Chapter 13
Conditions of Rotary Motion

KINESIOLOGY

Scientific Basis of Human Motion, 11th edition

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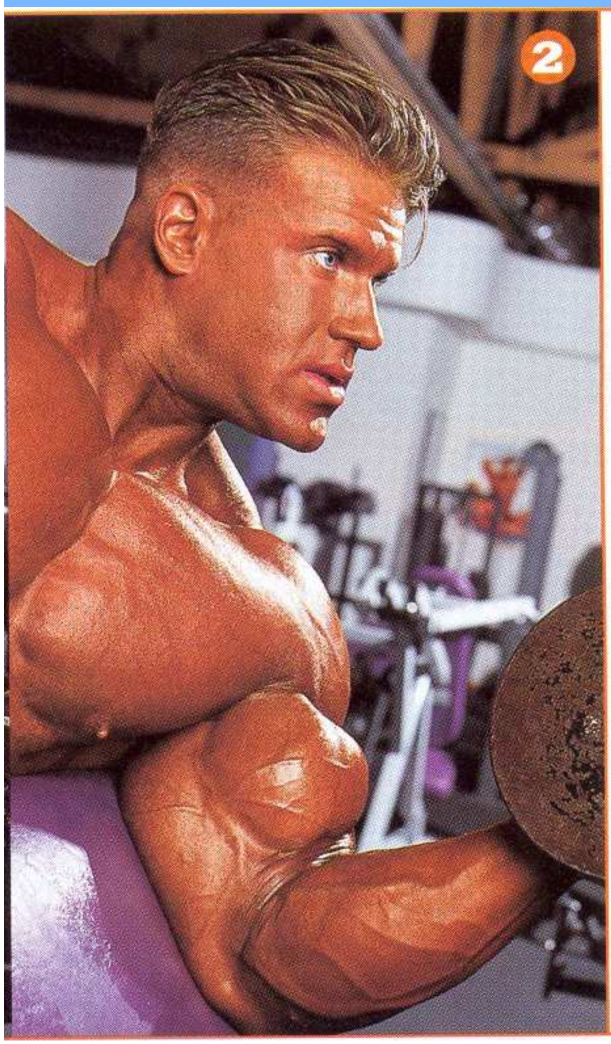
Agenda

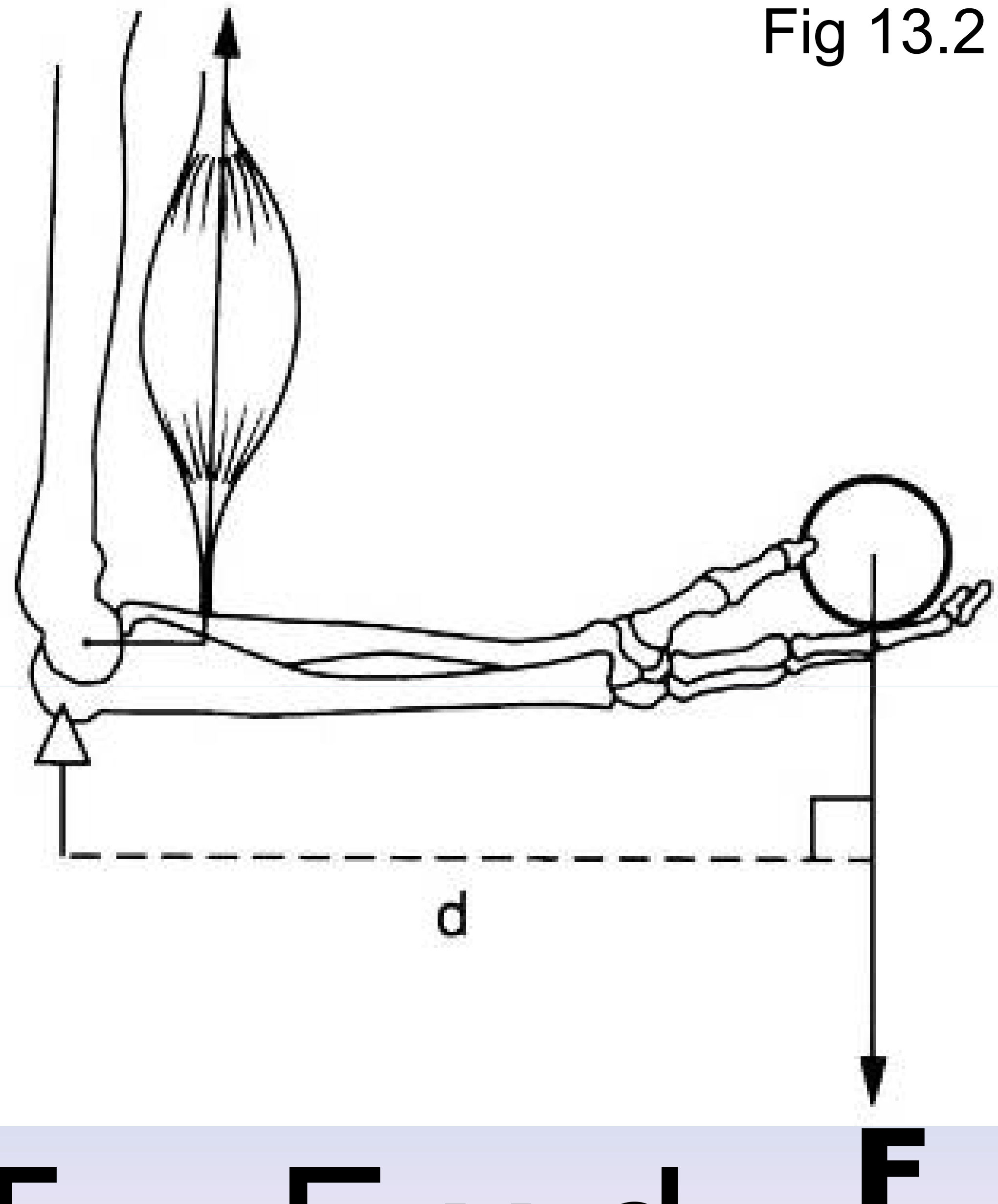
1. Eccentric Force → Torque (“Moment”)
2. Lever
3. Force Couple
4. Conservation of Angular Momentum
5. Centripetal and Centrifugal Forces

ROTARY FORCE ("Eccentric Force")

- Force not in line with object's center of gravity
- Rotary and translatory motion can occur

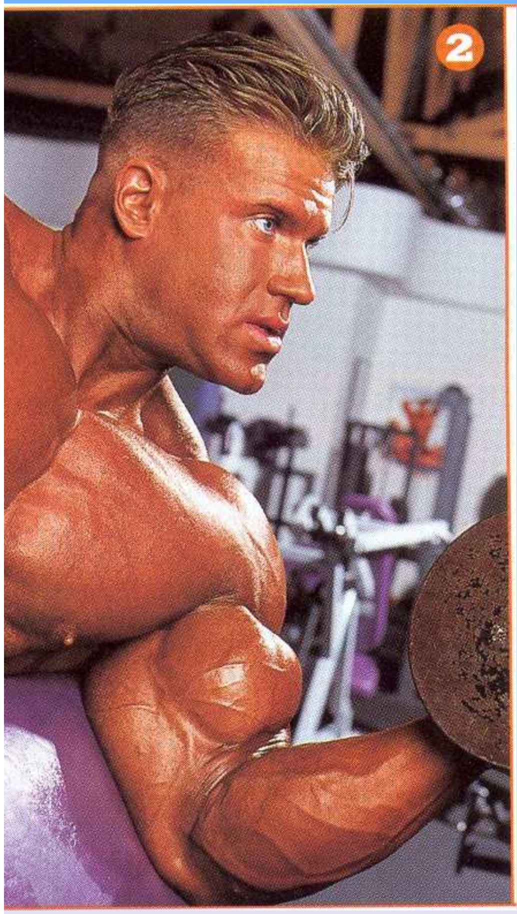
Torque ("Moment")

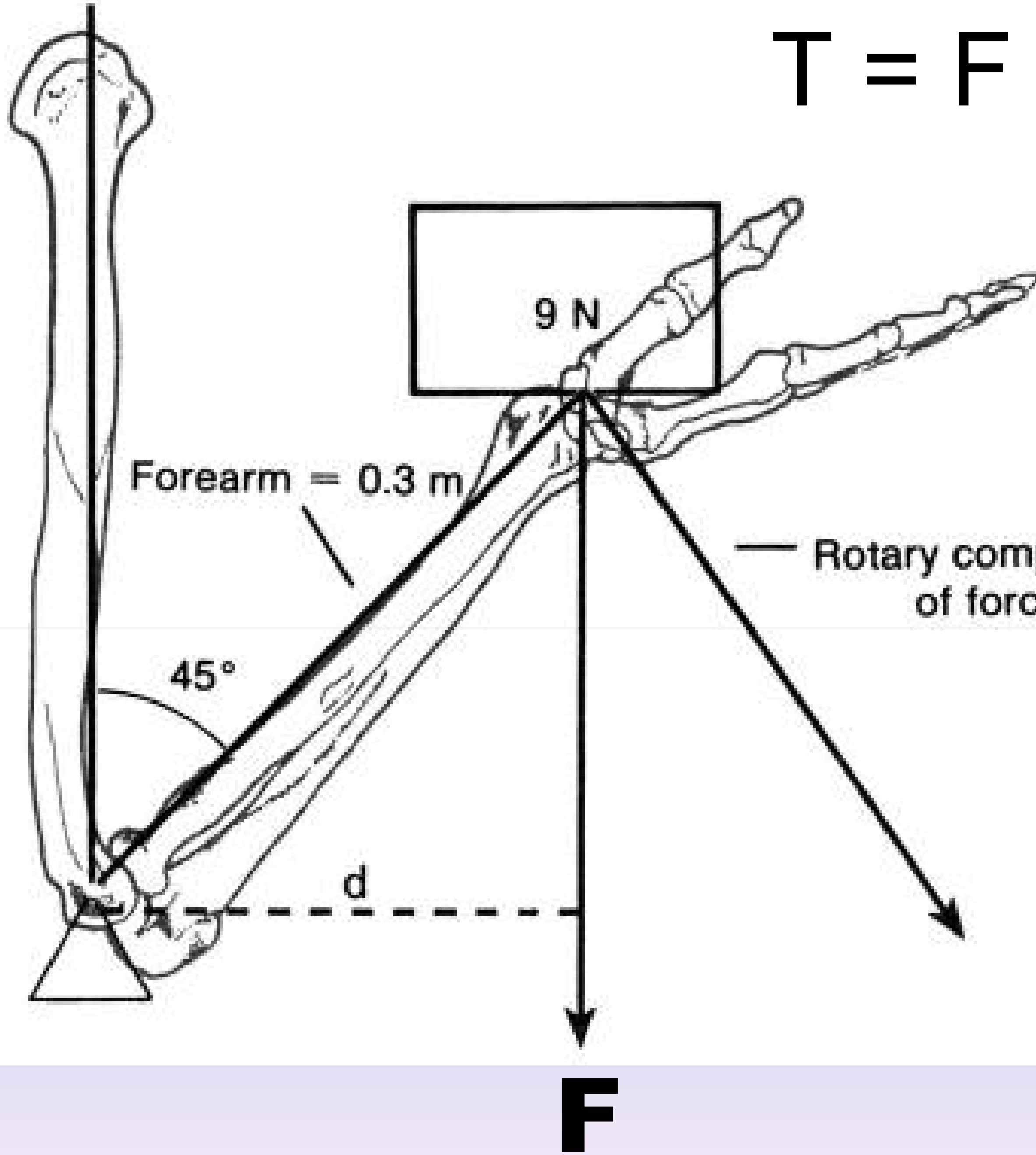




$$T = F \times d$$

Moment Arm

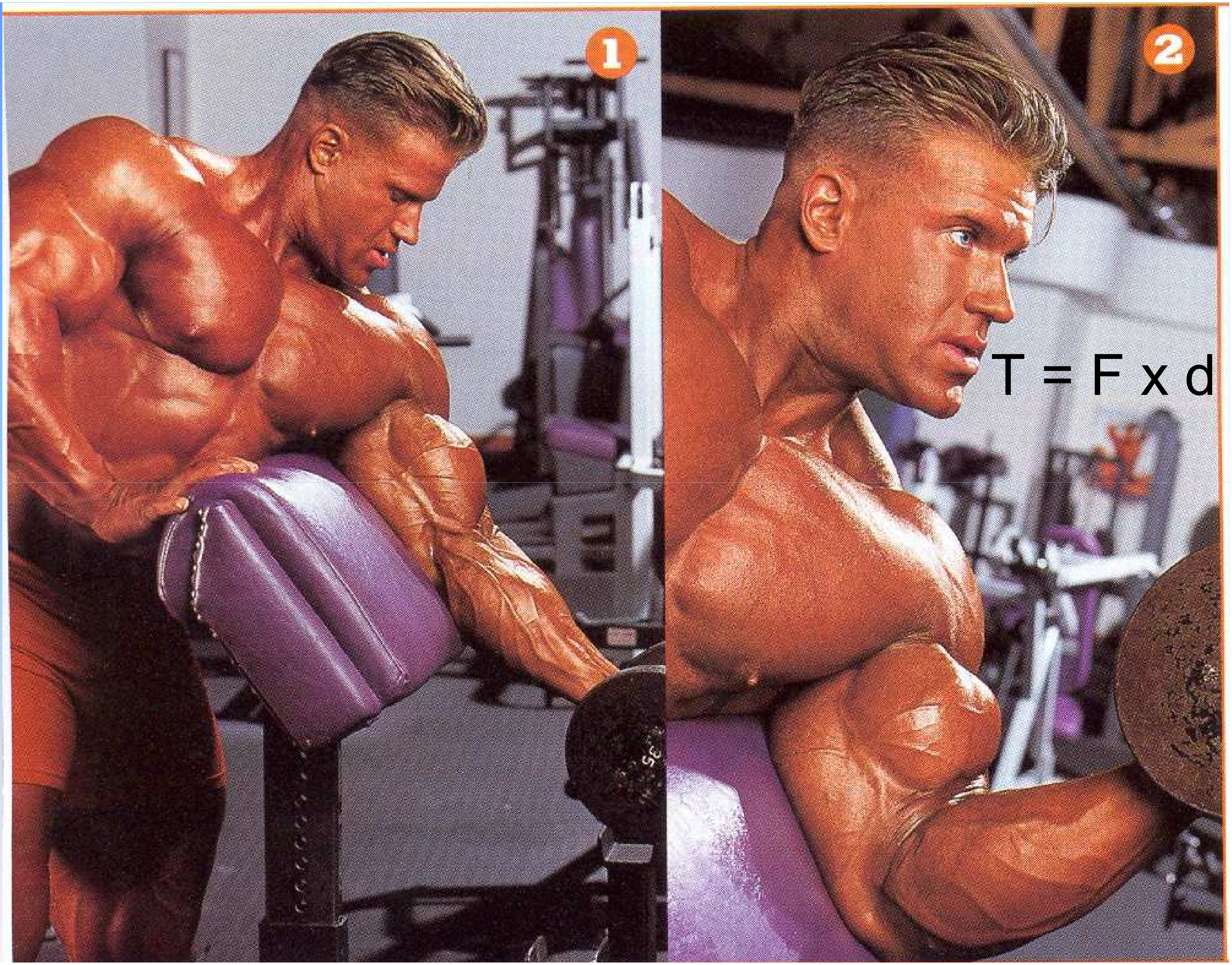




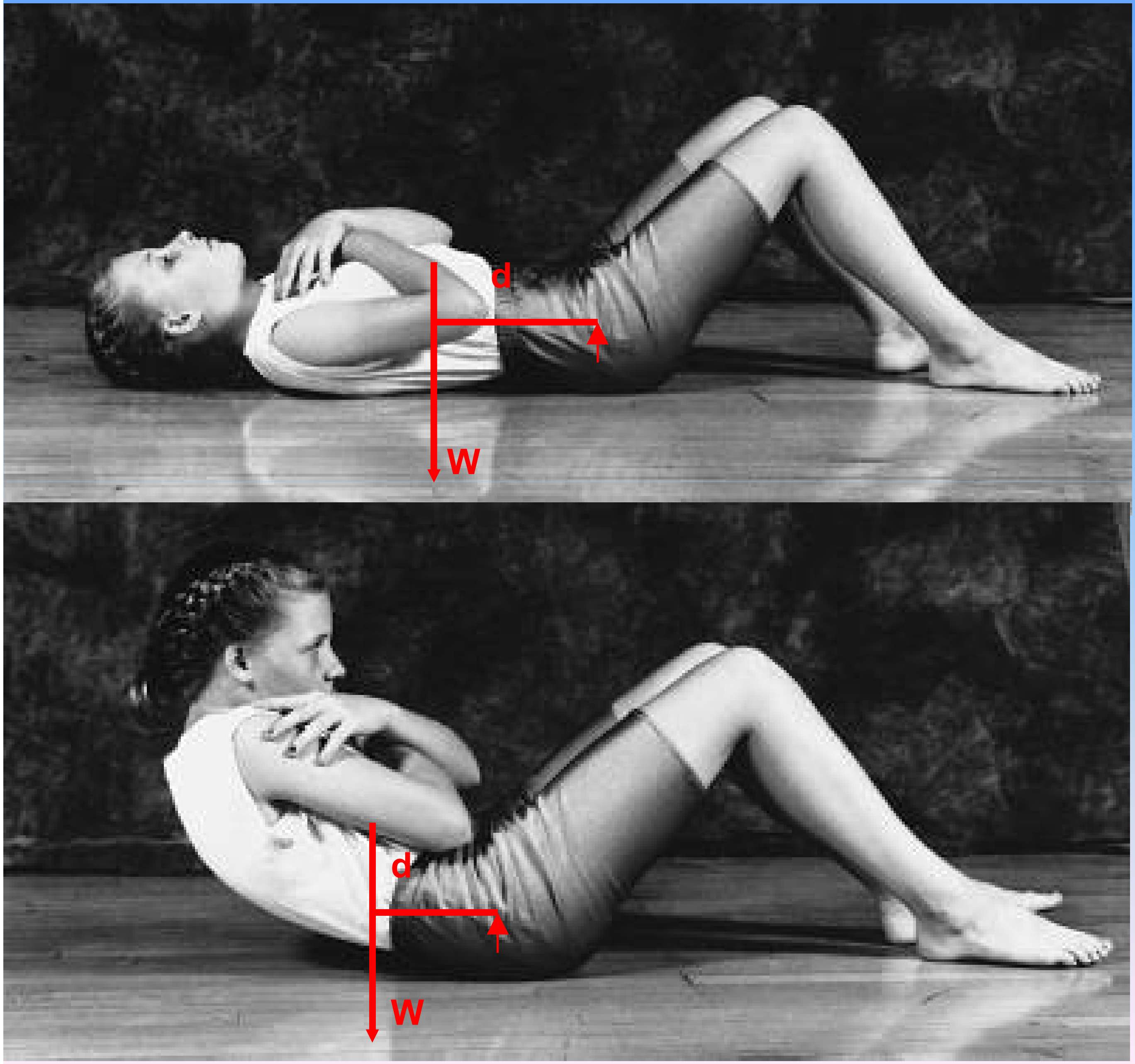
T = F x d

d = 0.3 cos (90-45)

Fig 13.3


1
2
T = F x d

Moment Arm



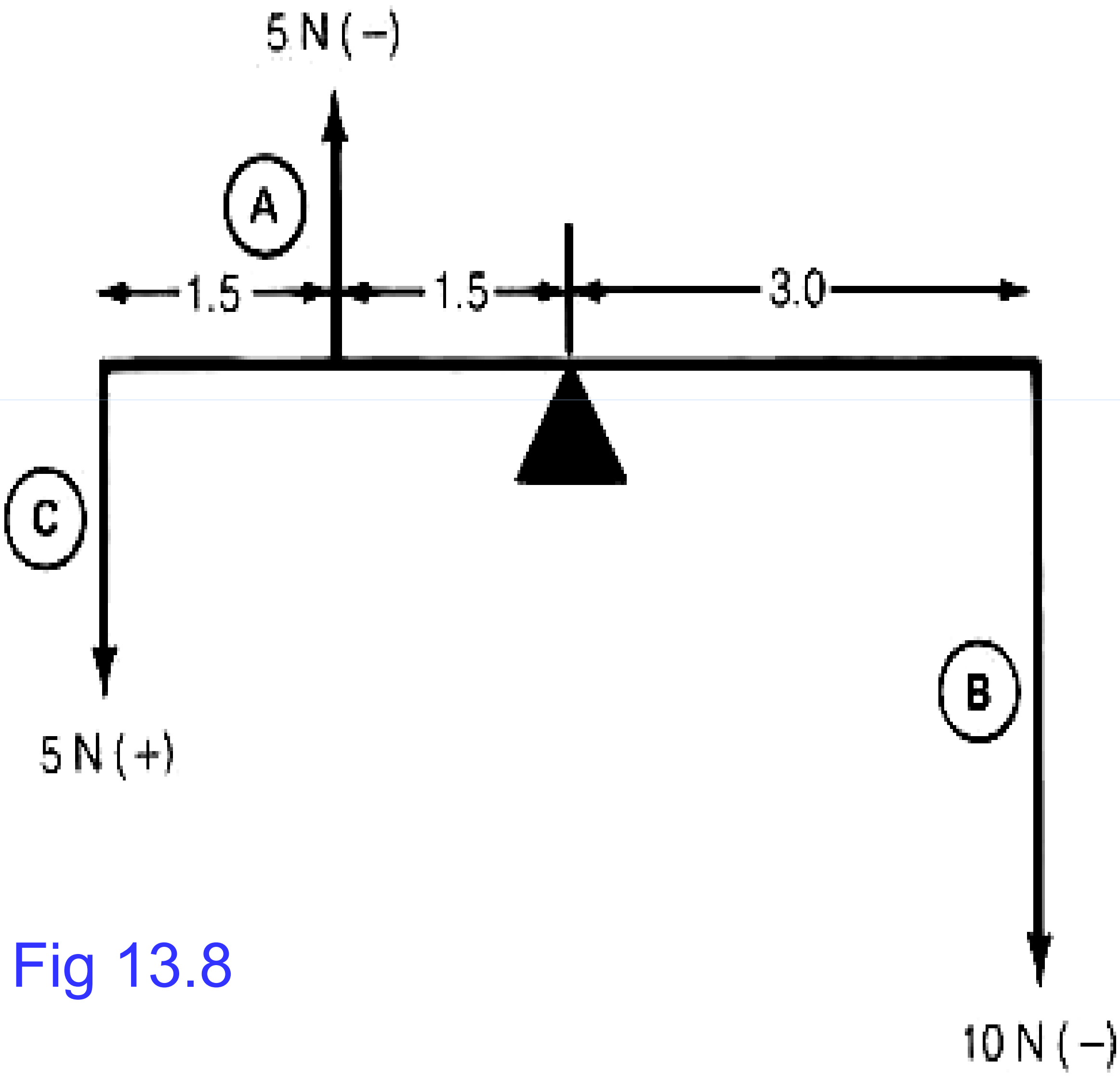
Torque changed by changing length of moment arm

$$T = F \times d$$

Fig 13.4

Sum of Torques ("Moments")

T = F x d



1. Distinguish between clockwise and counterclockwise moments. (Ans: *A* & *B* are CW; *C* is CCW).
2. Sum clockwise moments: $(-5 \times 1.5) + (-3 \times 10) =$ -37.5 Newton-meters
3. Sum counterclockwise moments: $5 \times 3 = 15$ Nm
4. Determine the resultant moment (CW + CCW moments)

   -37.5 Nm $+ 15$ Nm $=$

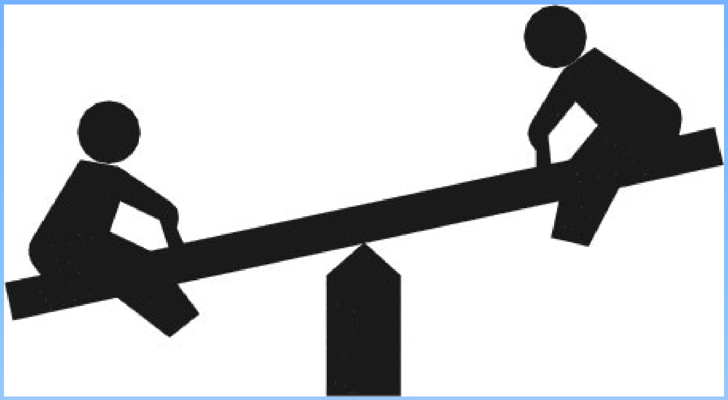
   -22.5 Nm.

Fig 13.8

Sum of Torques ("Moments")

T = F x d

- Sum of torques = 0
  - A balanced seesaw



- Linear motion if equal parallel forces overcome resistance
  - Rowers

Force Couple

T = F x d

- Effect of equal parallel forces acting in opposite direction

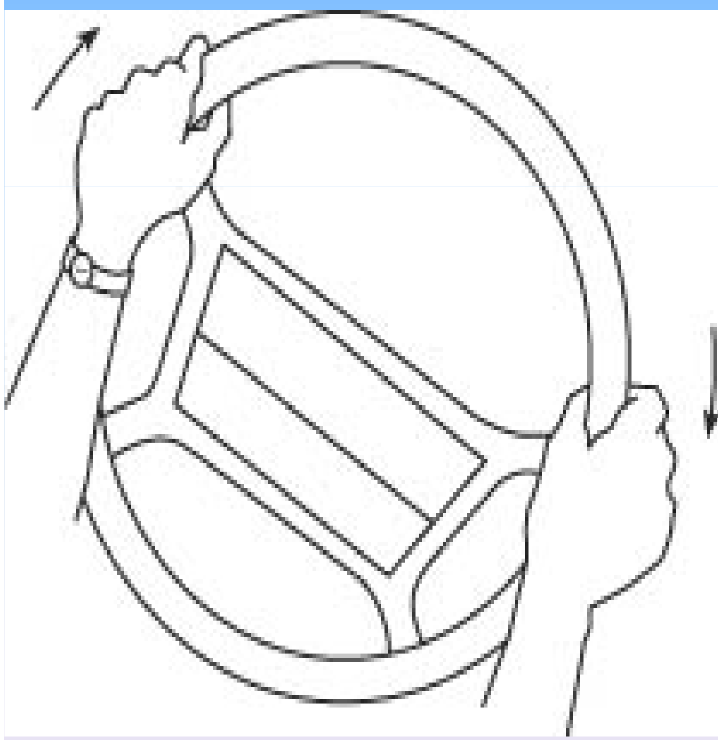
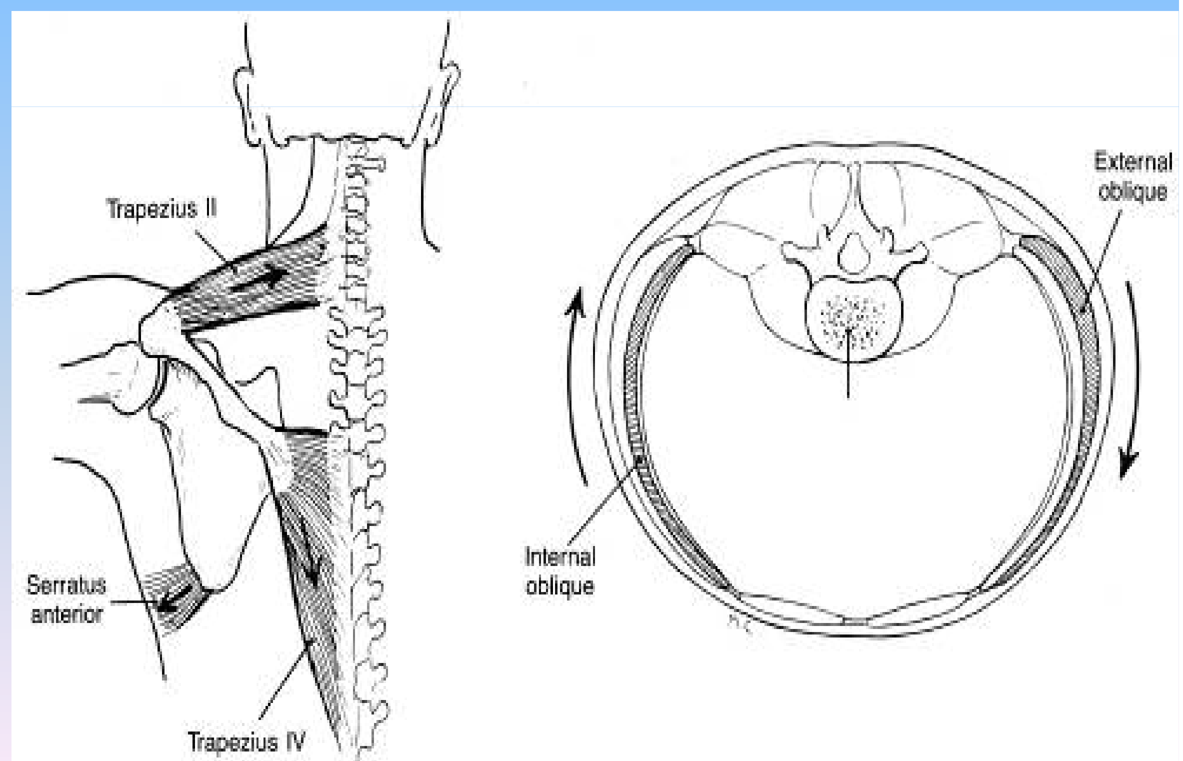
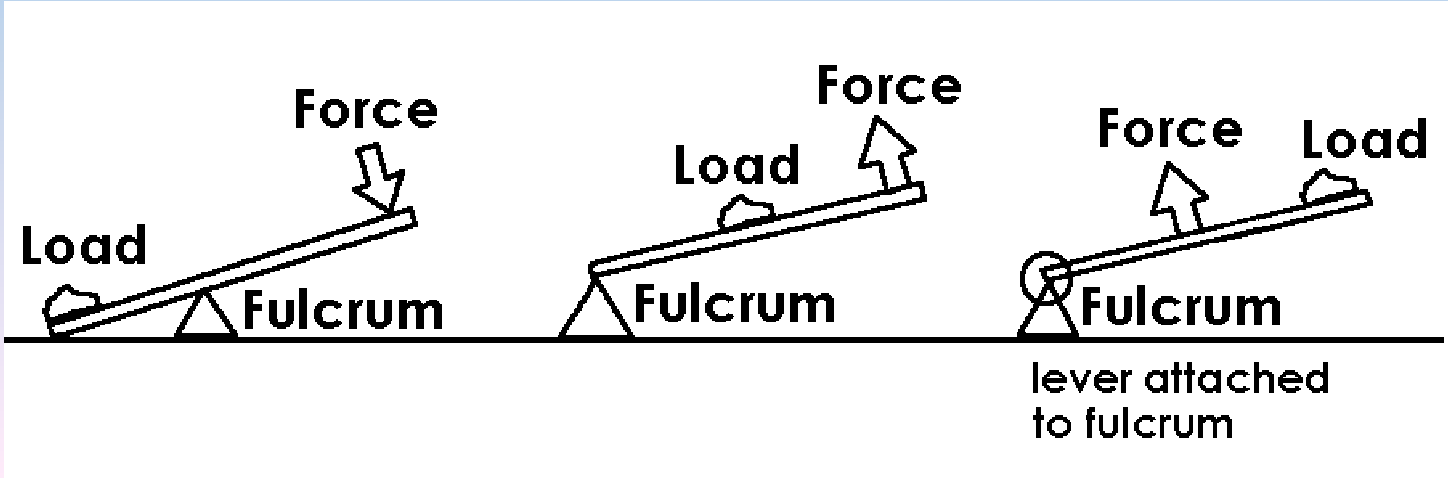


Fig 13.6 & 13.7

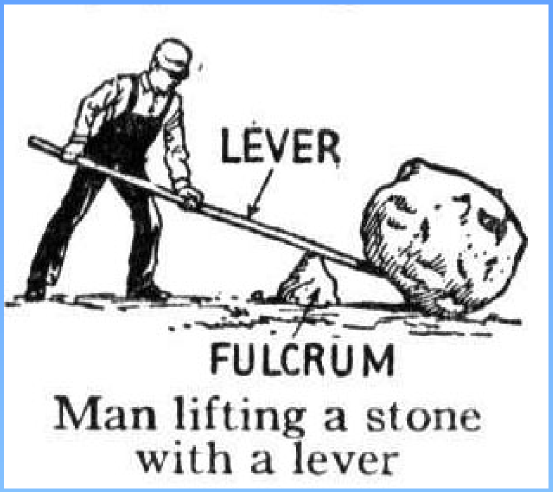


LEVER

- *"A rigid bar that can rotate about a fixed point when a force is applied to overcome a resistance"*
- Used to:
  - Balance forces
  - Favor force production
  - Favor speed and range of motion
  - Change direction of applied force

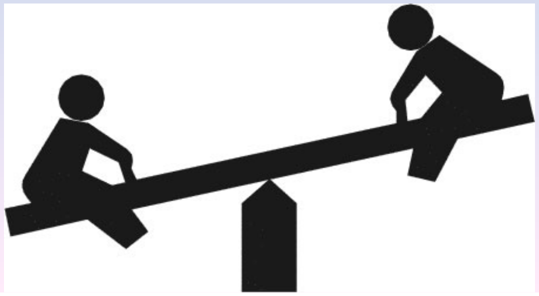


External Levers

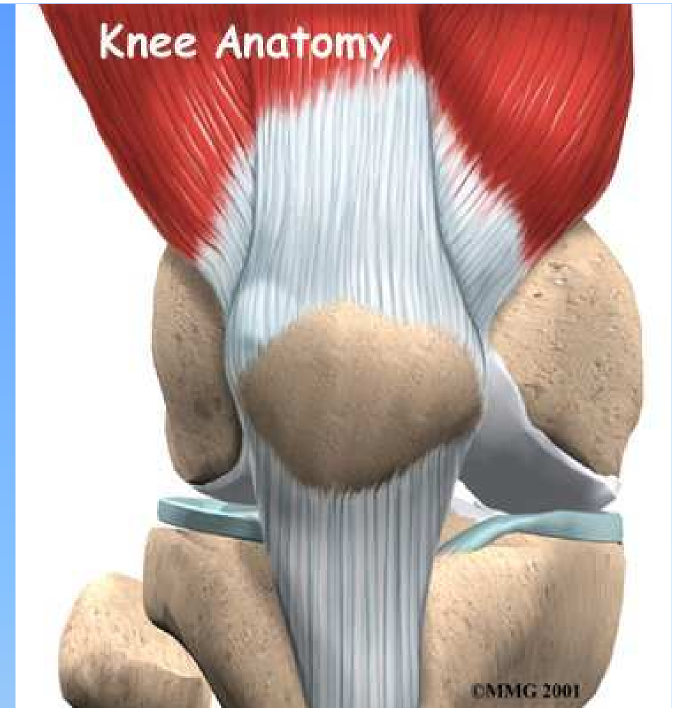


- Small force to overcome large resistance
  - Crowbar
- Large Range Of Motion to overcome small resistance
  - Hitting golf ball

- Balance force (load)
  - Seesaw

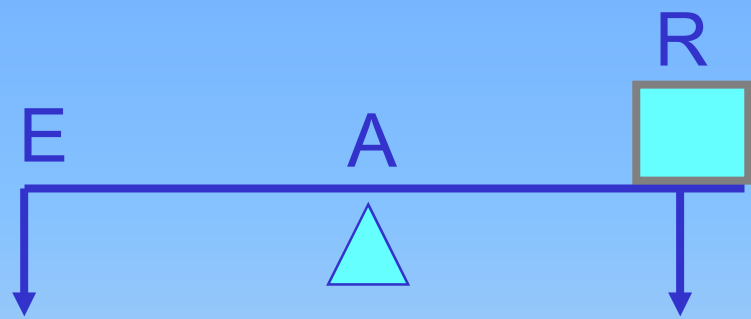


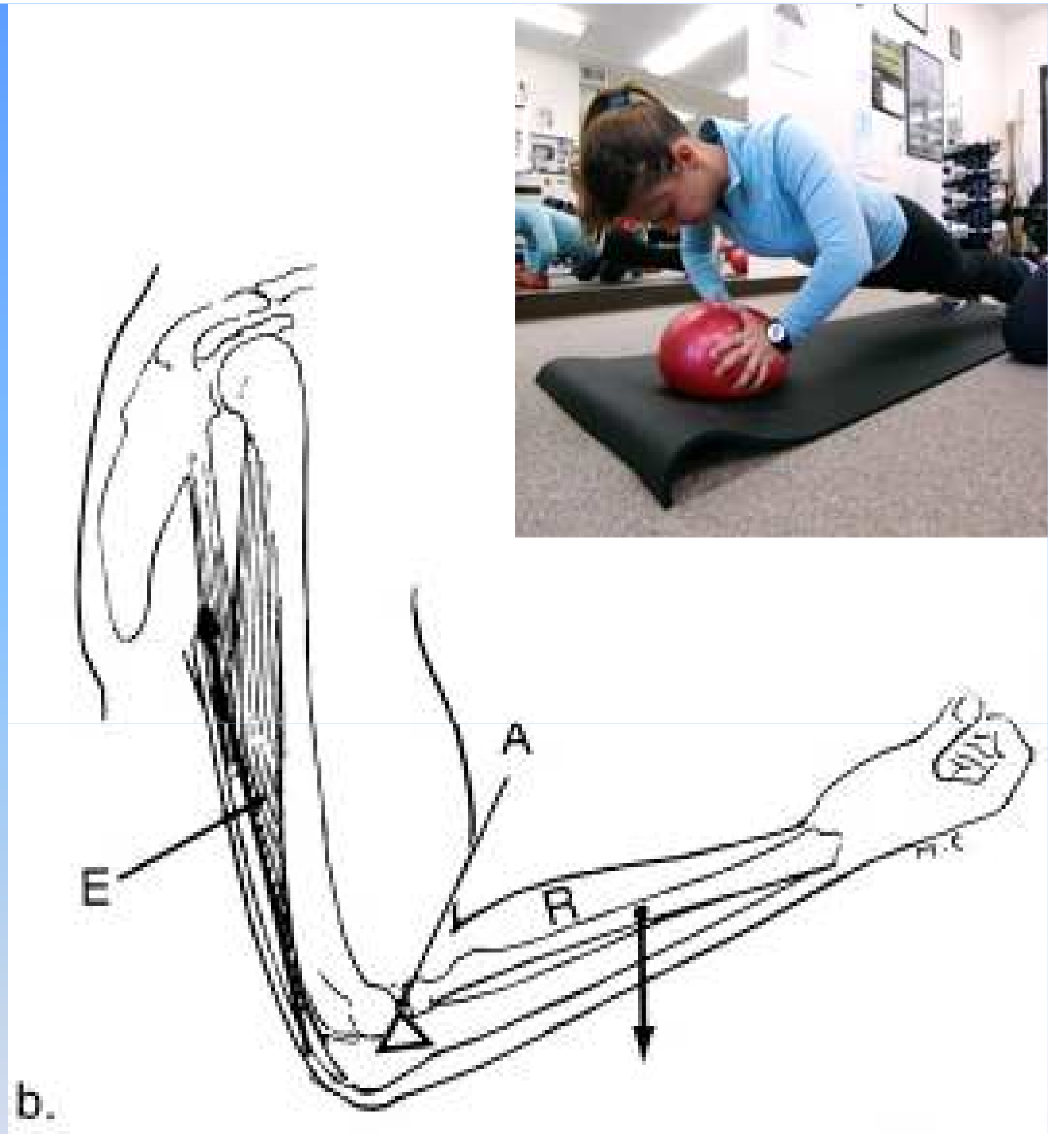
Anatomical Levers



- Nearly every bone is a lever
- The joint is fulcrum
- Contracting muscles are force
- Don't necessarily resemble bars
  - Skull, scapula, vertebrae
- Resistance point may be difficult to identify
- May be difficult to determine resistance
  - Weight, antagonistic muscles & fasciae

FIRST-CLASS Lever

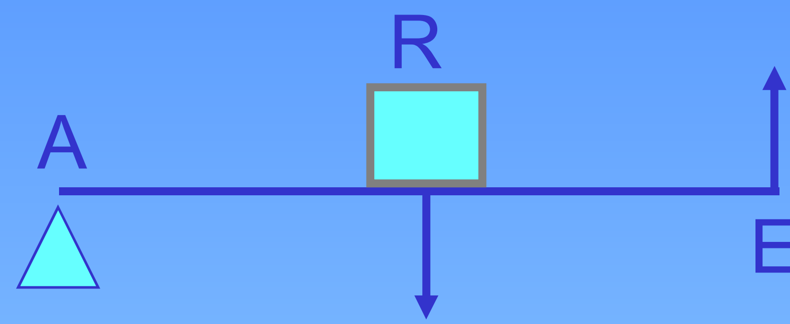




E = Effort
A = Axis or fulcrum
R = Resistance

Fig 13.12

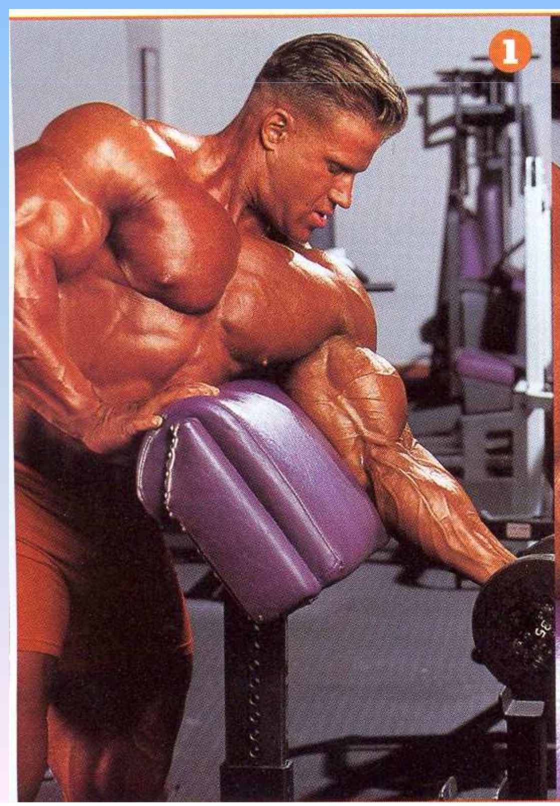
SECOND-CLASS Lever



E = Effort

A = Axis or fulcrum

R = Resistance



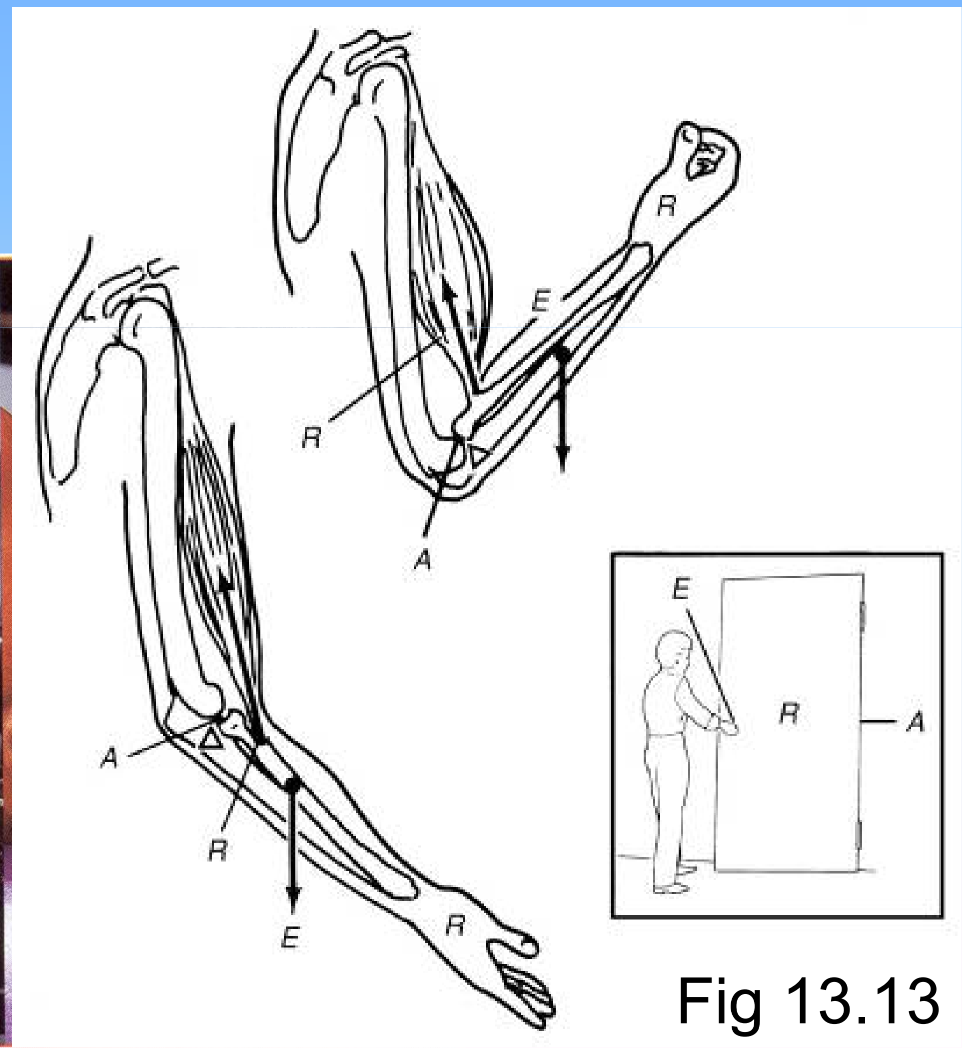
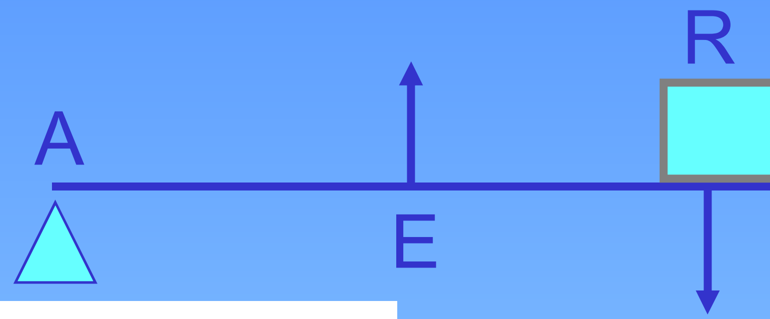


Fig 13.13

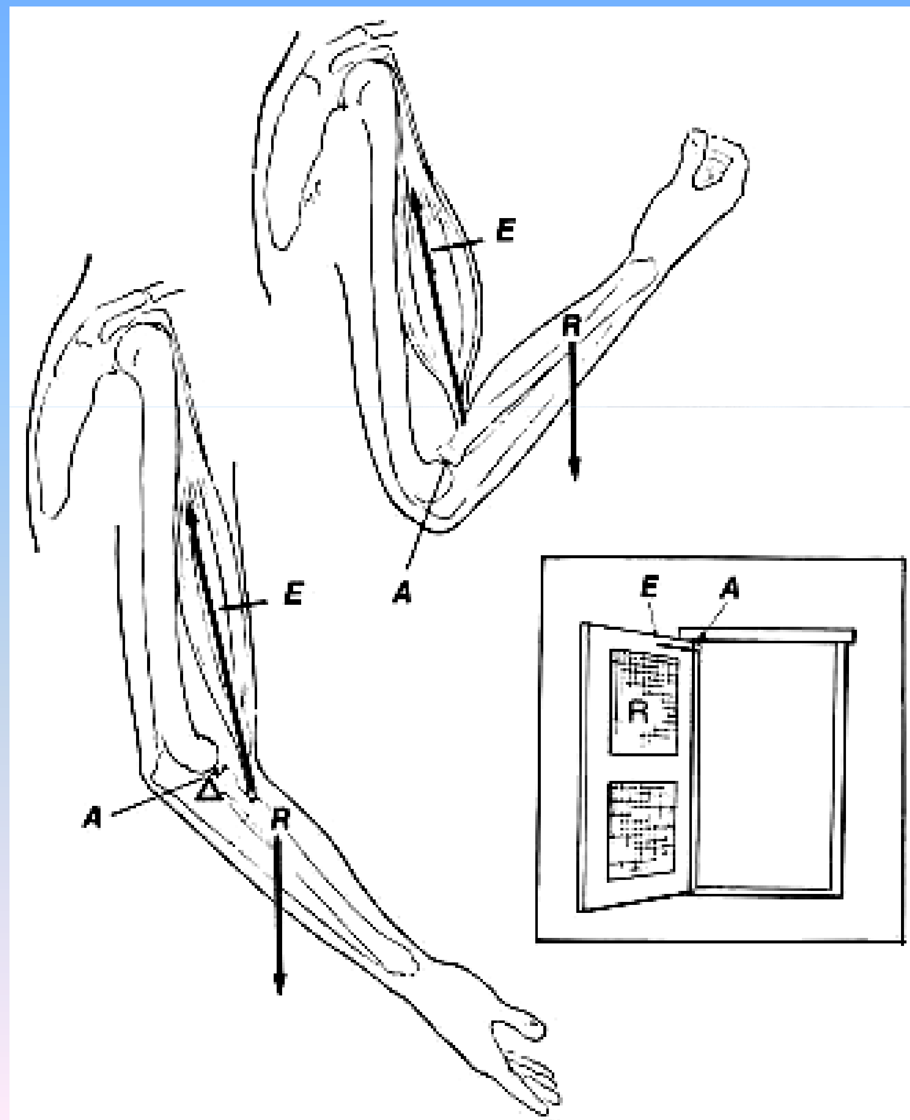
THIRD-CLASS Lever



E = Effort

A = Axis or fulcrum

R = Resistance



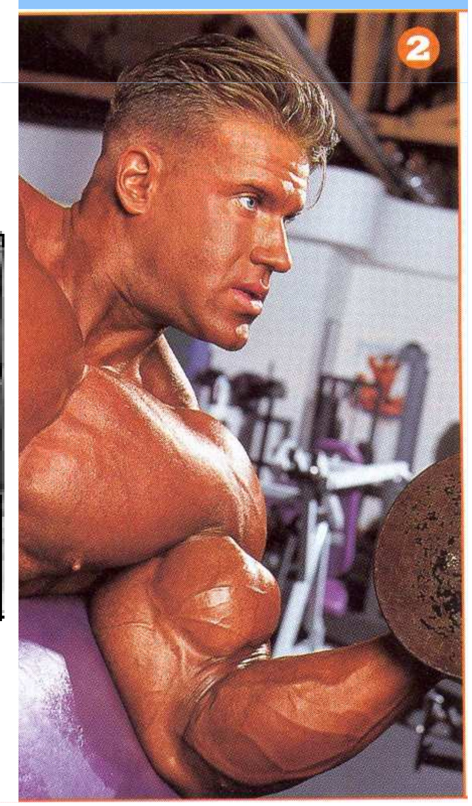


Fig 13.14

Muscle Force Vectors

- Rotary component for torque production
- Stabilizing component acts along mechanical axis of bone through axis of rotation
  - Thus not eccentric
    - Moment arm zero

Torque in Rotating Segments

Muscle forces that exert torque dependent on point of insertion of muscle, & changes in length, tension, and angle of pull

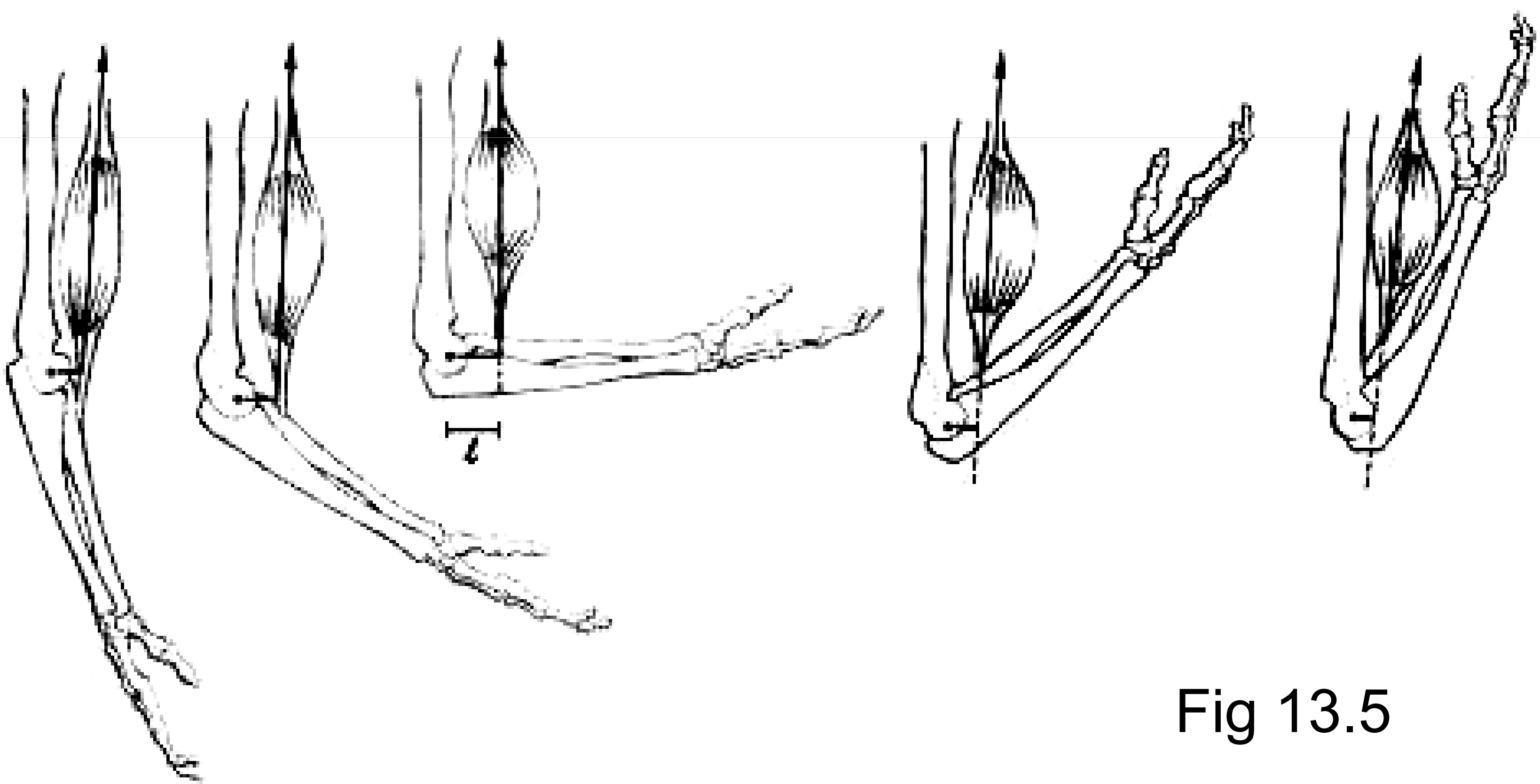
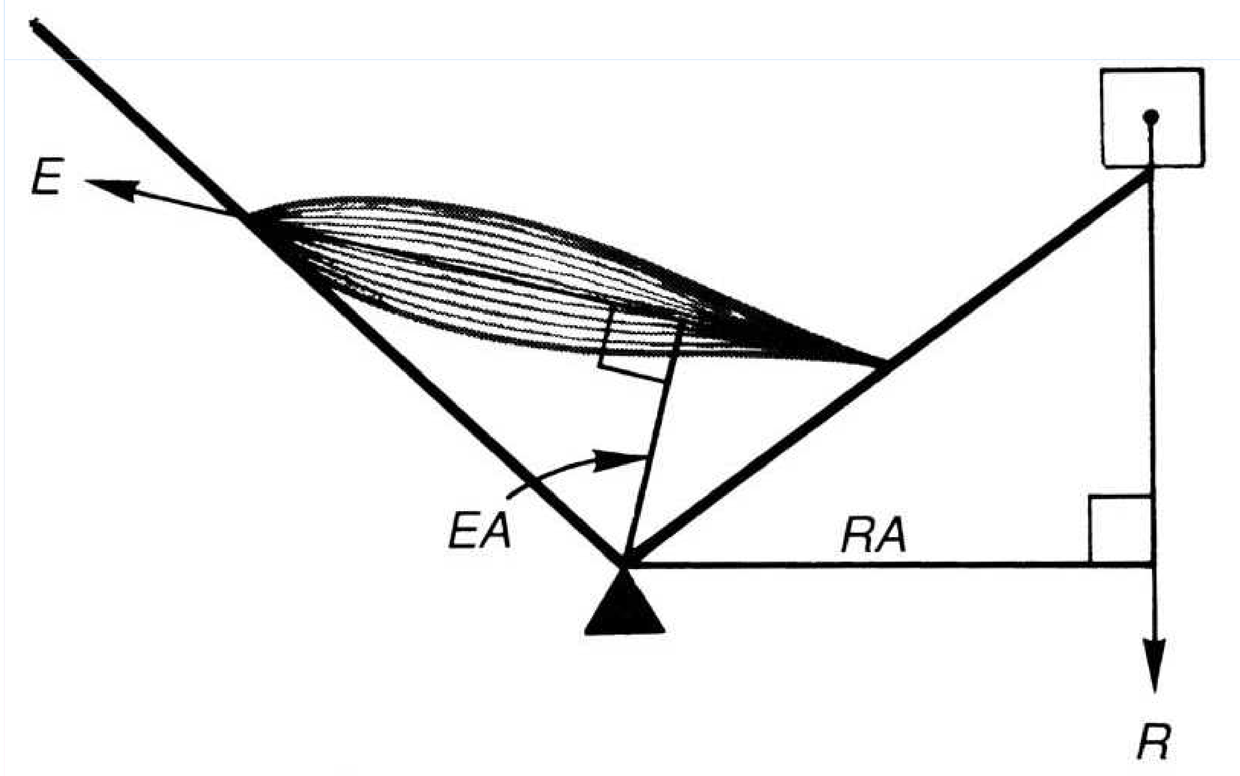


Fig 13.5

Lever Arms

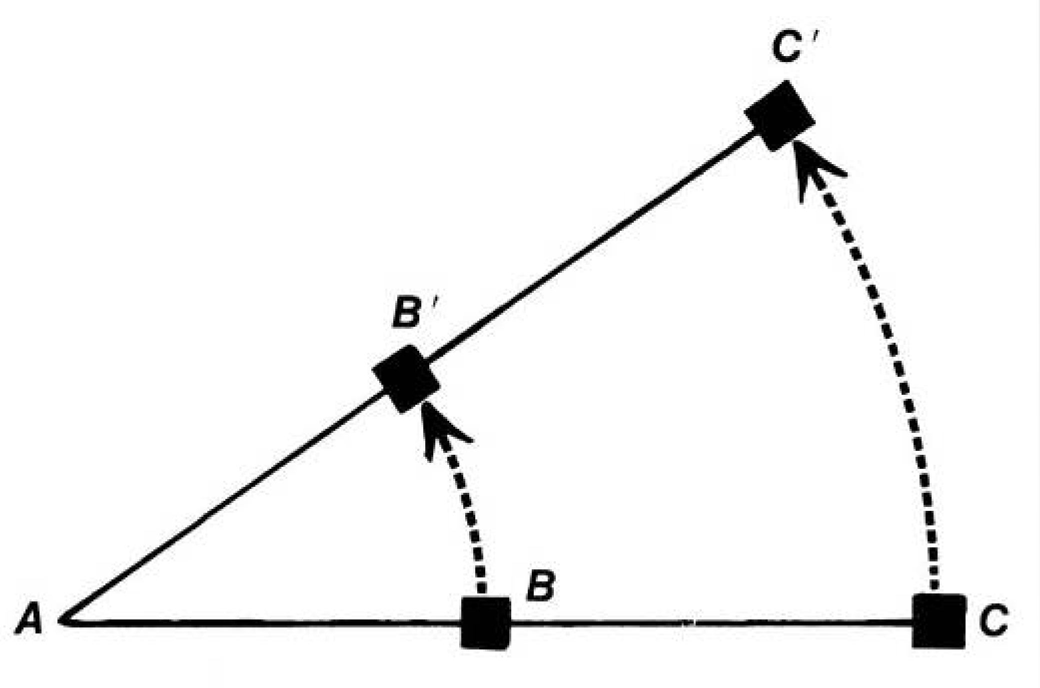
Fig 13.16



- Portion of lever between fulcrum & force application.
- **E**ffort **A**rm (**EA**):
  - Perpendicular distance between fulcrum & line of force of effort.
- **R**esistance **A**rm (**RA**):
  - Perpendicular distance between fulcrum & line of resistance force.

Selection of Levers

- Longest lever arm not always best
  - Short levers enhance angular velocity, while sacrificing linear speed and range of motion
  - Strength needed to maintain angular velocity increases as the lever lengthens



For every lever, ask:

1. Fulcrum, effort application & resistance application locations?
2. At what angle is effort applied to lever?
3. At what angle is resist applied to lever?
4. What is **<u>E</u>ffort <u>A</u>rm** of lever?
5. What is **<u>R</u>esistance <u>A</u>rm** of lever?
6. What kind of movement does this lever favor?
7. What is mechanical advantage?
8. What class of lever is this?

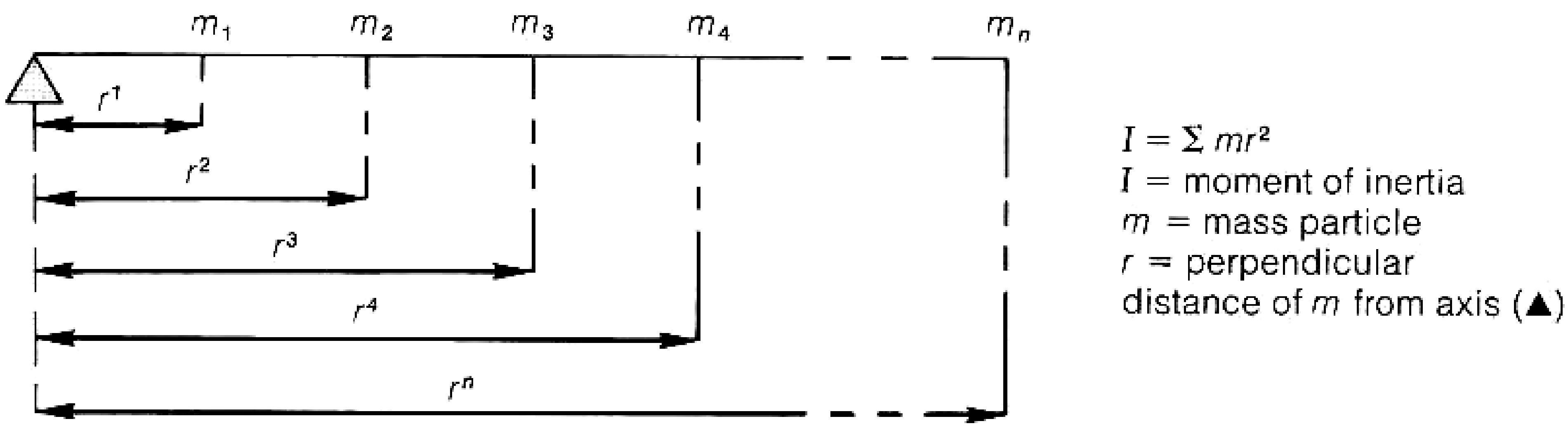
Moment of Inertia

Quantity of rotating mass and its mass distribution around the axis of rotation

$$I = \sum mr^2$$

m = mass

r = perpendicular distance between the mass particle and the axis of rotation.



Inertia in Human Body

- Body position affects mass distribution, and therefore inertia

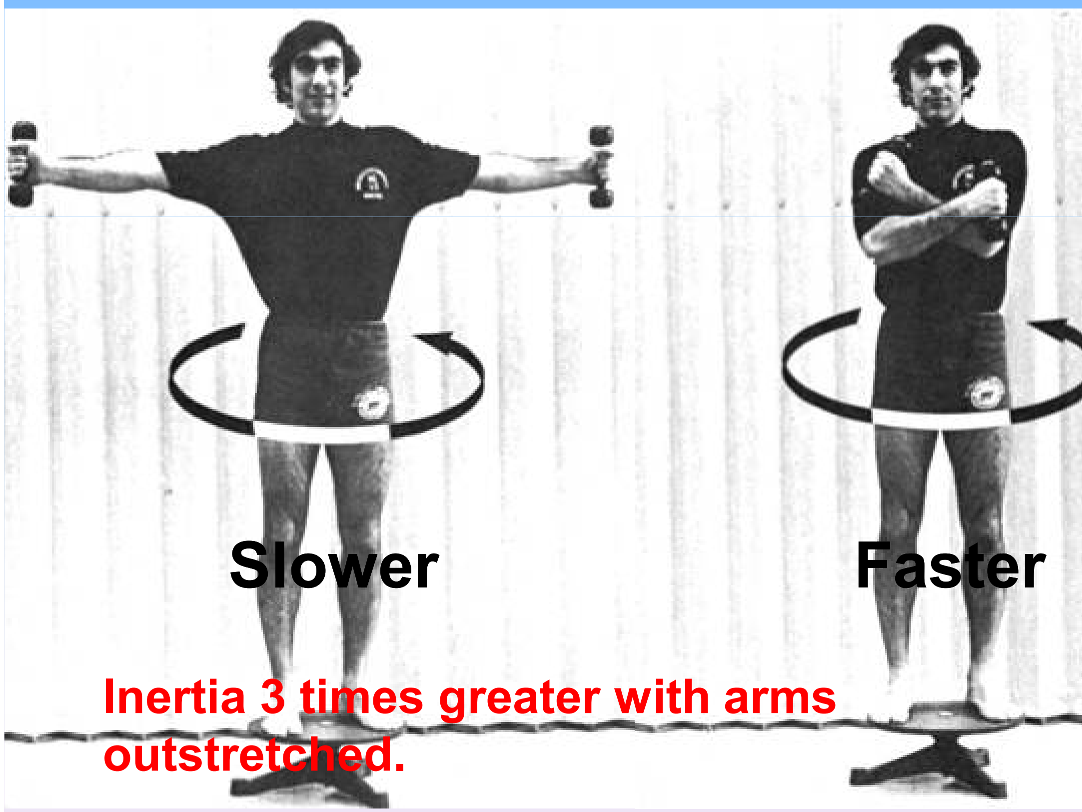


Fig 13.22

Torque due to Angular Acceleration

The rotational equivalent of

F = ma:

$$T = I\alpha$$

I = **Moment of Inertia**

α = **Angular Acceleration**

Angular Momentum

Tendency to persist in rotary motion

$$J = I\omega$$

I = **Moment of Inertia**

α = **Angular Acceleration**

Conservation of Angular Momentum

The total angular momentum of a rotating body will remain constant unless acted upon by an external torque

- A decrease in I produces an increase in ω:

$$J = I\omega$$

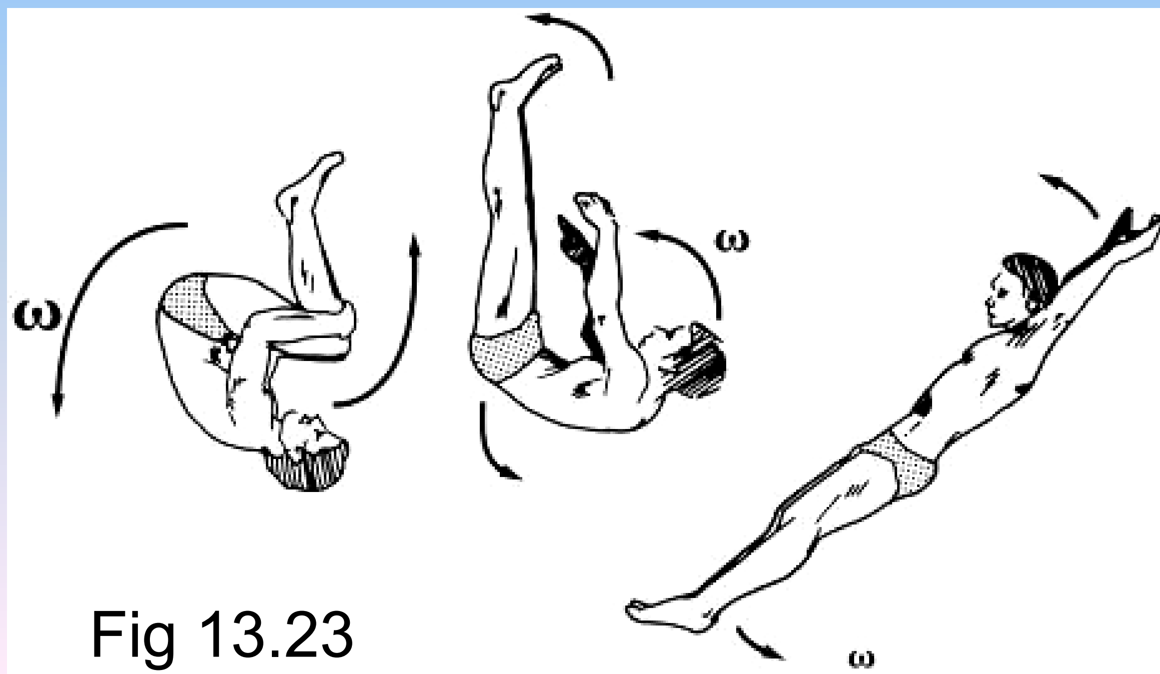


Fig 13.23

Conservation of Angular Momentum

Action and Reaction

- Any changes in moments of inertia or velocities of two bodies will produce equal and opposite momentum changes.

$$I\ (\omega_{vf1} - \omega_{vi1}) = I\ (\omega_{vf2} - \omega_{vi2})$$

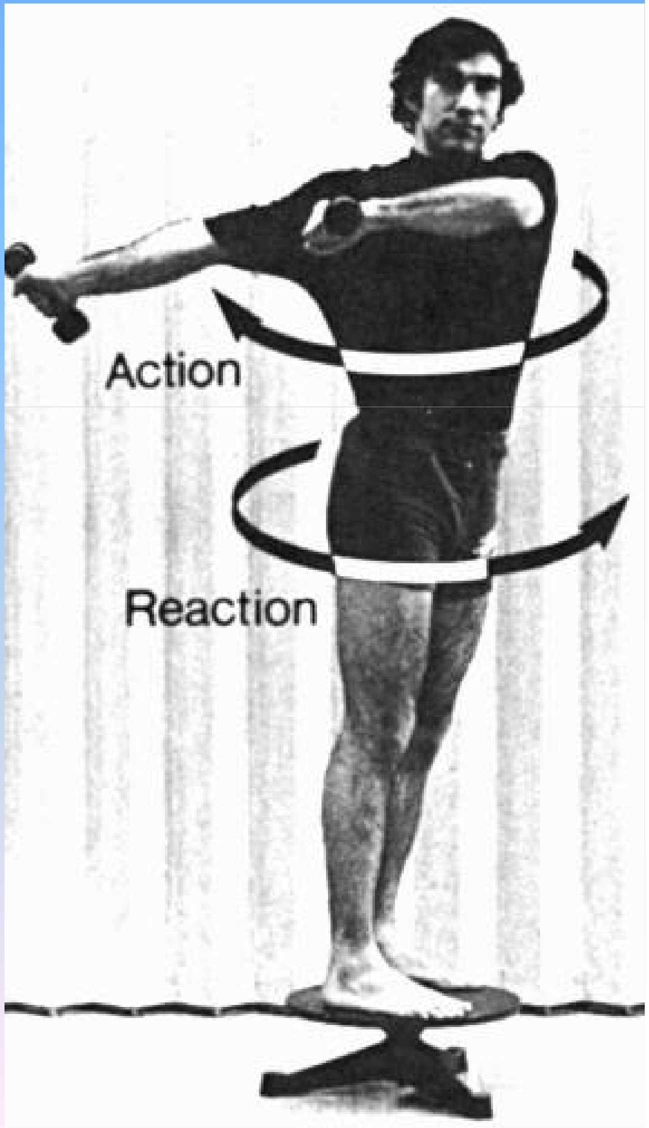


Fig 13.24

Transfer of Momentum

- Angular momentum may be transferred from one body part to another as total angular momentum remains unaltered
- Angular momentum can be transferred into linear momentum, and vice versa

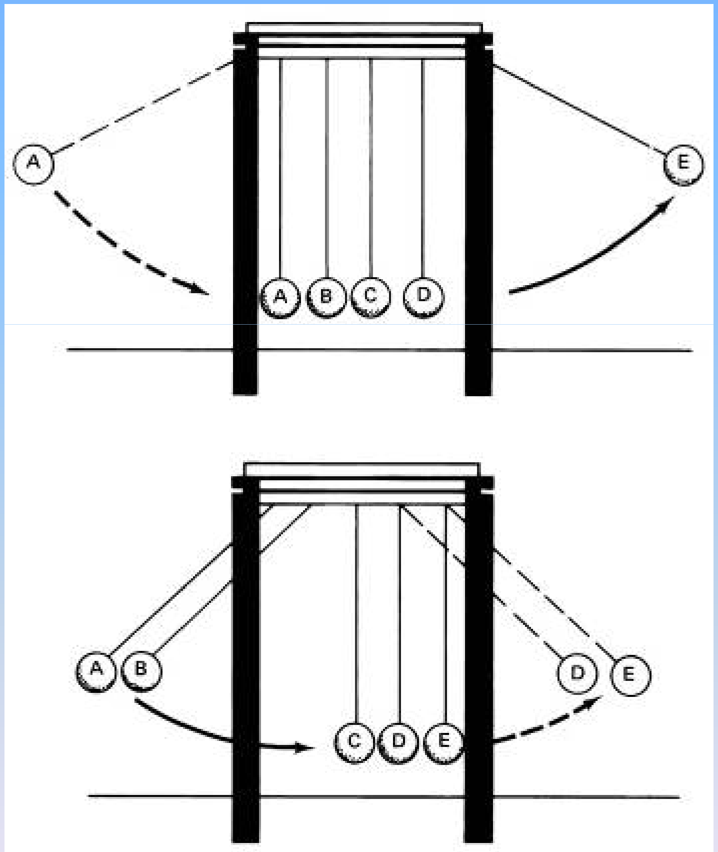
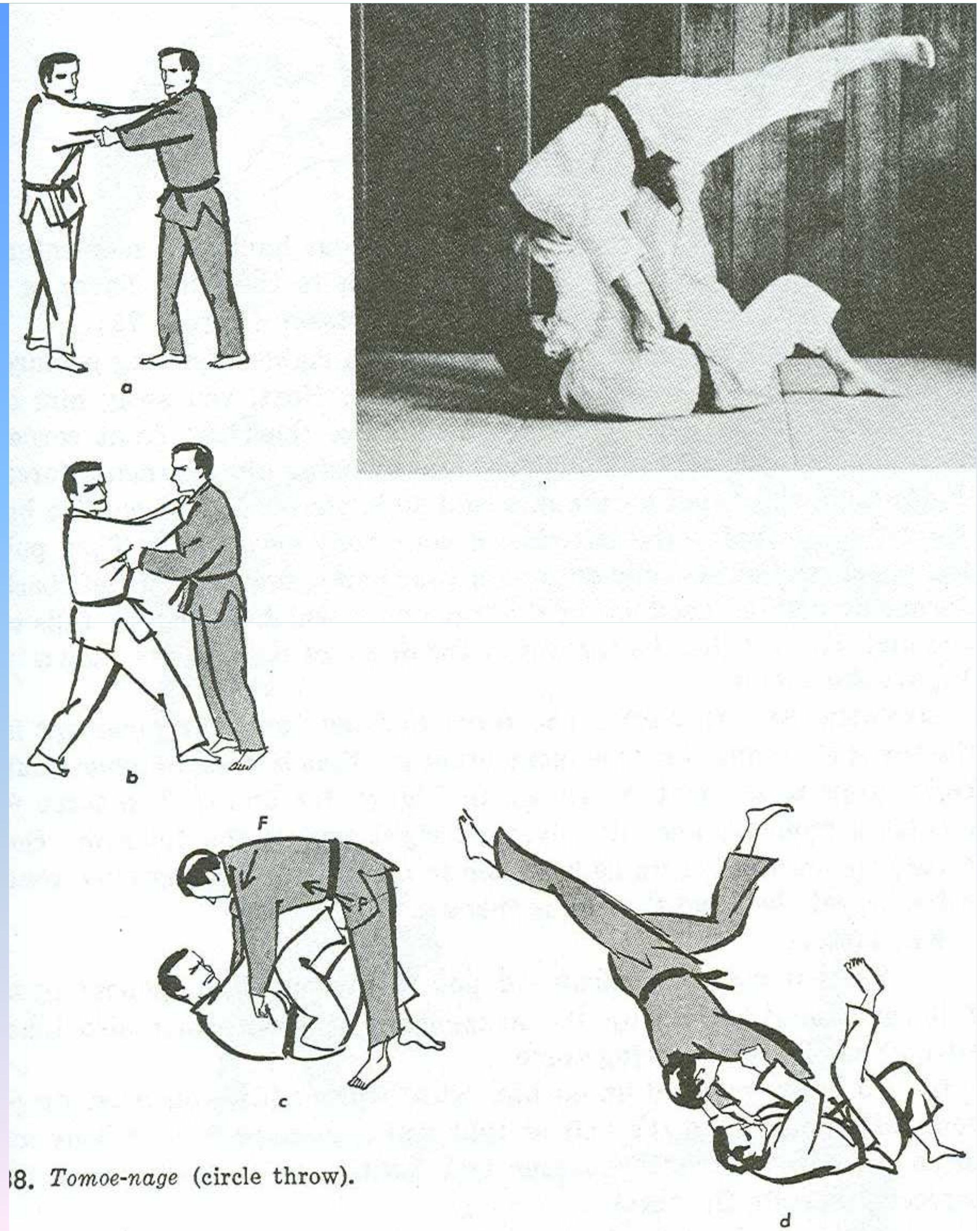


Fig 13.25

Transfer of Momentum

Transfer
of
Momentum



38. *Tomoe-nage* (circle throw).

CENTRIPETAL AND CENTRIFUGAL FORCES

Centripetal Force: a constant center-seeking force that acts to move an object tangent to the direction in which it is moving at any instant, thus causing it to move in a circular path.

Centrifugal Force: an outward-pulling force equal in magnitude to centripetal force.

Equation for both (equal & opposite forces):

$$F_c = mv^2 / r$$

General Principles of Rotary Motion

- The following principles need to be considered when analyzing rotary motion:
  - Sum of Torques
  - Conservation of Angular Momentum
  - Principle of Levers
  - Conservation and Transfer of Angular Momentum