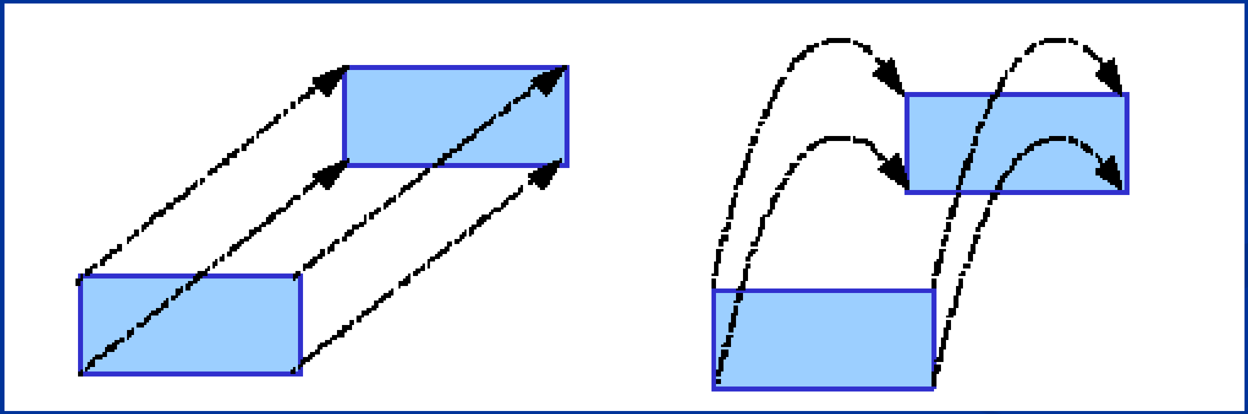
A particular case of movement is rest.

A body is considered to be resting in relation to other bodies if its position relative to those bodies, considered fixed, remains unchanged.

Position is the ratio of a body to its place in space.

Translation (or Linear Motion)

– all parts of an oject or system move the same distance in the same direction at the same time.



Rectilinear Motion — Translation along a straight line

Curvilinear Motion — Translation along a curved line

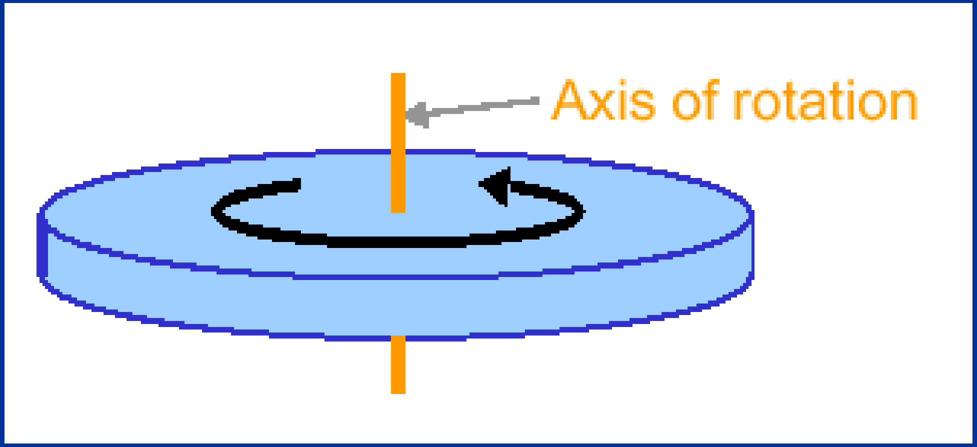
Translation (or Linear Motion)

Rectilinear Motion

Curvilinear Motion

Angular Motion

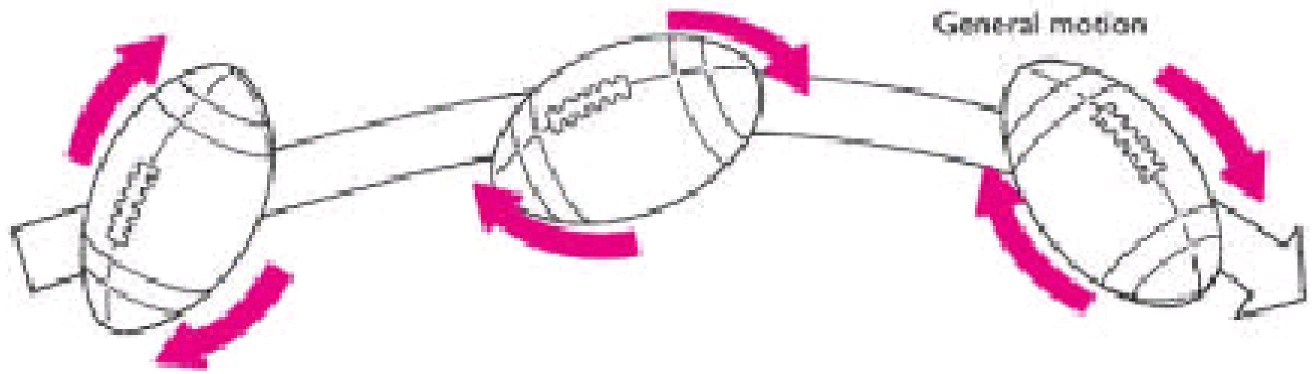
- All points in an object or system move in a circle about a single axis of rotation.
- All points move through the same angle in the same time.



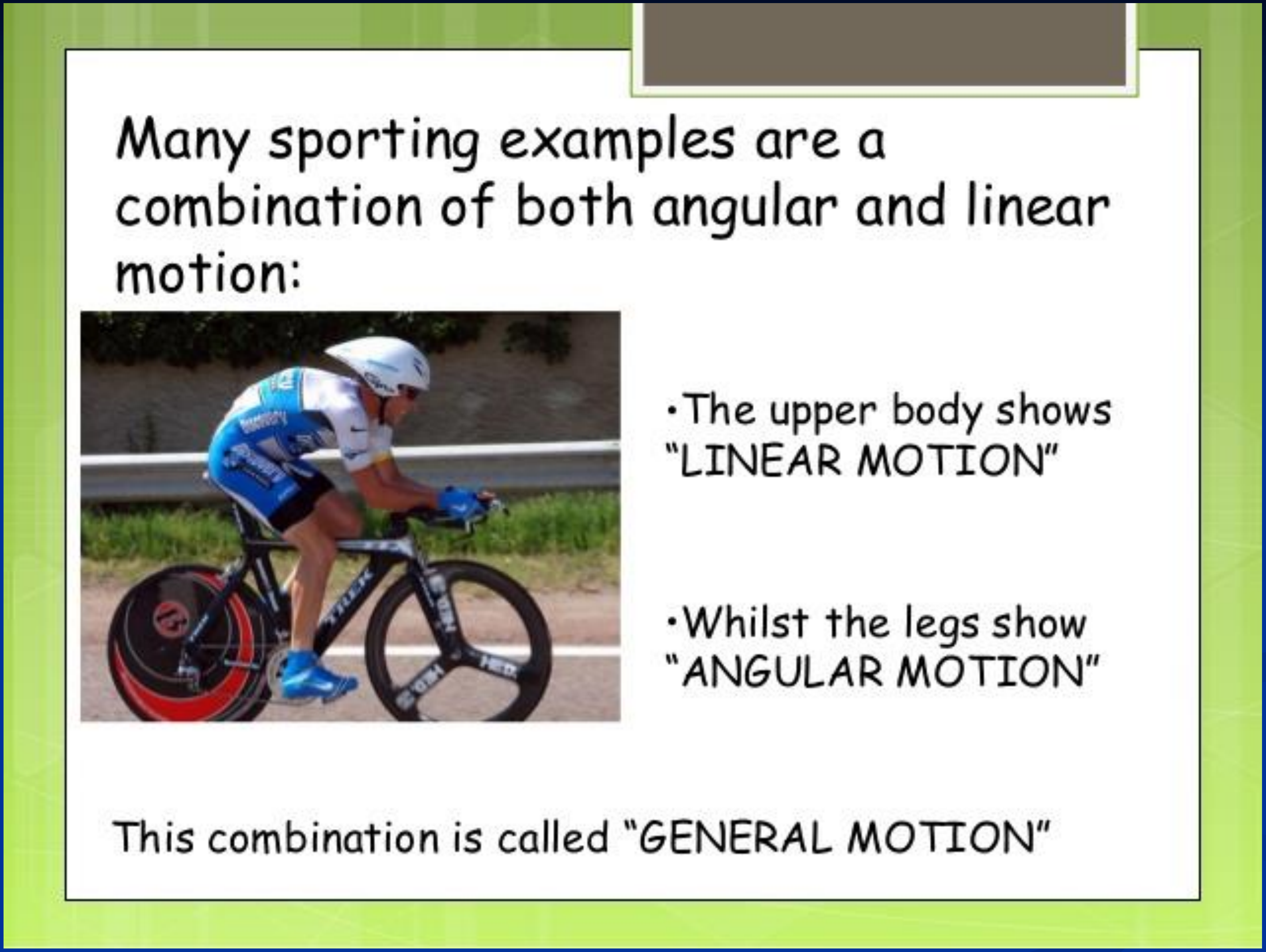
Axis of Rotation – imaginary line that the object spins about – oriented perpendicular to the plane of rotation.

General Motion

– combination of linear and angular motion;
– is the most common in human movement.

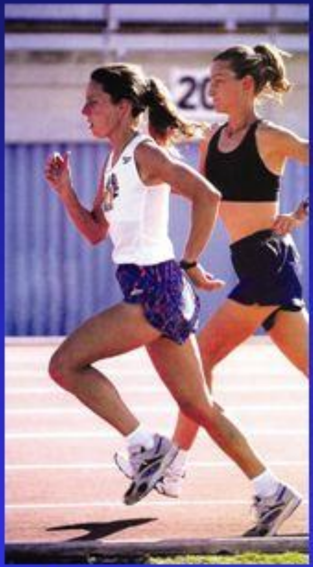


(Hall, 2003)

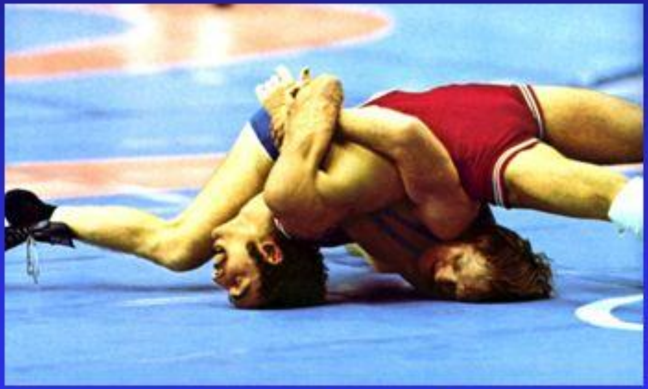


Cyclist uses several angular motions to produce linear motion of bicycle.

Types of Motion



Linear motion

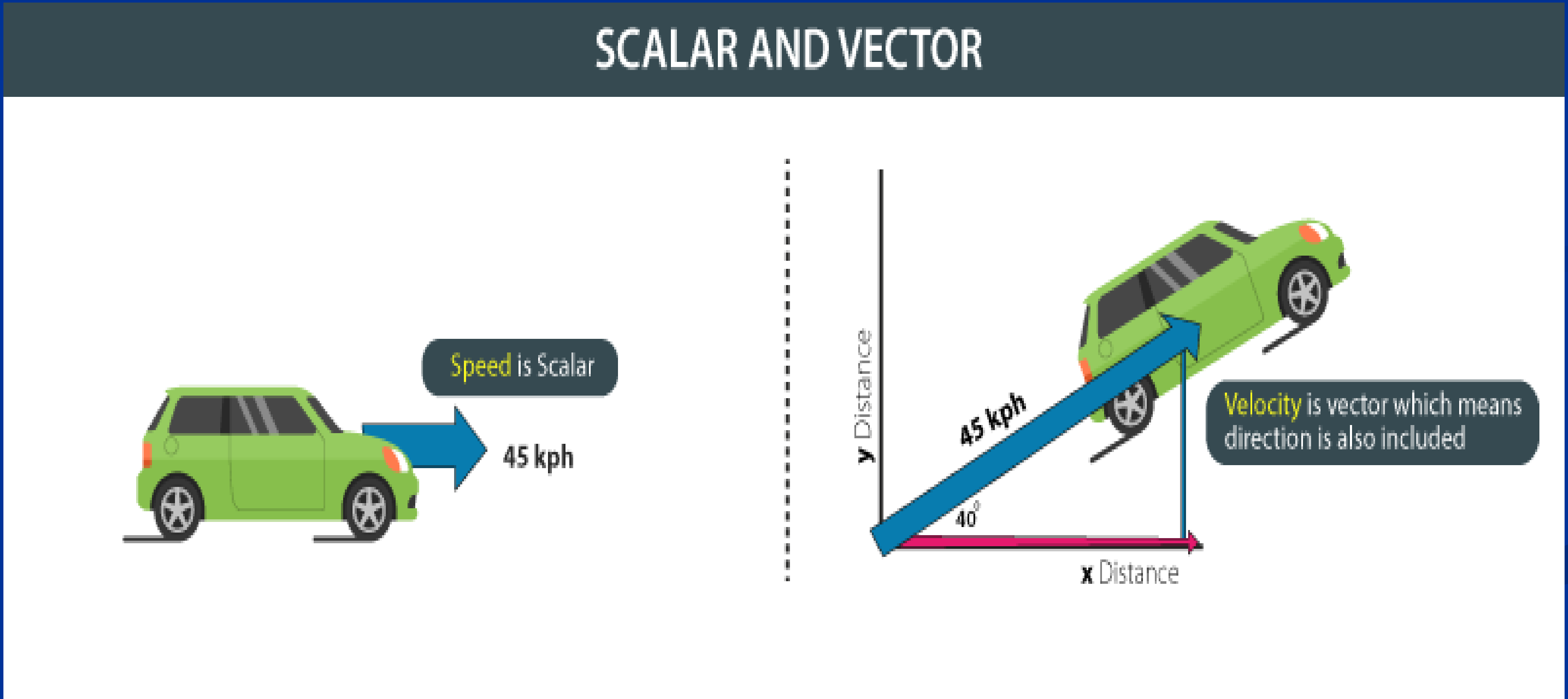


General motion

Angular motion

Sport/Activity	Linear	Angular	General
100m sprint			✓
Tobogganing down a hill	✓		
Teeing off at golf		✓	
The shoulder in a cricket bowling action		✓	
Cycling			✓
Going down a slide	✓		
An ice skater spinning		✓	

Scalars and Vectors



Scalars and Vectors

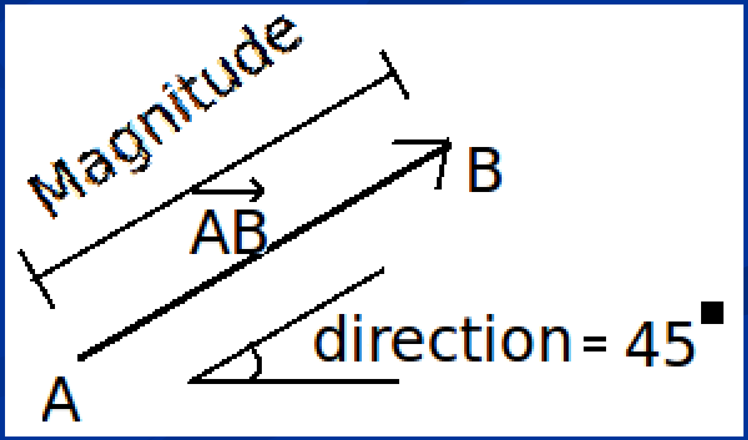
Scalar quantity is characterized by:

- number (size)
- an associated unit of measurement

Volume
- 120
- Liter (L)

Vector quantity is characterized by:

- number (size)
- an associated unit of measurement
- orientation: direction and sense



Scalars and Vectors

Example

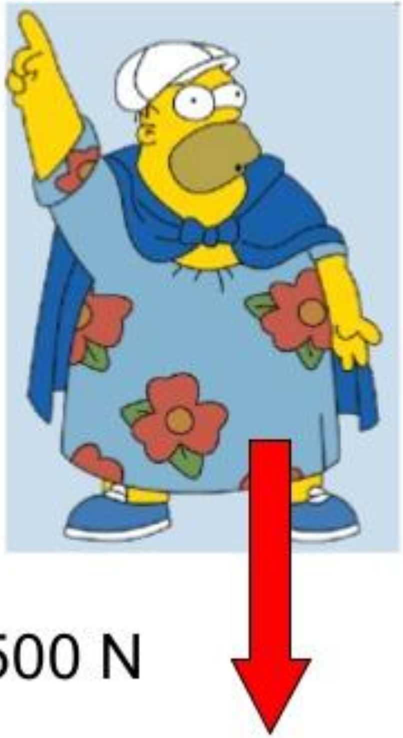
<u>Mass</u>

Ammount of matter

Scalar: 150 Kg

<u>Weight (Force)</u>

Attraction of an ammount of matter to the Earth



Vector: 1500 N

Scalars

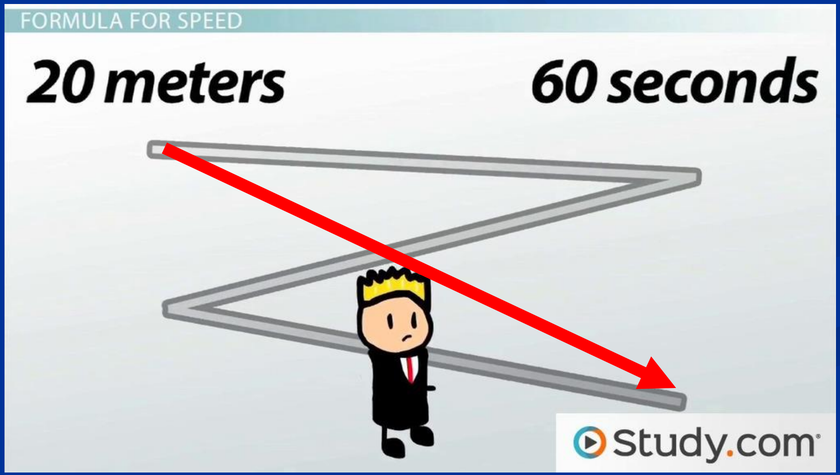
Time
Mass
Temperature
Distance
Power
Energy
Density
Volum
Speed

Vectors

Force
Weight
Momentum
Acceleration
Displacement
Velocity

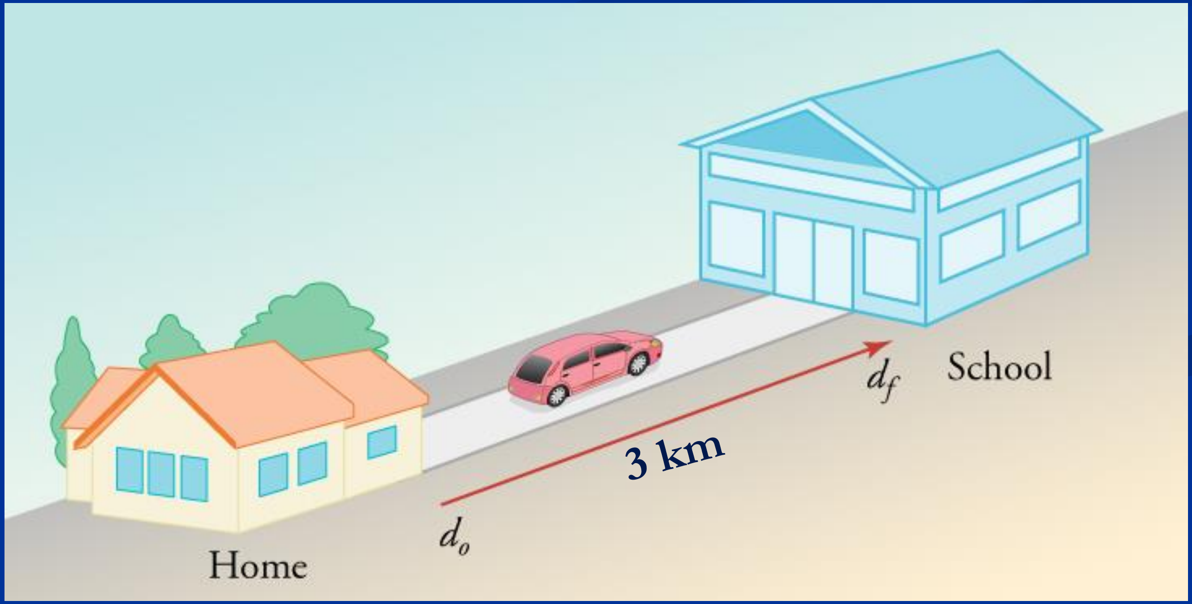
Distance and Displacement

Speed and Velocity

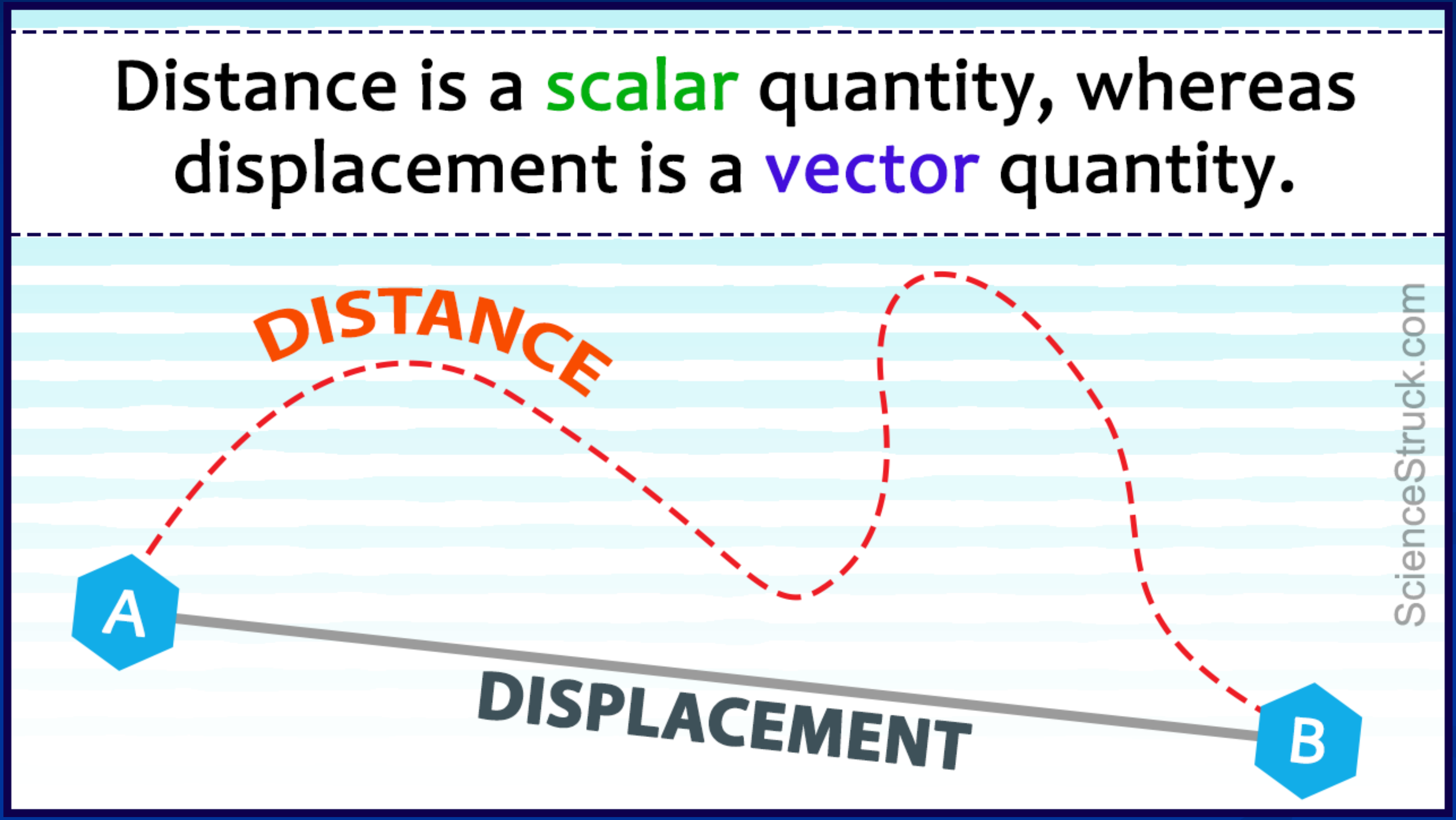


Distance

- is the length traveled between the starting point and the final point
- is the total movement of an object without any regard to direction.
- It’s a scalar quantity, has just magnitude
- It is measured in length units such as meters, km



Distance and Displacement

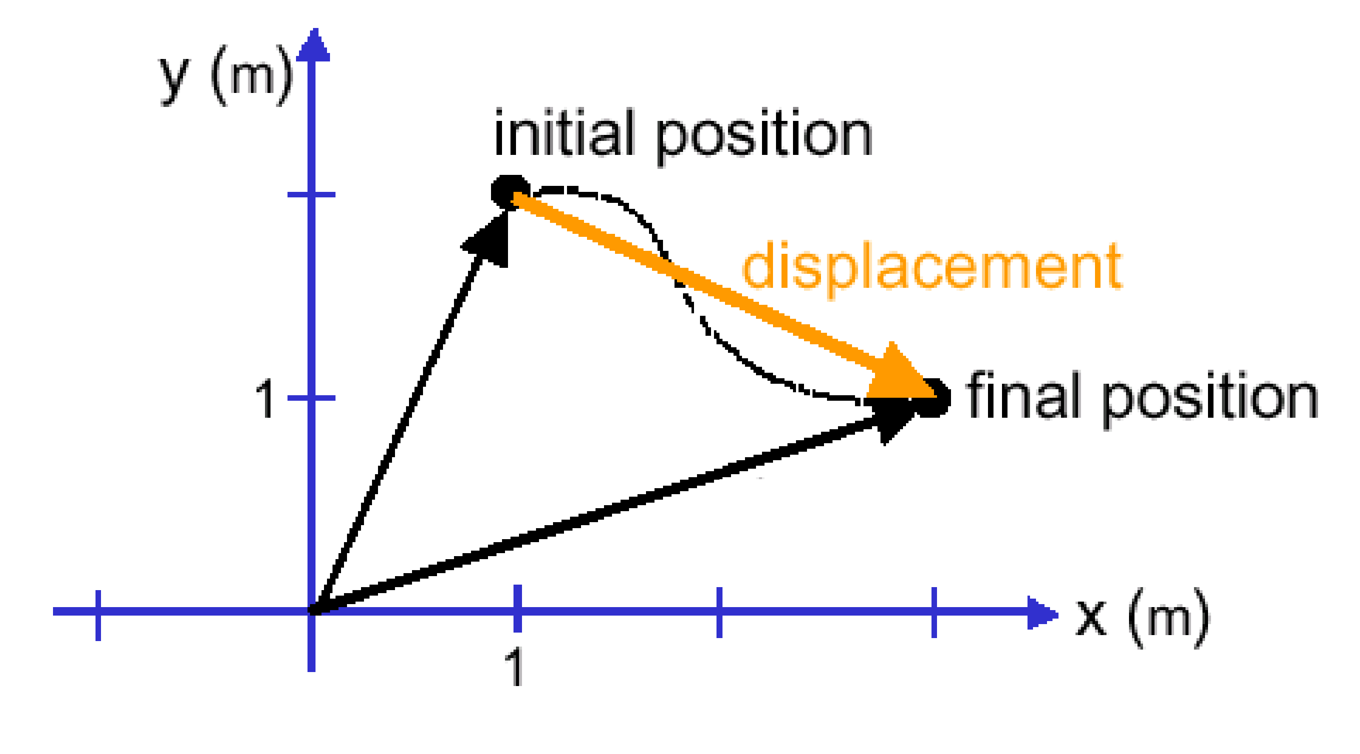


Distance measures the total distance travelled, no matter in which direction.

Displacement is the length measured from the starting point to the finishing point in a straight line.

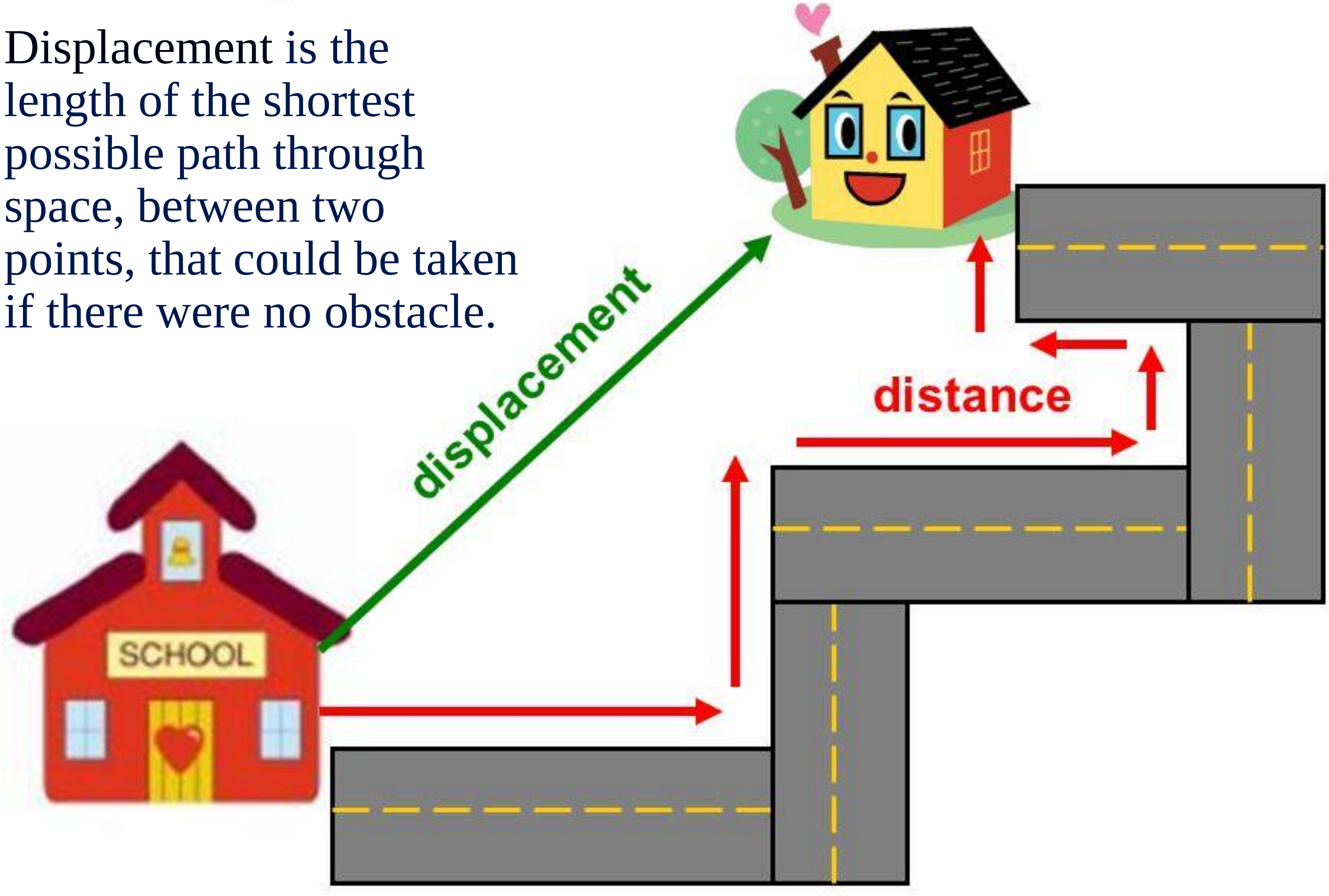
Linear Displacement

- It is defined as the change in position of an object
- It is represented as an arrow that points from the starting position to the final position
- It's a vector, has magnitude and direction
- It is measured in length units such as meters, km



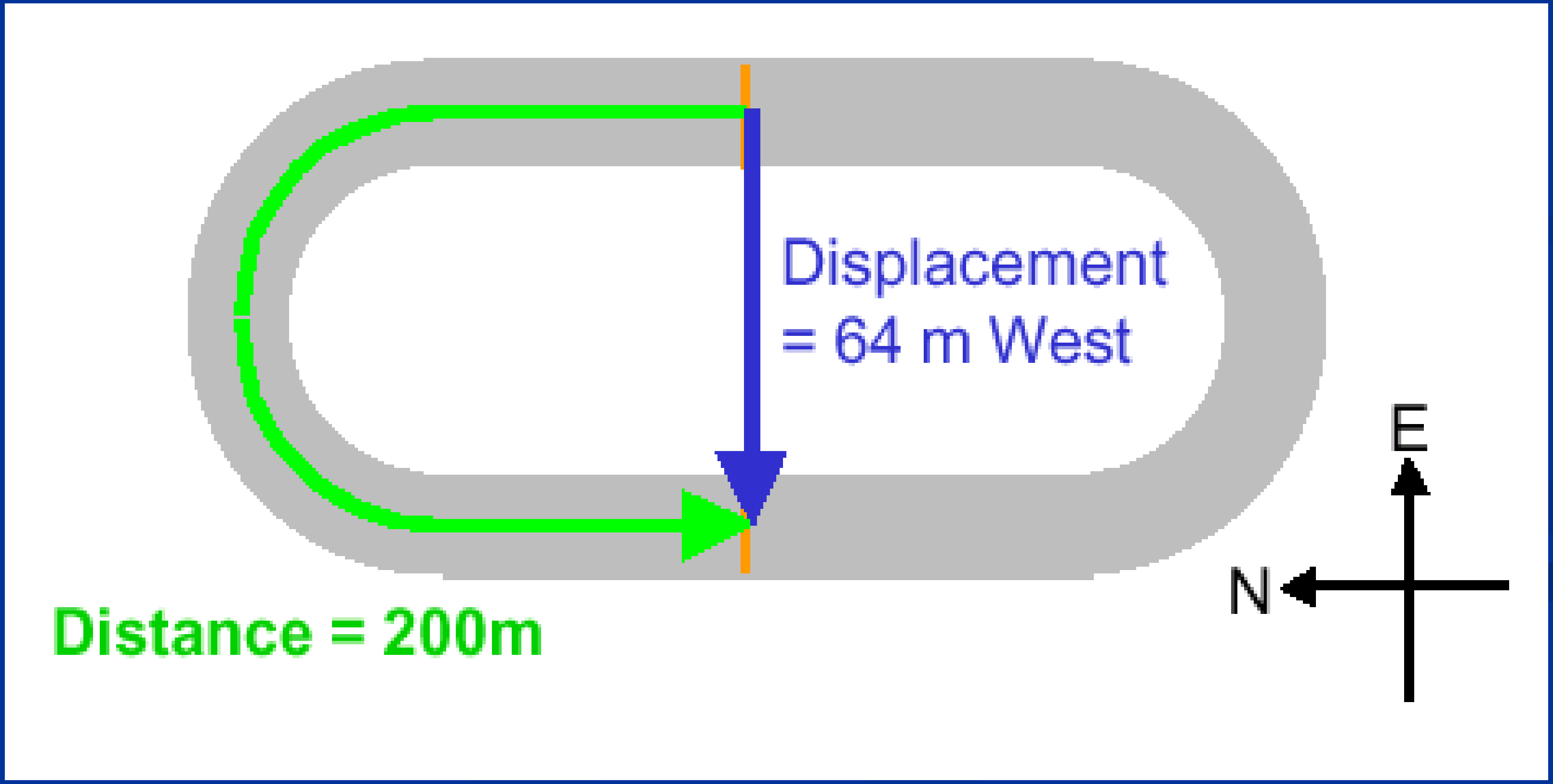
Displacement Vs distance

- Displacement is the length of the shortest possible path through space, between two points, that could be taken if there were no obstacle.

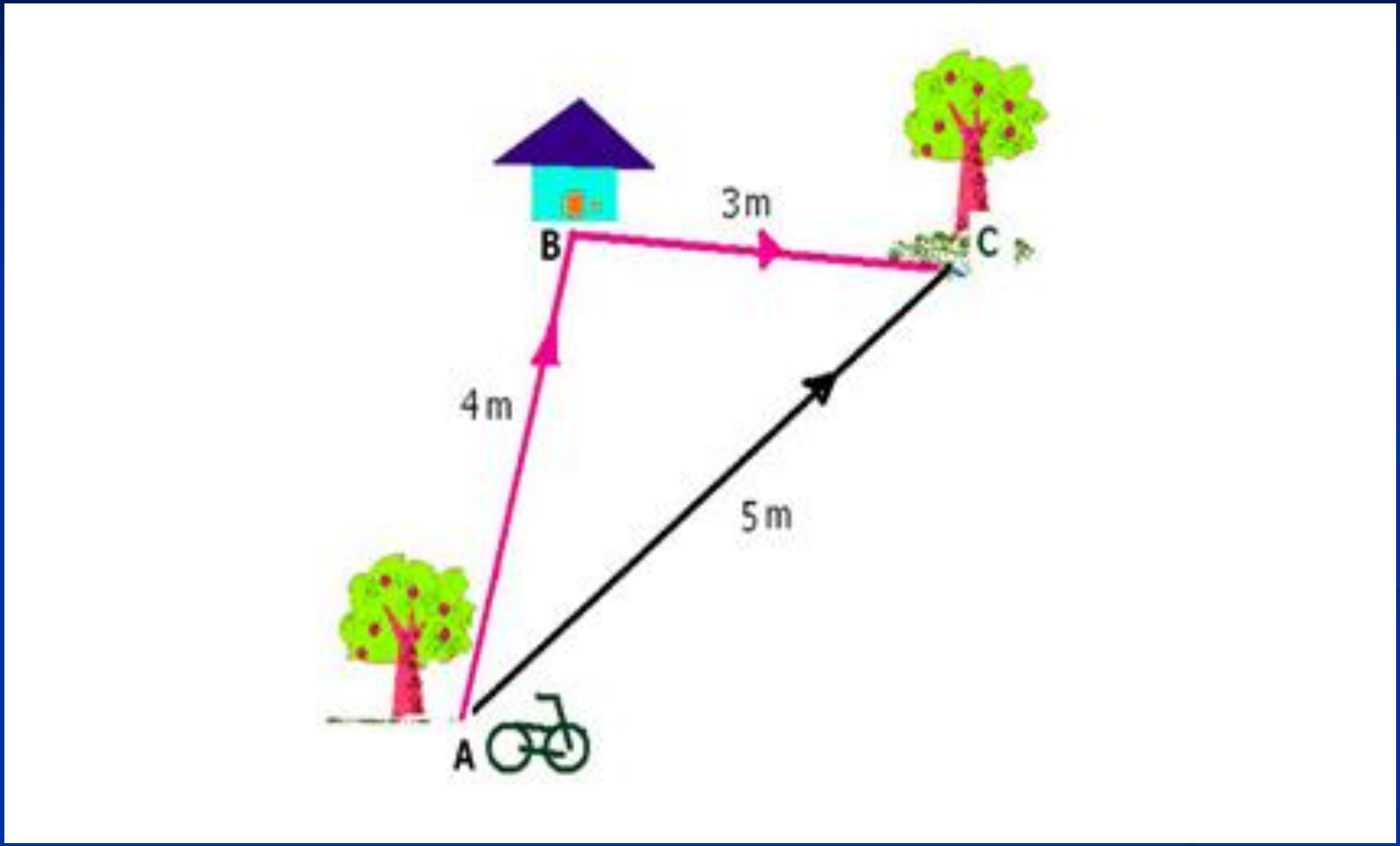


Distance and Displacement

- distance ≥ displacement



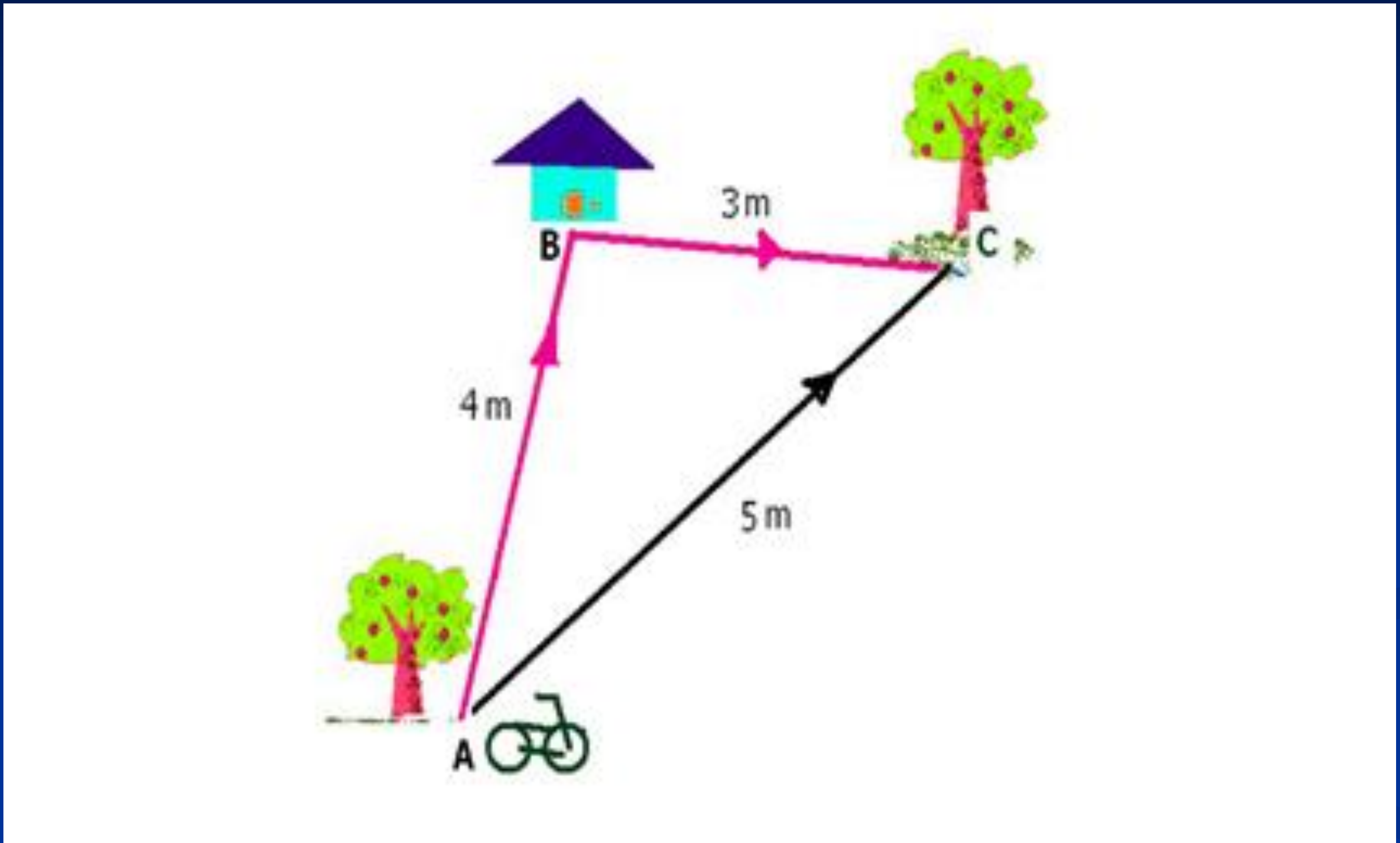
Distance and Displacement



A = initial position
B = intermediate position
C = final position

Distance?
Displacement?

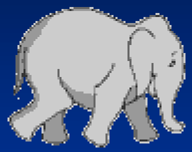
Distance and Displacement



Distance = AB + BC = 4+3 = 7 m

Displacement = final position – initial position = CA = 5 m

Distance and Displacement

A  5 steps B

A = initial position

B = final position

Distance?

Displacement?

Distance = AB = 5 steps

Displacement = final position – initial position = BA = 5 steps

Distance = Displacement *in this case*

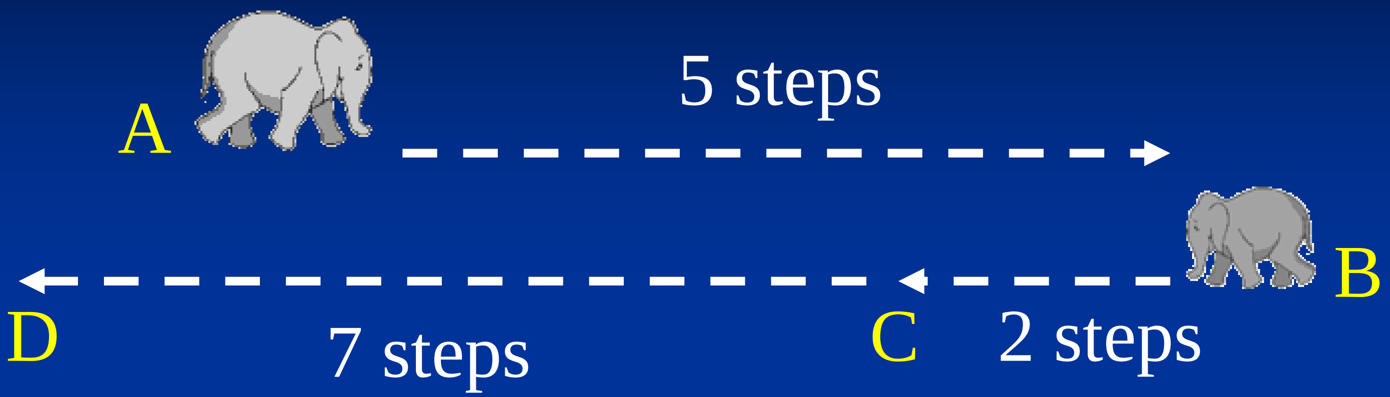
Distance and Displacement

A = initial position
B = intermediate position
C = final position

Distance?
Displacement?

Distance = AB + BC = 5 + 2 = 7 steps
Displacement = CA = 5 – 2 = 3 steps

Distance and Displacement



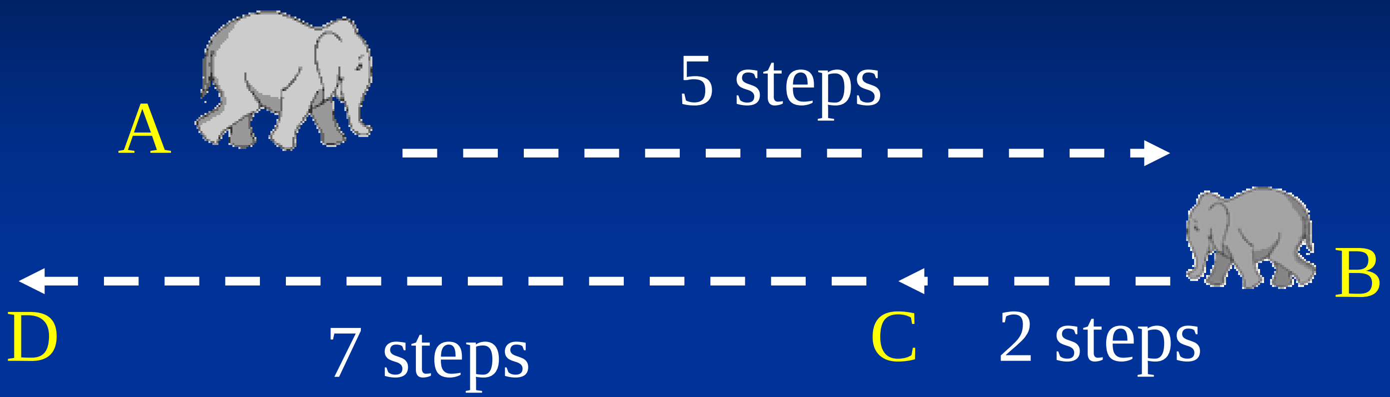
A = initial position
B = intermediate1 position
C = intermediate2 position
D = final position

Distance?
Displacement?

Distance = AB + BC + CD = 5+2+7 = 14 steps

Displacement = AB – BC – CD = 5 – 2 – 7 = – 4 steps

Distance and Displacement

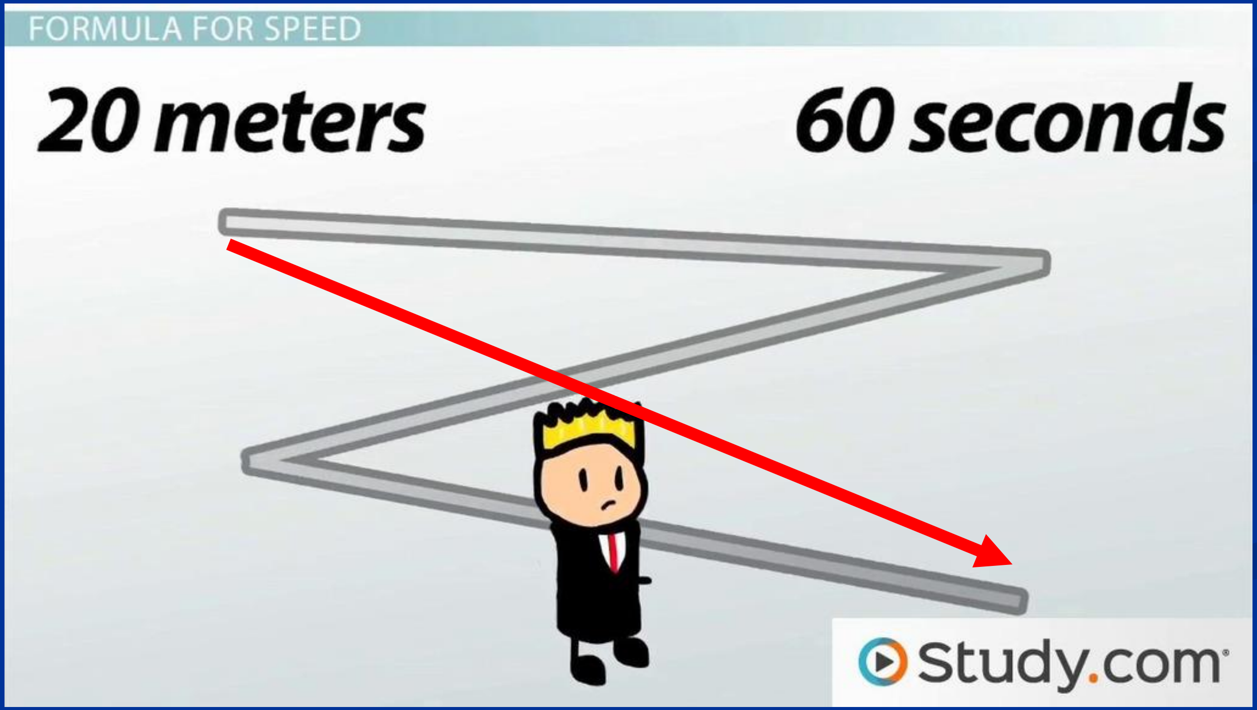


Distance = 14 steps

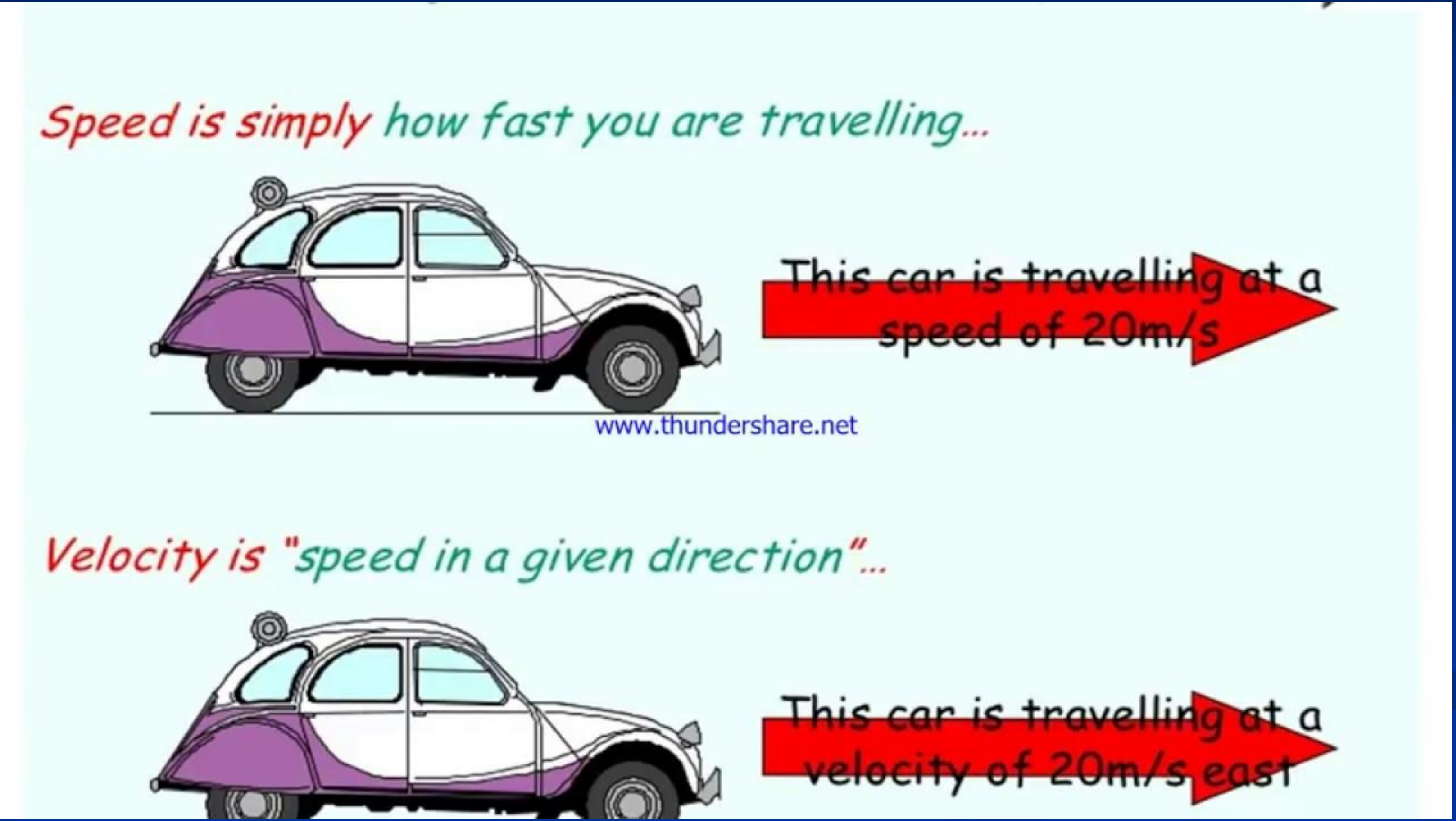
Displacement = – 4 steps

=> Displacement can be negative when you are on the other side of the starting point.

Speed and Velocity



Speed and Velocity



Speed and Velocity

- The scalar quantity
- magnitude of the rate of change of an object's movement.


=> 45 km/h

- The vector quantity
- magnitude of the rate of change of position and also the direction of an object's movement.


=> 45 km/h Est

Speed and Velocity

- **Speed** of a body is the distance travelled by it per unit time.
- SI unit: $\frac{m}{s}$

m/s, ms $^{-1}$

mph

$$\text{Speed} = \frac{Distance}{time}$$

$$v = \frac{d}{t}$$

- **Velocity** of a body is the distance travelled by it per unit time in a given direction.
- SI unit: $\frac{m}{s}$

$$\text{Velocity} = \frac{Displacement}{time}$$

$$v = \frac{D}{t}$$

Speed and Velocity - example

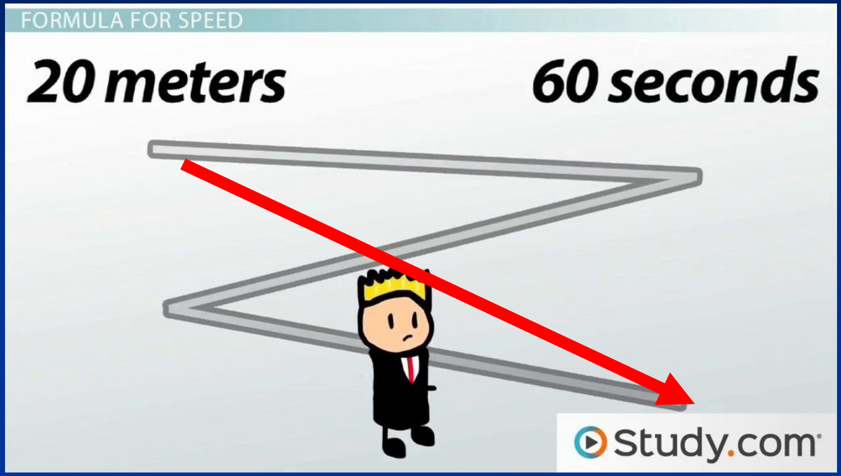
d = 20 m

t = 60 s

D = 7 m SE

v = ?

Velocity = ?



$$v = \frac{d}{t} \qquad v = \frac{20}{60} = 0{,}33 \text{ m/s}$$

$$\text{Velocity} = \frac{D}{t}$$

$$\text{Velocity} = \frac{7}{60} = 0{,}11 \text{ m/s SE}$$

Speed and Velocity - example

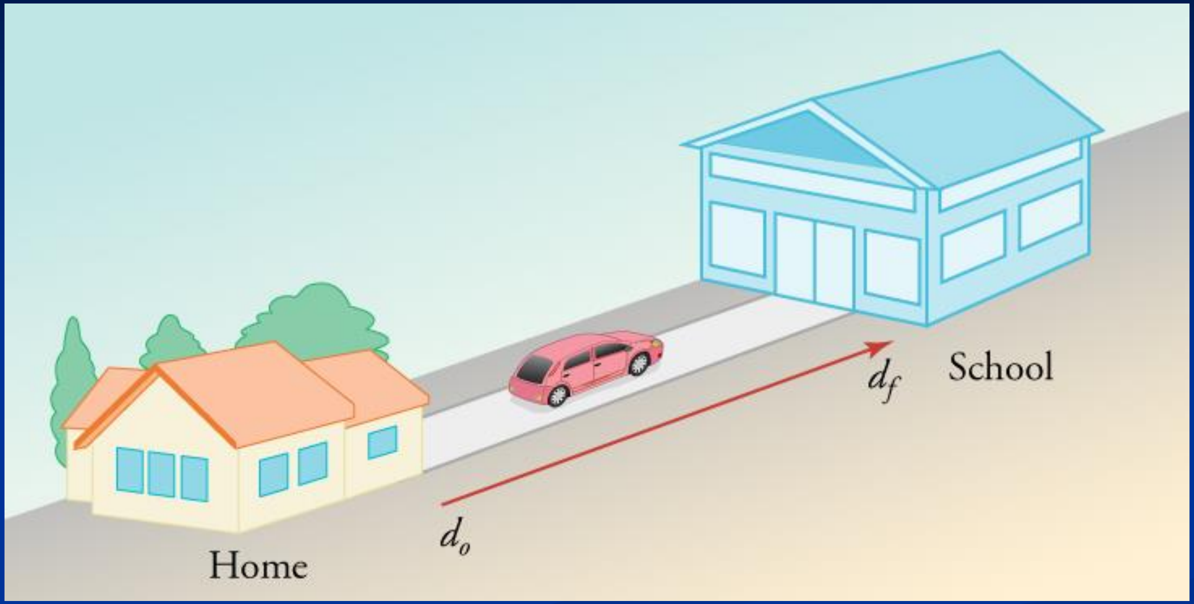
d = 45 km

t = 60 minutes

---

v = ?

Velocity = ?



We always start with the formula: $v = \frac{d}{t}$

Notice that the time is in minutes and the distance in kilometers.
So, we must to transform the time from minutes in hours.

We know that an hour has 60 minutes.
So we have to find out how many hours is 54 minutes
(x h = 54 min; x = ?)

Speed and Velocity

d = 45 km

t = 54 minutes

---

v = ?

Velocity = ?

1 h ……………… 60 min

x h ……………… 54 min

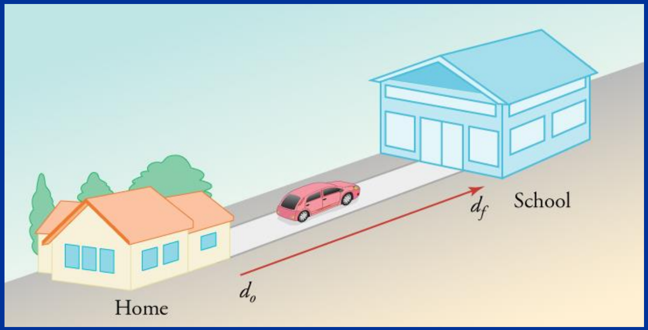
---

x = 54 / 60 = 0,9 h

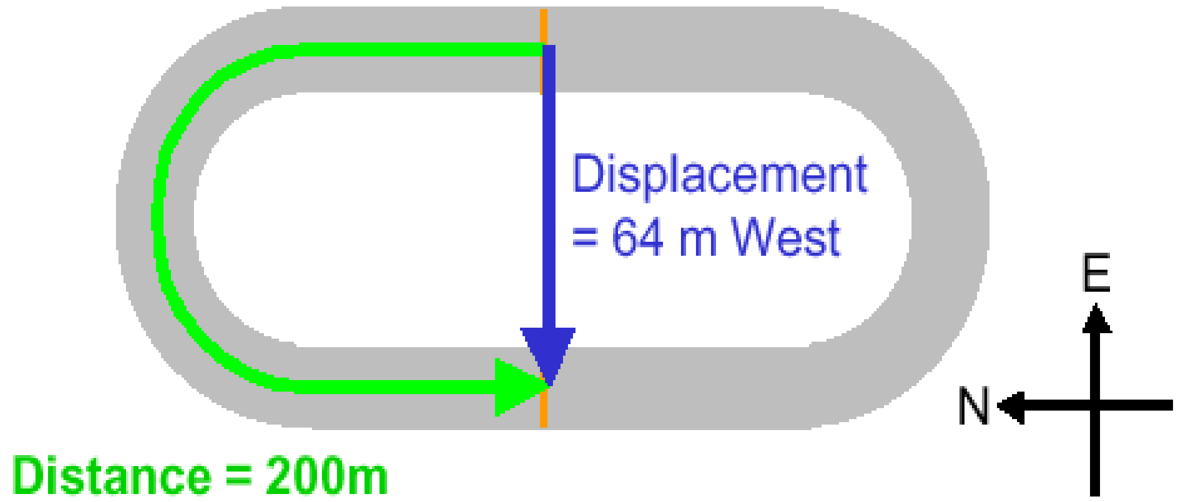
$$v = \frac{45}{0,9} = 50 \text{ km/h}$$

$$Velocity = \frac{D}{t}$$

$$Velocity = \frac{45}{0,9} = 50 \text{ km/h E}$$



Speed and Velocity



Assume a runner takes 25 s to run 200 m:

Speed= ?

Velocity = ?

Speed and Velocity

d = 200 m

t = 25 s

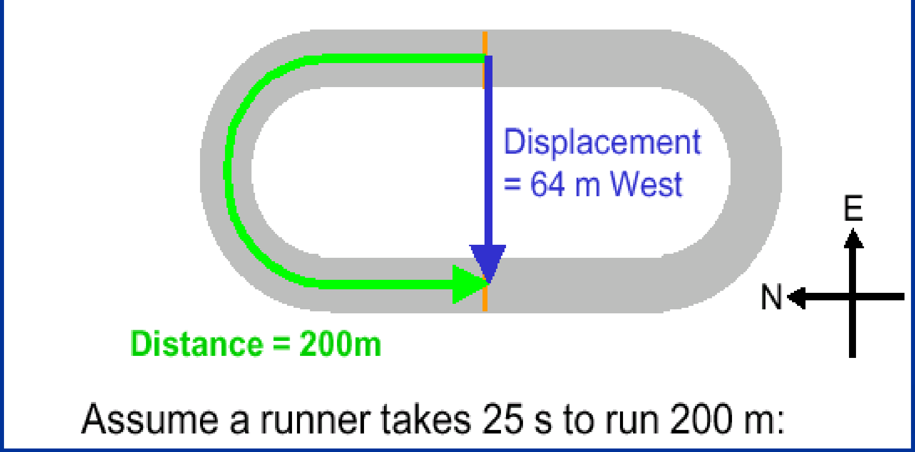
v = ?

Velocity = ?

$$v = \frac{d}{t}$$

$$v = \frac{200}{25} = 8\ \mathrm{m/s}$$

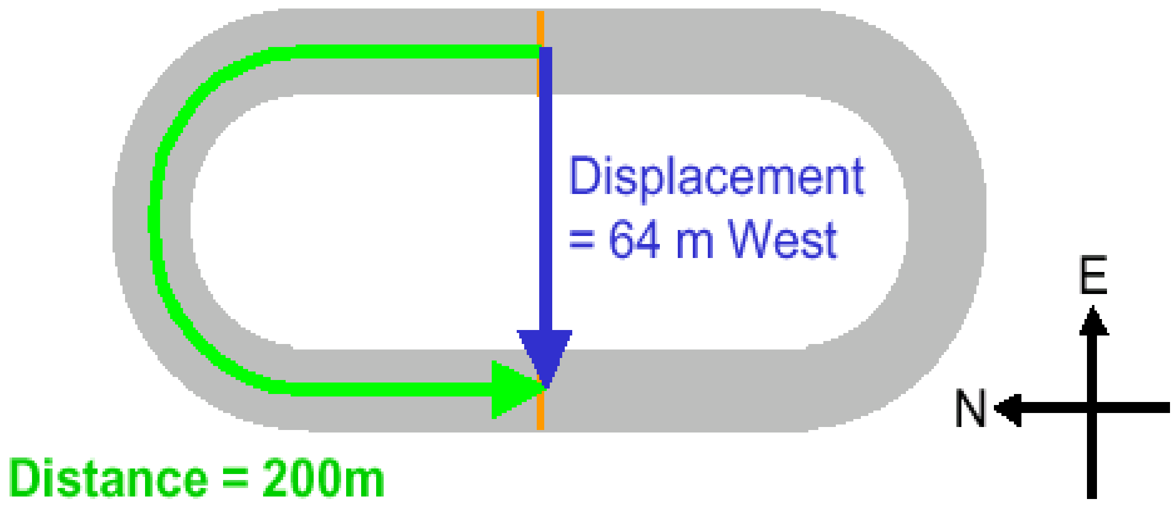
$$Velocity = \frac{D}{t}$$



$$Velocity = \frac{64}{25} = 2{,}56\ \mathrm{m/s\ West}$$

velocity = 2,56 m/s West

Speed and Velocity



Assume a runner takes 25 s to run 200 m:

$$\text{Speed} = \frac{200\ \text{m}}{25\ \text{s}} = 8\ \text{m/s}$$

$$\text{Velocity} = \frac{64\ \text{m West}}{25\ \text{s}} = 2.6\ \text{m/s West}$$

Speed and Velocity

d = 7 m

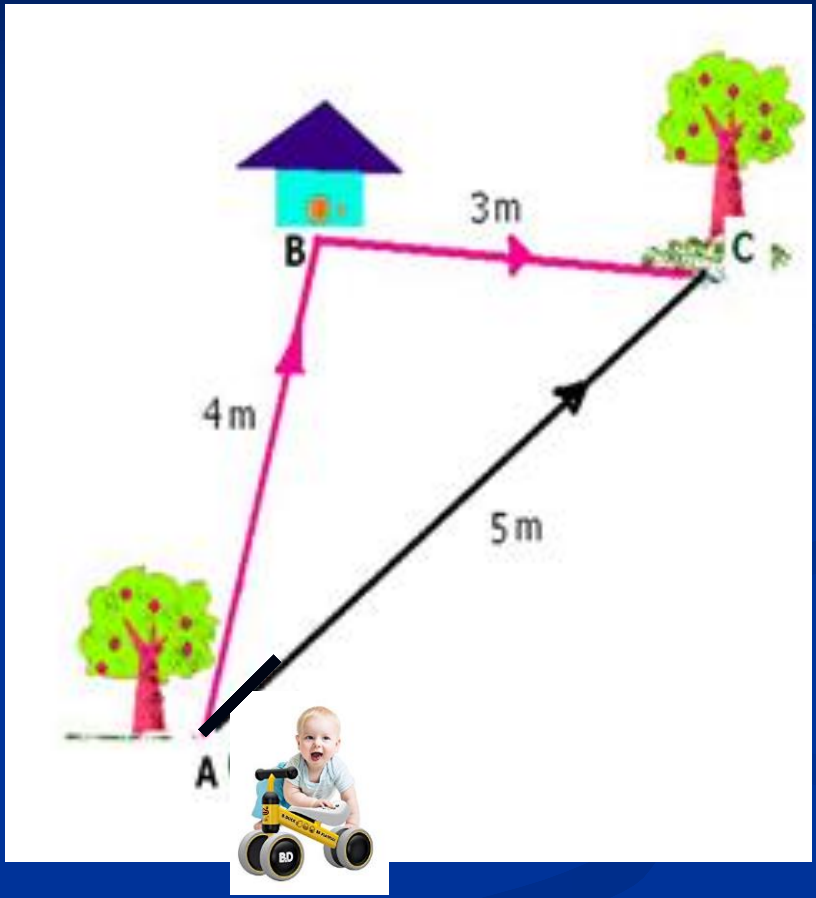
t = 6 minutes

D = 5 m

---

v = ?

Velocity = ?



Speed and Velocity

d = 7 m

t = 6 minutes

D = 5 m

---

v = ?

Velocity = ?

$$v = \frac{d}{t}$$

1 min ……………… 60 sec

6 min ……………… x sec

---

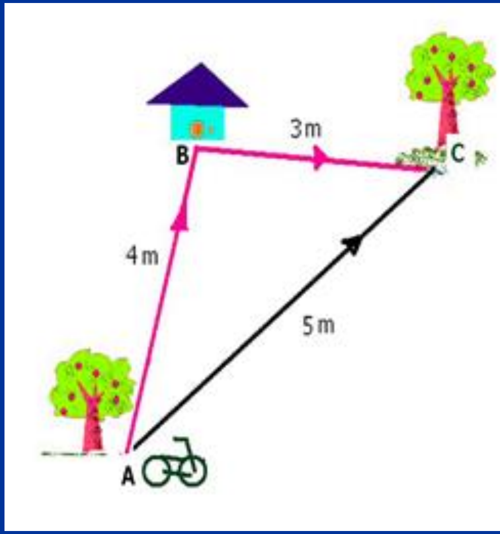
x = (60 * 6) / 1 = 360 sec

$$v = \frac{7}{360} = 0{,}029 \text{ m/s}$$

$$Velocity = \frac{D}{t}$$

$$Velocity = \frac{5}{360} = 0{,}013 \text{ m/s NE}$$

$$Velocity = 0{,}013 \text{ m/s NE}$$



Average Speed

- **Instantaneous Speed** = The speed of an object at a given moment.

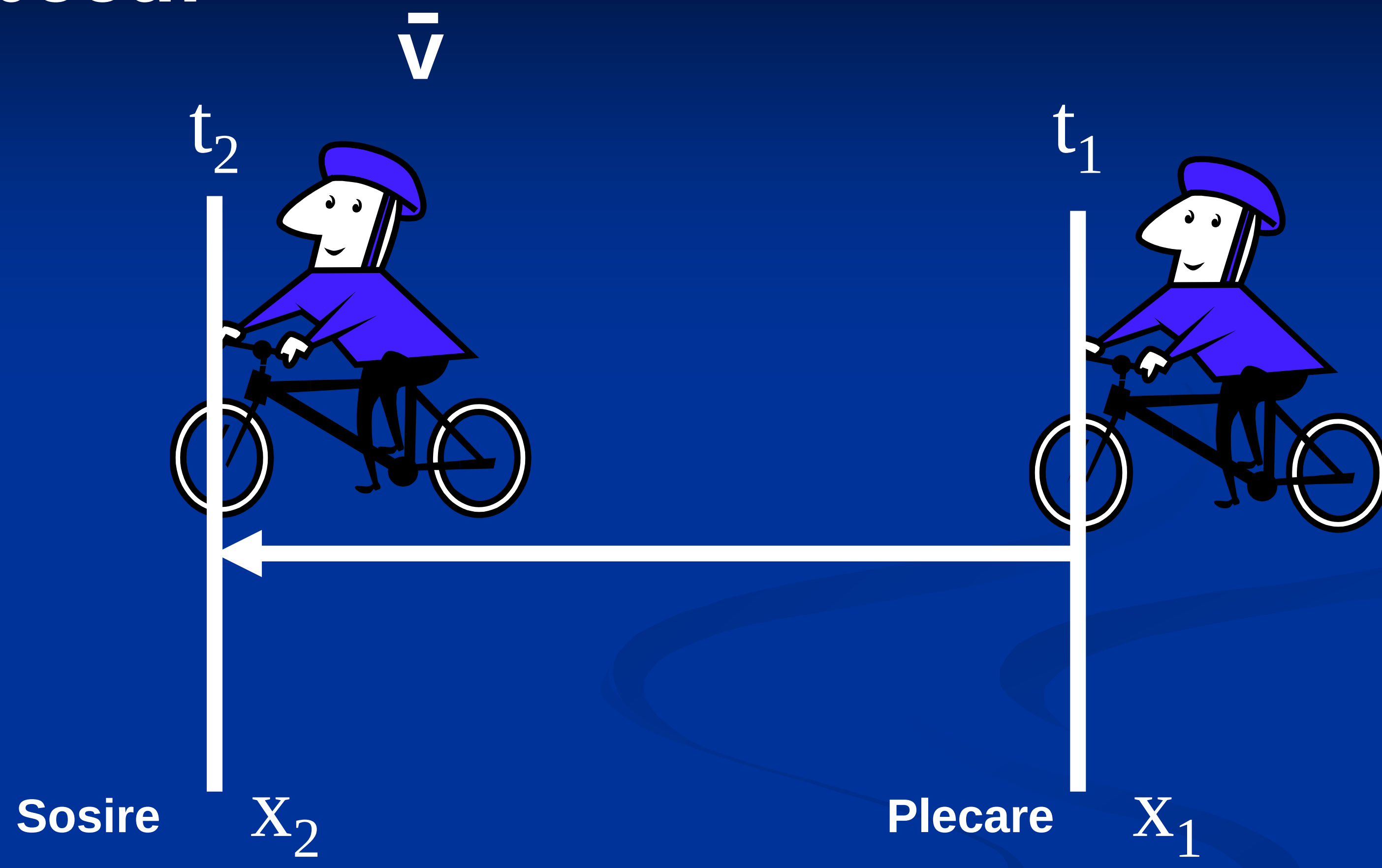
  ➡ The car may be travelling at 50 km/h at this moment, but it may slow down or speed up during the next hour.

- **Average Speed** - The average speed is calculated by the distance that an object traveled over a given interval of time.

  ➡ If a car traveled 50 km over the course of one hour then its average speed will be 50 km/h.

It may be that the car traveled at instantaneous speeds of 40 km/h and 60 km/h during that time, but the average speed is 50 km/h.

Average Speed:



$\bar{v} = (X_2 - X_1) / (t_2 - t_1)$

$= \Delta X / \Delta t$ (m/s or $m.s^{-1}$)

Δ = delta = variation

Average Speed - example

- A motorcycle traveled 250 kilometers in 5 hours. What was the average speed?

d= 250 km

t = 5 h

----

v = ?

v = d/t

v = 250 / 5 = 50 km/h

Linear Acceleration

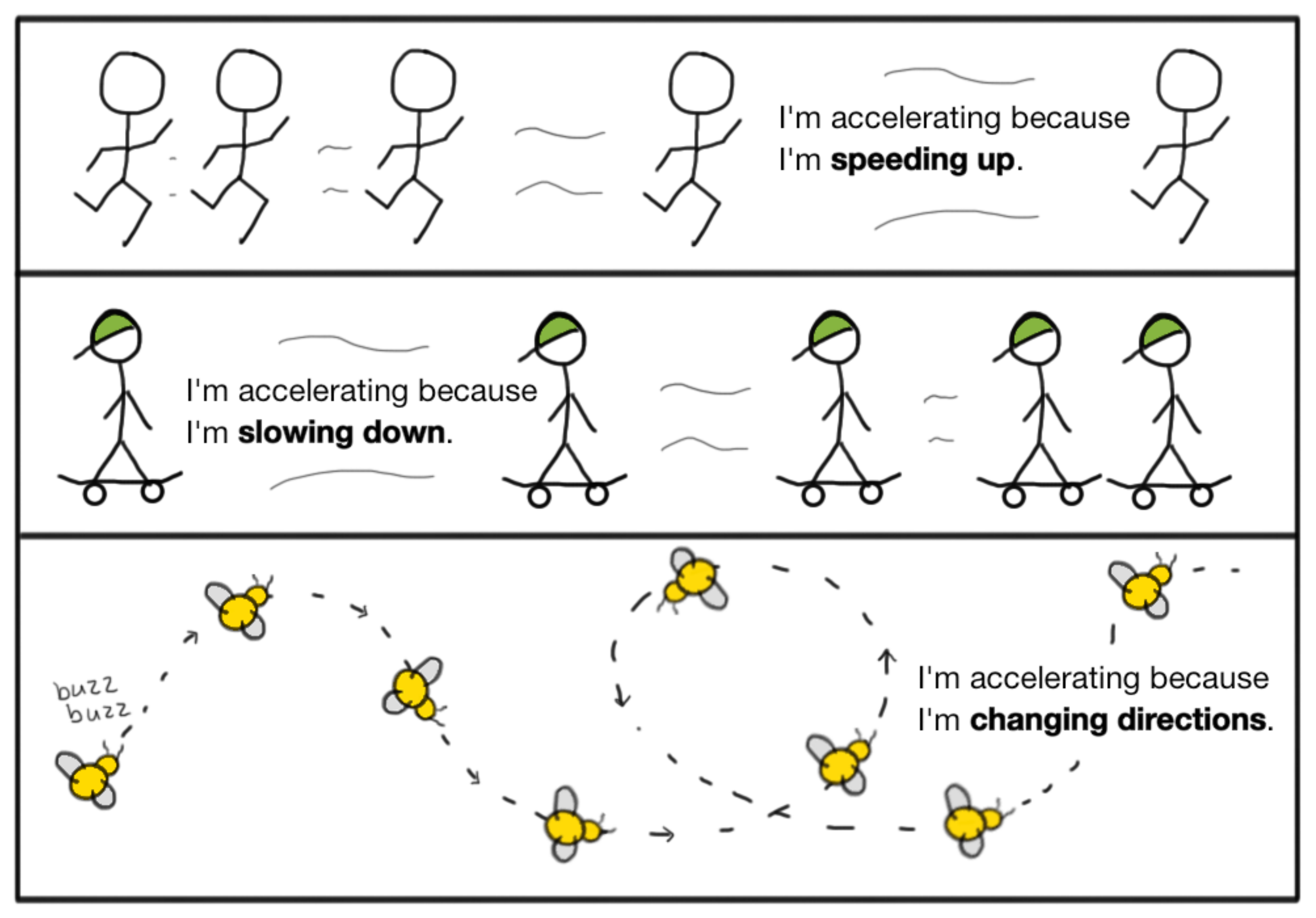
- the rate of change of linear velocity with respect to time; represents the velocity variation in time unit;
- is a vector; has magnitude and direction
- has units: length /time^2; m/s^2
- may be positive or negative, after the sign of Δ v

$$a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

If $v_2 > v_1$ => Δ v is positive => a = positive => accelerated movement

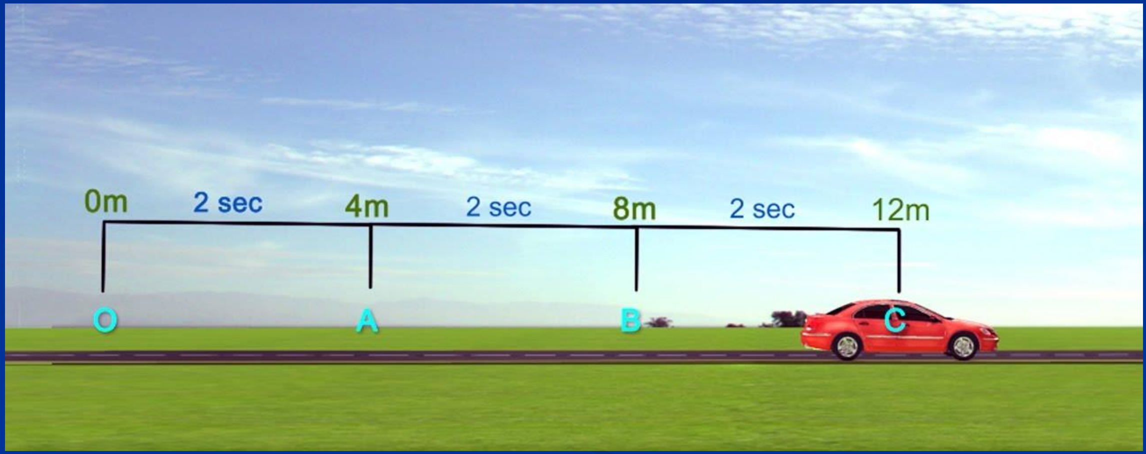
If $v_2 < v_1$ => Δ v is negative => a = negative => deccelerated movement

Acceleration is the name we give to any process where the velocity changes.
Since velocity is a speed and a direction, we can accelerate by: change the speed or change direction — or change both.

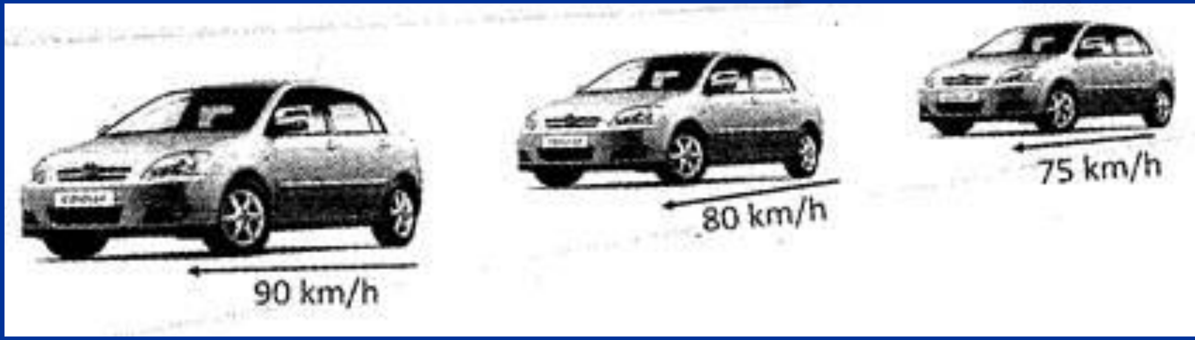


Depending on the two parameters, speed and acceleration, motion can be:

- **uniform: v = const., a = 0**
- **uniform variable: a = const. (uniform accelerated şi uniform decelerated)**



- **non uniform: a = variabile**



Uniform motion

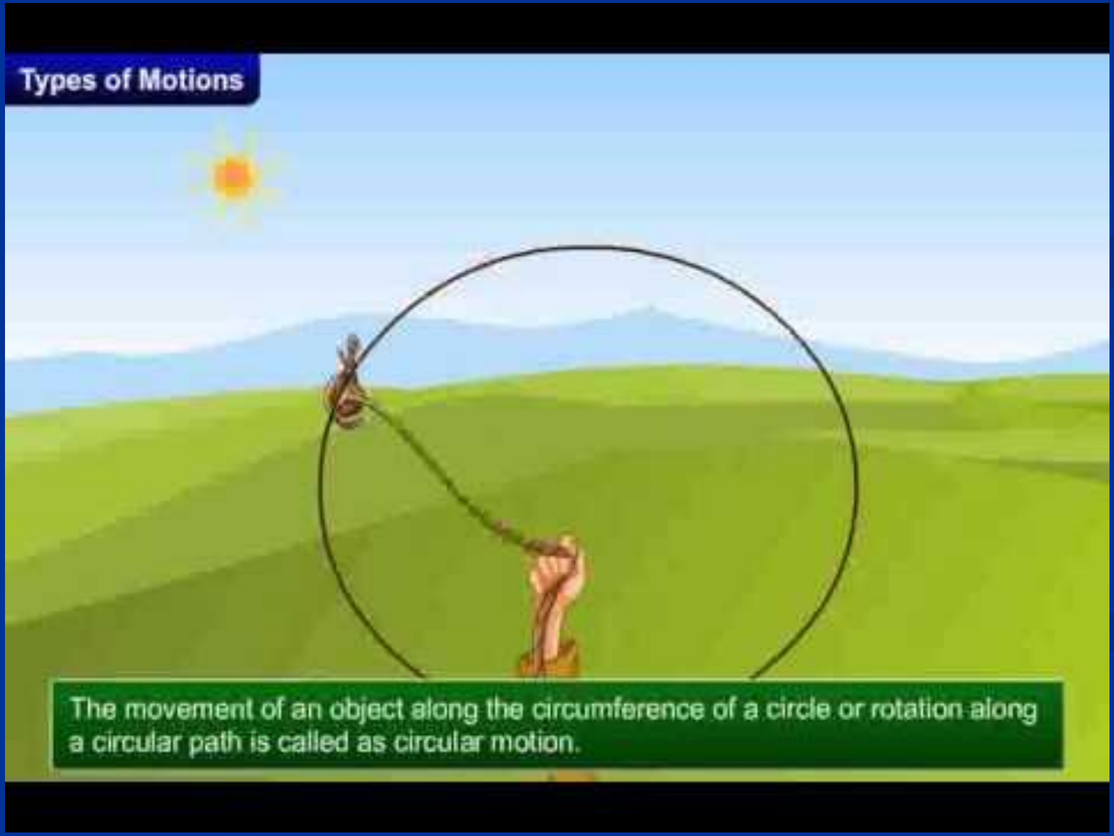
- Car A travels equal distances in equal intervals of time so it is in uniform motion.
- Example 3: The movement of the hands of the clock. They move equal distances in equal interval of time.

Non Uniform Motion

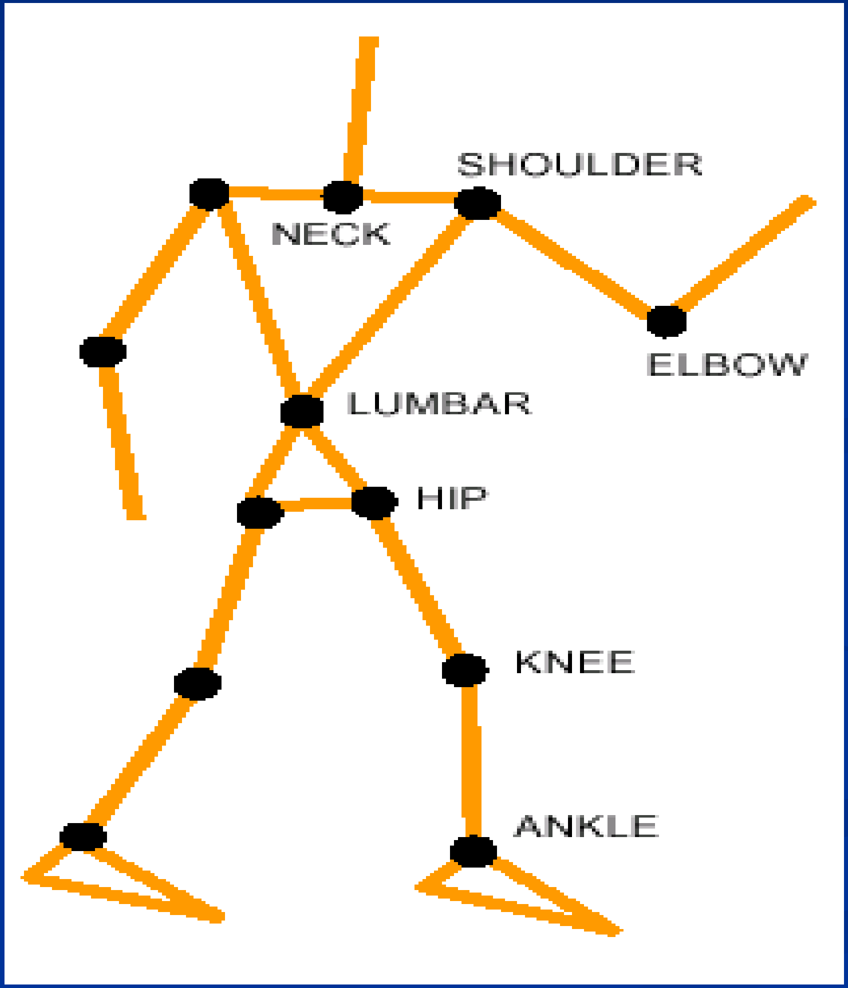
- Car B travels unequal distances in equal intervals of time so it is said to be in non uniform motion.
- Example 3: An athlete running in a race.

Angular motion

- All points in an object or system move in a circle about a single axis of rotation.
- All points move through the same angle in the same time.

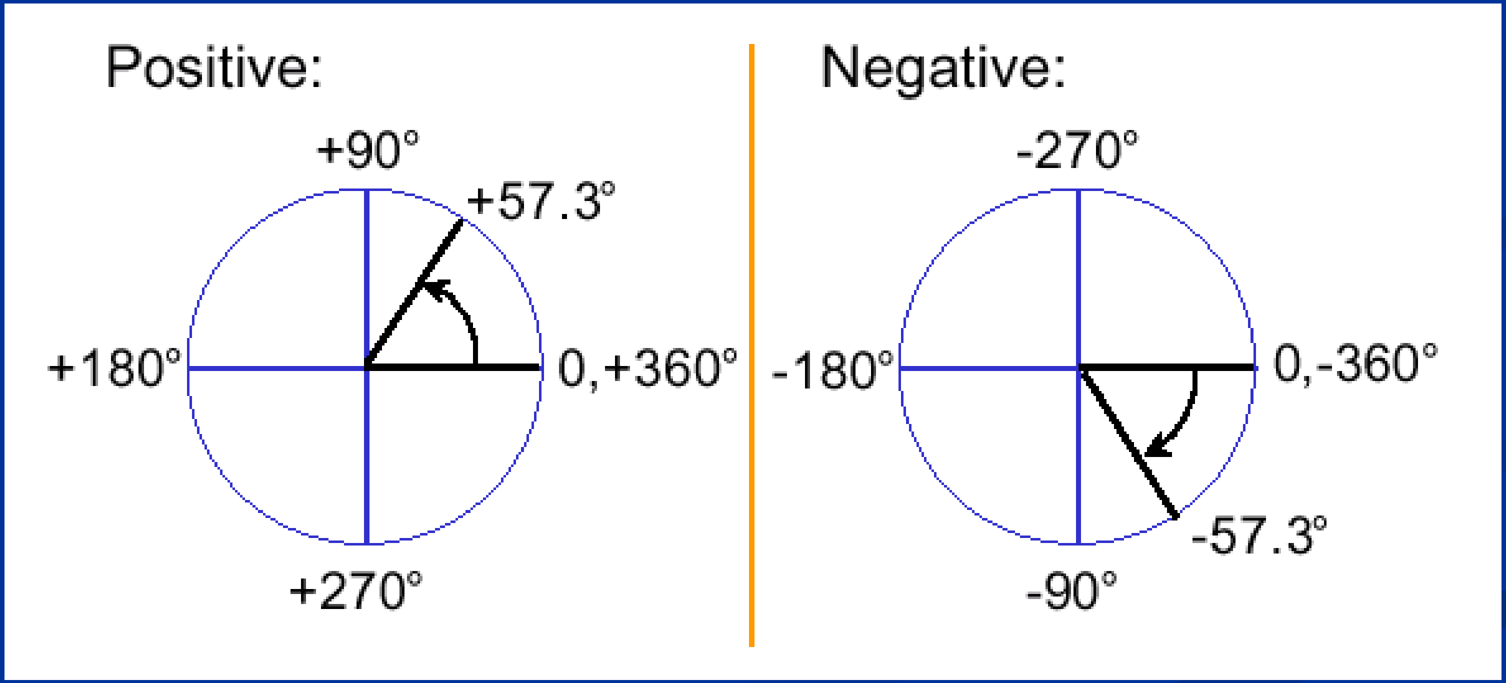


Most volitional movement is performed through rotation of the body segments.



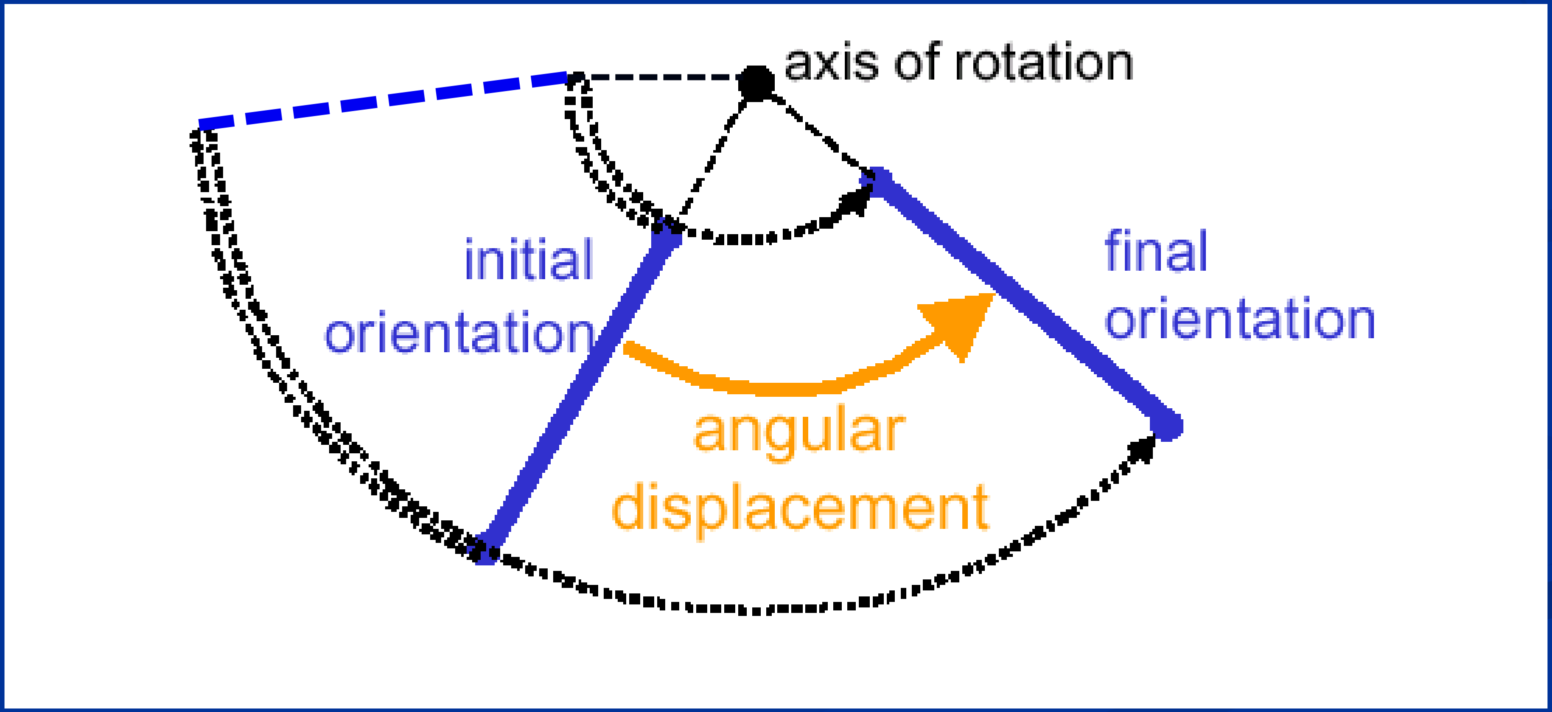
Positive and negative angles

- Positive angles: counterclockwise rotation
- Negative angles: clockwise rotation



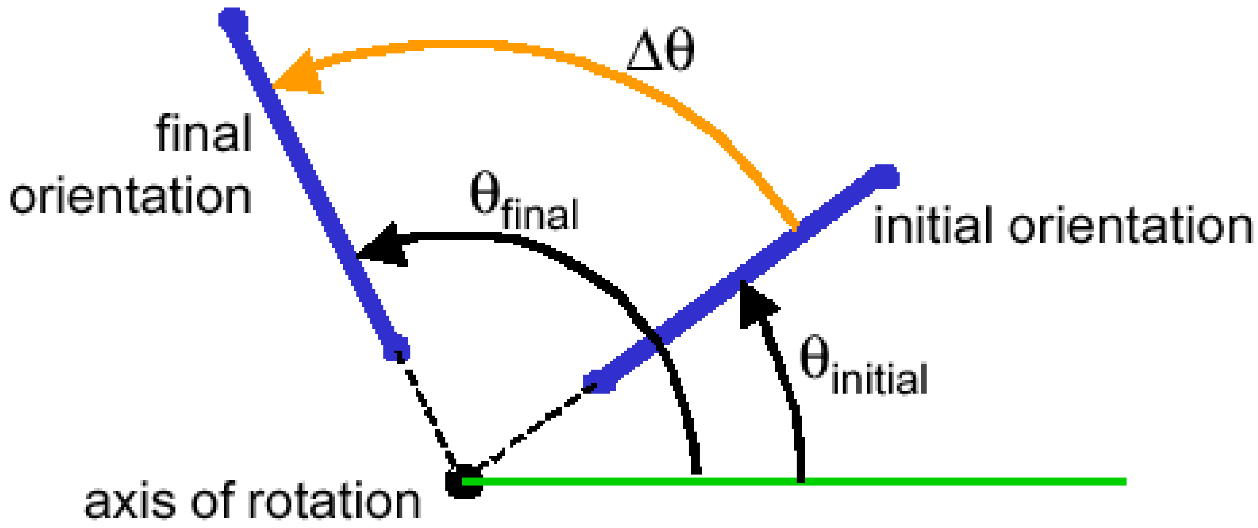
Angular Displacement

- Change in the angular position or orientation of a line segment
- Doesn't depend on the path between orientations
- Has angular units (e.g. degrees, radians)



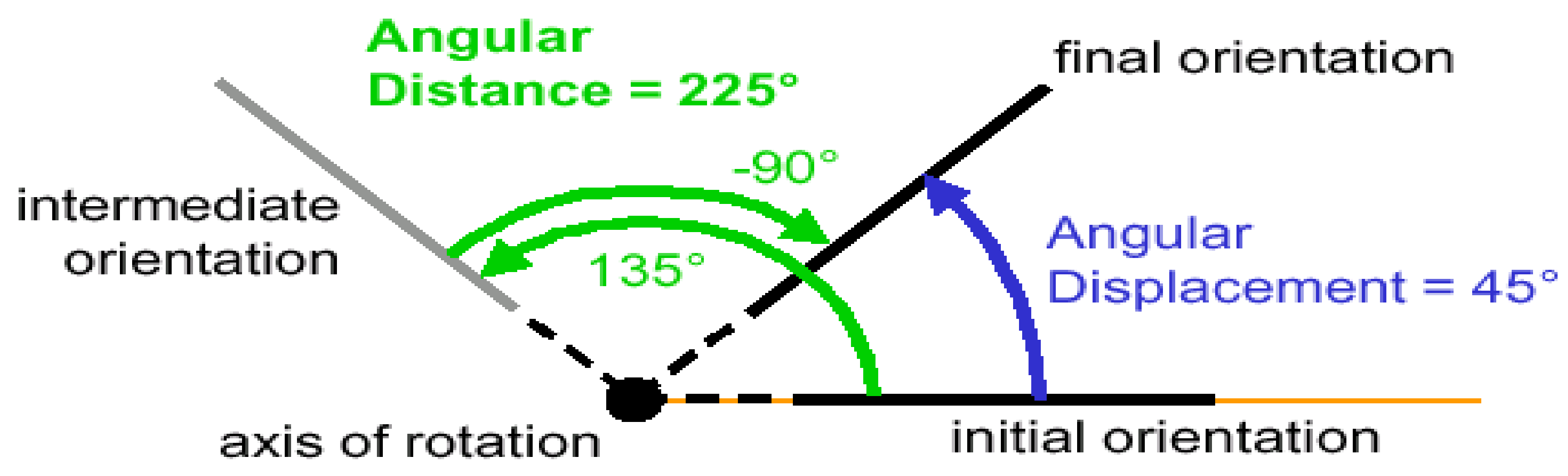
Angular Displacement

$$\Delta\theta = \theta_{final} - \theta_{initial}$$



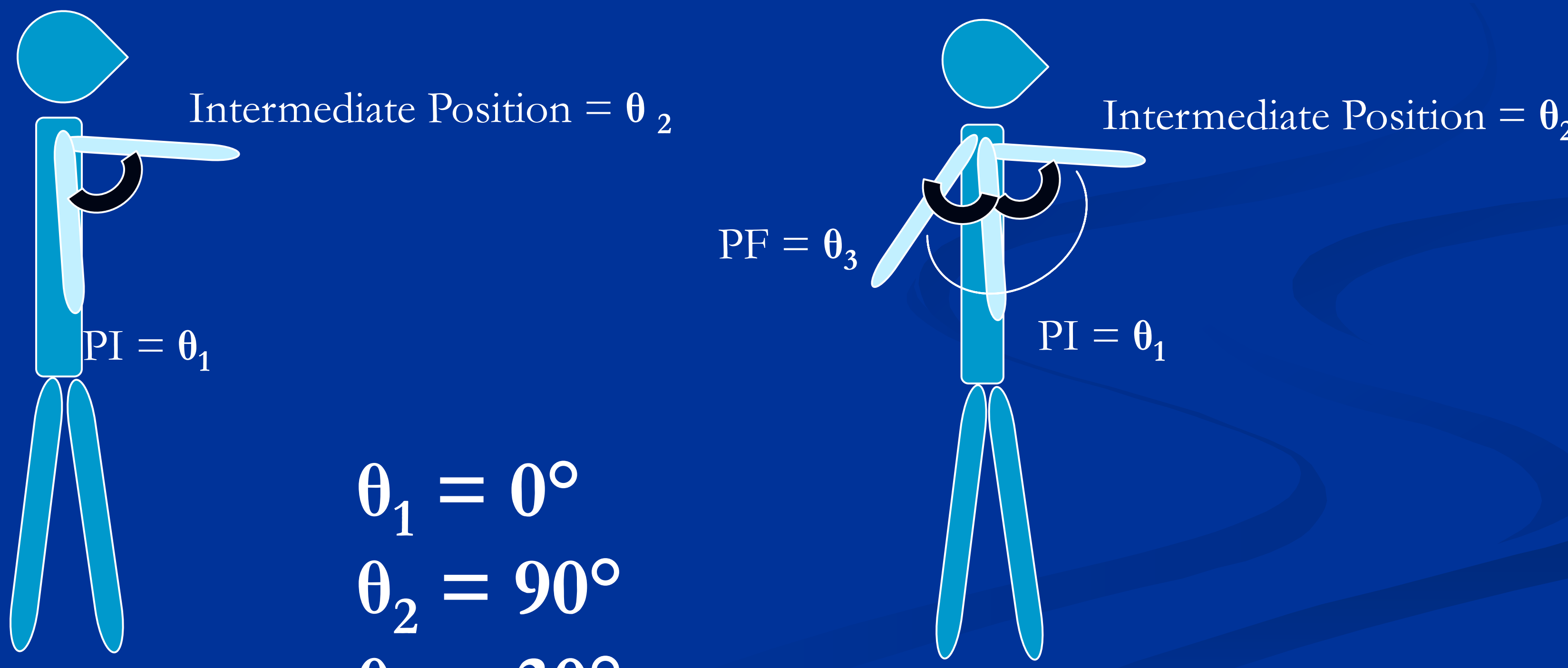
Angular Distance

- Sum of the magnitude of all angular changes undergone by a rotating body
- Has angular units of length (e.g. degrees, radians)
- Distance ≥ Magnitude of displacement



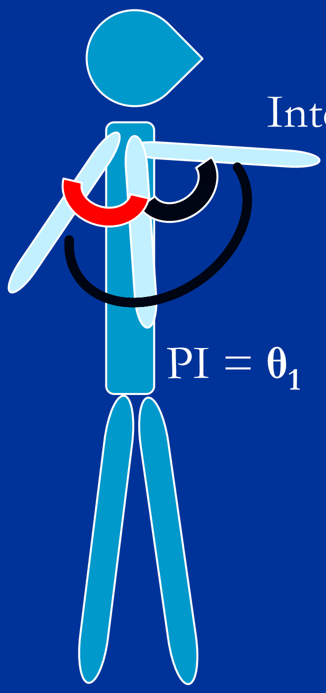
Tennis stroke

An individual performs the arm flexion on the trunk up to 90°, then the arm extension on the trunk up to 30°. What is the angular displacement of the arm and what is the angular distance?



$$\theta_1 = 0°$$
$$\theta_2 = 90°$$
$$\theta_3 = 30°$$

An individual performs the arm flexion on the trunk up to 90°, then the arm extension on the trunk up to 30°. What is the angular displacement of the arm and what is the angular distance?



$\theta_1 = 0°$

$\theta_2 = 90°$

$\theta_3 = (–)\ 30°$

Angular displacement

$= \Delta\theta = \theta_3 - \theta_1$

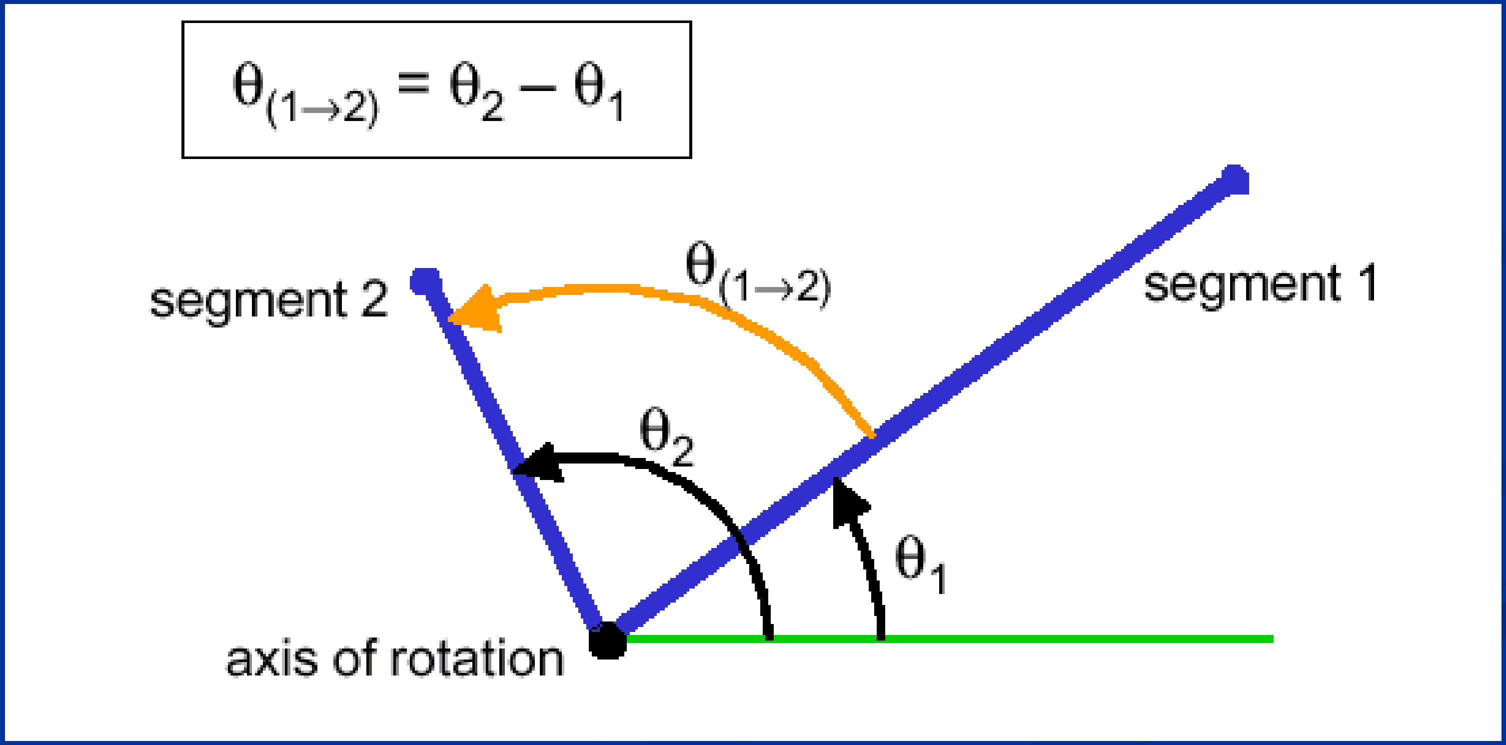
$\Delta\theta = -30° - 0° = -30°$

Angular Distance $= \theta_2 + \theta_2 + \theta_3$

Angular Distance $= 90° + 90° + 30° = 210°$

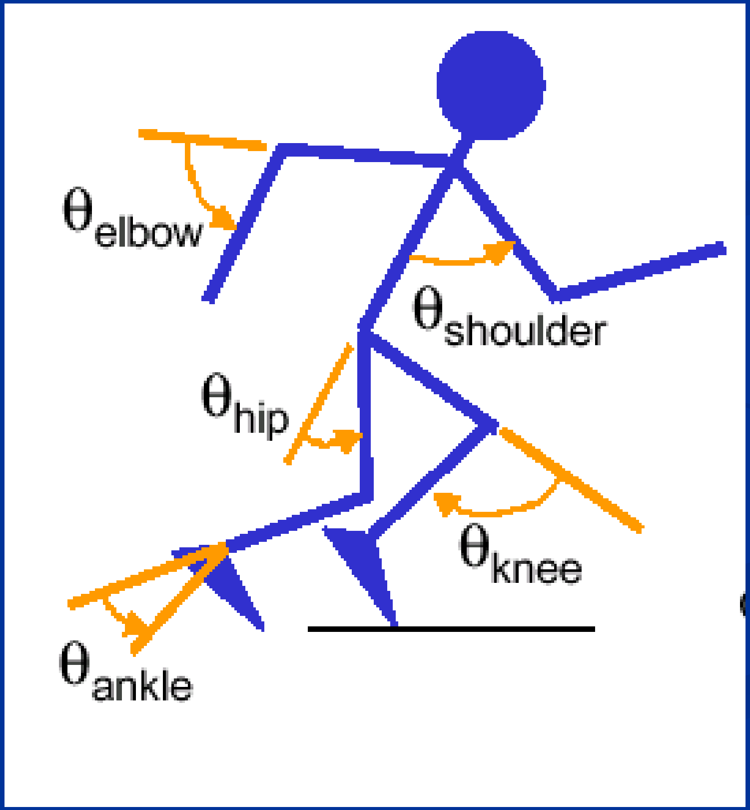
Relative angles

- are angles between two segments



Joint angles

- are relative angles between longitudinal axes of adjacent segments (or between anteroposterior axes for internal rotation)



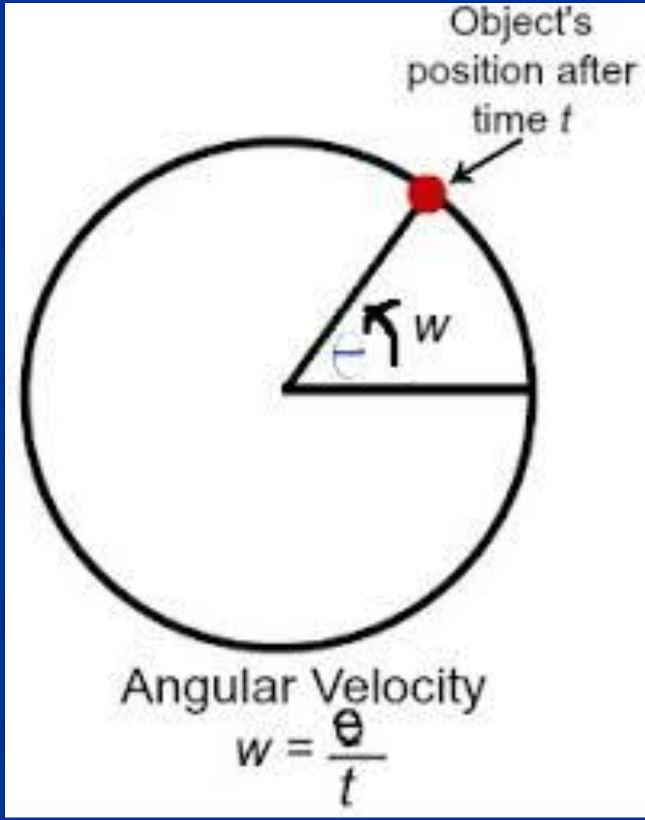
Angular Velocity

- The rate of change in the angular position or orientation of a line segment;

- Has units: rad/s, º/s

$$\begin{pmatrix}\text{angular}\\ \text{velocity}\end{pmatrix} = \frac{\begin{pmatrix}\text{change in angular}\\ \text{position}\end{pmatrix}}{\text{change in time}} = \frac{\begin{pmatrix}\text{angular}\\ \text{displacement}\end{pmatrix}}{\text{change in time}}$$

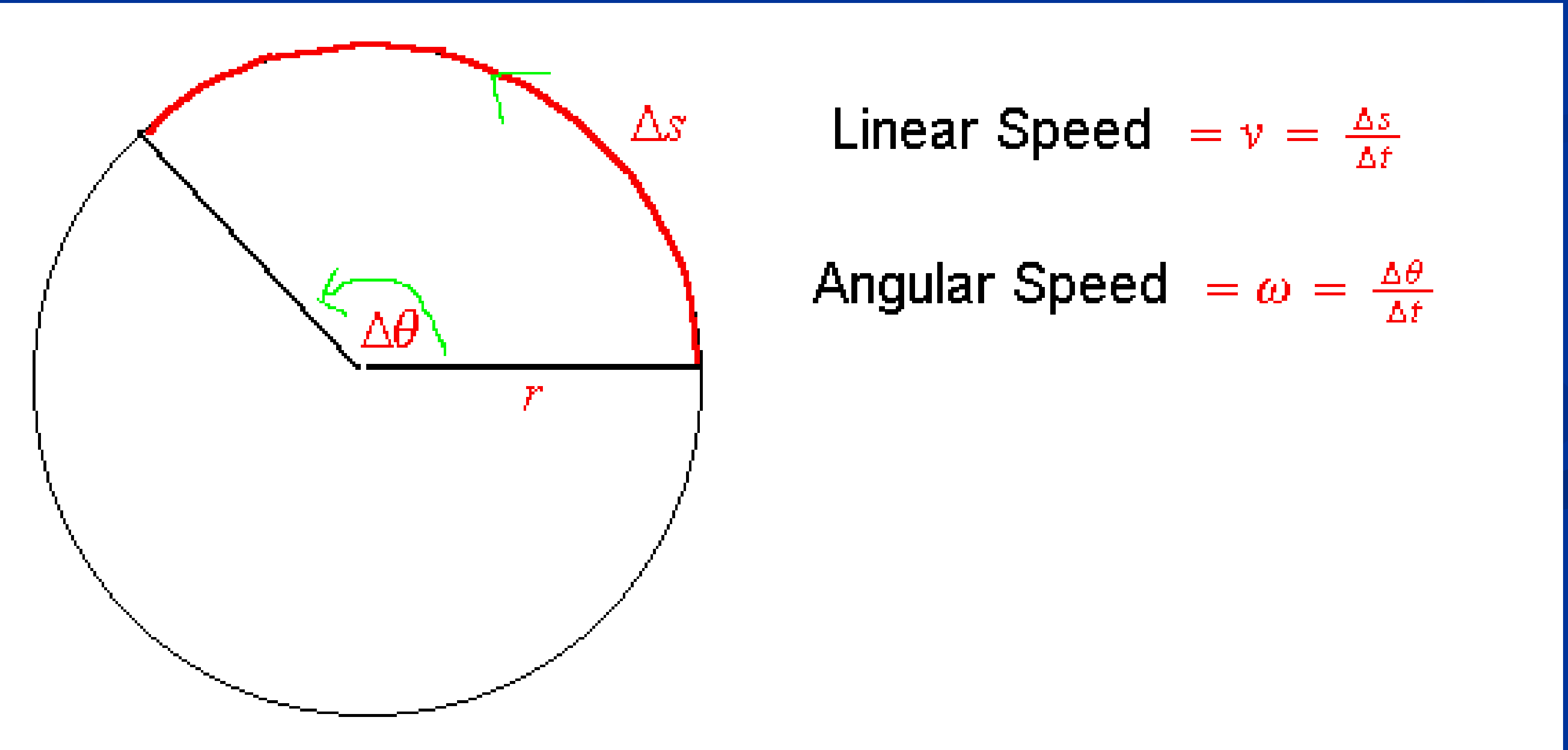
$$\omega = \frac{(\theta_{final} - \theta_{initial})}{(t_{final} - t_{initial})} = \frac{\Delta\theta}{\Delta t}$$



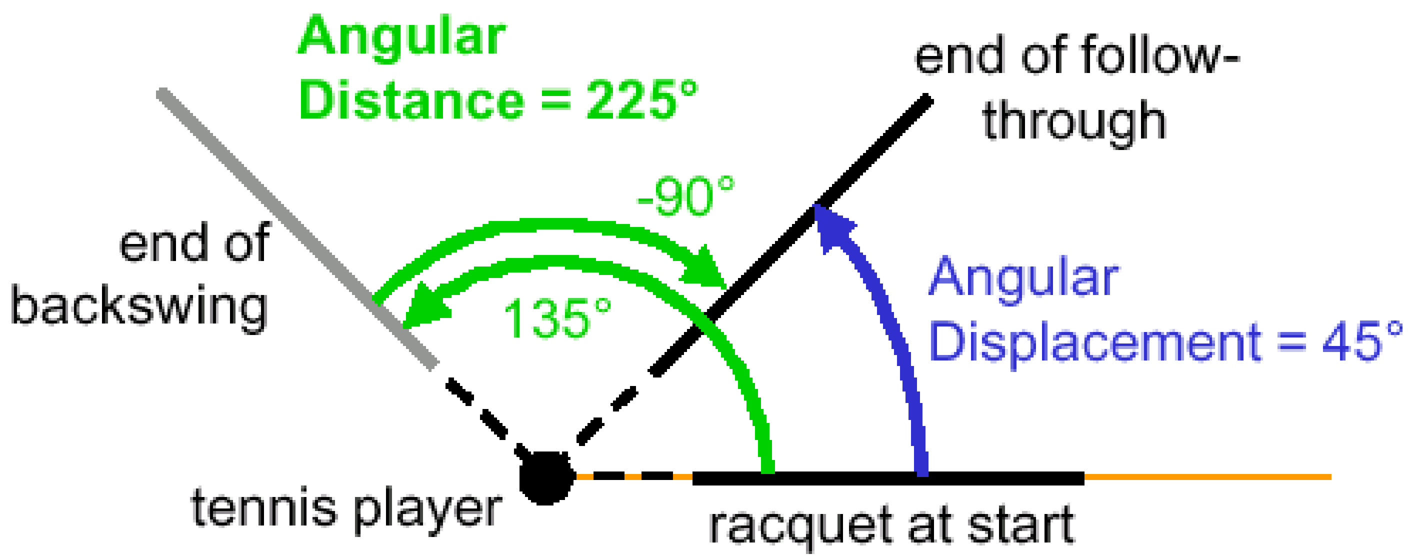
Angular Speed

- The angular distance traveled divided by the time taken to cover it;
- Has units: rad/s, º/s

$$\text{angular speed} = \frac{\text{angular distance}}{\text{change in time}}$$



Angular Speed vs velocity speed

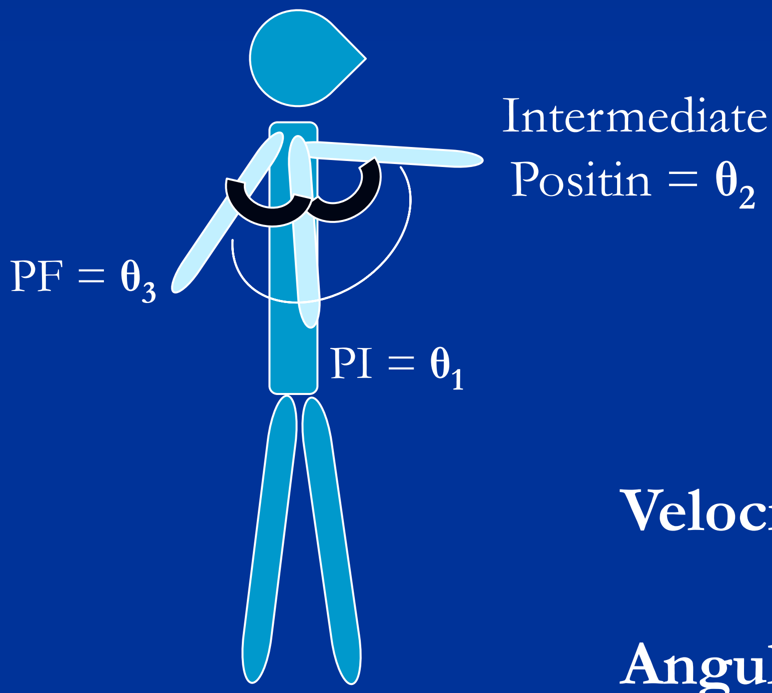


Assume tennis stroke shown takes 0.75 s:

$$\text{Speed} = \frac{225°}{0.75\ \text{s}} = 300°/\text{s}$$

$$\text{Velocity} = \frac{+45°}{0.75\ \text{s}} = +60°/\text{s}$$

An individual performs the arm flexion on the trunk up to 90°, then the arm extension on the trunk up to 30°. What is the angular velocity of the arm and what is the angular speed if the individual performs this movement in 2 seconds?



Angular Displacement =
$\Delta\theta = -30°$

Angular Distance = $\theta_2 + \theta_2 + \theta_3$
Angular Distance = 210°

Velocity = ω =– 30° /2s = – 15 °/s

Angular Speed = ω = 210° /2s = 105 °/s

Angular motion

Angular velocity

$$\omega = \frac{(\theta_{final} - \theta_{initial})}{(t_{final} - t_{initial})} = \frac{\Delta\theta}{\Delta t}$$

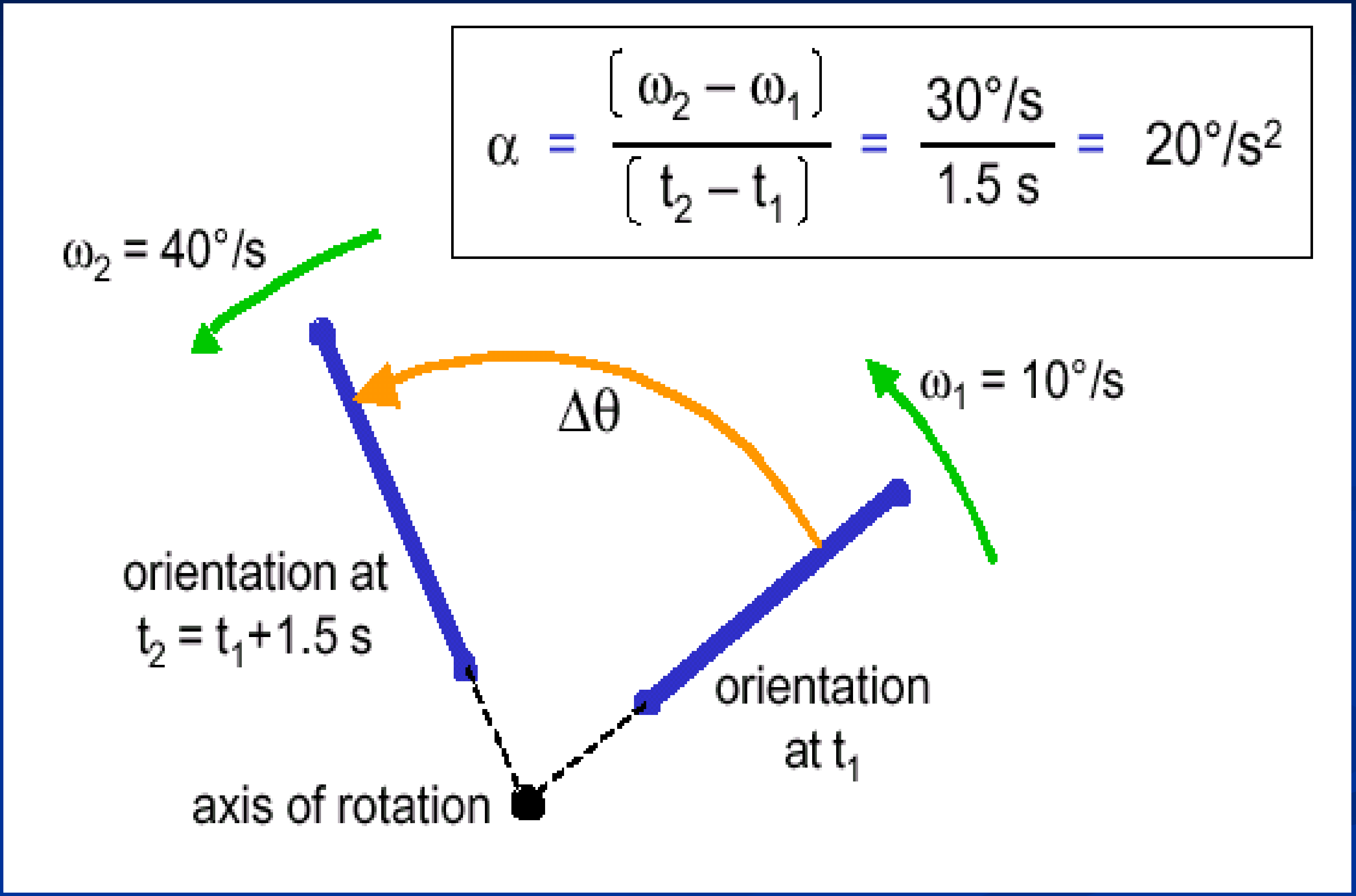
Angular acceleration:

- the rate of change of angular velocity with respect to time; represents the angular velocity variation in time unit.

$$\left(\text{angular acceleration}\right) = \frac{\left(\text{change in angular velocity}\right)}{\text{change in time}}$$

$$\alpha = \frac{(\omega_{final} - \omega_{initial})}{(t_{final} - t_{initial})} = \frac{\Delta\omega}{\Delta t}$$

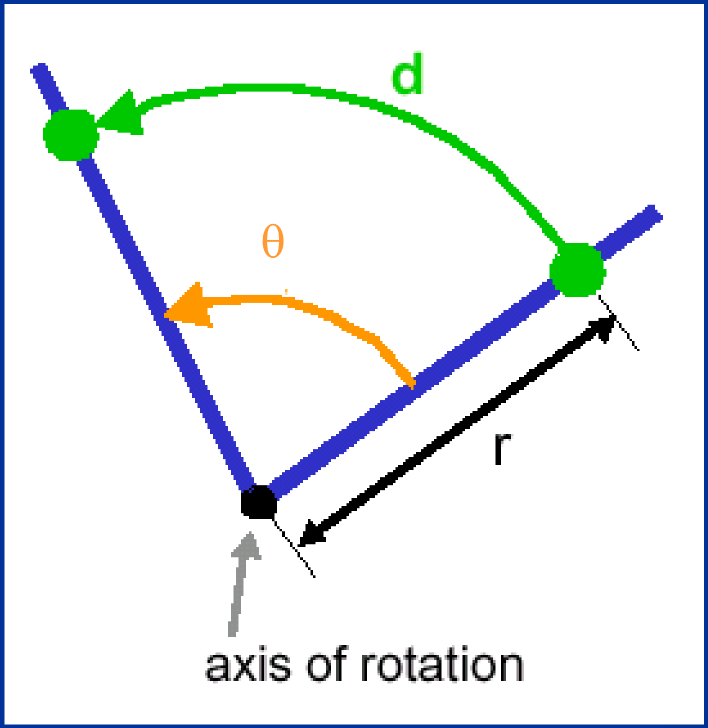
- has units: **rad/s^2 sau ^{o}/sec^2**

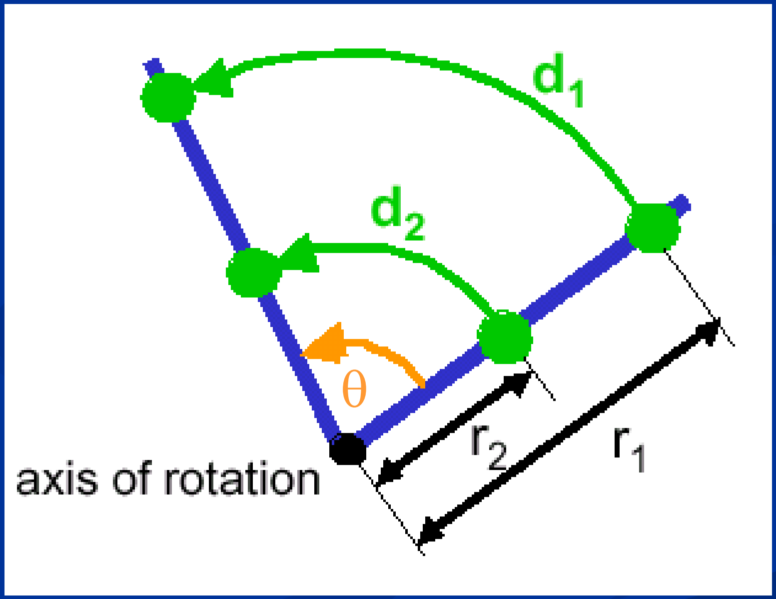

$\alpha = \frac{(\omega_2 - \omega_1)}{(t_2 - t_1)} = \frac{30°/s}{1.5\ s} = 20°/s^2$
$\omega_2 = 40°/s$
$\Delta\theta$
$\omega_1 = 10°/s$
orientation at
$t_2 = t_1 + 1.5$ s
orientation
at t_1
axis of rotation

The distance traveled by a point in the rotation motion is given by the formula: $d = r\,\theta$

r = radius of rotation (distance from point to axis of rotation)

θ = angular distance, in radiani



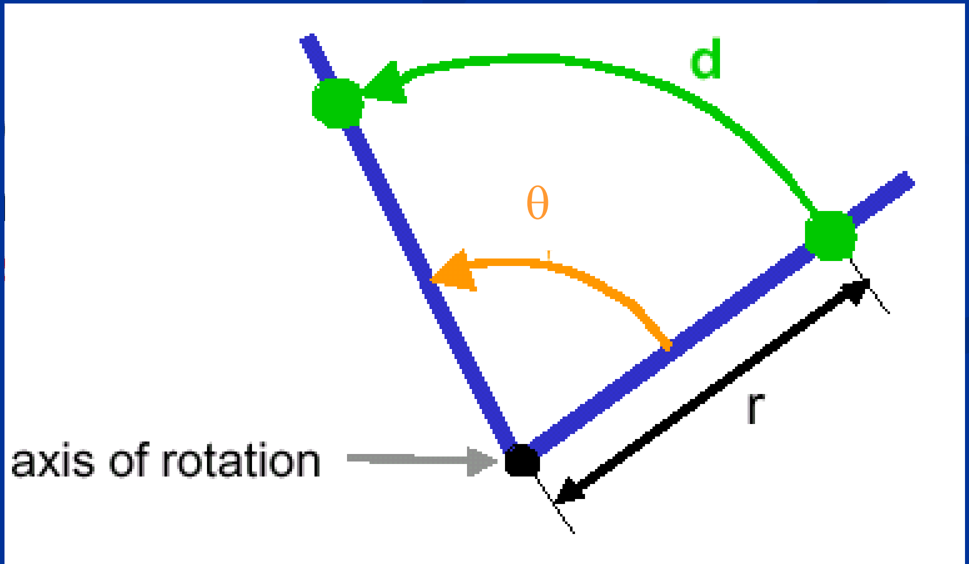


$d_1 = r_1\,\theta$ $d_2 = r_2\,\theta$

Linear speed is $v = \dfrac{d}{\Delta t}$ $\qquad d = r\,\theta$

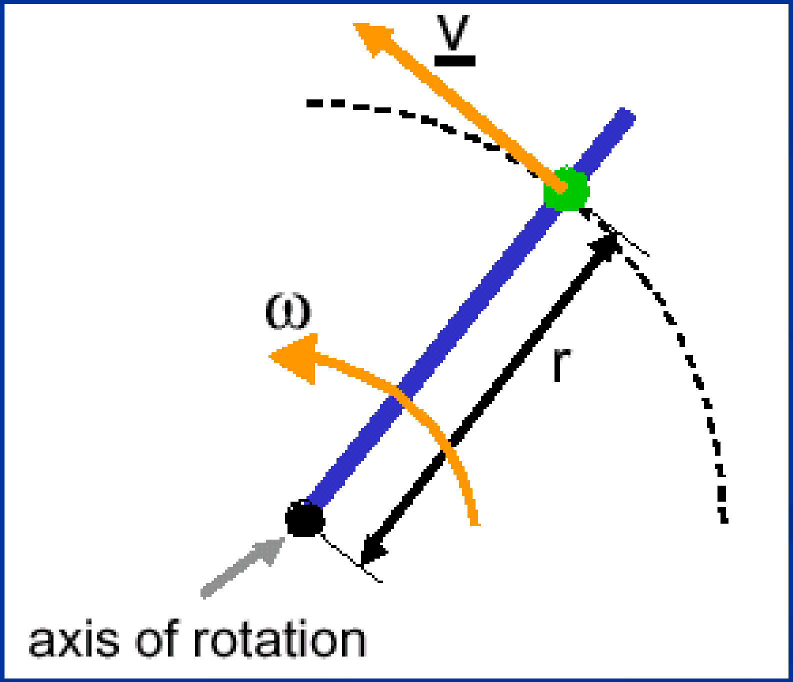
$$=> \quad v = \frac{r\,\theta}{\Delta t} = r\frac{\theta}{\Delta t} \qquad \omega = \frac{\theta}{\Delta t}$$

$=> \quad v = r\,\omega$ $\qquad \omega$ is angular speed, in rad / s



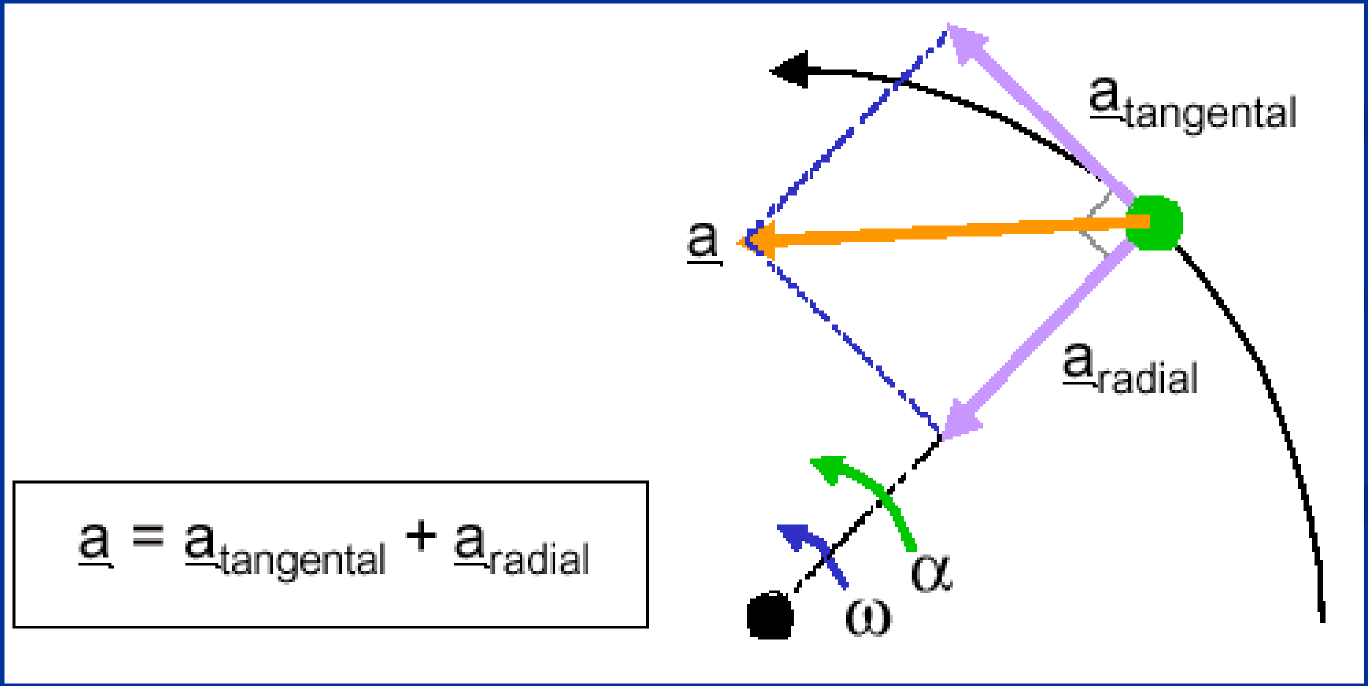
Linear velocity of a point in rotation:
- is tangent to the motion trajectory
- has the magnitude: $v = r\,\omega$

r = radius of rotation
ω = angular velocity, in rad/s



The acceleration of a point in circular motion can be separate into two components:

- one tangential to the motion trajectory
- the radial component, perpendicular to the motion trajectory



Tangential acceleration:

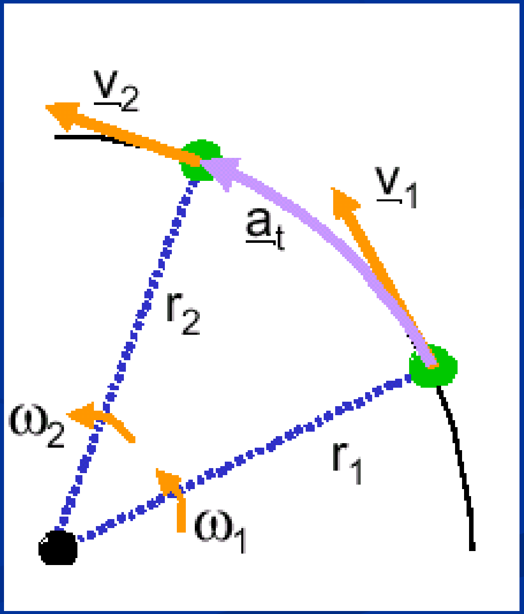
- the acceleration component having the tangent direction to the motion trajectory
- represents the variation in time of the linear speed

$$a_t = \frac{(v_2 - v_1)}{(t_2 - t_1)}$$

$$a_t = \frac{(r\omega_2 - r\omega_1)}{(t_2 - t_1)}$$

$$a_t = r\alpha$$

α in radian/s² !



$$\alpha = \frac{(\omega_{final} - \omega_{initial})}{(t_{final} - t_{initial})} = \frac{\Delta\omega}{\Delta t}$$

α = angular acceleration

Radial acceleration:

- the acceleration component having the perpendicular direction to the motion trajectory
- points towards the center of the circle; is centripetal acceleration
- represents the changing in direction of velocity

$$a_r = \frac{v^2}{r}$$

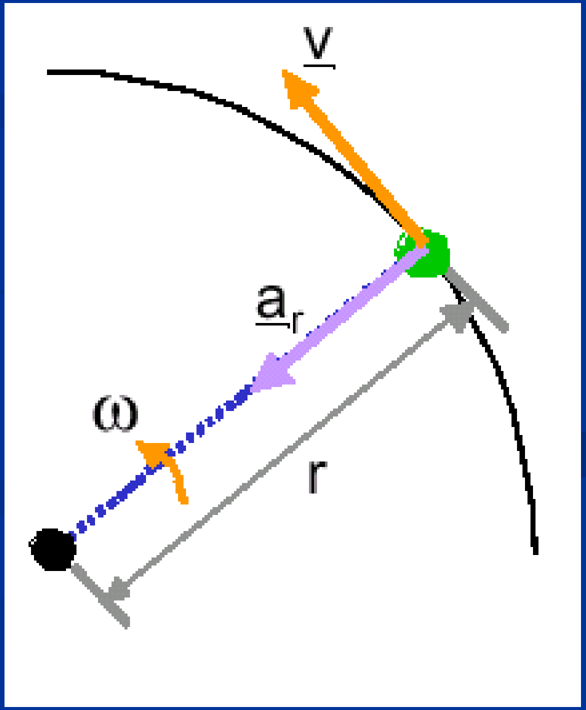
$v = r\,\omega$

ω is angular speed, in rad / s

$$a_r = \frac{(r\,\omega)^2}{r}$$

$$a_r = r\,\omega^2$$

ω in radian/s !



Verification of knowledge

1. What is acceleration? (Definition, formula, unit of measure)
2. If a car is running at a constant speed of 48 km / h, will it have a uniform movement or accelerated movement?
3. If a car is running at a speed of 48 km / h, and then speed increases to 56 km / h, will it have a uniform movement, an accelerated movement or a decelerated movement?
4. If a car is running at a constant speed of 65 km / h, then the speed drops to 56 km / h, will it have a uniform movement, an accelerated movement or a decelerated movement?

Verification of knowledge

5. An individual performs the arm abduction on the trunk up to 90°. What is the angular displacement of the arm and what is the angular distance?

6. An individual performs the arm abduction on the trunk up to 90°, then the arm adduction on the trunk 15°. What is the angular displacement of the arm and what is the angular distance?

7. An individual performs the arm horizontal adduction on the trunk up to 90°, then the arm horizontal abduction on the trunk 120°. What is the angular displacement of the arm and what is the angular distance?

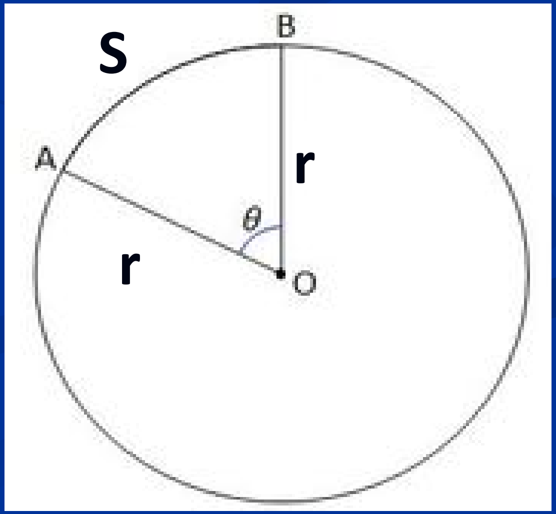
Verification of knowledge

8. What is the difference between angular velocity and angular speed?

9. What is the difference between linear speed and angular speed?

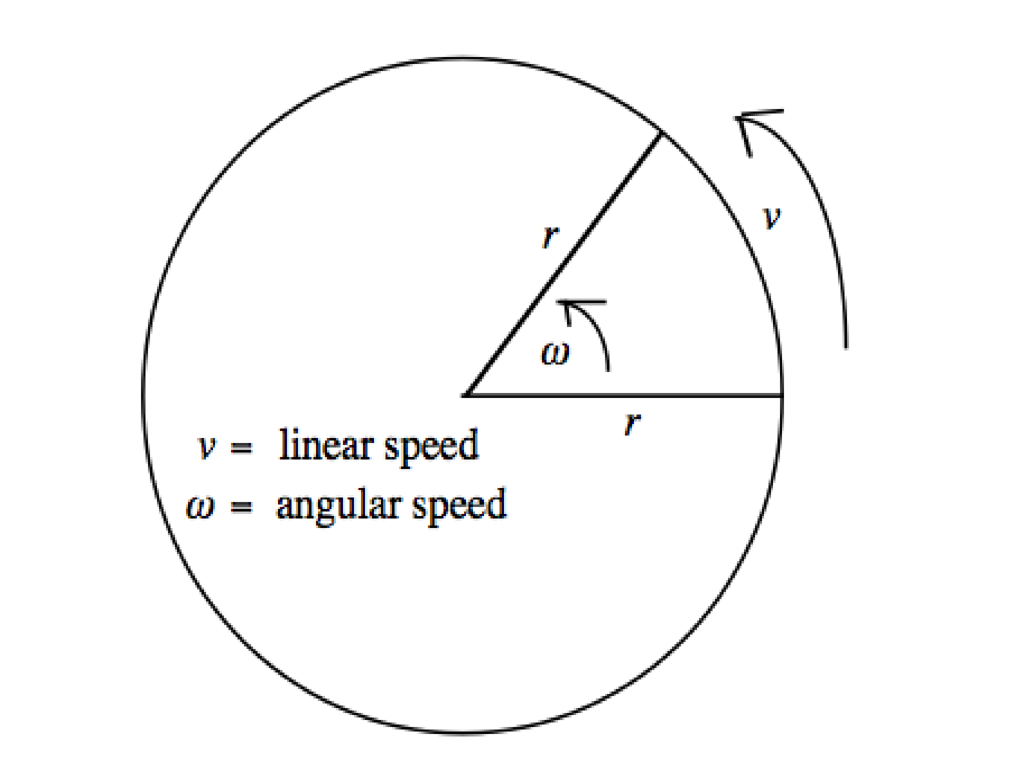
10. What is the relationship between the arc length and the central angle?

S = AB = arc lenght (arc of a circle),
Θ = central angle,
r = OA = radius

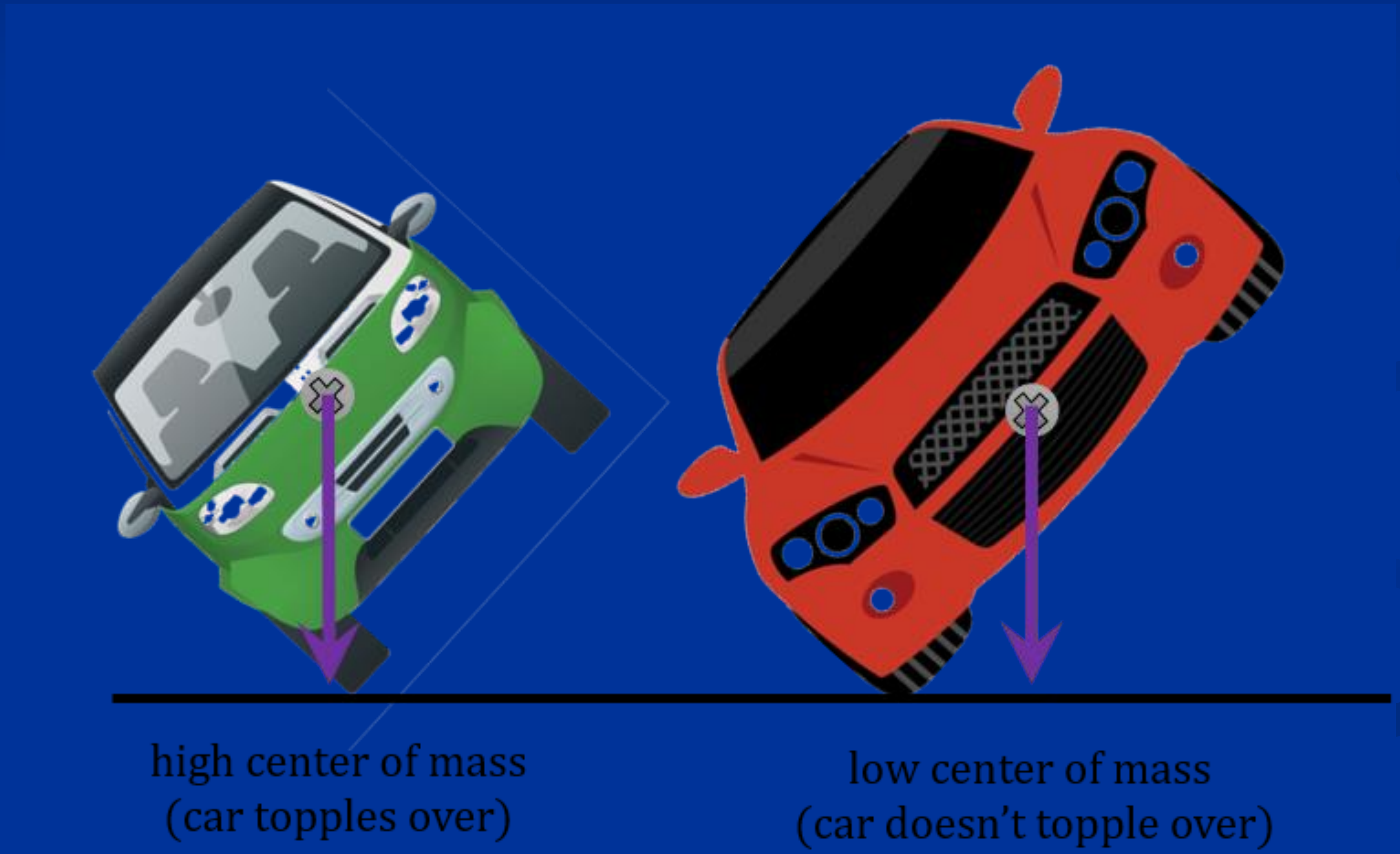


Verification of knowledge

11. What is the relationship between the linear speed and angular speed?



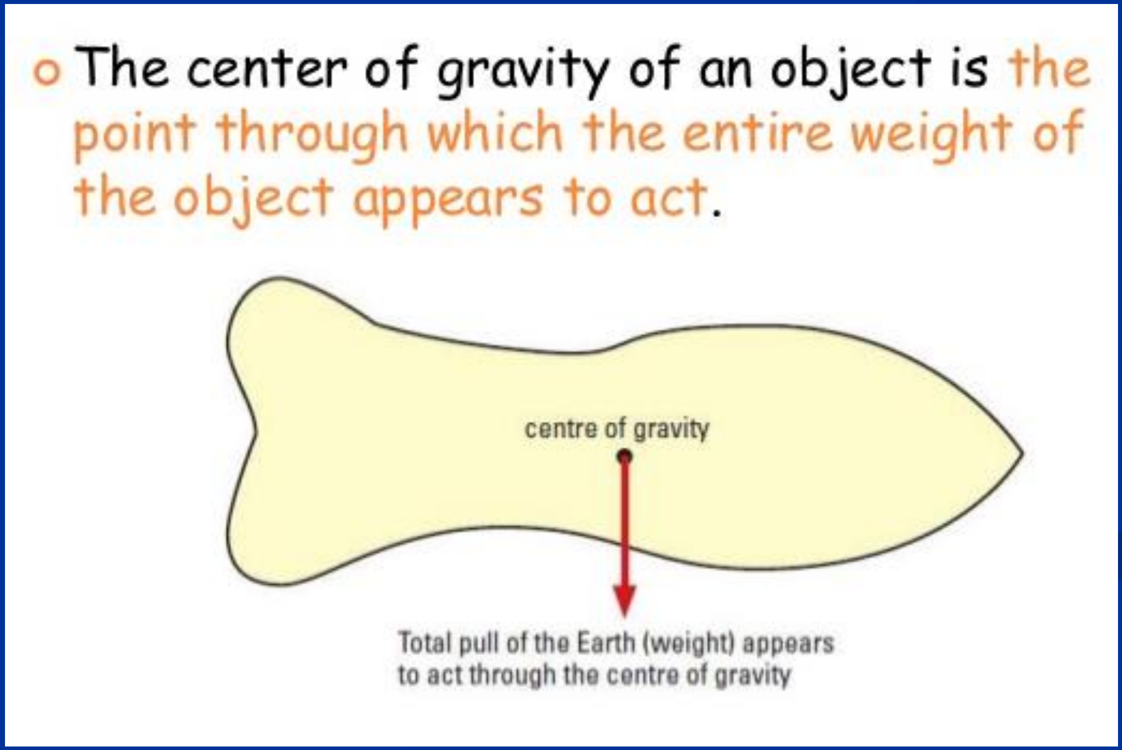
Center of gravity (CG)



Center of gravity (CG)

A body's **center of gravity** is the point at which gravity appears to be acting upon an object.

This is, for the most part, the point around which the body's weight is equally balanced, no matter how the body is positioned.
$\Rightarrow$ **center of mass**

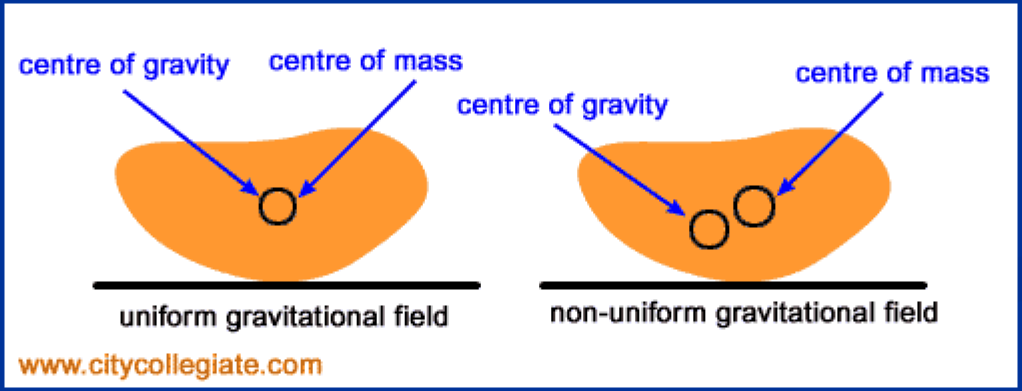


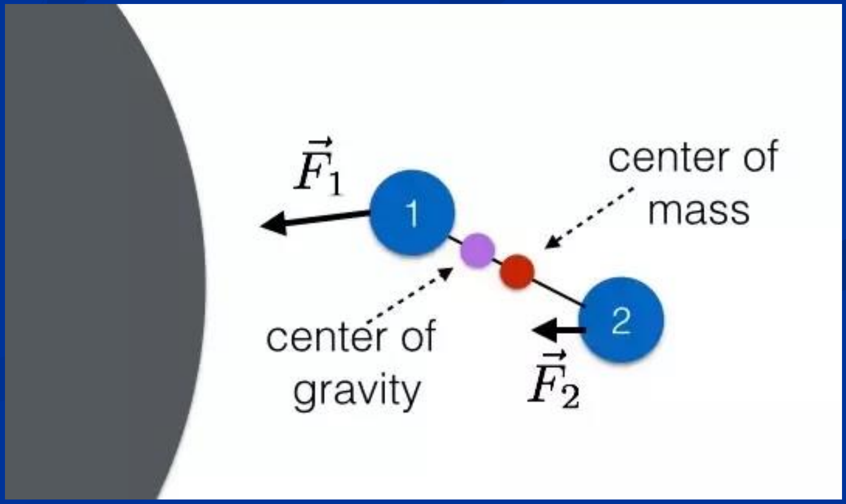
Center of gravity (CG) / Center of Mass

Center of mass is the point at which the distribution of mass is equal in all directions, and does not depend on gravitational field.

is the point at which the is equal in all directions, and does depend on gravitational field.

The center of mass and the center of gravity of an object are in the same position if the gravitational field in which the object exists is uniform.

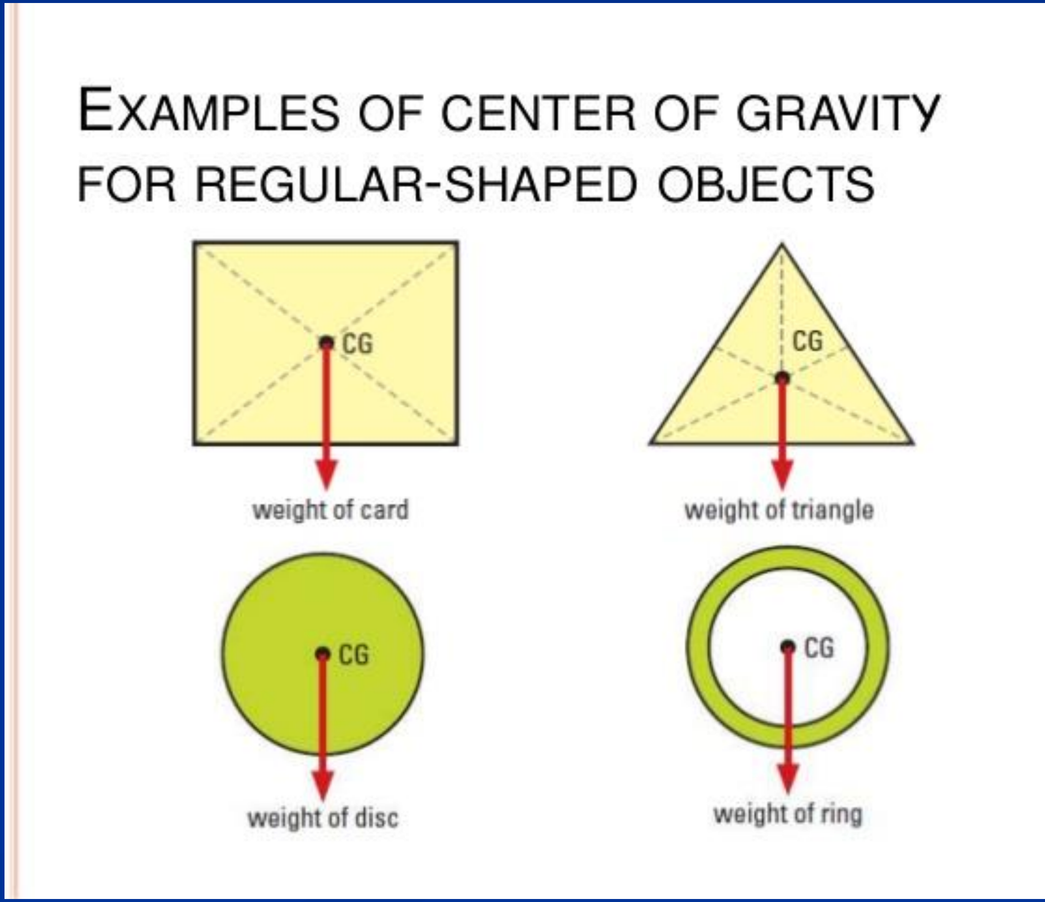




Center of gravity (CG)

For a regular object, the center of gravity is at the center of the object.

When the object is supported at that point, it will be balanced.



Center of gravity (CG)

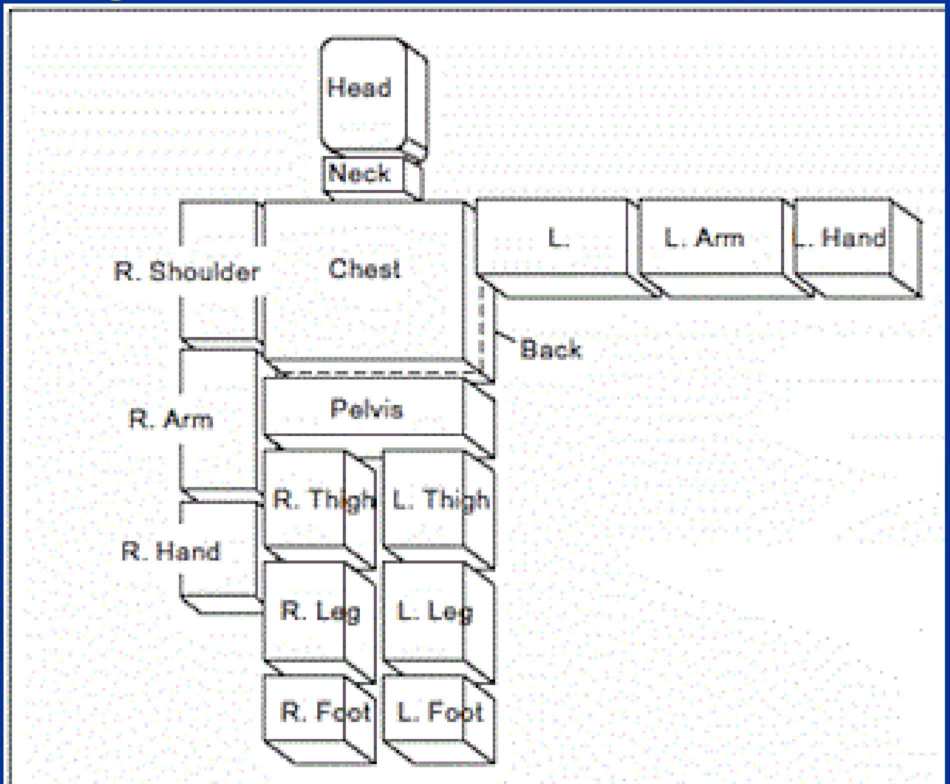
If the direction of a force passes through the CG, it transmit a translational movement to the body.

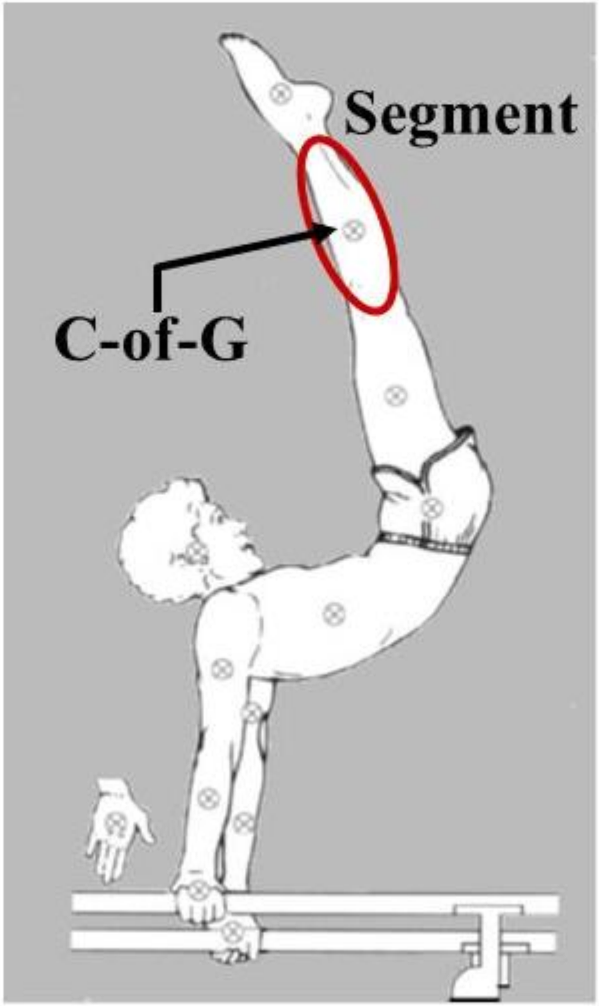
If the force does not pass through the CG, then it transmit a rotating motion to the body..

In living beings there is a center of body weight and a center of gravity of the segments.

Segments are modeled as rigid mechanical links of known physical shape, size, and weight.
Joints are modeled as single-pivot hinges.

Important to know the location of the effective center of gravity (or mass) of segments.





[Kreighbaum & Barthels, 1996]

Segment center of gravity

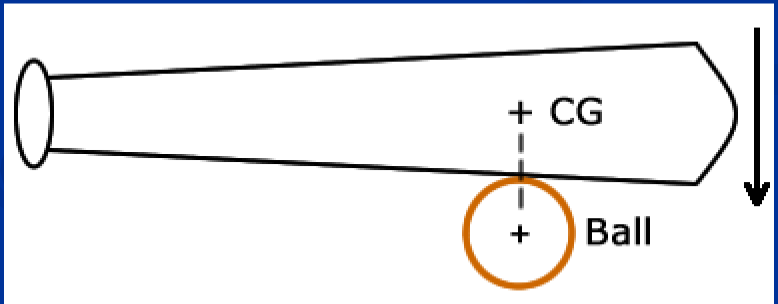
- Gravity actually pulls on every particle of mass, therefore giving each part weight.
- For the body, each segment is treated as the smallest division of the body.
- Can obtain CG for individual segments or group of segments CG usually slightly closer to the “thicker” end of the segment

Location of the CG

It depend on the Body's shape and position

=> If distribution of mass is symmetrical - Square block or cylinder: At the center of object

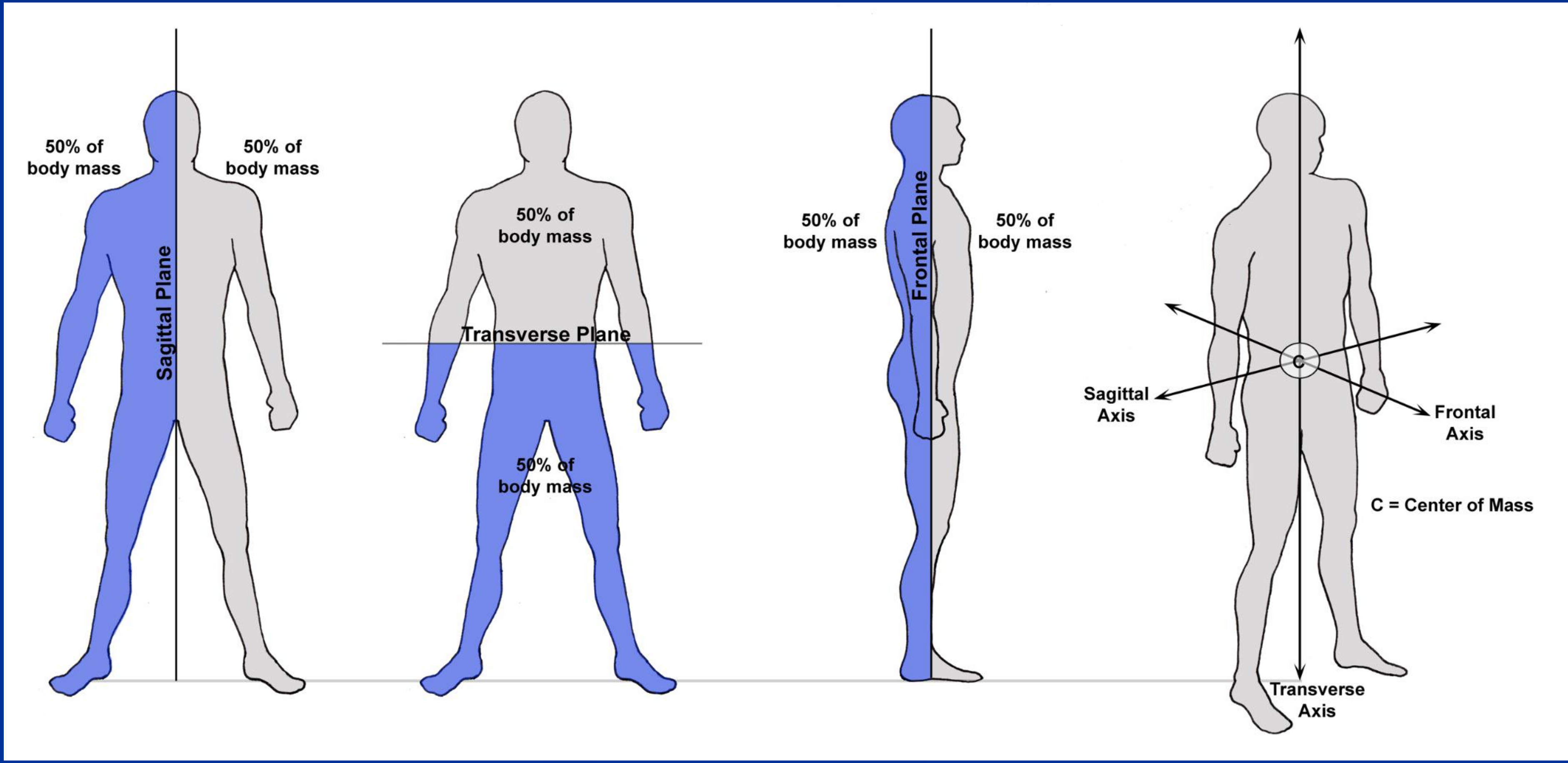
=> If distribution of mass is asymmetrical: Nearer to the larger & heavier end.



The exact location is not the same between individuals since there are factors affecting it.

Location of the CG

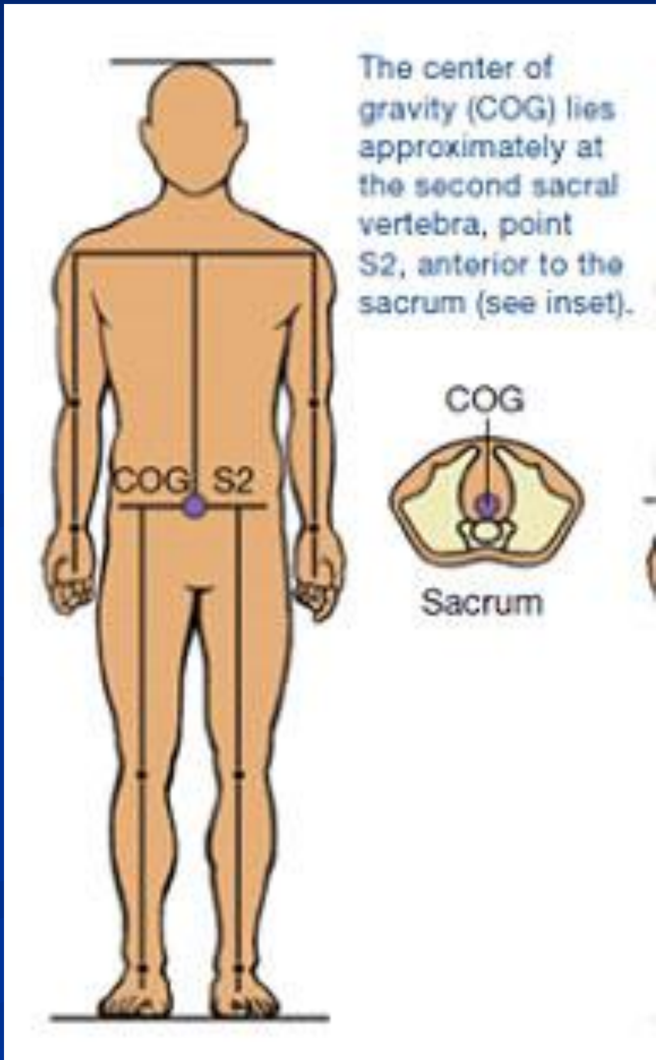
Anatomically, CG can be represented by the point of intersection of the three cardinal body planes (sagittal, frontal and transverse).



Center of gravity (CG)

It’s is located anterior to the second sacral vertebra in the anatomical position (standing) in normal adult person.

In orthostatic position, CG is in the space between sacral vertebrae 1-5, approximately 4-5 cm above the transverse axis passing through the hip joint.

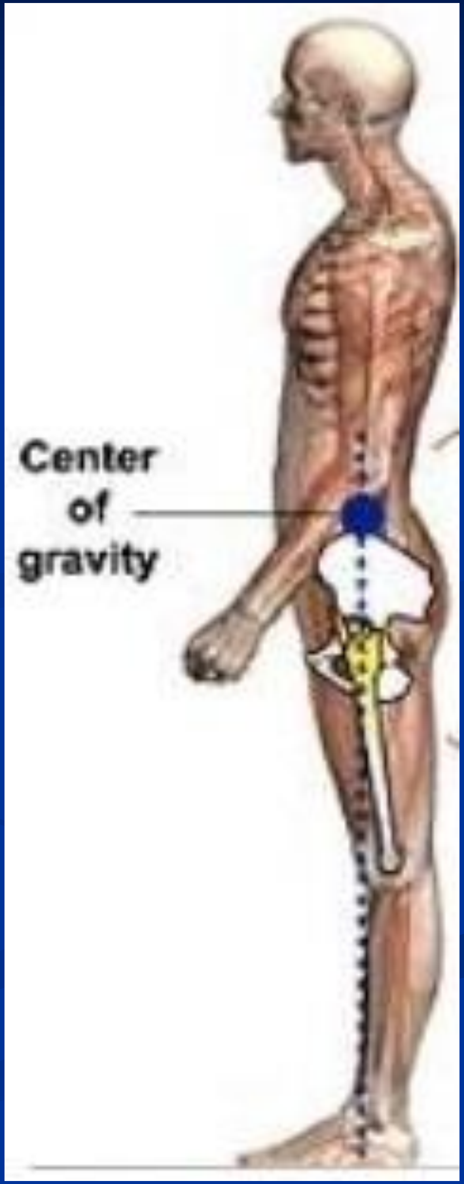


Location of the CG

The sagittal plane passing through the CG is slightly to the right than the medio-sagital plane,

- since the right half of the body in most people is 400-500 g heavier than the left,

- due to the asymmetric disposition of internal organs and uneven development of the locomotor apparatus.



Factors affecting location of CG in the body

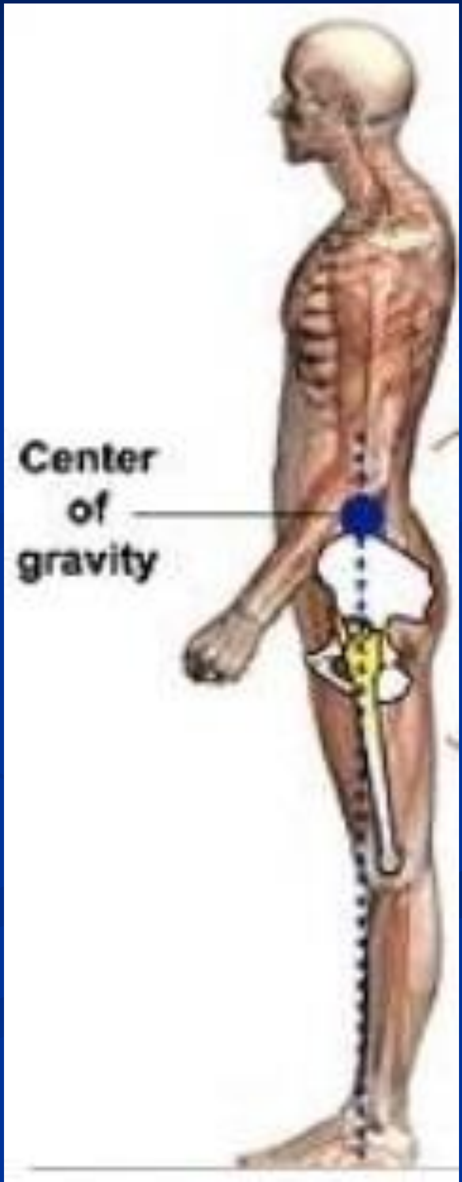
1. Age

2. Gender: female / male

3. Height

4. Movements/Position of segments in relation to total body segments

5. Weight - Addition and subtraction of weight



Factors affecting location of CG in the body

1. AGE

CG drops down as age is increasing.

The ratio of body’s mass changes while growing up leading to a change in CG location.

Factors affecting location of CG in the body

1. AGE

CG in newborns is higher than in adults.
There is no balance in body's mass in newborn.

The upper body part is heavier than lower one → High CG
While development, redistribution of body mass occurs → lowering CG reaching ant of 2nd vertebra.

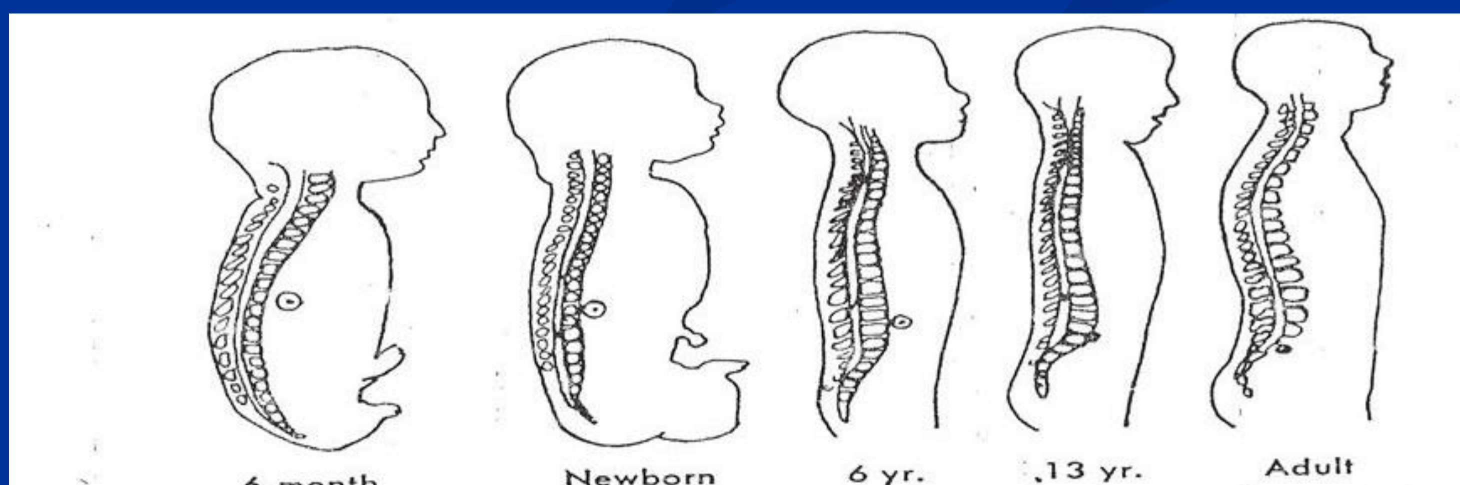
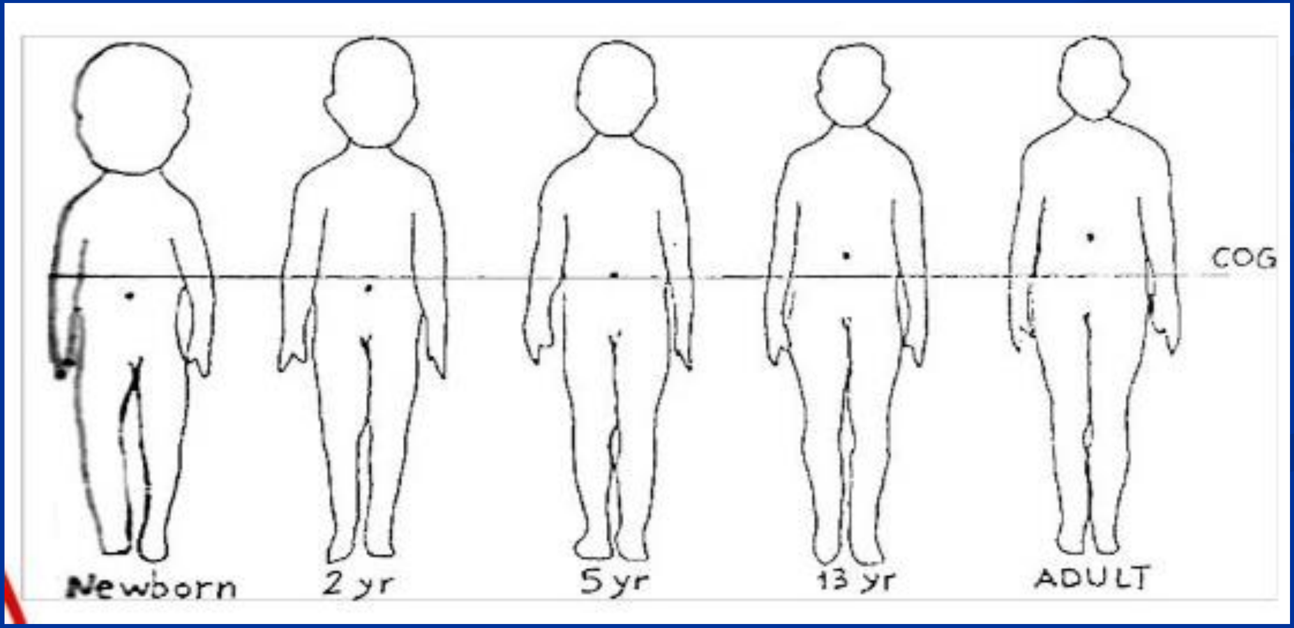


Fig. 2 Position of the center of gravity with reference to the spine at five ages. (Modified from Palmer, C. E.: Child Dev. 15:99, 1944.)

Factors affecting location of CG in the body

1. AGE

1) In new born: above umbilicus.
2) At six month: at the level of six thoracic vertebra.
3) At two years: at the level of umbilicus.
4) At five years: below the level of umbilicus.
5) Adult: anterior to the second sacral vertebra.



Factors affecting location of CG in the body

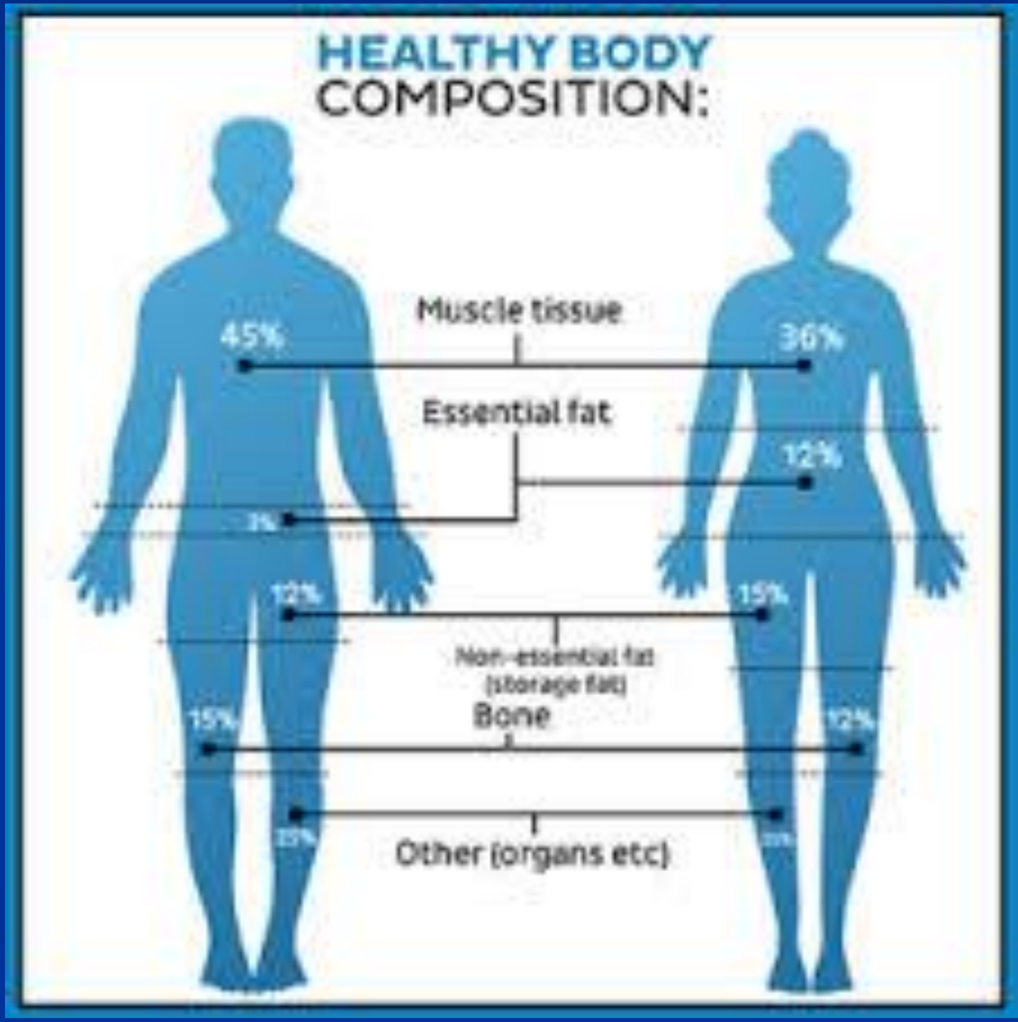
2. Gender

The difference between the muscular mass on the upper body will affect the CG position.

The height of CG is:

=> 57 % of standing height for men

=> 55% of standing height for women

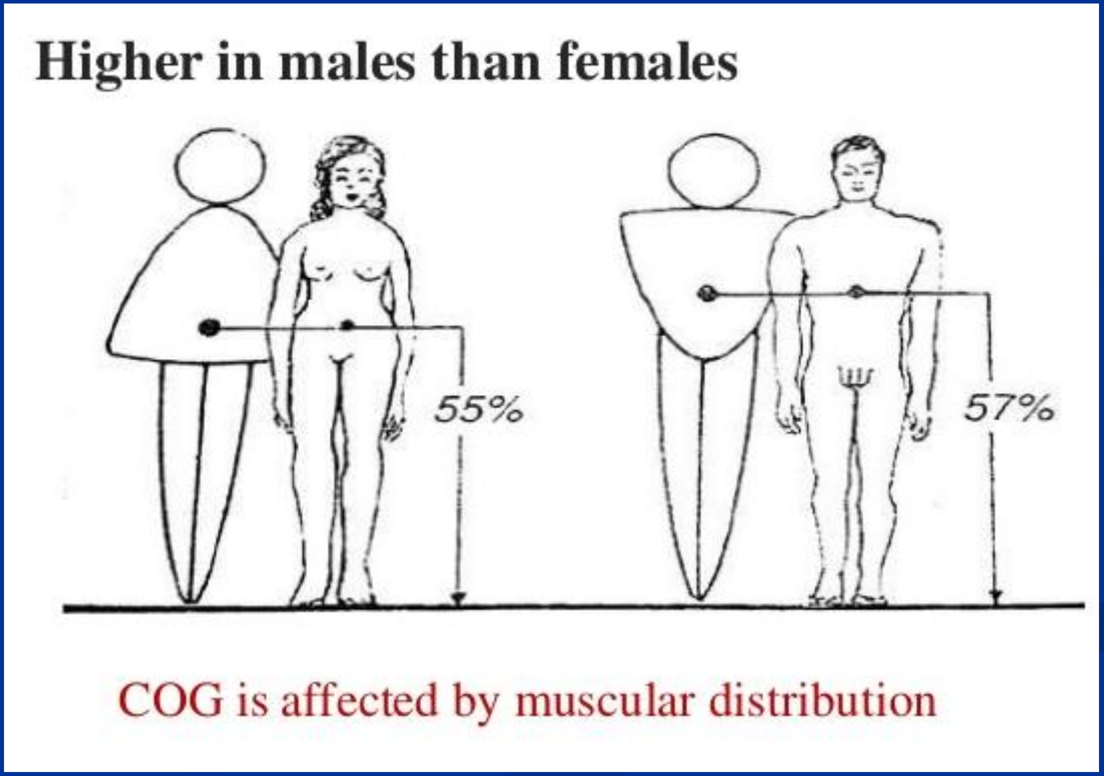


Factors affecting location of CG in the body

2. Gender

In males: The muscles of upper division weights more than lower division => CG higher 57 % of standing height

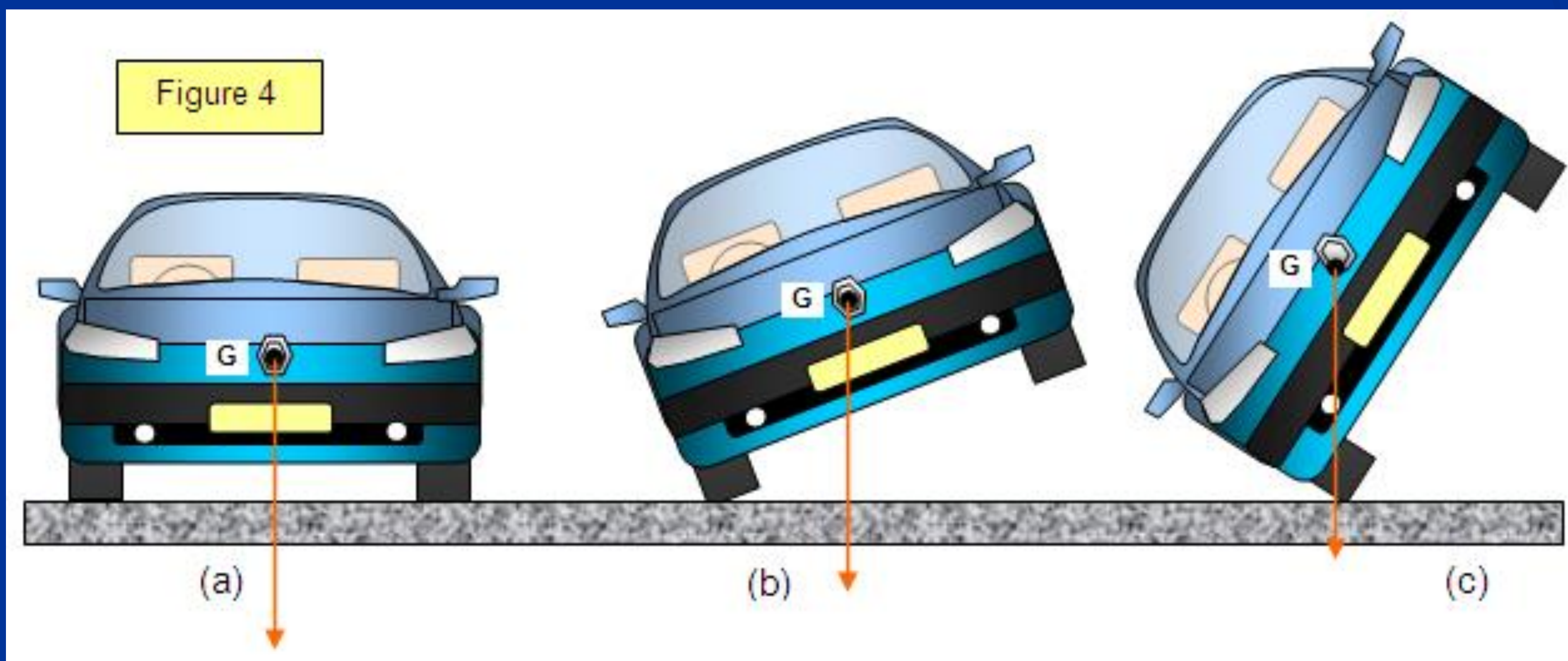
In females: The pelvis is wider & lower than male's pelvis
=> CG higher 55% of standing height



Factors affecting location of CG in the body

3. Height

The higher the body height, the higher the CG



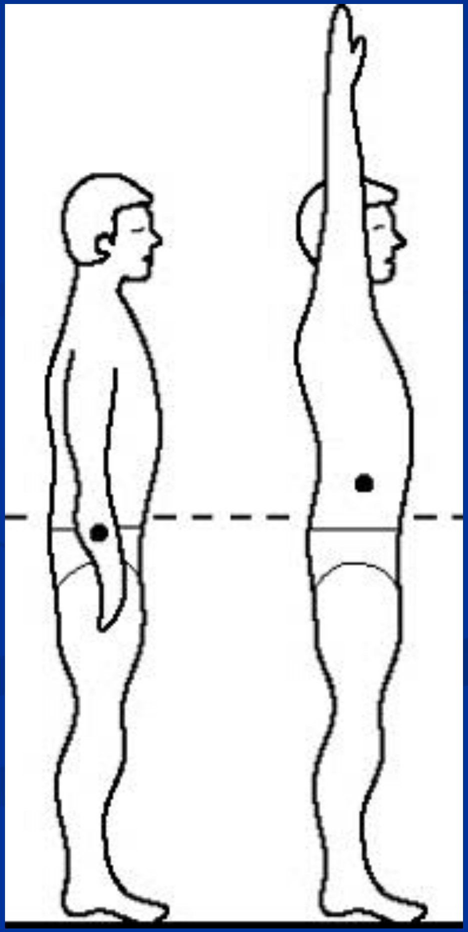
Factors affecting location of CG in the body

4. Movement of segments

CG moves towards the heavy mass

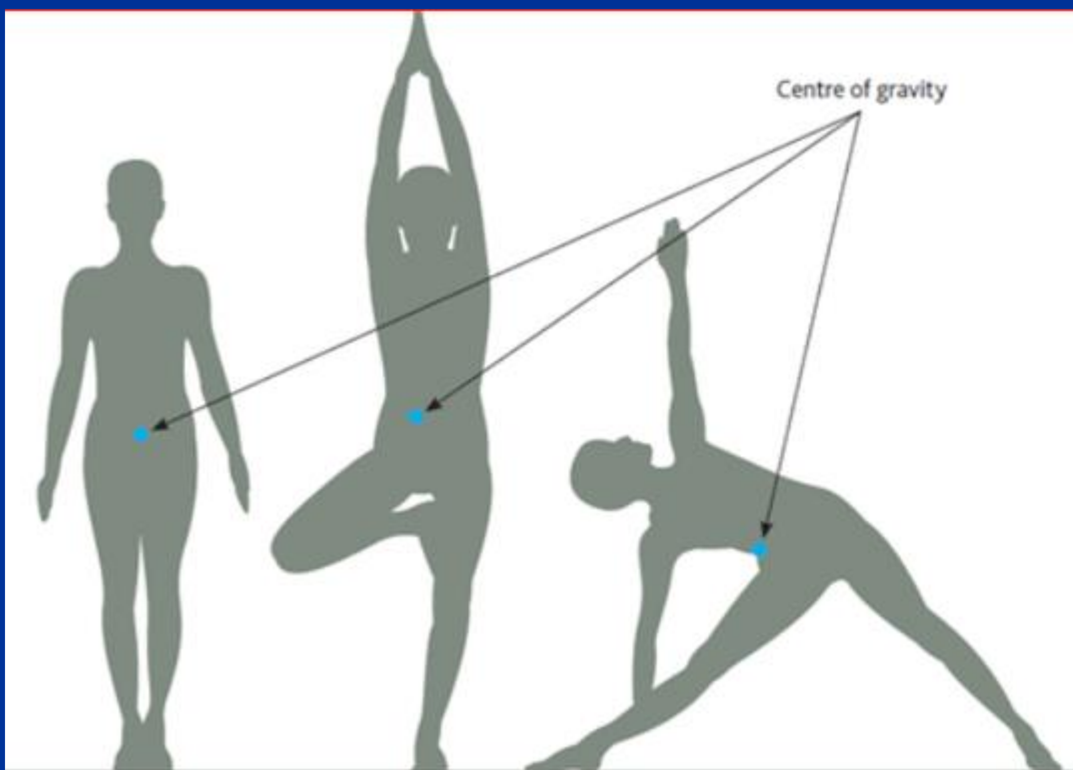
The CG changes its position whenever we move the limbs:

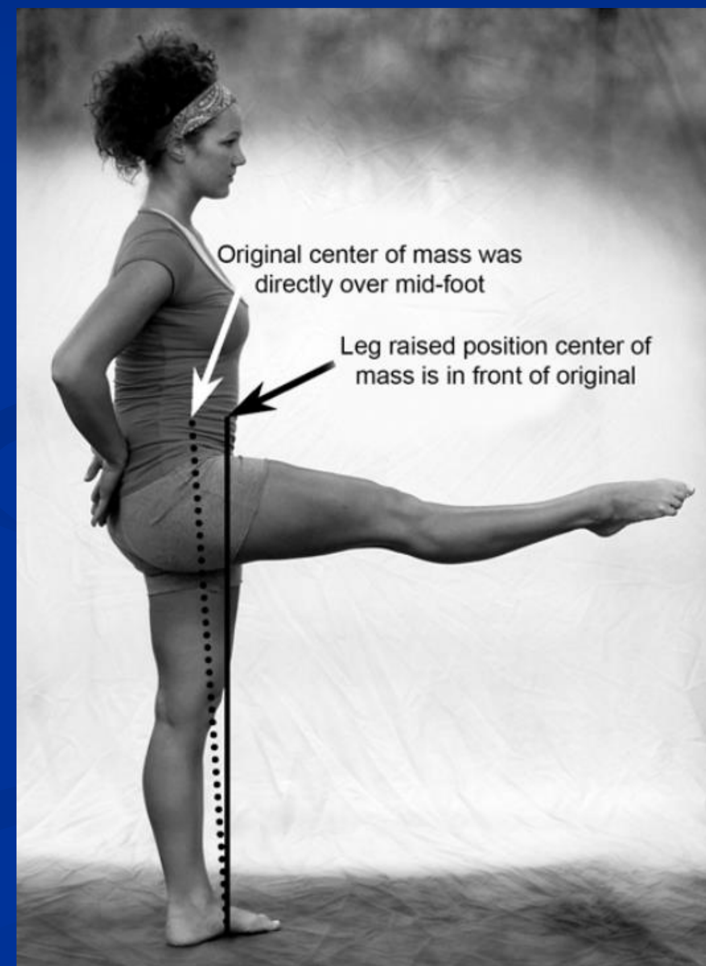
- Flexion of arms => CG moves upword and forward
- Flexion of right arm => CG moves upword, forward and to the right.



Factors affecting location of CG in the body

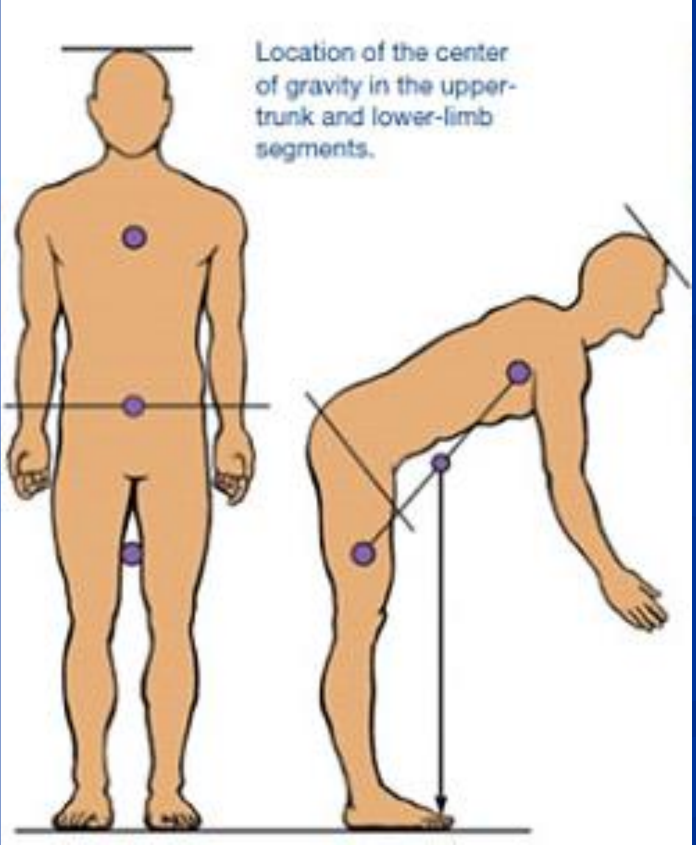
4. Movement of segments





Factors affecting location of CG in the body

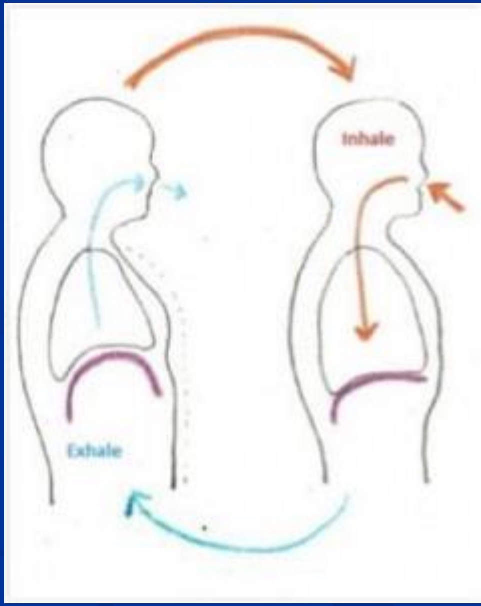
4. Movement of segments



Factors affecting location of CG in the body

4. Movement of segments

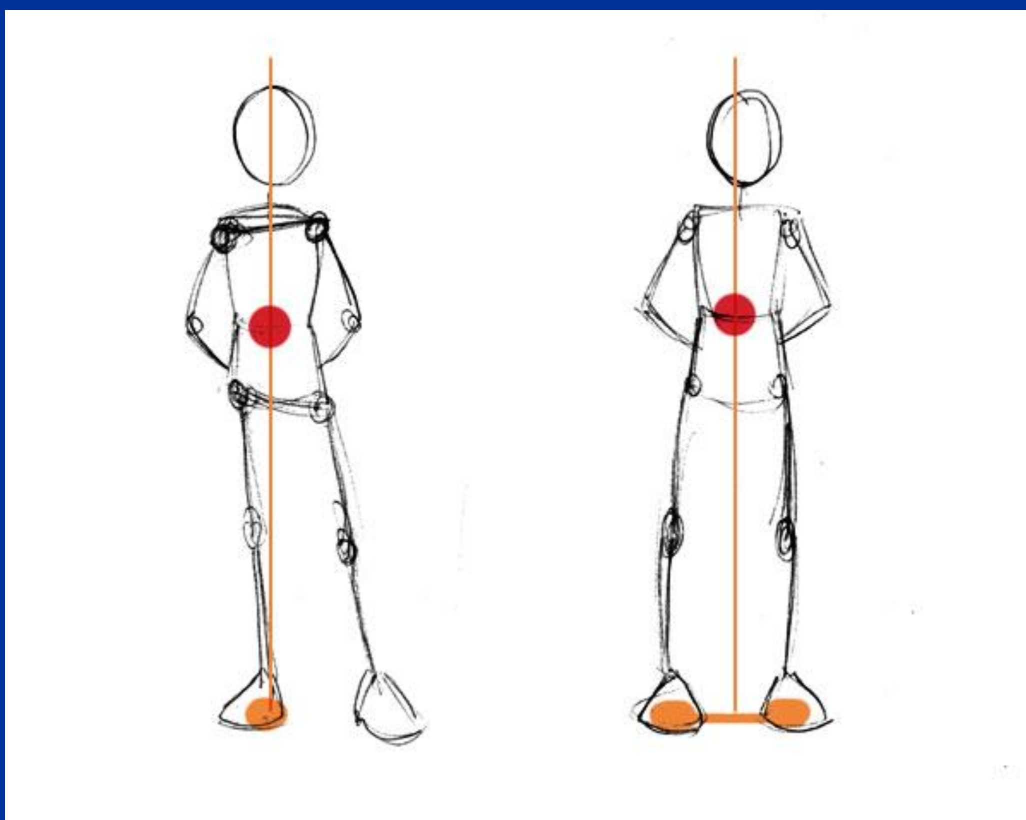
The center of gravity changes its position depending on the respiratory movements (in inspiration is lower), the amount of fluid and food in the stomach, etc.

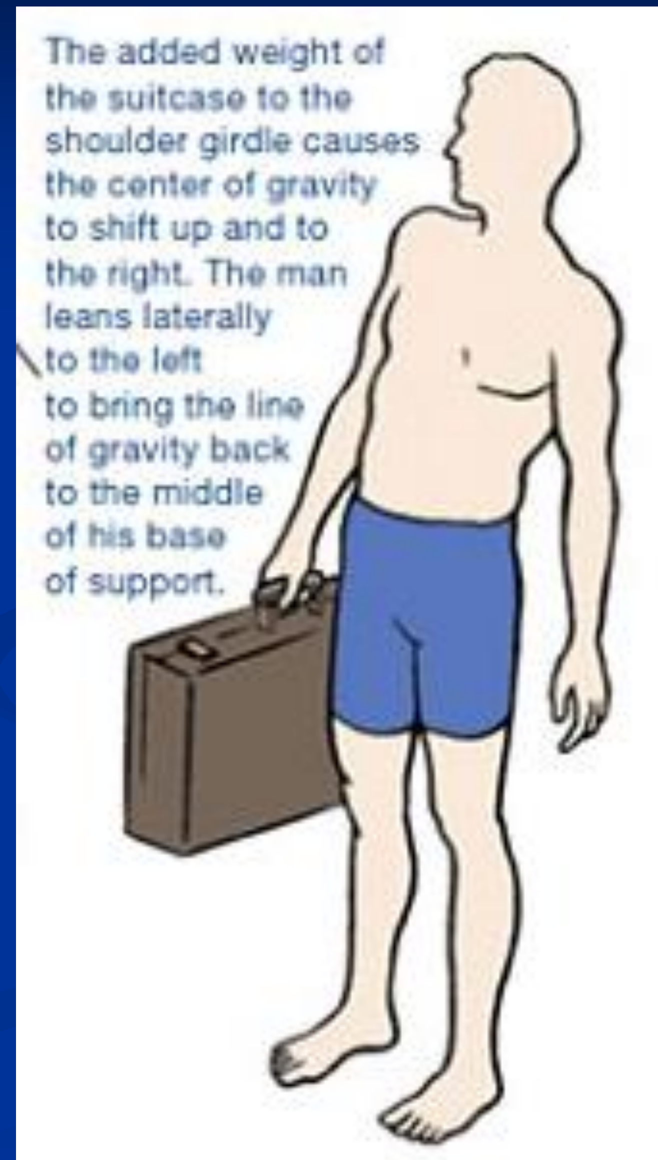


Factors affecting location of CG in the body

5. Weight

Weight addition:





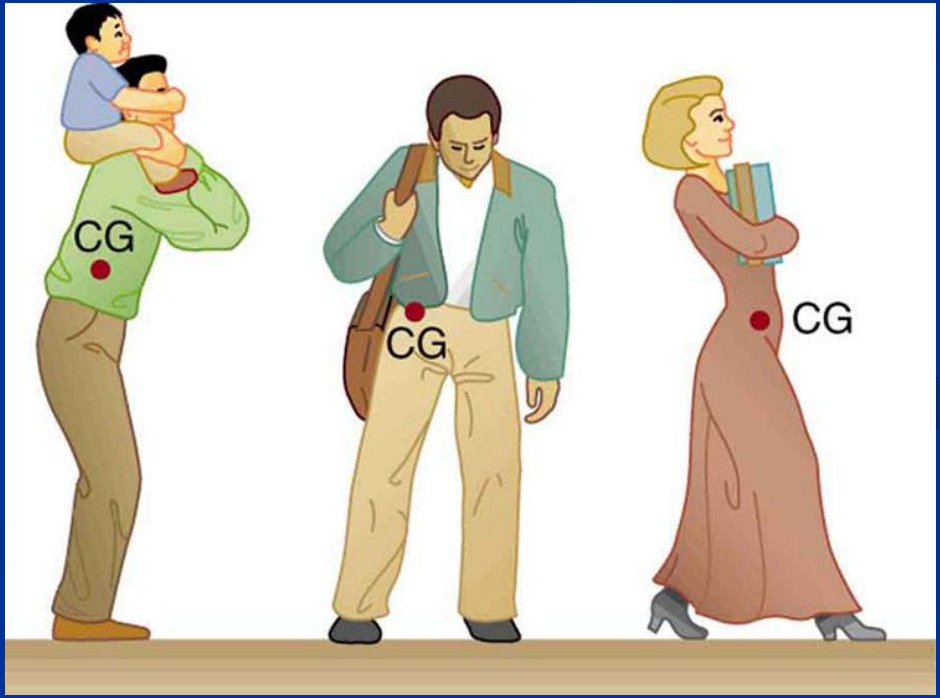
Factors affecting location of CG in the body

5. Weight

Weight addition:

If the weight was behind the trunk => COG moves backward => person will make a forward trunk movement or else the backward weight will pull him back

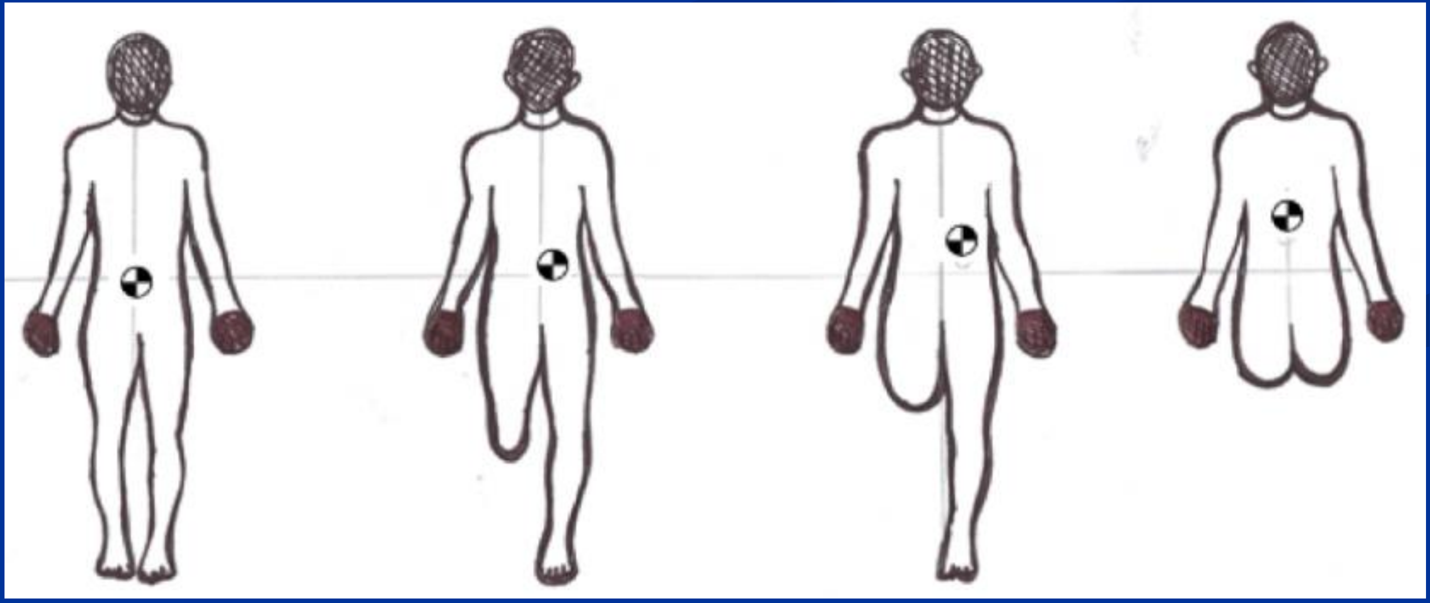
If the weight was in front the trunk => COG will move forward => person will make a backward trunk movement => leads to increase lumbar lordosis and back pain later on.



Factors affecting location of CG in the body

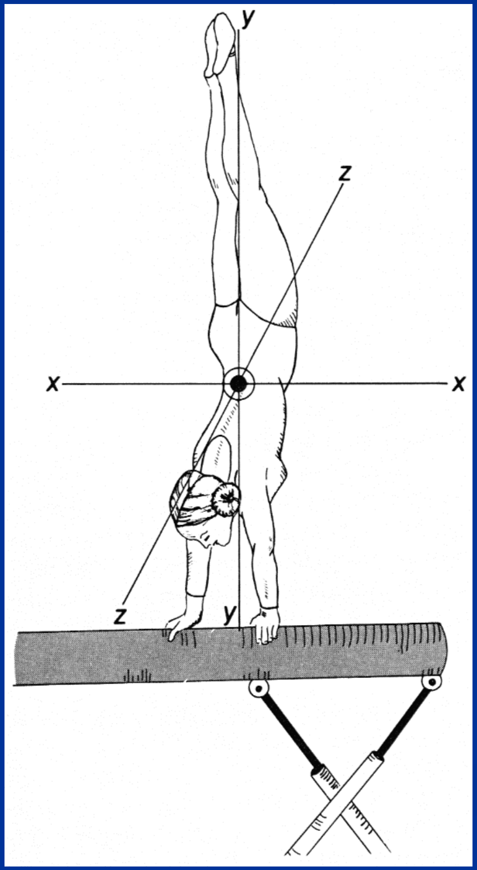
5. Weight - Subtraction of weight

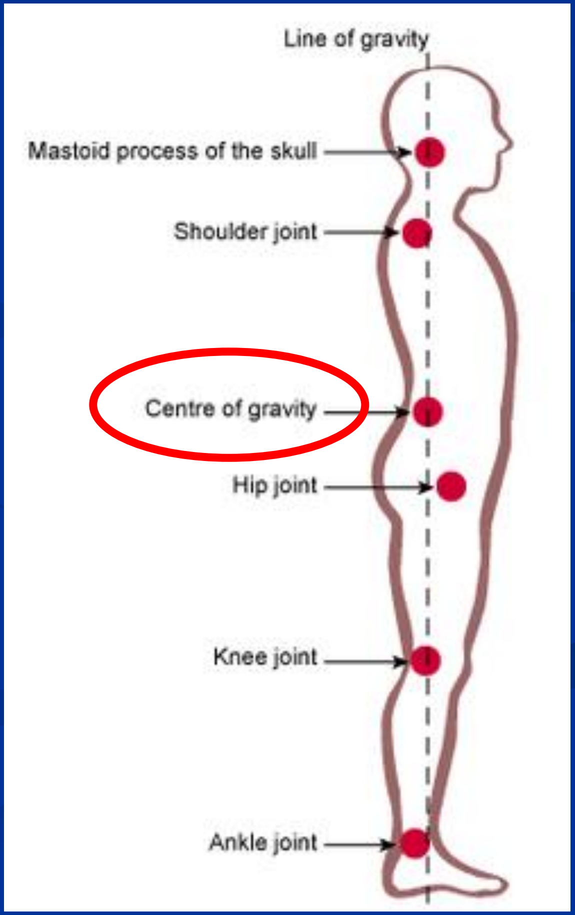
- In case of amputation CG moves away from amputated limb toward the healthy side.
- To have a normal gait and distributed body segment, the artificial limb's weight & the normal limb's weight should be identical.
- This identical limb will balance in body's weight thus returning CG to normal.



Center of gravity (CG)

From a kinetic perspective, the location of a center of mass determines the way in which the body responds to external forces.





Importance of determining the center of gravity location

- To maintain balance through locating CG at its level during physical therapy treatment.
- To enhance patients gait during reeducation of walking via pushing or grasping the patient near to his CG.

Importance of determining the center of gravity location

- Total CG must be well known to identify and determine the level of performance of athletic player.

As a result, it will help the biomechanics to improve the players performance.

- Segmental CG must be known especially in amputation. The distribution of the weight of artificial limb must be equivalent to that of the amputated limb.

If the weight of the artificial limb increases, the segmental CG level will change and as a result the total CG level will change which may place overload on a diseased part which may cause pain.

Determining the CG location

The total body COG can be determined using

- mathematical

or

- laboratory methods.

<u>Mathematical determination of CG</u>:

a) Regarding to gender: “Croskey formula”

b) Regardless to gender: "Palmar formula“

Center of gravity (CG)

Mathematical determination of CG:

a) Regarding to gender: "Croskey formula"

In female: $$\frac{H*55.4}{100} = h_{CG}$$

In male: $$\frac{H*56.18}{100} = h_{CG}$$

Center of gravity (CG)

Mathematical determination of CG:

b) Regardless to gender: "Palmar formula“

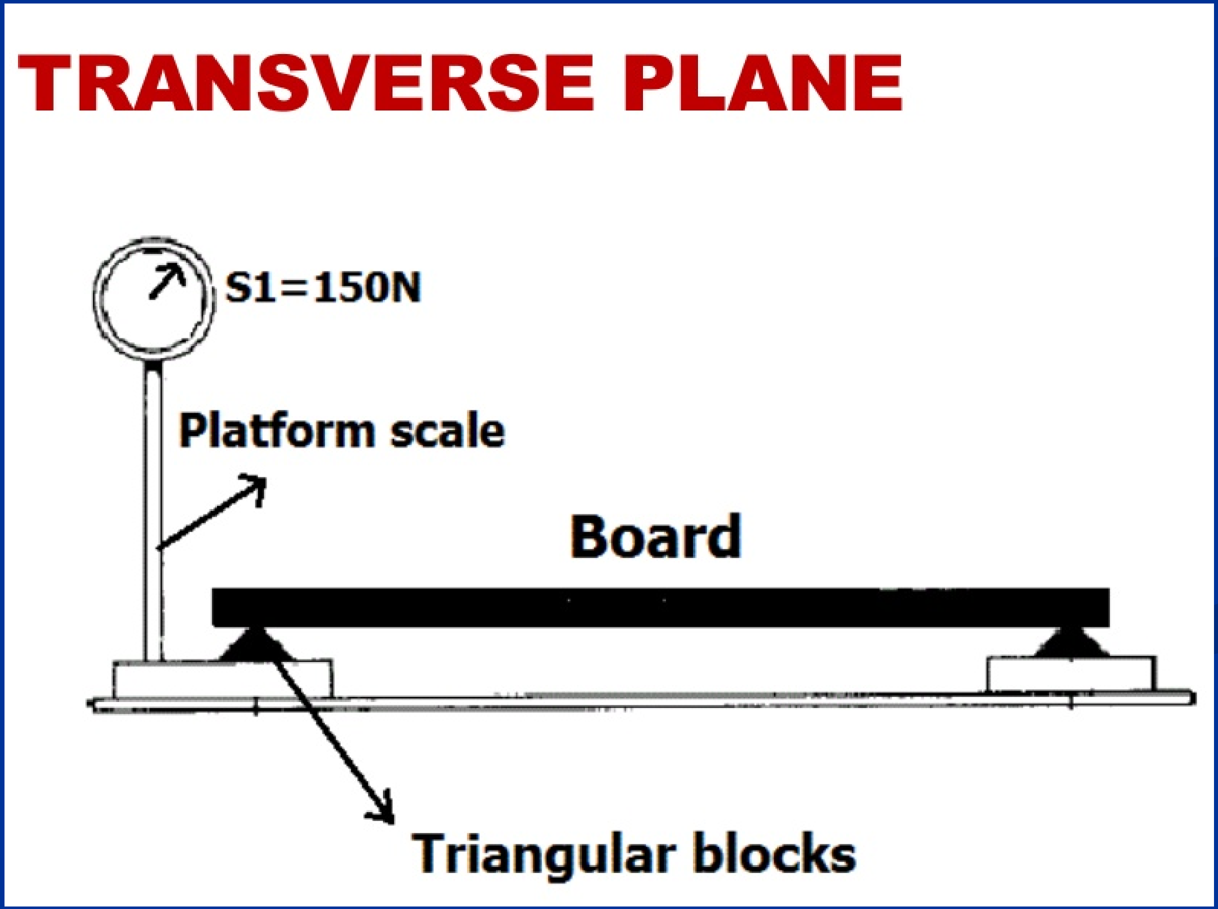
=> by multiplying 55.7 of height and then adding 1.4 cm.

$$\frac{H*55.7}{100} + 1.4 = \mathrm{h}_{\mathrm{CG}}$$

Determination of CG location

Laboratory determination of CG:

"Board and scale method" or "Balance Board Method"

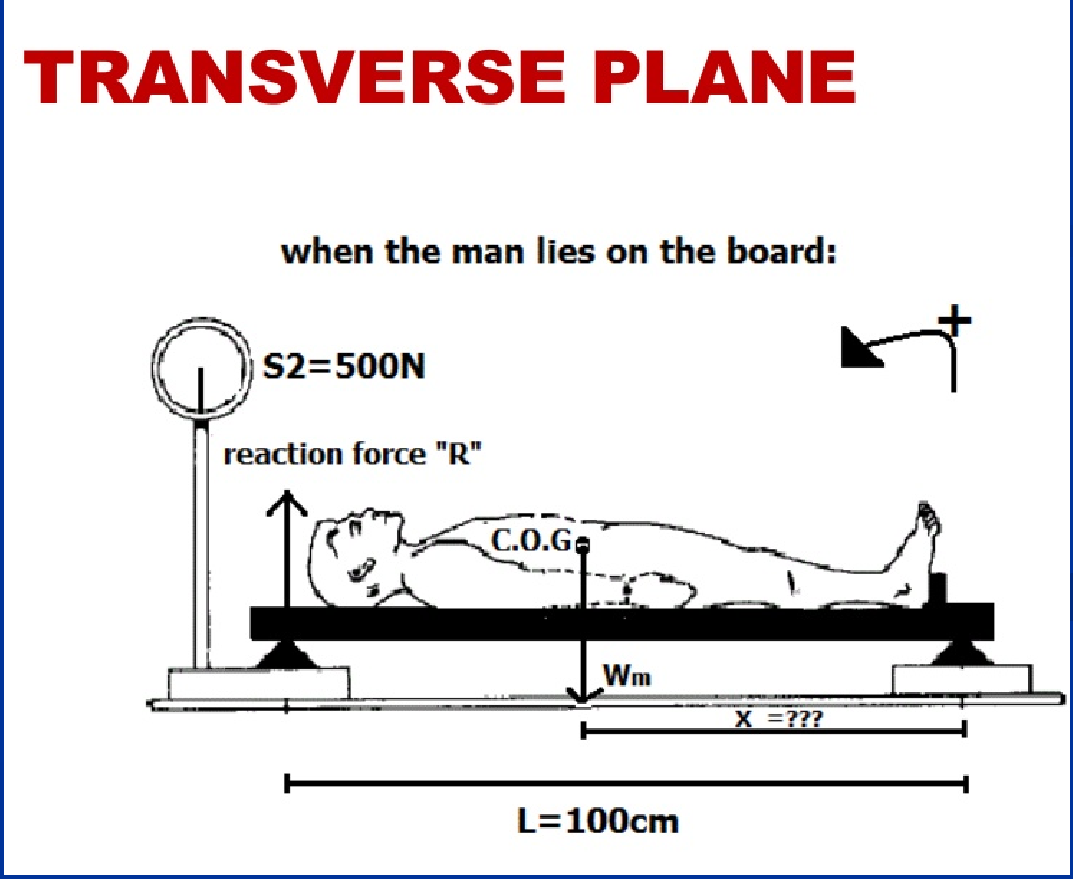


Determination of CG location

Laboratory determination of CG:

"Board and scale method" or "Balance Board Method"

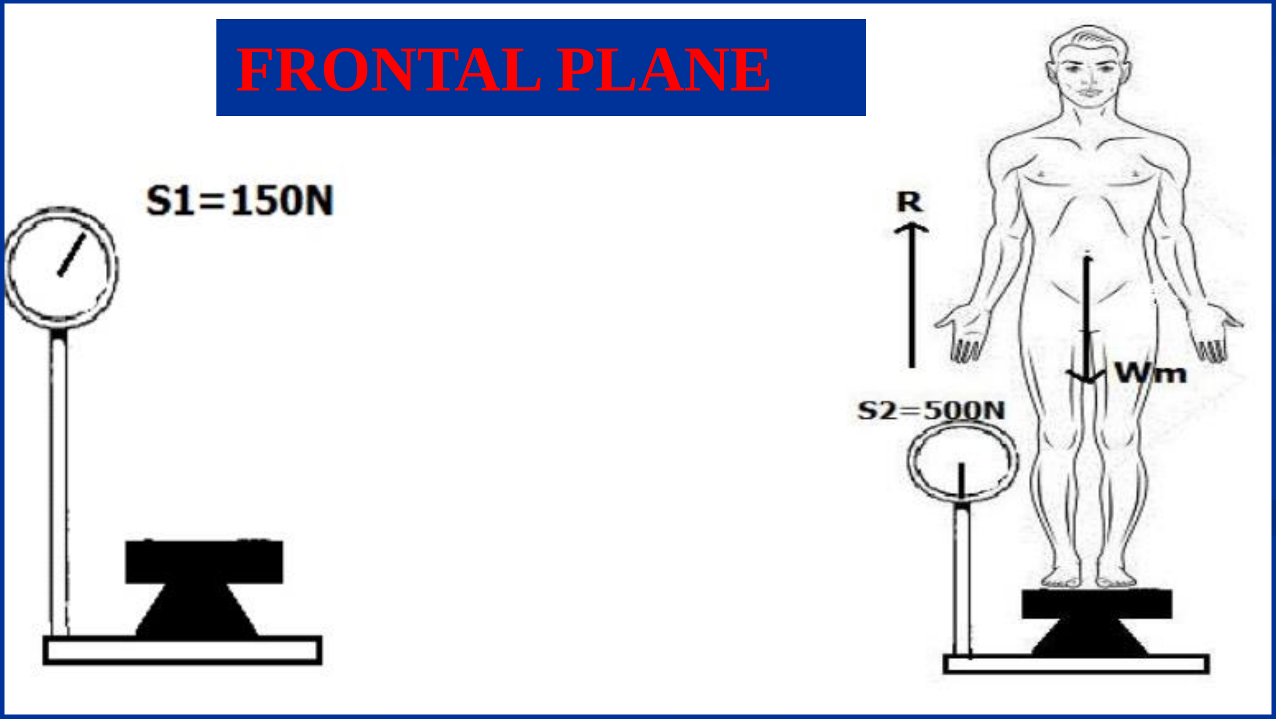
$$x = \frac{R * L}{W_m}$$



Determination of CG location

Laboratory determination of CG:

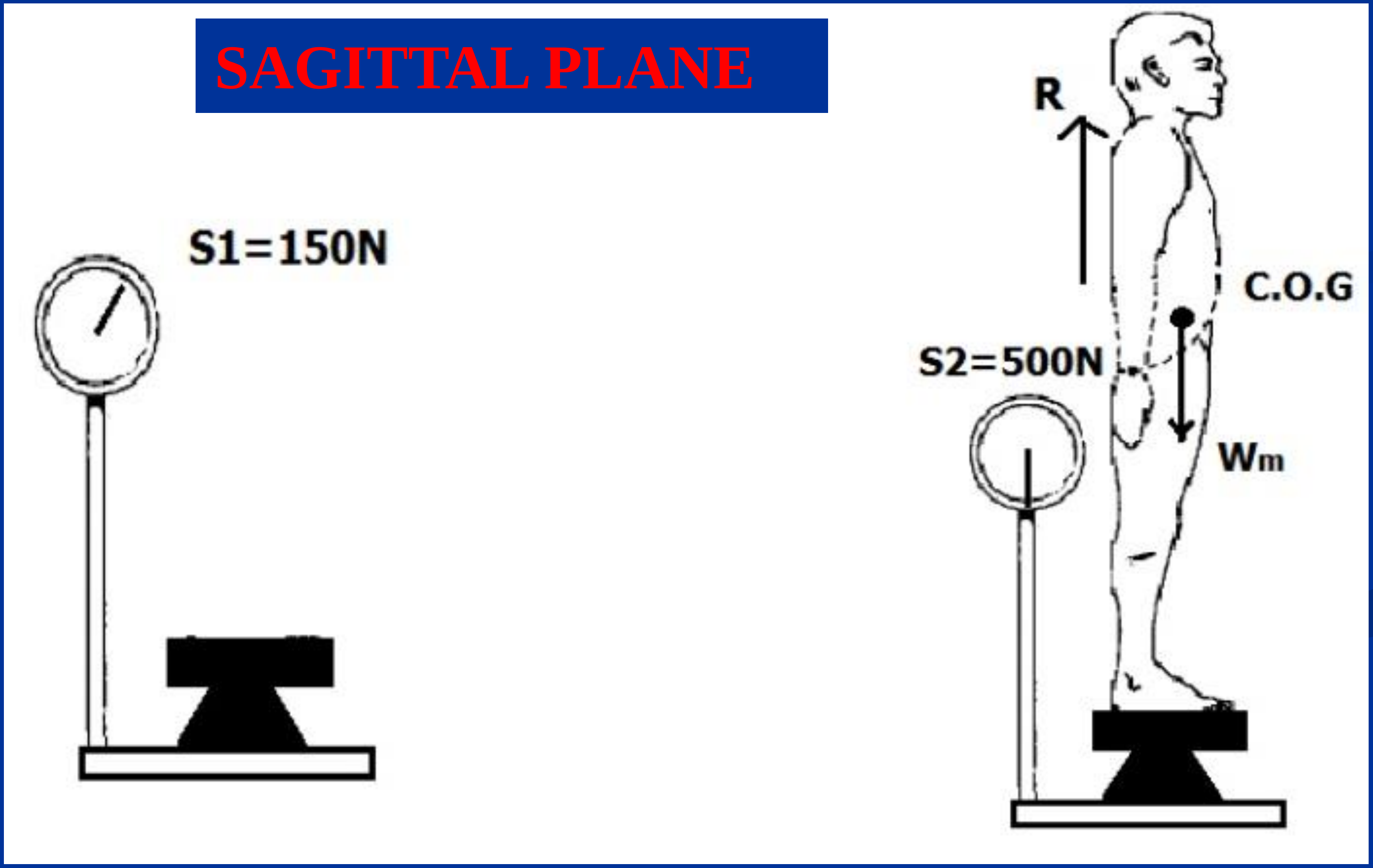
“Board and scale method” or “Balance Board Method”



Determination of CG location

Laboratory determination of CG:

"Board and scale method" or "Balance Board Method"



Determination of segmental CG location

Segmental method

The segmental method is the estimation of the location of the body's total centre of gravity;
It is based on the concept that each individual segment has its own centre of gravity.

Body segment: - the body is made up of eight segments

1. Head and Neck
2. Trunk
3. Arm
4. Forearm
5. Hand
6. Thigh
7. Leg
8. Foot

Determination of segmental CG location

Segmental method

The segmental method is the estimation of the location of the body's total centre of gravity;
It is based on the concept that each individual segment has its own centre of gravity.

Body segment: - the body is made up of eight segments

1. Head and Neck
2. Trunk
3. Arm
4. Forearm
5. Hand
6. Thigh
7. Leg
8. Foot

Determination of segmental CG location

Segmental method

Study on cadavers by Dempster (1955):

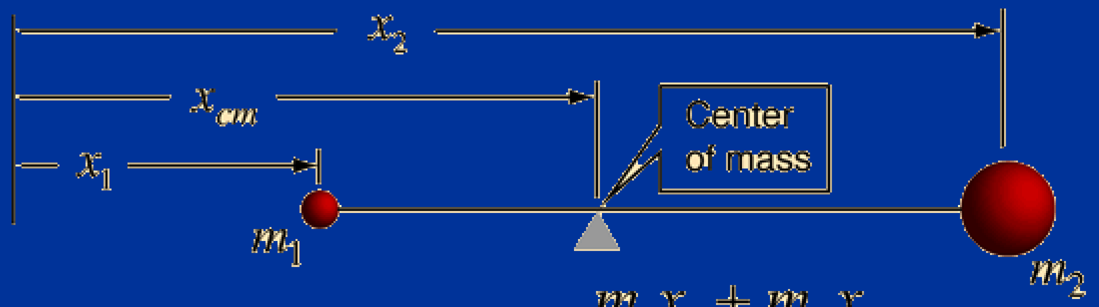
Segment	Centre of Gravity Location (% of length)	Relative Mass (%)
Head	59.8% from Vertex	6.94
Trunk	44.9% from supersternale	43.46
Upper Arms	57.7% from shoulder	5.42
Forearms	45.7% from elbow	3.24
Hands	79.0% from wrist	1.22
Thighs	41.0% from hip	28.32
Shanks	44.6% from knee	8.66
Feet	44.2% from heel	2.74

Center of gravity (CG)

Segmental method

The center of gravity of an object is calculated by taking the sum of its moments divided by the overall weight of the object.

The moment (M) is the product of the weight and its location as measured from a set point called the **origin**.



For two masses: $x_{cm} = \dfrac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$

Center of gravity (CG)

Segmental method

$$(m_1 + m_2)x_{cm} = m_1 x_1 + m_2 x_2$$

Total mass

Effective distance for the total mass = distance to the center of mass.

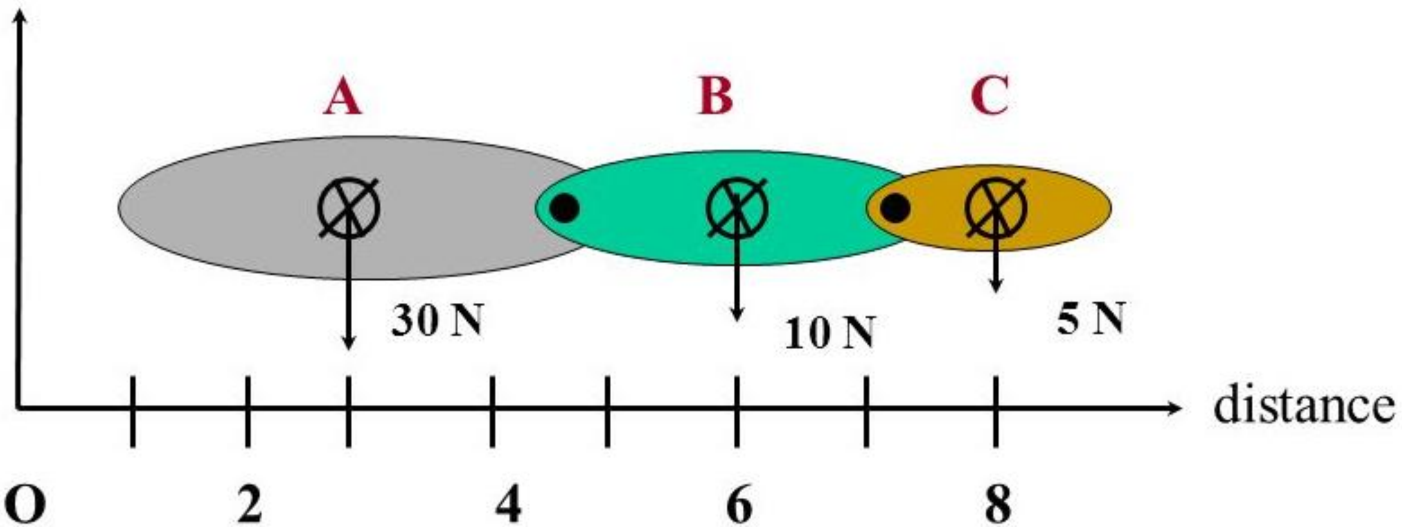
Sum of moments of individual masses.

$$: x_{cm} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}$$

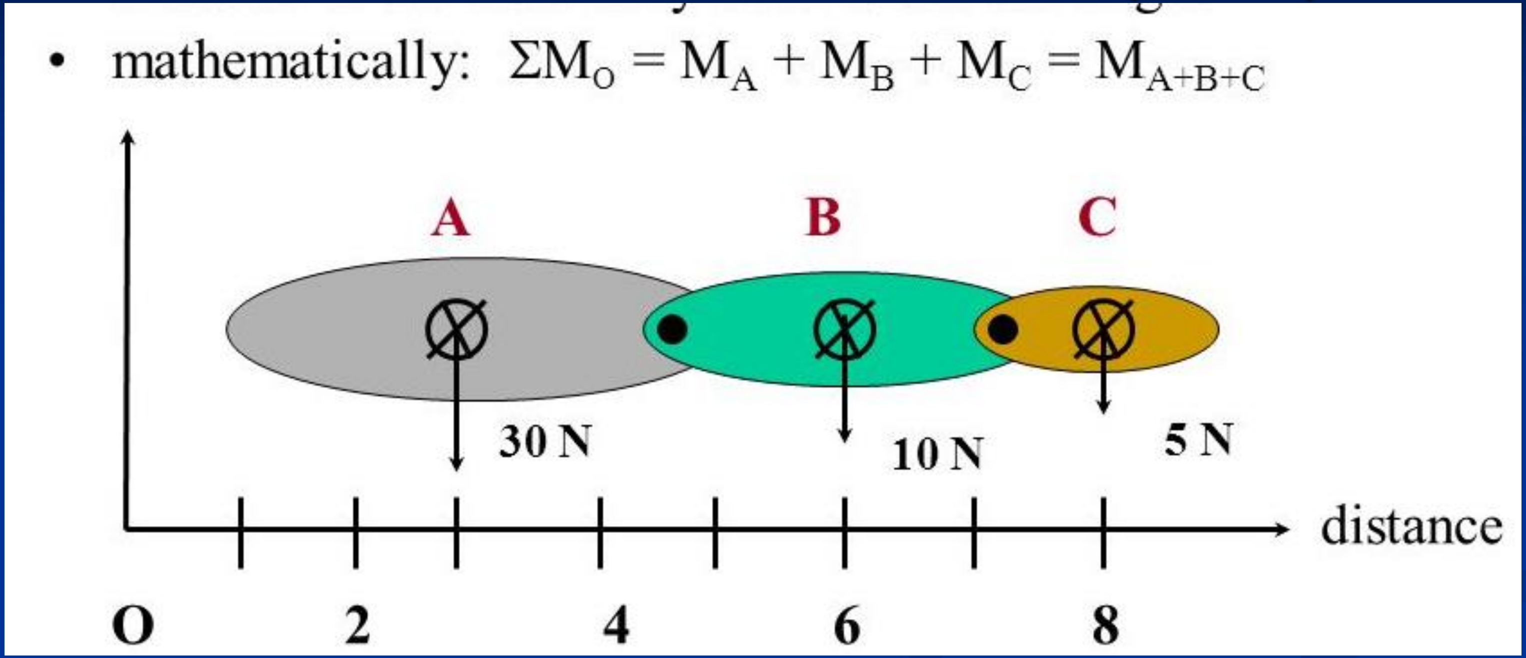
Center of gravity (CG)

Multi-Segment Method

- Imagine a body composed of three segments, each with the C-of-G and mass as indicated
- sum of Moments of each segment mass about the origin = Moment of the total body mass about the origin
- mathematically: $\Sigma M_O = M_A + M_B + M_C = M_{A+B+C}$



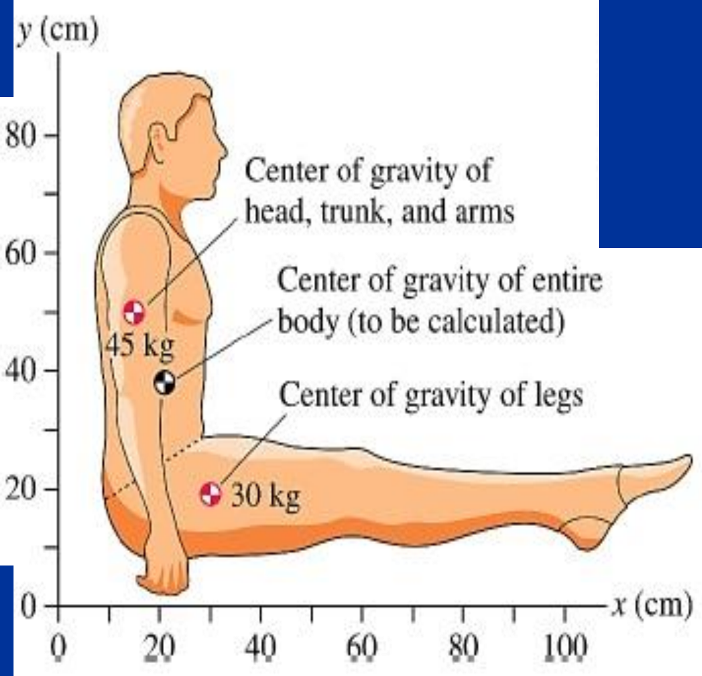
Center of gravity (CG)



x= 4.22

Center of gravity (CG) - Segmental method

A gymnast performing on the ring holds himself in the pike position. Figure shows how we can consider his body made up of two segments whose masses and **COG** positions are shown. **Locate** overall **COG** of the gymnast.



$x_1 = 15$ cm
$y_1 = 50$ cm

$x_2 = 30$ cm
$y_2 = 20$ cm

Center of gravity (CG) - Segmental method

$m_1 = 45$ kg

$x_1 = 15$ cm

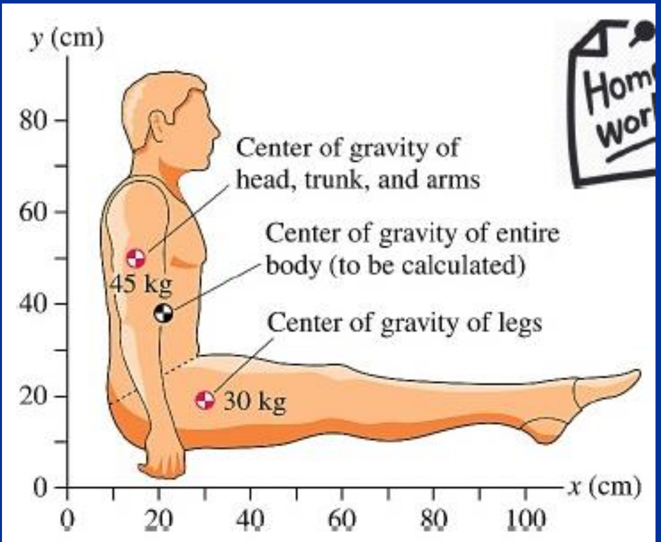
$m_2 = 30$ kg

$x_2 = 30$ cm

$(m_1 + m_2)\, x_{cm} = m_1\, x_1 + m_2\, x_2$

$(45 + 30)\, x_{cm} = 45 * 15 + 30 * 30$

$x_{cm} = 21$ cm



$y_{cm} = 38$ cm

Stability

Stability is a measure of the body's ability to maintain its original position.

Stability — the capacity of an object to return to equilibrium or to its original position after being displaced.

As nouns the difference between and

- **stability** is the condition of being stable or in equilibrium, and thus resistant to change

while

- **equilibrium** is the condition of a system in which competing influences are balanced, resulting in no net change.

Stability

Equilibrium: a body is in balance when the sum of all forces acting on a body is zero,

=> in human being the complex process that interests

- reception and organization of the sensory impulse,

as well as

- the program and execution of the movements,

- elements that ensure the right posture,

=> meaning the permanent maintenance of the CG within the support base (the ability to maintain or mobilize the body without falling).

Stability

In many sports, the athletes do not want to be moved from a certain position.

Wrestlers, football lineman, basketball players are more successful at certain techniques if they adopt stable positions.

In other sports, success may be determined by how quickly an athlete is able to move out of a position.

Receiver of a serve in tennis or racquetball, a sprinter, a swimmer, a downhill skier, a goalie in soccer more successful during certain skills if less stable.

Equilibrium

- The body is at rest
- The sum of all forces acting on the body is zero.

is the state of zero acceleration (static or dynamic)

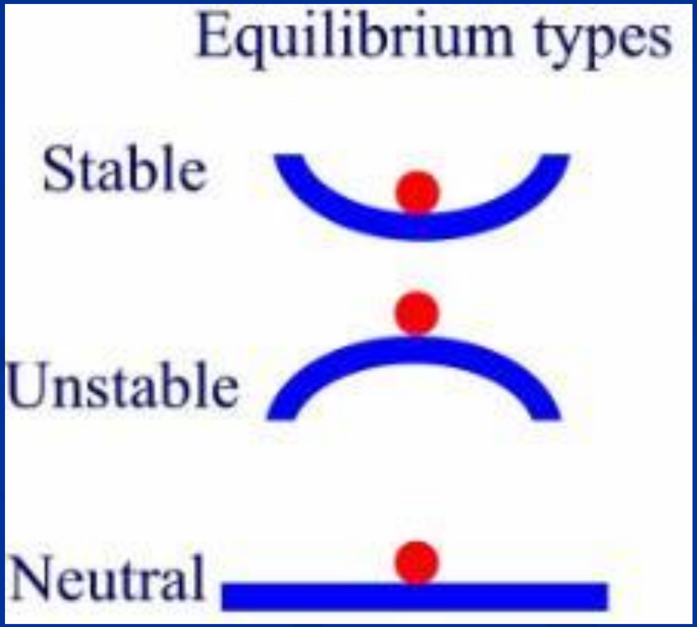
is the ability to control equilibrium

is a resistance to the disturbance of equilibrium

Equilibrium

Types of Equilibrium – depending of stability:

- Stable equilibrium
- Unstable equilibrium
- Neutral equilibrium



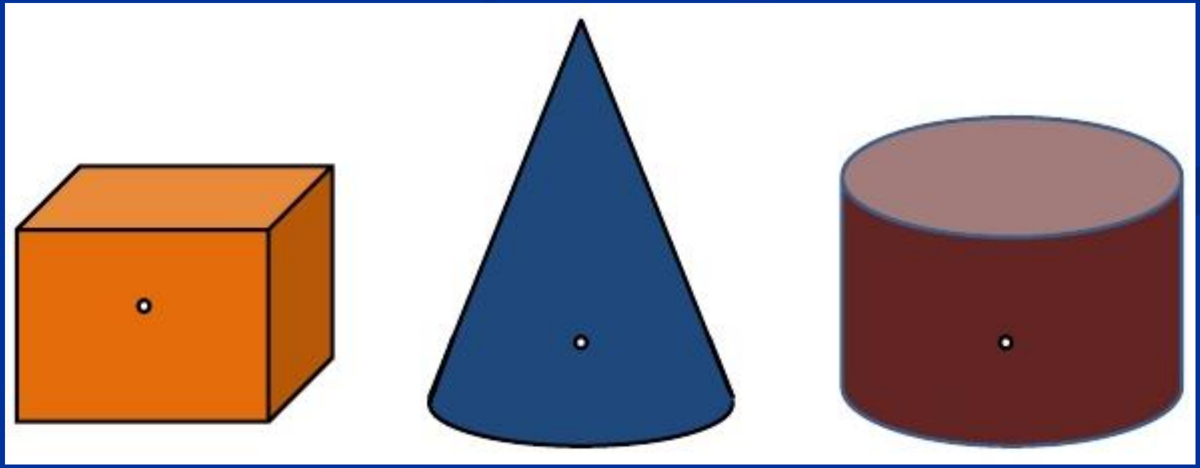
Equilibrium

a) Stable equilibrium

- The CG is at lowest possible position

- After a small displacement the body returns to its original equilibrium position.

- Its center of gravity is raised when it is displaced.



Equilibrium

a) Stable equilibrium

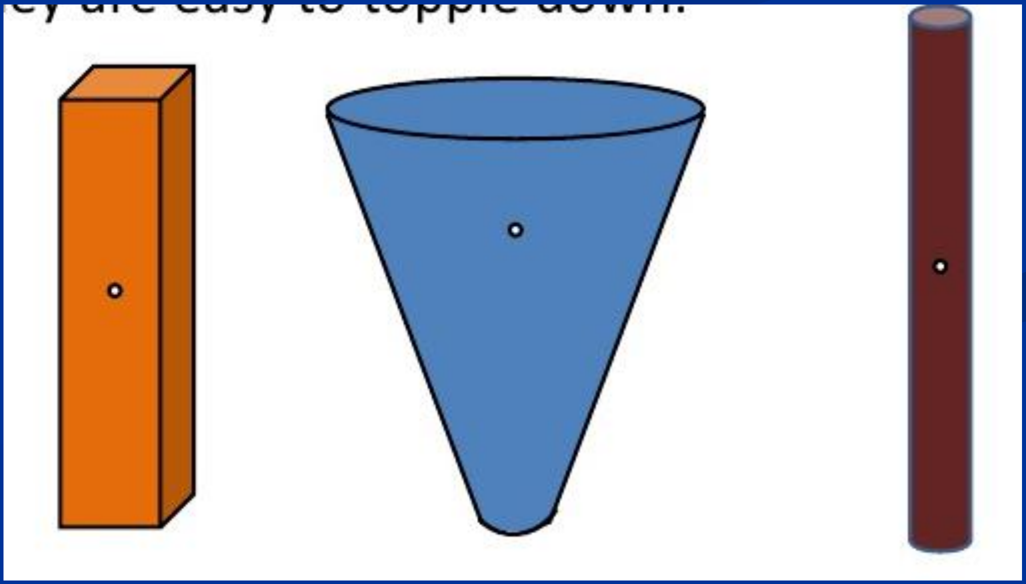
- The CG is located below the support point.

- It can be tilted through quite a big angle without toppling

Example: hung on the fixed bar or rings.
Under the action of a momentary impulse, the body returns to its original state.

b) **Unstable equilibrium**

- The CG is at the highest possible position;
- They are easy to topple down;
- After a small displacement the body does not returns to the original equilibrium position and moves to a new equilibrium position.



b) **Unstable equilibrium**

- The CG is located above the support point.
- It will topple with the slightest tilting.
- Its center of gravity is lowered when it is displaced.

Example: orthostatic position, sitting

At the smallest deviation of the body from the equilibrium position, its weight does not pass through the support point and the body does not return to its original position.

c) Neutral equilibrium

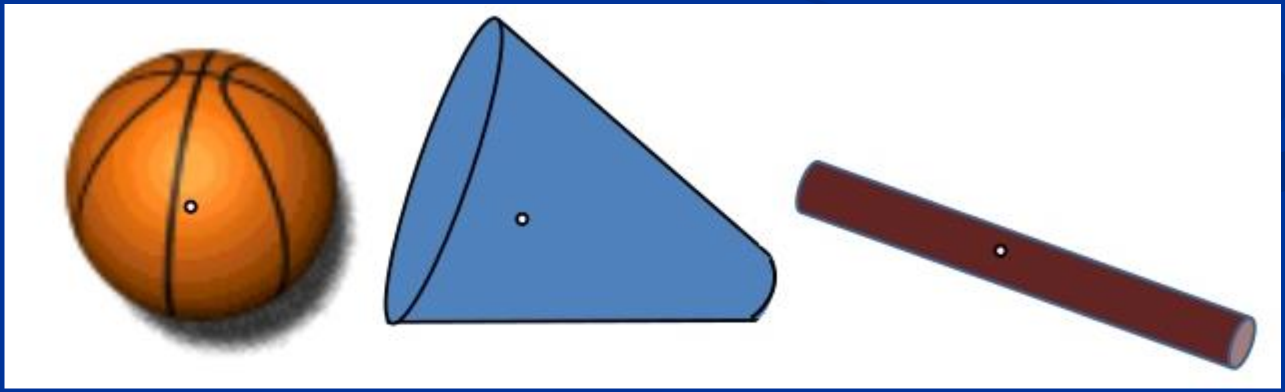
- CG coincides with the support point.
- After a small displacement the body remains in the displaced position.
- If a body is placed in such state that if it is displaced then neither it topples over nor does it come back to its original position, then such state is called neutral equilibrium.
- When a body is disturbed its centre of gravity is neither raised nor lowered but it remains at the same height.

c) Neutral equilibrium

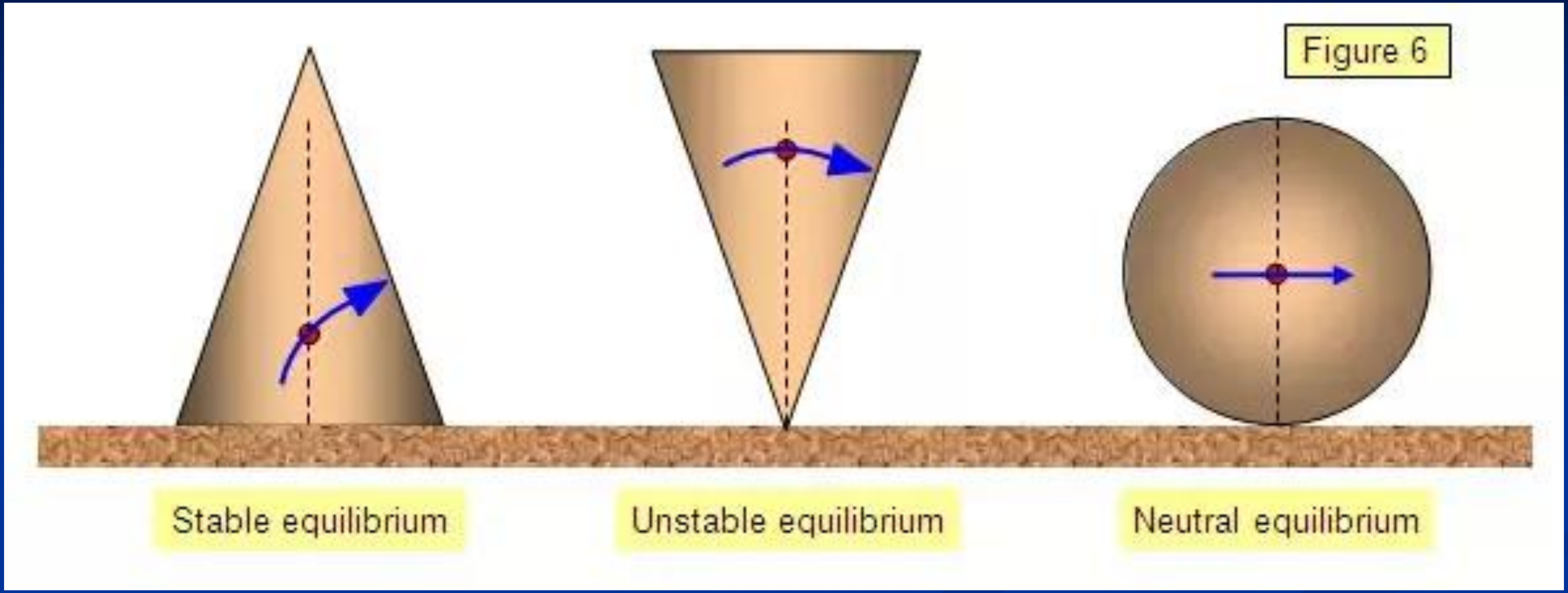
Example: rolling ball, circular and spherical bodies

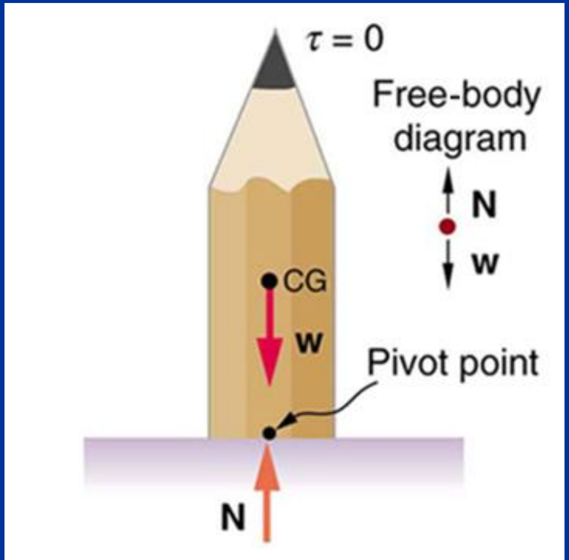
- It will roll about but does not topple
- Its center of gravity remains at the same height when it is displaced.
- The body will stay in any position to which it has been displaced.

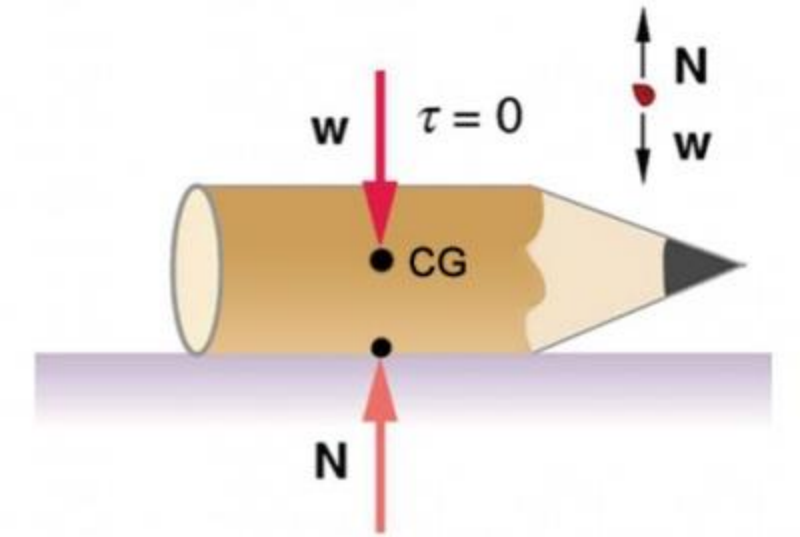
- In living beings this equilibrium position does not exist.



Equilibrium







Equilibrium

Types of Equilibrium – depending of motion:

- Static equilibrium
- Dynamic equilibrium

Equilibrium

- **Static equilibrium**

- When the body is in the state of rest under the influence of many force
- No motion

- **Dynamic equilibrium**

When the body is motion although it is under the influence of many forces
- The body will moving with a constant velocity.
- Dynamic balance = The ability to maintain equilibrium while moving.

Static Equilibrium

1) keep the body in a desired position,

Static equilibrium –The equilibrium is maintained in a FIXED POSITION, usually while stood on one **foot.**
maintenance of body posture relative to gravity while the body is still.

Static balance control

- Activities to promote static balance control include
  - sitting, half-kneeling, tall kneeling, and standing postures on a firm surface.
- More challenging activities include practice in the tandem and single-leg stance.



Dynamic Equilibrium

2) move the body in a controlled way

Dynamic equilibrium The equilibrium must be maintained while performing a task which involves MOVEMENT e.g. Walking the beam. – maintenance of the body posture (mainly the head) in response to sudden movements. Tracking a moving object.

Factors Influencing Stability

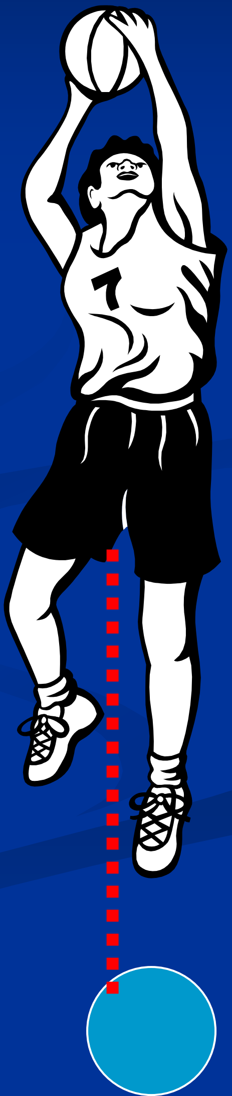
The degree of stability of bodies in unstable equilibrium depends on:

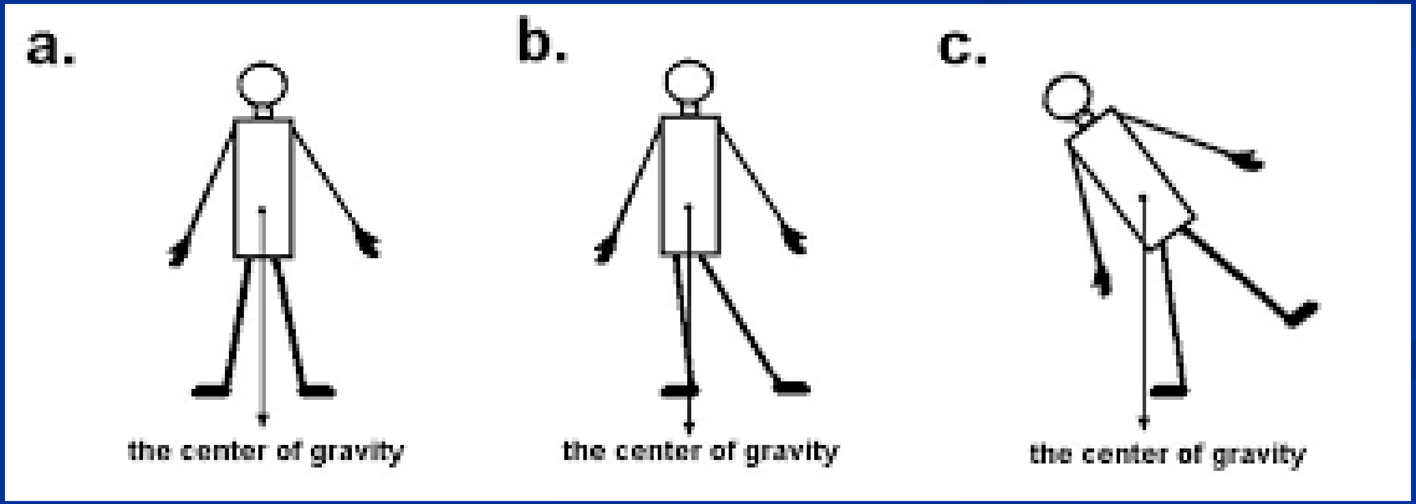
1. Location of the center of gravity in relation to the base of support
2. Size of the base of support
3. Mass of the person
4. Height of the center of gravity
5. Traction/friction
6. Sensory perceptions

Factors Influencing Stability

1. **Location of the center of gravity in relation to the base of support**

The body is stable when the line of gravity falls inside the support base.





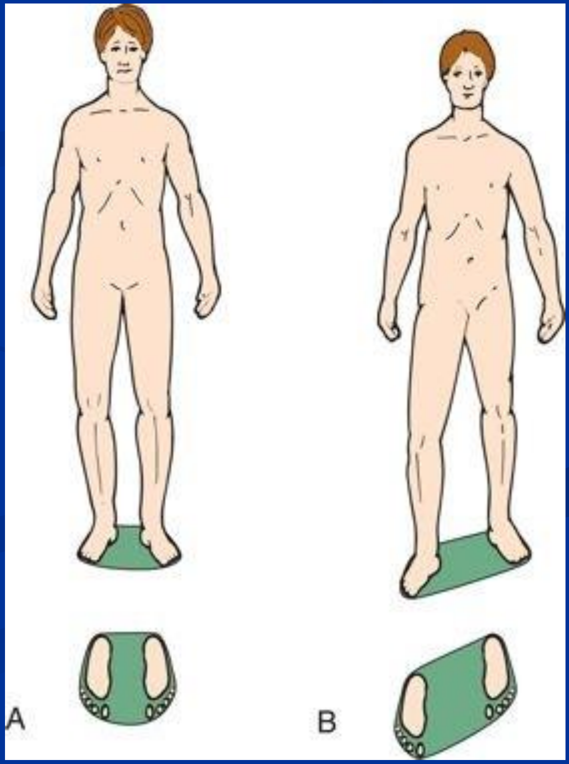
Factors Influencing Stability

2. **Size of the base of support**

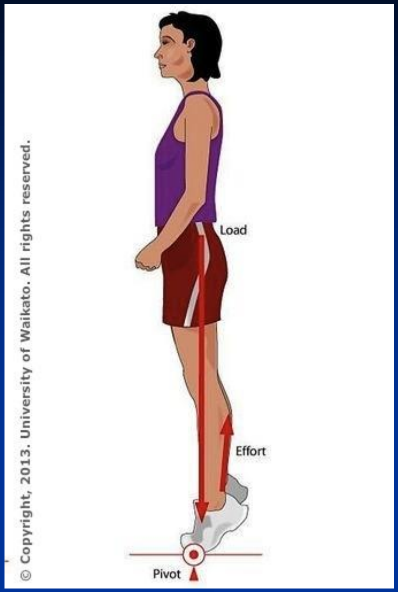
Is the base increases, the stability increases and vice-versa.

Easier with larger base of support

➔ The lower the body's stability (standing on one leg, sitting on the hands), the more muscle effort required to maintain the position will be greater.



Factors Influencing Stability



2. **Size of the base of support**

Example:

a. a person standing on toes has - very less degree of stability - ;

b. both feet together - ;

c. both feet apart - ;

d. the person with both hands and feet on the ground

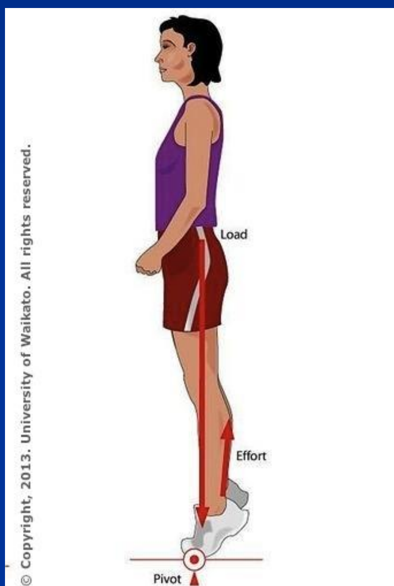
(four point football stance) - ;

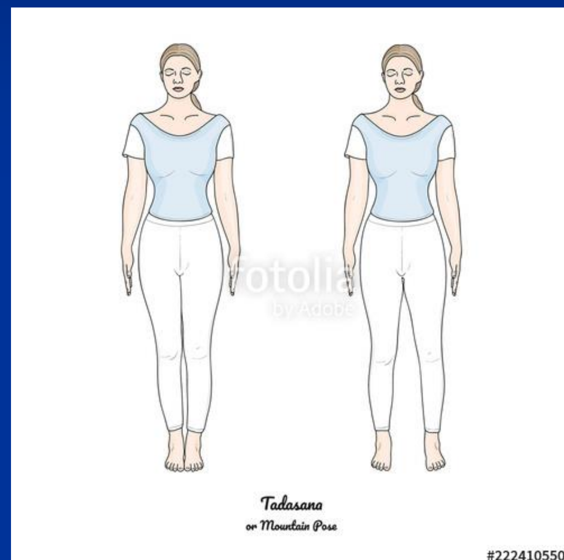
e. wrestler's defensive down position - ;

f. a person lying on the floor - .

Factors Influencing Stability

2. **Size of the base of support**





Factors Influencing Stability

2. **Size of the base of support**

Greater stability is obtained if the base of support is widened in the direction of the line of force.

3. **Mass of the person** (

- stability is directly proportional to the weight of the base

  => the heavy body will have more stability.

- If two individuals of different weights are standing, it is difficult to more the equilibrium of heavier person.

Figure 5.25a unstable

Figure 5.25b base area increased

Figure 5.25c centre of gravity lowered by adding lead to base

REAL LIFE APPLICATIONS

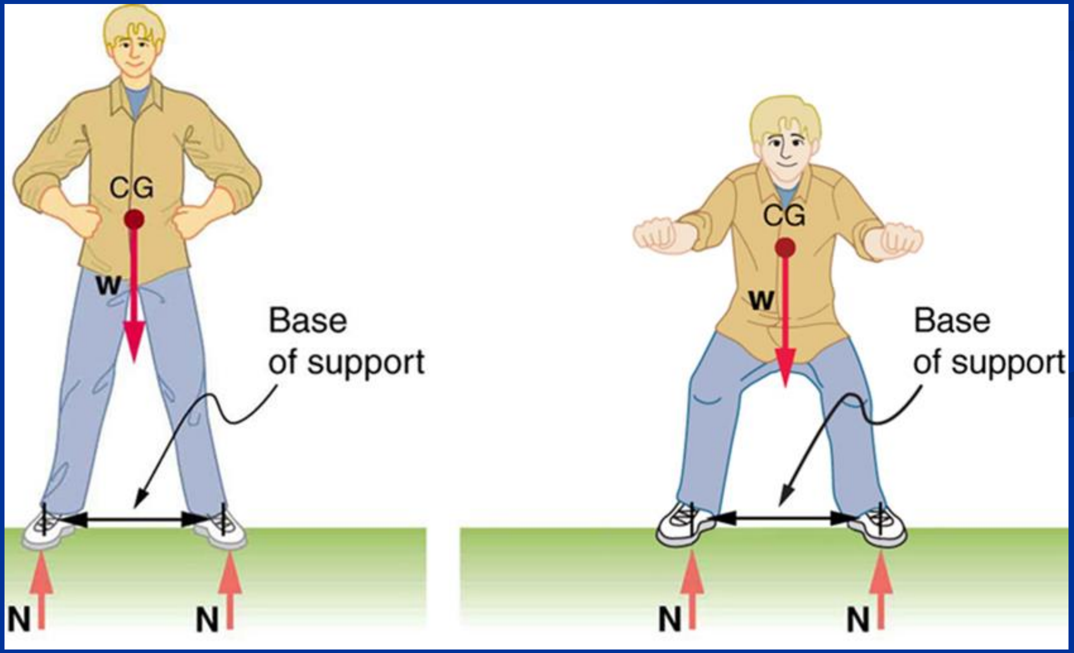
- It is for reasons of stability that the luggage compartment of a tour bus is located at the bottom and not on the roof
- Extra passengers are similarly not allowed on the upper deck of a crowded double-decker bus.

4. Height of the center of gravity

Stability is inversely proportional to the height of center of gravity.

⇒ As the height of the center of gravity (CG) increases, the stability decreases and vice- versa.

The stability is higher as the CG is lower, closer to the support base.



5. **Traction/friction**

Insufficient friction reduces the stability and vice – versa.

Insufficient friction leads to slipping.

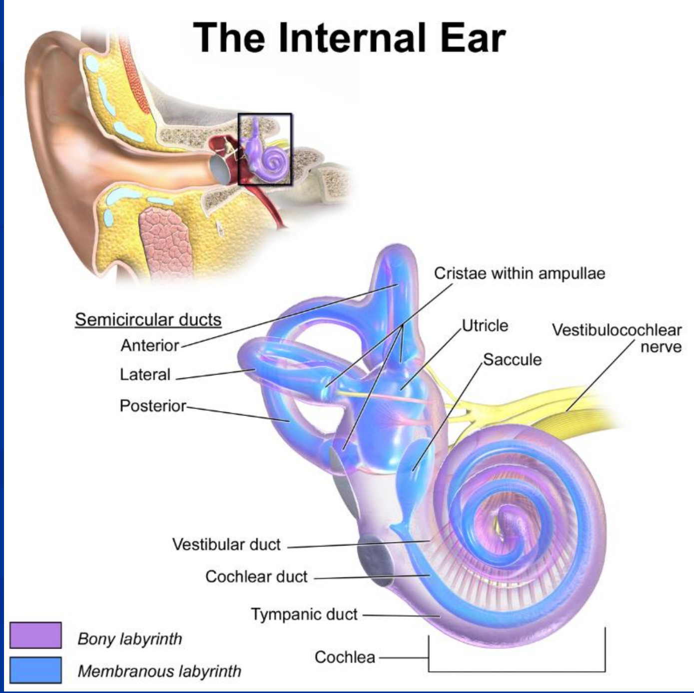
For dynamic stability to exist there must be sufficient friction between body support parts and base surface.

5. Sensory perceptions

- Majority of the times dynamic stability or equilibrium is obtained involuntarily by the physiological mechanism governing posture and equilibrium, which includes kinesthetic perception and certain body reflexes.

- The fluid found in the three semi-circular canal inside the ears is also responsible for stability.

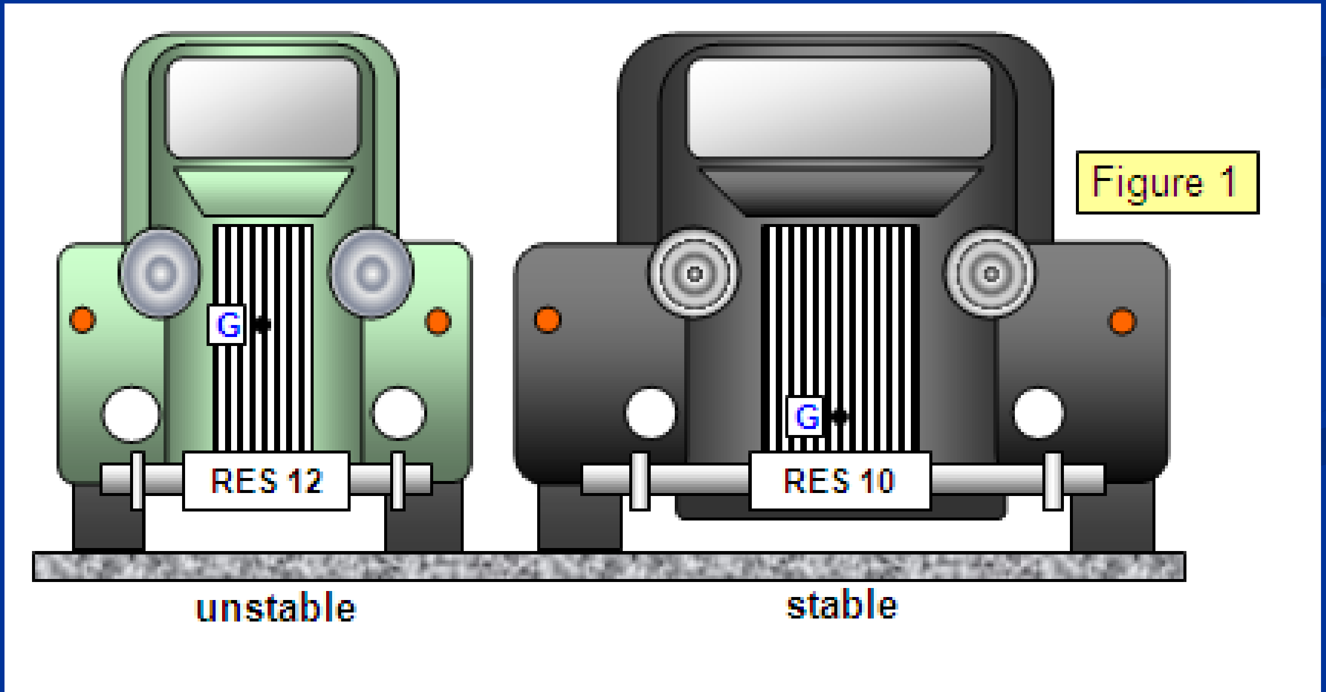
- Visual and Psychological Factors: When walking on a danger area the visual stimulus may affect the stability.



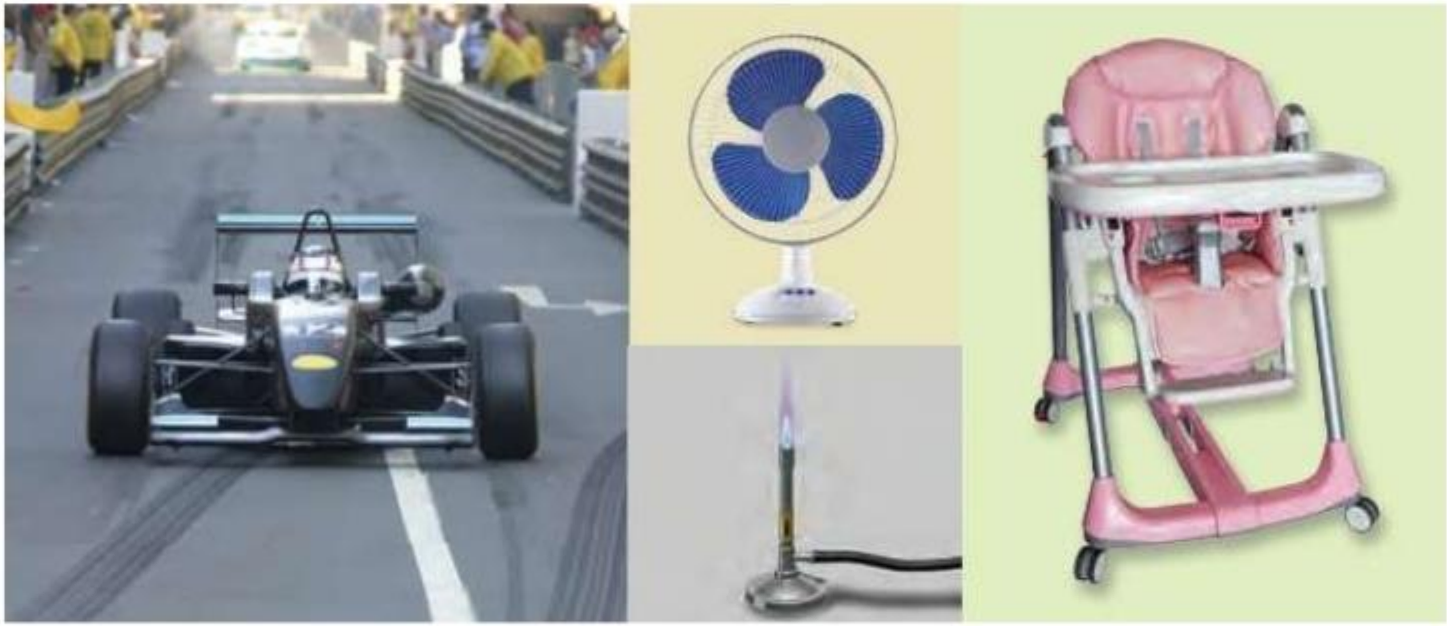
Factors Influencing Stability

To make body more stable:

- **Size of the base of support =►** increasing the base area
- **Height of the center of gravity =►** lowering the center of gravity



REAL LIFE APPLICATIONS



- Racing cars are built low and broad for stability
- Bunsen burners, table lamps and fans are designed with large, heavy bases to make them stable.
- The legs of a baby's highchair are set wide apart so that the chair is stable.

- **Equilibrium** is a state of balance in which all the forces are equal.

- **Stability** is a resistance to the disturbance of equilibrium.

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

Conclusions derived from the equilibrium conditions

1. to start quickly in one direction, keep the CG as high as possible and as near as possible to the edge of the base in the direction of movement.

E.g. Set position in sprints and swimming.

Conclusions derived from the equilibrium conditions

2. a body is said be in equilibrium when is CG falls within its base and loses its equilibrium when the CG falls outside its base.

E.g. wrestler's lying position and dribble low in basketball.

Conclusions derived from the equilibrium conditions

3. to stop quickly during rapid motion, drop the CG as low as possible, create greater area of base as possible and move the CG away from the edge of base nearest to the direction of movement.

E.g. sudden stop of moving basketball player.

Conclusions derived from the equilibrium conditions

4. in all arm support activities the CG of the body should be as near as possible over point of support.

E.g. vaulting horse and exercises on bar.