Objectives

1. Understand mechanical work and its relationship to various forms of mechanical energy: kinetic, potential gravitational, and potential strain
2. Understand the difference between positive and negative work within a biomechanics context
3. Understand mechanical power

Summary

- Mechanical work (U) is a quantity describing the extent to which a force can move an object: $U = F \cdot d$
- Mechanical energy (E) is the ability to perform work; work results a change in energy: $U = F \cdot d = \Delta E$
- In this context, three forms of mechanical energy are considered: kinetic, potential gravitational, and potential strain

  $KE = \frac{1}{2} \cdot m \cdot v^2$; $GE = wt \cdot ht$; $SE = \frac{1}{2} \cdot k \cdot x^2$

- Mechanical power is the rate of change of work; work that can be performed in a certain amount of time.

Work, Energy, & Power

Another way of describing the effect of a force:

- Mechanical work (U) is done on an object when a force causes a change in position
- Work done on a body by a force equals average force multiplied by displacement

$$U = F \cdot d$$

- Units of measurement: Nm or Joule (J)

Work, Energy, & Power

A relatively simple example:

Lifting a 22 N barbell 0.4 m,

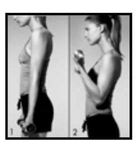
Lowering a 22 N barbell the same displacement…

Positive Work is often associated with concentric muscle action, while Negative Work is often associated with eccentric muscle action

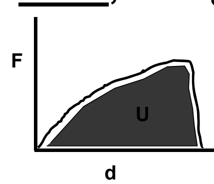
Work, Energy, & Power

Another way to view mechanical work performed on the barbell…U = Area under the force—displacement curve

22 N barbell 0.4 m from the floor



Work, Energy, & Power



$U = F \cdot d$

Work, Energy, & Power

Another example: Asimo can walk up stairs. He walks up a flight of stairs, raising his body mass some vertical displacement (d*)*, that is represented by the height of the stairs.

How much mechanical work is performed when Asimo (52 kg) climbs up a flight of 20 stairs (25 cm steps)?

He can also serve tea.

Work, Energy, & Power

Energy is the capacity to do work, or U = ΔE:

Kinetic energy (KE): energy due to motion

$KE = \frac{1}{2} \cdot m \cdot v^2$

Potential energy:

1) energy due to height, gravitational energy (GE):

$GE = wt \cdot h = m \cdot |g| \cdot h$

2) energy due to deformation, strain energy (SE):

$SE: = \frac{1}{2} \cdot k \cdot x^2$

Units are the same as for work: J or Nm

Work, Energy, & Power

Energy is the capacity to do work:

Kinetic energy (KE): energy due to motion

$KE = \frac{1}{2} \cdot m \cdot v^2$

How much KE does a baseball (145 g) that is traveling 80 mph has?

$KE = \frac{1}{2} \cdot m \cdot v^2$

$KE = \frac{1}{2} \cdot 0.145\ kg \cdot (35.8\ m/s)^2$

= 92.7 J

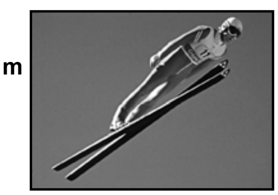
Work, Energy, & Power

Energy is the capacity to do work:

energy due to height, gravitational potential energy (GE)

$GE = wt \cdot h = m \cdot |g| \cdot h$

How much GE does a 200-lb ski-jumper at the have at the top of an 80-m skill hill?



$GE = 90.33\ kg \times 9.81\ m/s/s \times 80\ m$

= 70,894 J

Work, Energy, & Power

Energy is the capacity to do work:

energy due to deformation, strain energy (SE):

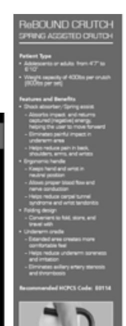
$SE: = \frac{1}{2} \cdot k \cdot x^2$

How much strain energy is stored in a tendon that is stretched 5 mm, if the stiffness of that tendon is 10,000 N/m?

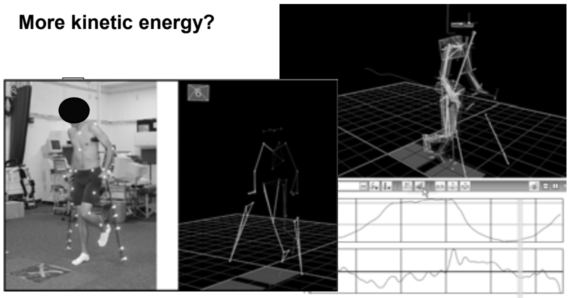
$SE = \frac{1}{2} \cdot 10{,}000 \cdot (.005\ m)^2$

= 0.125 J

Spring-loaded Crutches

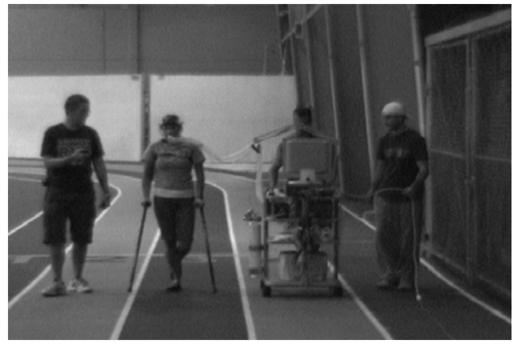


More kinetic energy?



	Millennial Crutches	Traditional Crutches
Peak Velocity (m/s)*	1.29 ± 0.08	1.23 ± 0.10
Peak Kinetic Energy (J)*	57.3 ± 12.0	52.3 ± 11.6
Strain Energy (J)	2.50 ± 1.96	Negligible
Ambulation Speed (m/s)	0.96 ± 0.04	0.97 ± 0.02

Less metabolic energy?



Work–Energy Relationship

When a force other than gravity does work on an object, there is a change in total mechanical energy

This work is equal to the change in total energy that it produces on the object

$$U = \Delta KE + \Delta GE + \Delta SE + \Delta TE + \Delta ME$$

Note: Energy sources other than KE and GE are more difficult to measure and will be excluded from our analyses.

Work–Energy Relationship

$U = \Delta KE + \Delta GE$

Consider the barbell we discussed previously: prior to the lift, what was the barbell's energy?

No velocity, no height, no energy.

After the lift, what was the barbell's energy?
No velocity, but some height and some energy.

The change in energy equals the work done.

Work, <u>Energy</u>, & Power

<u>Conservation of mechanical energy:</u> When gravity is the only external force, mechanical energy remains constant.

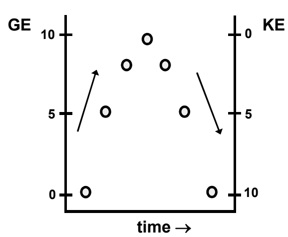
KE + GE = Constant

On the way up:

GE ↑ KE ↓

On the way down:

GE ↓ KE ↑

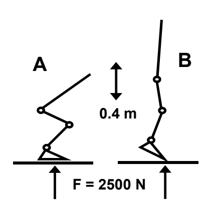


Work–Energy Relationship

A basketball player (90 kg) jumps straight up to dunk the basketball. Assume that:

At point A, the center of mass height is 0.5 m

Average ground reaction force of 3000 N was applied to the center of mass throughout a vertical distance of 0.4 m (from point A to point B, just prior to takeoff)



Work–Energy Relationship

1. How much work was performed?
2. How much total mechanical energy did the athlete have 1-ms after leaving the ground? How about at 100 ms?
3. Comparing these times (from 1 ms to 100 ms), did KE and GE increase or decrease?
4. Using conservation of energy, how high was the center of mass raised?
5. Check your answer using the projectile motion equations from Chapter 2.

Work, Energy, & Power

Power is the rate at which work is performed

$$\text{power} = \frac{\text{work}}{\text{change in time}} = \frac{U}{\Delta t}$$

$$\text{power} = \frac{\text{force x distance}}{\text{change in time}} = \frac{F \cdot d}{\Delta t}$$

Since $v = \frac{d}{\Delta t}$, power = $F \cdot v$

Units of measurement: J/s or Watts 1 Watt = 1 J/s

Work, Energy, & Power

Back to the stair climbing example (see slide 7)

W = 3500 J Case 1: t = 20 s
Case 2: t = 5 s

What is the power?

Case 1: $P = \frac{3500 \text{ J}}{20 \text{ s}} = 175 \text{ J/s} = 175 \text{ W}$

Case 2: $P = \frac{3500 \text{ J}}{5 \text{ s}} = 700 \text{ J/s} = 700 \text{ W}$

Power is an indicator of the intensity of the task.

Work, Energy, & Power

Components of human power production:

strength (force producing ability) and speed of muscle contraction

What does it mean to be "powerful"?

- Cars - main advantage of high hp engine is not in producing a high top speed, but high acceleration (e.g., 0-60 mph in short time)
- Human sprinter - high power output capability is especially important to success
  - tied to ability to accelerate to top speed
  - capability of producing high muscle forces with relatively high speeds of muscle shortening

Work, Energy, & Power

Power is important as we seek the ideal balance between force and speed.

Force × Velocity Relationship: as speed increases, maximal force production capability decreases (think of pedaling a multi-speed bicycle)

What is best?

It likely depends most upon the nature of the task, and especially the duration, of the task. Somewhere in the middle is often best.

Summary

- Mechanical work (U) is a quantity describing the extent to which a force can move an object: $U = F \cdot d$
- Mechanical energy (E) is the ability to perform work; work requires a change in energy: $U = \Delta E$
- In biomechanics, we often most concerned with kinetic energy, and potential energy related to height and deformation

  $KE = \frac{1}{2} \cdot m \cdot v^2$; $GE = wt \cdot ht$; $SE = \frac{1}{2} \cdot k \cdot x^2$
- Power is the rate of change of work, or the amount of work that can be performed in a certain amount of time