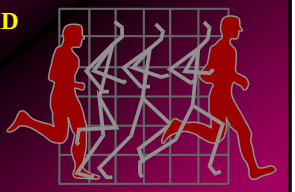
Measurement of Internal Work

D. Gordon E. Robertson, PhD

Biomechanics Laboratory,
School of Human Kinetics,
University of Ottawa, Ottawa, CANADA



Mechanical Energy

- Four forms
  - Gravitational potential $m g y$
  - Elastic potential $\frac{1}{2} k s^2$
  - Translational kinetic $\frac{1}{2} m v^2$
  - Rotational kinetic $\frac{1}{2} I \omega^2$
- Total mechanical energy is sum of all four
- Elastic potential energy is usually omitted because it cannot be measured accurately

Total Body Mechanical Energy

- Sum of all segmental total mechanical energies (E_s)
- Segmental total energy

$$E_s = m_s g y_s + \frac{1}{2} m_s v_s^2 + \frac{1}{2} I_s \omega_s^2$$

- Total body energy

$$E_{total} = \Sigma E_s$$

External Work

- Mechanical work = change in mechanical energy

$$W_{ext} = \Sigma (\Delta E_{total})$$

- or simplified

$$W_{ext} = E_{total}(t_n) - E_{total}(t_0)$$

Zero-work Paradox

- If a body moves at constant velocity along a horizontal path no "external" mechanical work is done!
- Mechanical cost of moving body parts cancel out if motion is cyclic.
- Problem exists with all locomotor tasks but if body speeds up or rises, some external work is done, however, additional costs of "cycling" the body parts are not included.

Work Allowing No Transforms or Transfers of Energy

- Work done that prevents changes of forms of energy, i.e., from potential to kinetic, etc.

$$W_n = \Sigma\,\Sigma\,|\,\Delta\, m_s\, g\, y_s\,| + |\,\Delta\, \tfrac{1}{2}\, m_s\, v_s^2\,| + |\,\Delta\, \tfrac{1}{2}\, I_s\, \omega_s^2\,|$$

- First summation is over all time intervals
- Second summation is over all segments
- Norman et al. (1976)

Work Allowing within Segment Transforms

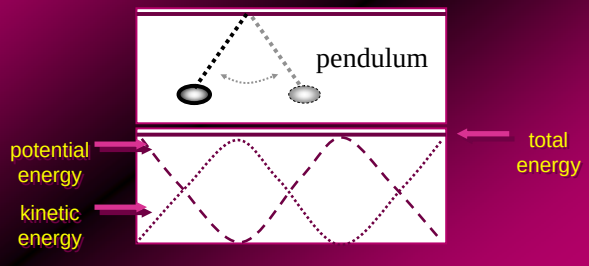
- Work done that permits changes of forms of energy within a segment (kinetic to potential and *vice versa*) but no transfers from segment to segment

$$W_w = \Sigma\,\Sigma\,|\,\Delta\, E_s\,|$$

- First summation is over all time intervals
- Second summation is over all segments
- Winter (1979)

Energy Conservation by Transforming Energy within a Segment

- simple pendulum



Internal Work

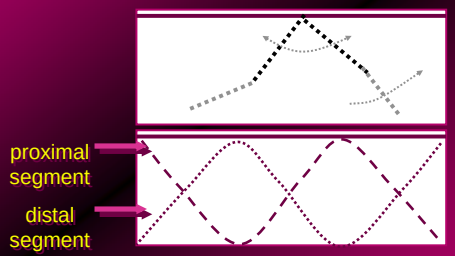
- **Internal work measures the mechanical costs of moving the limbs during a cyclic motion. The equation permits transfers of energy from segment to segment and from one form to another.**

$$W_{int} = \Sigma \mid \Delta E_{total} \mid - W_{ext}$$

- **Absolute values prevent decreases in mechanical energy from canceling increases**

Energy Conservation by Transferring Energy between Segments

- **compound pendulum**



Energy Saved by Transfers and Transforms

- **Energy saved by permitting transfers of energy from segment to segment**

$$E_{transfers} = W_w - W_{int}$$

- **Energy saved by permitting transforms of energy from one form to another (potential ot kinetic)**

$$E_{transforms} = W_n - W_w$$

Segment Energies during Walking