Body Segment Parameters

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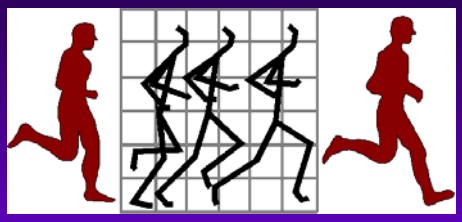

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Body Segment Parameters

Subdivision of Anthropometry

- Necessary to derive kinetics from kinematics (I.e., $\Sigma \underline{F} = m \underline{a}$, $\Sigma \underline{M}_{cg} = I \alpha$, $\underline{a}$ is acceleration of centre of gravity, α is ang. acceleration)
- Called "inverse dynamics"
- Need to compute:
  - segment mass
  - segment centre of gravity
  - segment moment of inertia

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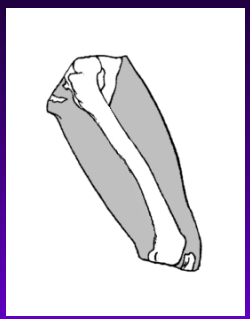
Segment Mass

Definition



- mass is a body's resistence to changes in linear motion
- need to measure total body mass using "balance scale"
- each segment is a proportion of the total

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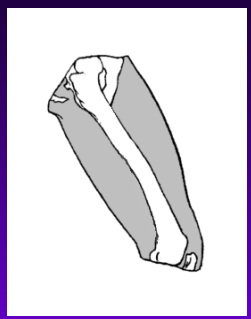
Segment Mass

Thigh segment



- $P_{thigh} = m_{thigh} / m_{total}$
- P_{thigh} = thigh's mass proportion
- m_{total} = total body mass
- Therefore, $m_{thigh} = P_{thigh}\, m_{total}$
- Note, $\Sigma P_i = 1.000$

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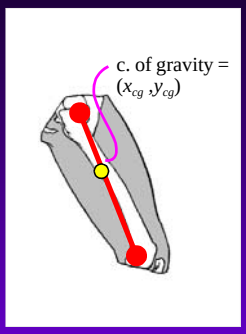
Centre of Gravity

Definition



- point at which a body can be balanced
- (x_{cg}, y_{cg}) = centre of gravity
- also called centre of mass
- first moment of mass
- i.e., turning effect on one side balances turning effect of other side of centre of mass

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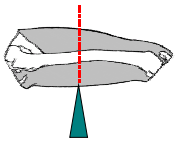
Centre of Gravity

Empirical method

c. of g. is above the vertical line



mass on one side balances the other

- balance body on a "knife edge"
- balance along a different axis
- intersection is c. of g.

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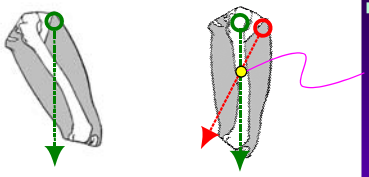
Centre of Gravity

Empirical method

suspend body from two different points



- record plumb lines
- intersection of plumb lines is centre of gravity

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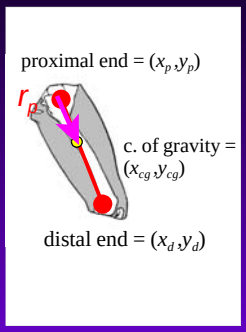
Segment Centre of Gravity

Proportional method



- $R_p = r_p$ / seg. length
- r_p = distance from proximal end to c. of g.
- *need table of proportions derived from a population similar to subject*
- for many segments R_p is approximately 43% of segment length

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Table of Proportions

Segment	P	K_{cg}	$R_{proximal}$	R_{distal}
Hand	0.006	0.297	0.506	0.494
Forearm	0.016	0.303	0.430	0.570
Forearm and hand	0.022	0.468	0.682	0.318
Arm	0.028	0.322	0.436	0.564
Upper extremity	0.050	0.368	0.530	0.470
Foot	**0.0145**	**0.475**	**0.500**	**0.500**
Leg	0.0465	0.302	0.433	0.567
Leg and foot	0.061	0.416	0.606	0.394
Thigh	0.100	0.323	0.433	0.567
Lower extremity	0.161	0.326	0.447	0.553
Head and neck	**0.081**	**0.495**	**1.000**	**0.000**
Trunk	0.497	0.500	0.500	0.500
Trunk, head & neck	0.578	0.503	0.660	0.370

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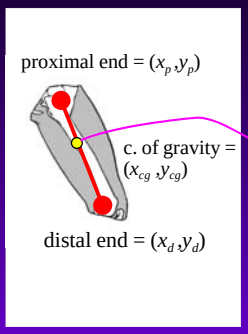
Segment Centre of Gravity

Thigh segment



- R_p = distance to c.of g. from proximal end as proportion of seg. length
- $x_{cg} = x_p + R_p (x_d - x_p)$
- $y_{cg} = y_p + R_p (y_d - y_p)$
- (x_{cg}, y_{cg}) = centre of gravity
- (x_p, y_p) = proximal end
- (x_d, y_d) = distal end

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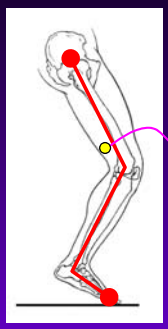
Centre of Gravity of a Limb

Lower extremity



- weighted average of segment centres
- $x_{limb} = \Sigma(P_i x_i) / \Sigma P_i$
- $y_{limb} = \Sigma(P_i y_i) / \Sigma P_i$
- (x_i, y_i) = mass centre of segment "i"
- P_i = mass proportion of segment "i"

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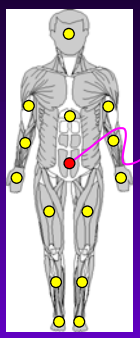
Total Body Centre of Gravity

Need to compute centres of each segment



- weighted sum of all segments' centres
- $x_{total} = \Sigma P_i x_i$
- $y_{total} = \Sigma P_i y_i$
- (x_{total}, y_{total}) = total body centre of gravity

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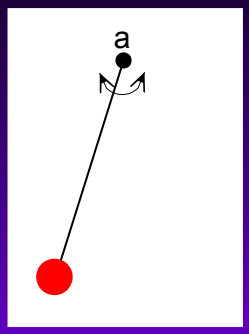
Moment of Inertia

Definition



- body's resistence to change in its angular motion
- second moment of mass (squared distance)
- for a point mass
  - $I_a = mr^2$
- for a distributed mass
  - $I_a = \int r^2\, dm$

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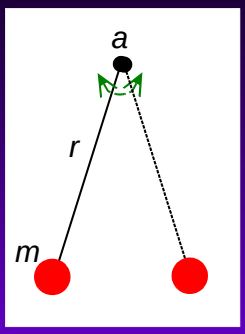
Moment of Inertia

Empirical method



- $I_a = mgrt^2 / 4\pi^2$
- m = mass
- r = radius of pendulum
- g = 9.81 m/s^2
- t = period of oscillation (time 20 oscillations then ÷20)
- oscillations must be less than ±5 degrees

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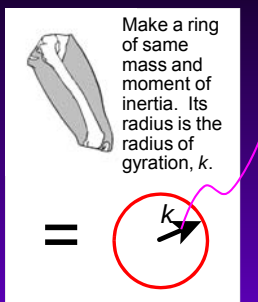
Segmental Radius of Gyration

Thigh segment



- $I_{thigh} = m_{thigh}\, k_{thigh}^2$
- Thus, $k_{thigh} = \sqrt{(I_{thigh} / m_{thigh})}$
- k_{thigh} = radius of gyration
- Define K_{thigh} = radius of gyration as proportion of segment length
- $L_{thigh} = \sqrt{[(x_d - x_p)^2 + (y_d - y_p)^2]}$
- $K_{thigh} = k_{thigh} / L_{thigh}$

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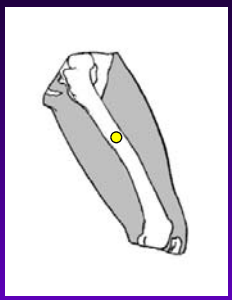
Segmental Moment of Inertia

Thigh's moment of inertia about thigh centre of gravity



- $I_{thigh} = m_{thigh}\, (K_{thigh}\, L_{thigh})^2$
- I_{thigh} = moment of inertia about centre of mass
- m_{thigh} = segment mass
- K_{thigh} = radius of gyration as proportion of segment length
- L_{thigh} = segment length

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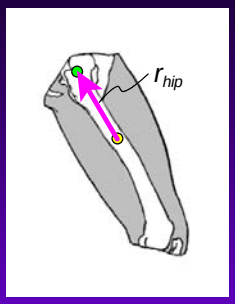
Parallel Axis Theorem

Thigh's moment of inertia about hip



- r_{hip} = distance from centre of gravity to hip
- $r_{hip} = \sqrt{[r_x^2 + r_y^2]}$
- $I_{hip} = I_{thigh} + m_{thigh}\, r_{hip}^2$
- I_{thigh} = moment of inertia about centre of mass
- m_{thigh} = segment mass

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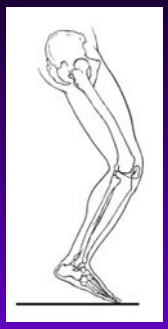
Limb/Total Body Moment of Inertia

Repeatedly apply Parallel Axis Theorem



- $I_{total} = \Sigma\, I_i + \Sigma\, m_i\, r_i^2$
- I_i = segment moments of inertia about each segment's centre of gravity
- m_i = segment masses
- r_i = distance of each segment from limb or total body centre of gravity

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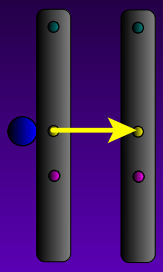
Impact at Centre of Gravity

Translation Only



- an impact to the centre of gravity causes the object to move in pure translation
- arrow represents translation

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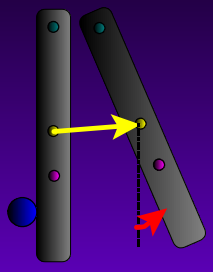
Eccentric Impact

Translation and Rotation



- an eccentric impact causes the object to rotate and translate
- arrow represents translation
- arc represents rotation

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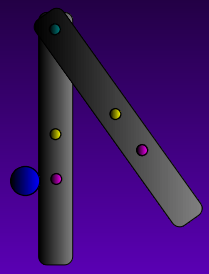
Centre of Percussion

Translation and Rotation about Suspension Point



- point (q) at which an impact will cause no shock (translation) at the grip or point of suspension

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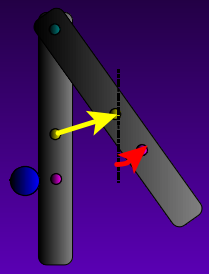
Centre of Percussion (q)

Translation and Rotation about Suspension Point



- $q = k^2 / r = I / mr$
- arrow represents amount of translation
- k is radius of gyration about suspension point
- r is distance to mass centre
- I is moment of inertia about suspension point

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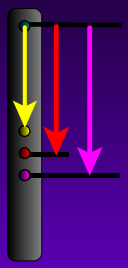
Relationships among Centres and Radius of Gyration



- centre of gravity is nearest centre of rotation
- radius of gyration is past centre of gravity
- centre of percussion is past radius of gyration

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"Sweet Spots" on Racquets, Bats, Hockey Sticks & Clubs

There are at least three!

- centre of percussion gives the least shock (acceleration or force) at point of suspension
- point where coefficient of restitution is largest (i.e., gives greatest rebound speed)
- node of first harmonic, which produces least vibration from an impact

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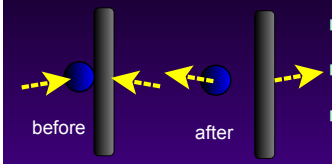
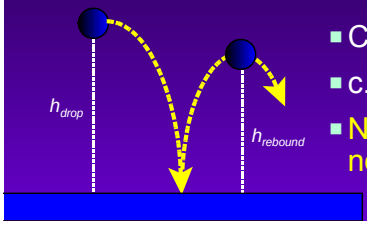
Coefficient of Restitution

Collision between two objects or an object and a surface



- Collision of two objects
- c.of r.= $-(\Delta v_{after} / \Delta v_{before})$
- Velocities should taken after any deformation.



- Collision with a surface
- c.of r.= $\sqrt{(h_{rebound} / h_{drop})}$
- Note, ball should have no spin.