**Power**

**Human Power Output**

Hamill & Knutzen (Ch 3 & 11)

**Power**

Power = Force x Velocity

Maximum power occurs at about 30-33% of maximal velocity of shortening and about the same percentage of maximum concentric force.

Negative Power????

**Optimal Power**

Athletes must find as high a level of power output as possible that can be sustained for the duration of their event.

**Next Slide**

Human Power Output *Intensity*

<table>
<thead>
<tr>
<th>Metabolic power (watts)</th>
<th>Mechanical power (watts)</th>
<th>Predominant energy system</th>
<th>Time to exhaustion</th>
<th>Example of activity type</th>
</tr>
</thead>
<tbody>
<tr>
<td>6,000</td>
<td>1,380</td>
<td>Phosphagen</td>
<td>1 second</td>
<td>Olympic Lifts</td>
</tr>
<tr>
<td>4,000</td>
<td>920</td>
<td>Phosphagen + a little Glycolytic</td>
<td>14 seconds</td>
<td>100-m sprint</td>
</tr>
<tr>
<td>2,000</td>
<td>460</td>
<td>Oxidative + some Glycolytic</td>
<td>6 minutes</td>
<td>2-km row</td>
</tr>
<tr>
<td>1,000</td>
<td>230</td>
<td>Oxidative</td>
<td>2 hours</td>
<td>40-mile bike</td>
</tr>
</tbody>
</table>

Graph from “Champion Athletes” Wilkie 1960

Sustaining 375 Watts for 30 minutes? Impressive!

Estimate of Thruster Average Work and Power Calculations

http://www.crossfit.com/

Seems simple enough – but there is a problem with relating the external work done in such movements to the metabolic cost to the athlete?
The “Back-Swing” or “Wind-Up”

Movements that cause a muscle to shorten immediately after a period of stretching are often referred to as a “wind-up” or “back-swing”. However, this term is misleading.

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Pre-stretch (plyometrics)

- Return of stored energy from passive elastic structures within the muscle (cross-bridges and connective tissue (70-75% of increase?)
- Prior activation (time to develop force reduced)
- Initial increased force potentiation (eccentric contraction)
- Reflex augmentation (stretch reflex)
  - Small amplitude – high velocity – no delay
Positive work done by (a) an isolated muscle during a shortening contraction preceded by an isometric contraction and (b) a shortening contraction preceded by a lengthening contraction.

The work done by the muscle (area under phase c of the length force curve) is greater for the lengthening-shortening contraction (stretch-shortening).
Effects of Plyometric Training

- Adaptations to muscles include increased rate of force development and hypertrophy of type IIx fibres.
- Training with rats (Dooley et al. 1990)
  - 15% increase in tetanic force
  - 3% increase in max rate of force development
  - 15% increase in fatigability
  - 4% decrease in type IIa fibres

Elasticity and Force Transmission

- If we study Kangaroos we find out that for a given speed they are more efficient than a quadruped like a cheetah.
- They are not as fast but they use less oxygen for a given speed (very sub-maximal for a Cheetah)
- This is because the muscle can work almost isometrically controlling the stretch and recoil of a VERY long achilles tendon.

Work loops for (a) the plantaris muscle of a wallaby during hoping and (b) the pectoralis muscle of a pigeon during flying.

Comfort versus speed?

- So a highly cushioned shoe seems like a good safety feature but maybe not.
- Too much elasticity ("give") may affect stability
- Too much “give” may slow you down (you have to compress the elasticity material of the midsole before you can drive off again)
- Static stretching has been shown to reduce force transmission as it increases tendon compliance
Olympic Lifting and Powerlifting Power Outputs

Jerk ≈ 2,140 W (56 kg) ≈ 4,786 W (110 kg)

Second pull
Average power output from transition to maximum vertical velocity ≈ 5,600 Watts (100 kg male); 2,900 Watts (75 kg female).

Average Power (Powerlifting)
- bench ≈ 300 W
- squat ≈ 1,000 W
- deadlift ≈ 1,100 W
- Why are “Powerlifting” events less powerful?

Power to Weight Ratio

- In many sports it is not just about how much power you output … it is also about how much you weigh.

- For events like the Tour de France it is a matter of watts per kilogram of body weight, that is, the specific power output at lactate threshold - the amount of power/weight that the body can sustainably generate. It turns out that 6.7 is more or less a magic number - the power/weight ratio required to win the TDF.

Energy/Power Analysis

- The previous is OK for a fitness test or an estimate of workrate (power) during exercise.
- However, to calculate energy change (power) segment by segment we need to do a dynamic analysis.
- We need to take accelerations into account if the movement is too dynamic for a static analysis.

Inverse Dynamic Analysis

\[ \sum F_x = m a_x \]
\[ \sum F_y = m a_y \]
\[ \sum M = I \alpha \]
Patella Tendon Rupture.
Force in patella tendon \[\times\] 14.5 kN (17.5 x body weight)

Load weight 175 kg

Muscle Moment Power

Mechanical Work of Muscles

\[
W_{m} = \int_{t_1}^{t_2} P_m \cdot dt
\]

\[
W_{m} = \int_{t_1}^{t_2} M_j \omega_j \cdot dt
\]

Mechanical Energy Transfer Between Segments

- Muscles can obviously do work on a segment (muscle moment power).
- However, if there is translational movement of the joints there is mechanical energy transfer between segments. (i.e. one segment does work on an adjacent segment by force-displacement through the joint centre).
- Transfer of energy is very important in improving the overall efficiency of human movement patterns.
Human Energy Harvesting

- Biomechanical Energy Harvesting: Generating Electricity During Walking with Minimal User Effort
- J. M. Donelan, Q. Li, V. Naing, J. A. Hoffer, D. J. Weber, A. D. Kuo
- Science 8 February 2008: Vol. 319. no. 5864, pp. 807 - 810

Rate of change of the energy of a segment (power) \( [P_s] \)

- Muscle moment power for the proximal joint
- Muscle moment power for the distal joint
- Joint force power for the proximal joint
- Joint force power for the distal joint

\[
P_s = M_p \omega + M_d \omega + F_p V_p + F_d V_d
\]
Total Instantaneous Energy of a Body

$$E_T = \frac{1}{2}mv^2 + mgh + \frac{1}{2}I\omega^2$$

Example I discussed with a spinning tennis ball – it would have all three of these types of energies

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**Efficiency**

- *Metabolic efficiency* is a measure of the muscles ability to convert metabolic energy to tension.
- A high metabolic efficiency does not necessarily mean that an efficient movement is taking place (e.g. cerebral palsy).
- The ability of the central nervous system to control the tension patterns is what influences the *mechanical efficiency*.

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**Overall Muscular Efficiency**

Muscular Eff. = \(\frac{\text{Net mechanical work}}{\text{Net metabolic energy}}\)

Net mechanical work

\[= \text{Internal work} + \text{External work}\]

- **Internal work**: Work done by muscles in moving body segments.
- **External work**: Work done by muscles to move external masses or work against external resistance.
- Approx. 20-25% efficiency.
Efficiency

All efficiency calculations involve some measure of mechanical output divided by a measure of metabolic input. **Metabolic work is not too difficult to estimate if we do gas analysis. External work also easy to calculate.** But we need to calculate internal mechanical work. Clearly we must at least calculate absolute energy changes (negative work is still an energy cost to the body). However, isometric contractions against gravity still a problem.

Causes of Inefficient Movement

- Co-contraction
- Isometric Contractions Against Gravity
  - Example of hands out straight. No mechanical work being done!
- Jerky Movements
  - High accelerations & decelerations waste energy compared to gradual acceleration
- Generation of energy at one joint and absorption at another (walking example)
- Joint friction (small)

Flow of Energy

Burning Calories!

So does a treadmill, lifecycle or stair master give you an accurate value for calories burnt or power output?