Human Factors
in Accident Prevention

People / Environment / Work
Force / Frequency / Posture

FPST 3213

Biomechanics

Objectives

- Know how different forces are applied on the human body
- Use equations for solve biomechanics problems

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Definitions

- Ergonomics – How work affects people
- Human factors – Human machine interface
- Anthropometry - Measurement of humans
- Biomechanics – Science of Human Movement

MSD’s and human error prevention

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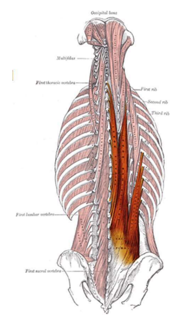
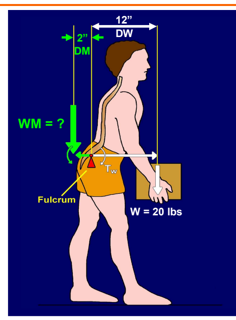
How much force is developed by erector spinae?





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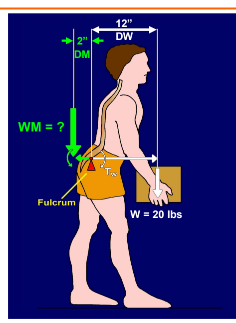
How much force is developed by erector spinae?

WM = ?

Moment 2 = Moment 1

(W) X (DW) = Moment 1

(WM) X (DM) = Moment 2



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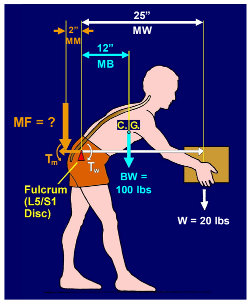
Add Reaching

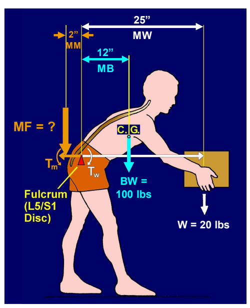
How much force is developed by erector spinae?



Add Reaching

MF = ?

Moment 2 = Moment 1 + Moment 3



Conclusion

With a 20 lb box the erector spinae supports 120 lb.

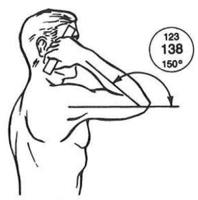
With reaching and a body weight of 100 lb in CG, the erector spinae supports 850 lb

Biomechanics

Types of Body Movements

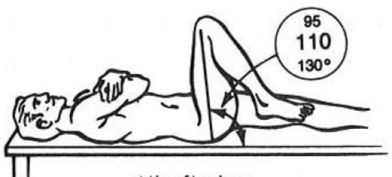
Flexion

- A movement of a segment of the body causing a decrease in the angle at the joint.



Elbow flexion

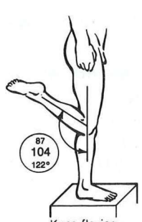
Types of Body Movements



Hip flexion

Types of Body Movements

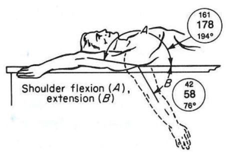
Extension



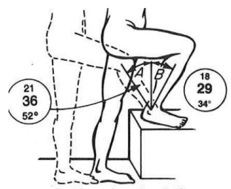
Knee flexion, standing

- A movement in the opposite direction of flexion which causes an increase in the angle of the joint

Types of Body Movements



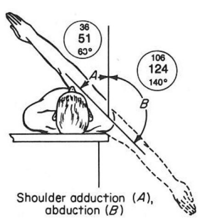
Shoulder flexion (A), extension (B)



Ankle extension (A), flexion (B)

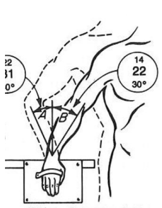
Types of Body Movements

- Abduction
  - A movement of a body segment in a lateral plane away from the midline of the body such as raising the arm sideways
- Adduction
  - A movement of a body segment toward the midline as when moving the arm from the outward horizontal position downward to the vertical position

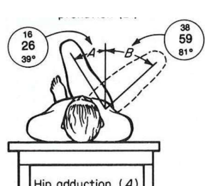


Shoulder adduction (A), abduction (B)

Types of Body Movements

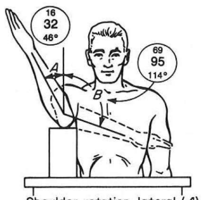


Wrist abduction (A), adduction (B)



Hip adduction (A), abduction (B)

Types of Body Movements

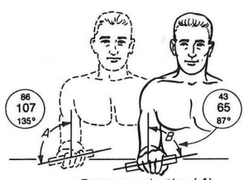


Shoulder rotation, lateral (A) medial (B)

Rotation

- The movement of a segment around its own longitudinal axis
- Medial rotation
  - toward the midline of the body
- Lateral rotation
  - away from the midline of the body

Types of Body Movements



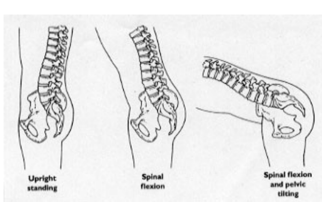
Forearm supination (A), pronation (B)

Rotation

- Pronation
  - Palms down
- Supination
  - Palms up

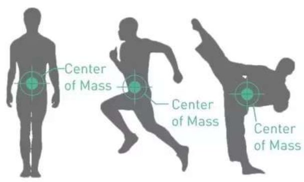
Biomechanics of Spine & Hip

- Movements of spine
  - Flexion, rotation, extension
- Hip Movements
  - Elevation, flexion, extension



Body Segment

- Center of mass



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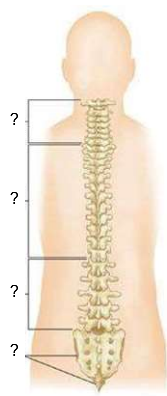
The Spine

- Low back pain
- Soft tissue injuries
- Acute fractures
- Stress fractures
- Disc herniation
- Whiplash injuries
- Other ailments



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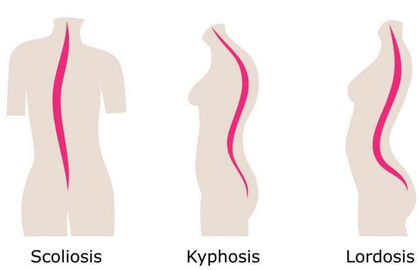
Posture

- What exactly is “good posture”



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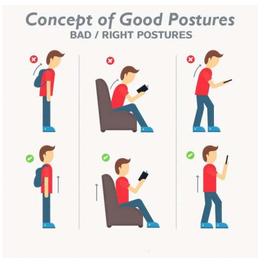

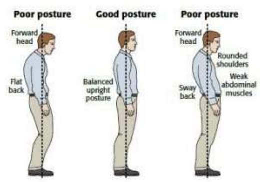

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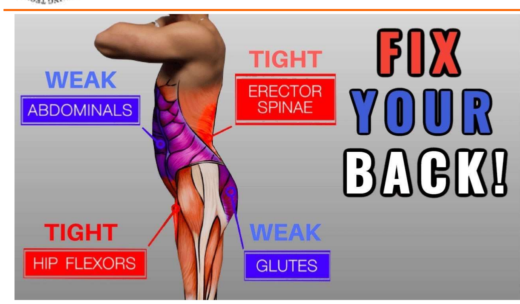
Improving your general posture



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Classes of Movement

- Discrete movements
  - A singular reaching movement to a stationary target
- Repetitive movements
  - Repetition of a single movement to a stationary target

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Classes of Movement

- Sequential movements
  - Discrete movements to a number of stationary targets regularly or a regularly spaced
- Continuous movements
  - Require muscular control adjustments to some degree during the movement
- Static posturing
  - Maintaining a specific position of a body member for a period of time

Classes of Movement

Discrete movements	Holding a part in one hand while soldering it
Repetitive movements	Reaching for a switch
Sequential movements	Operating the steering wheel of a car
Continuous movements	Hammering a nail
Static posturing	Typing on a keyboard

Body Segment

Body Segment Density

Body Segment	Year = 1860	Year = 1955
Head and Neck	1.11 g/cm^3	1.11 g/cm^3
Trunk	--	1.03
Upper Arm	1.08	1.07
Forearm	1.10	1.13
Hand	1.11	1.16
Thigh	1.07	1.05
Lower Leg	1.10	1.09
Foot	1.09	1.10

Density = Mass / Volume *Human Segment Density ~ 1 g/cm^3*

Pressure

Equal and opposite reaction force

$$P = \frac{F}{A}$$

P = pressure
F = force
A = area

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Sir Isaac Newton

- Formulated 3 physical “laws”
  - Movement produced by a system of levers.
    - Movement (dynamic)
    - Stabilization (static)

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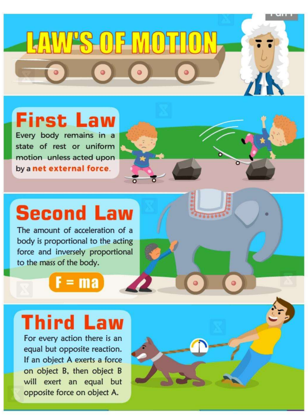

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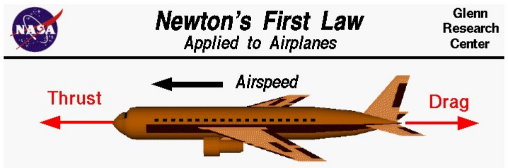
Newton’s 1th Law of Inertia



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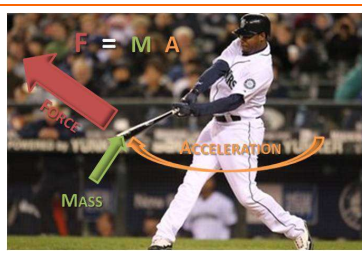
Newton’s 2nd Law of Motion



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Newton’s 2nd Law of Motion

- Muscles contract and create force on the body’s levers (connective tissue, bones)
- With any human movement, F=ma can be used to create a simplified calculation of force including static positions

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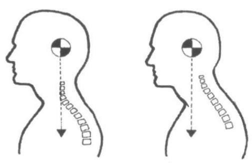
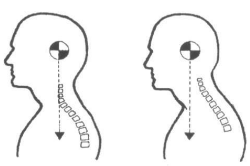
Newton's 2^{nd} Law of Motion



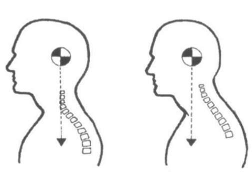
What is preventing your head from snapping off?

Newton's 2^{nd} Law of Motion



- levator scapulae
- upper trapezius
- posterior cervical muscles

Newton's 2^{nd} Law of Motion



mass of the head

$$F = m * a$$

$9.8 m/s^2$

calculate the muscle forces necessary to prevent movement

Newton's 3rd Law Action and Reaction

- An important consideration here is the concept that gravity is ALWAYS touching every object

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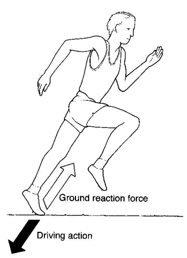
Newton's 3rd Law Action and Reaction

- Example
  - Ground reaction forces
  - Running on soft ground will result in much less impact forces than running on hard concrete



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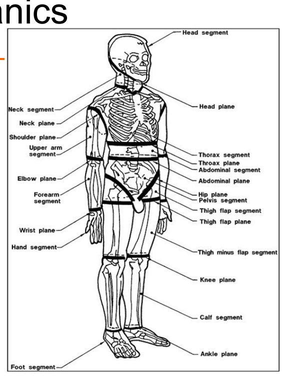
Biomechanics

- Human body is a system of links



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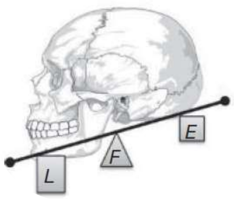
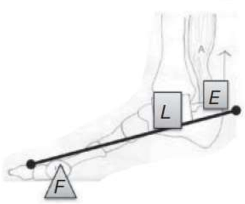
Lever System

First class lever



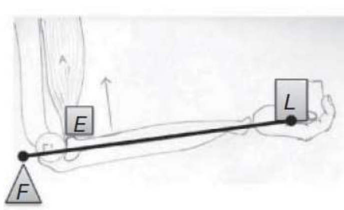
Lever System

Second class lever

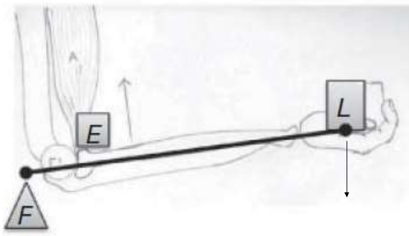


Lever System

Third class lever



Lever System



Newton's 2nd Law of Motion

$$F = m * a$$

Where: F is the net force applied
m is the mass of the body
a is the body's acceleration

Torque or Moment

- When the force of gravity does not act exactly through the center of a joint, there is a tendency for rotation about the joint axis

$$M = F * d$$

Where:
M is the moment
F is the net force
d is the perpendicular distance from the axis of rotation

Units

$$F = m * a$$

$$\underbrace{kg \quad m/s^2}_{\text{N (Newton)}}$$

$$M = F * d$$

N * m

Note:
Some books mention that Moments can also be expressed as inch-pounds or foot-pounds

$$M = W * d$$

lb * in

Weight is the force generated by the gravitational attraction of the earth on the mass of an object. Weight is expresses in pound-force (lb) an opposed to pound-mass (lbm)

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Newtonian Principle

- The sum of the moments in any one direction equals the moment of inertia of the object times its angular acceleration in that direction

$$\sum M = I\alpha$$ Dynamic Condition

Where: M is the moment
I is the moment of inertia
α is the angular acceleration
I depends on its mass and the distribution of that mass within the segment (constant)

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Governing Equation

- Moments that tend to cause rotation about the joint in one direction (e.g., clockwise) must be exactly counterbalanced by moments that tend to cause rotation about the joint in the opposite direction (counterclockwise)

$$\sum M = 0$$ Static Condition

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EXAMPLE OF

TORQUE CALCULATIONS

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Example 1

How much is the clockwise rotation force, the moment, at the elbow while holding a 40 lb dumbbell?

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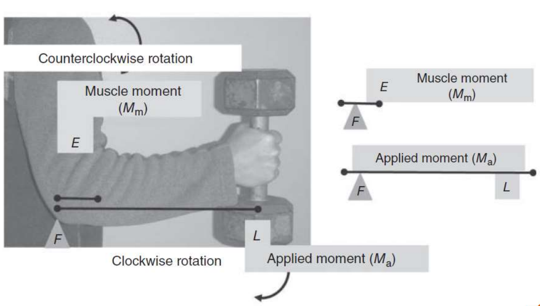
Example 1



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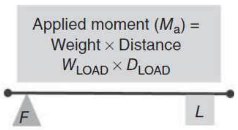
Example 1



$M_a = W_{LOAD} \times D_{LOAD}$

Weight = 40 lb

Distance = 12 in.

$M_a = 40 \text{ lb} \times 12 \text{ in.}$

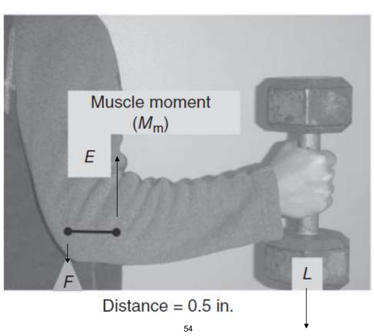
$M_a = 480 \text{ in. lb}$

Example 1

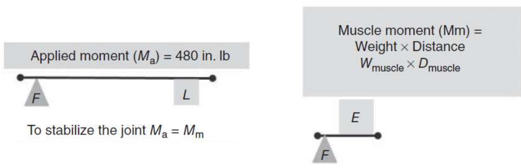
The moment at the elbow is 480 in. lb.

What is the force that the muscles need to generate to stabilize the joint?

Example 1



Example 1



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Example 1

$$M_m = W_{effort} \times D_{effort}$$

Weight = ? lb

Distance = 0.5 in.

$$M_m = M_a \text{ and } M_a = 480 \text{ in. lb}$$

$$480 \text{ in. lb} = W_{effort} \times 0.5 \text{ in.}$$

$$480 \text{ in. lb}/0.5 \text{ in.} = W_{effort}$$

$$960 \text{ lb} = W_{effort}$$

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Example 1

This means the muscles must respond with 960lb of force to generate the 480 in. lb moment that is needed to stabilize the joint.

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Example 2

Example 2

How much torque is produced at the elbow by the biceps brachii inserting at an angle of 60° on the radius when the tension in the muscle is 400 N?

(Assume that the muscle attachment to the radius is 3 cm from the center of rotation at the elbow point.)

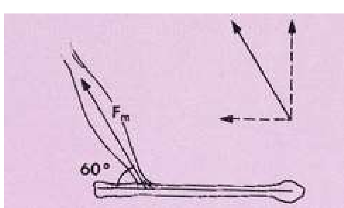
Example 2

Known:

$F_m = 400 \text{ N}$

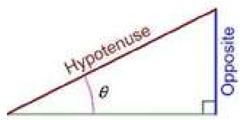
$\alpha \;= 60^\circ$

$d_\perp = 0{,}03 \text{ m}$



Example 2

Only the component of muscle force perpendicular to the bone generates torque at the joint.



$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

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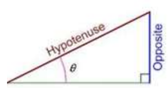
Example 2



$$\sin\theta = \frac{\text{Opposite}}{\text{Hypotenuse}}$$

Therefore

$$F_P = F_m \sin\theta$$
$$F_p = (400\ \text{N})(\sin 60)$$
$$F_p = 346{,}4\ \text{N}$$

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Example 2

The force is $F_p = 346{,}4\ \text{N}$.

However, the questions is about the torque at the elbow.

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Example 2

$$M = F * d$$

Because $T_{orque(M)} = F_p d_{\perp}$

Thus $T_{orque(M)} = (346.4\ N)(0.03\ m)$

$T_{orque(M)} = 10{,}4\ N\text{-}m$

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Example 2

The torque produced at the elbow is 10,4 N-m

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Example 3

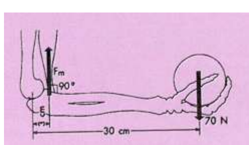
How much force must be produced by the biceps brachii, attaching at 90˚ to the radius at 3 cm from the center of rotation at the elbow joint, to support a weight of 70 N held in the hand at a distance of 30 cm from the elbow joint? (Neglect the weight of the forearm and hand and neglect any action of other muscles.)

Known

$d_m = 3\ cm$

$wt = 70\ N$

$d_{wt} = 30\ cm$



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Example 3

Since the situation described is static, the sum of the torques acting at the elbow must be equal to 0.

$$\sum T_e = 0$$
$$\sum T_e = (F_m)(d_m) - (wt)(d_{wt})$$
$$0 = (F_m)(0.03\text{ m}) - (70\text{ N})(0.30\text{ m})$$
$$F_m = \frac{(70\text{ N})(0.30\text{ m})}{0.03\text{ m}}$$
$$F_m = 700\text{ N}$$

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Example 3

To support a weight of 70 N held in the hand the biceps brachii needs to produce a force of 700 N

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Influence of the distance

If rotational force or **moment = weight × distance**, how much rotational force or moment is generated on the L5/S1 spinal unit when the 40 lb weight is lifted?

It Depends on the Distance!

- Holding 40 lb, 20 in. from the L5/S1 results in XXXX in. lb of rotational force.
- Holding 40 lb, 15 in. from the L5/S1 results in XXXX in. lb of rotational force.
- Holding 40 lb, 10 in. from the L5/S1 results in XXXX in. lb of rotational force.

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Influence of the distance

- Holding 40 lb, 20 in. from the L5/S1 results in 800 in. lb of rotational force.
- Holding 40 lb, 15 in. from the L5/S1 results in 600 in. lb of rotational force.
- Holding 40 lb, 10 in. from the L5/S1 results in 400 in. lb of rotational force.

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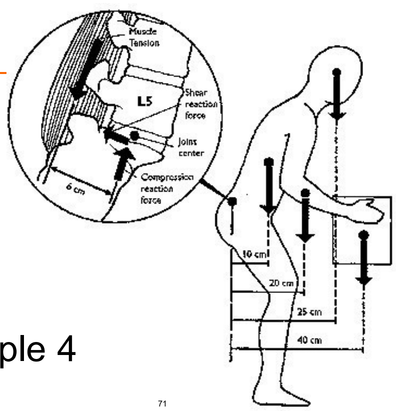

Example 4

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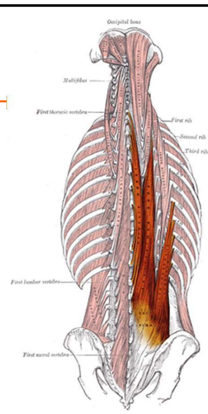
Example 4

- How much force is developed by erector spinae?



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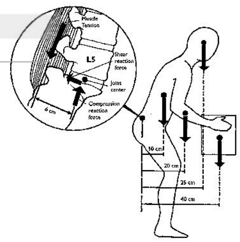
Example 4

Segment	Weight	Moment Arm From Spine
Head	13 lbs.(58N)	25 cm
Trunk	73.75 lbs.(328N)	10 cm
Arms	18.2 lbs. (81N)	20 cm
Box	24.95 lbs.(111N)	40 cm



1 lb = 4.448 Newtons

Example 4

Torque =

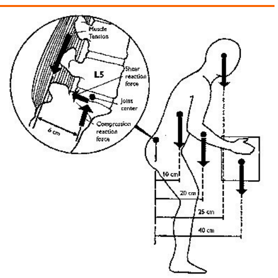
(328N)(10cm) + (81N)(20cm) + (58N)(25cm) + (111N)(40cm) = 10,790 Ncm

Example 4

Force in Erector Spinae = ?

Static position

$\sum M = 0$

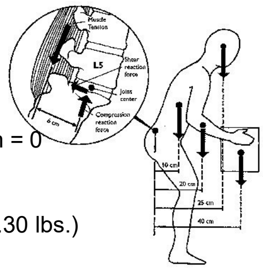


Example 4

$\sum M = 0$

(F)(6cm) - 10,790 Ncm = 0

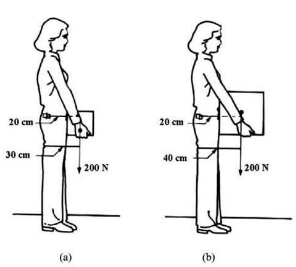
F = 1798.33 N (or 404.30 lbs.)



Holding

- Factors
  - Posture
  - Size and shape of an object

Influence of Box Size

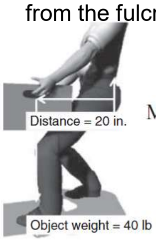


Twice Wide

- Ma = 60 Nm
- Mb = 80 Nm

Example 5

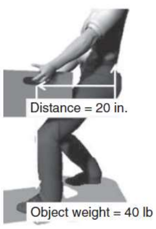
For the situation presented bellow, how much is the muscle moment, if the muscle is located 1 in from the fulcrum?



$$\text{Muscle moment } (M_m) = \text{applied moment } (M_a)$$

Example 5

$$\text{Muscle moment } (M_m) = \text{applied moment } (M_a)$$



$$M_m = M_a$$

$$M_a = 800 \text{ in. lb (which is } 40 \text{ lb} \times 20 \text{ in.)}$$

$$M_m - 800 \text{ in. lb}$$

$$M_m = \text{distance} \times \text{force } (W_{muscle})$$

$$800 \text{ in. lb} = 1 \text{ in.} \times W_{muscle}$$

$$800 \text{ lb} = W_{muscle} \text{ or muscle force}$$

Example 5

800 lb of muscle force

Do you think the result is going to chance if we include the weight of the human that is moving the box?

Example 5

- The torso contains approximately 60% of your body weight.
- A 200 – lb person
- 6 in from the center of mass to the fulcrum

$$\text{Muscle moment } (M_\text{m}) = \text{Total applied moment } (M_\text{total})$$

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Example 5

$$M_\text{m} = M_\text{total}$$

where

$$M_\text{total} = 800 \text{ in.-lb (Ma)} + 720 \text{ in.-lb } (M_\text{body})$$
$$M_\text{total} = 1520 \text{ in.-lb}$$
$$\text{Mm} = M_\text{total}$$
$$M_\text{effort} = \text{distance} \times \text{force } (W_\text{muscle})$$
$$1520 \text{ in.-lb} = 1 \text{ in.} \times W_\text{muscle}$$
$$1520 \text{ lb} = \text{Muscle Force}$$

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Example 5

If we include the weight of the human that is moving the box, the muscle force increases from 800 lb to 1520 lb

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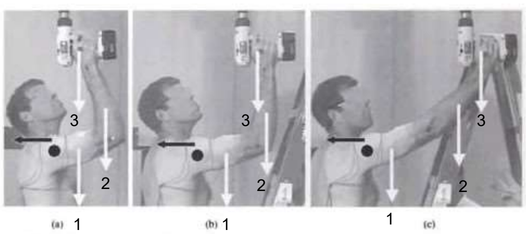
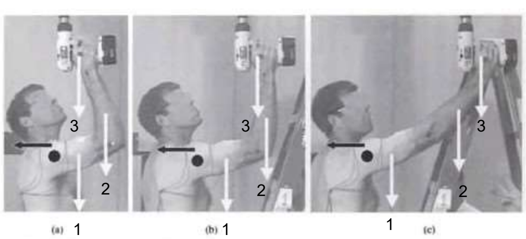
Overhead Drilling

Overhead Drilling



Overhead Drilling

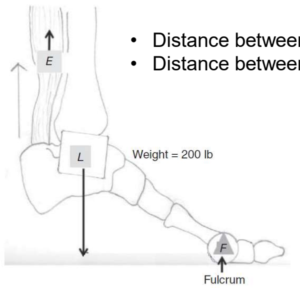


13 Nm 21 Nm 29 Nm

Example 6

How much is the muscle moment?

- Distance between load and fulcrum 6.5 in
- Distance between muscle and fulcrum 8 in



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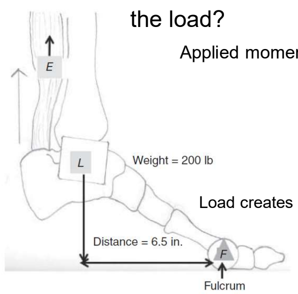
Example 6

How much is the applied moment by the load?

Applied moment (M_a) = distance × weight

M_a = 6.5 in. × 200 lb

M_a = 1300 in. lb



Load creates an applied moment = 1300 in. lb

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Example 6

How much is the muscle moment?

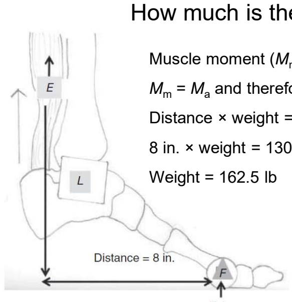
Muscle moment (M_m) = Applied moment (M_a)

M_m = M_a and therefore M_m = 1300 in. lb

Distance × weight = 1300 in. lb

8 in. × weight = 1300 in. lb

Weight = 162.5 lb



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Example 6

Muscle moment or the effort = 162.5 lb

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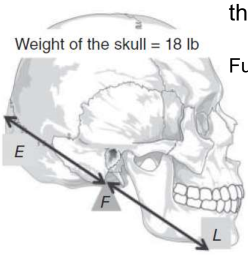
Example 7

How much is muscle moment if the muscle is centered on the spine?



Fulcrum is 4 in from both (E and L)

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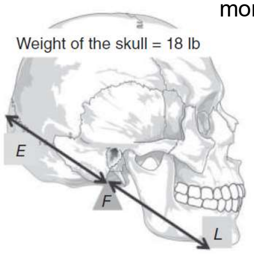
Example 7

How much is the applied moment by the load?



Applied moment (M_a) = distance × weight

M_a = 4 in. × 18 lb

M_a = 72 in. lb

The skull, if centered on the neck, results in a 72 in. lb rotational force

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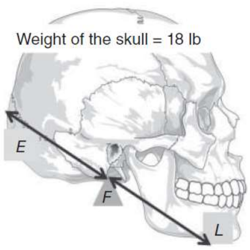
Example 7

How much is muscle force?



Muscle moment (*c*) = Applied moment (M_a)

M_a = M_a, where Ma is 72 in. lb, therefore

M_a = 72 in. lb

Distance × weight = 72 in. lb

4 in. × weight = 72 in. lb

Weight or muscle force = 18 lb

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Example 7

It takes 18 lb of force to hold up the 18 lb skull if the skull is centered on the spine

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