The cost of comfort: what's it worth to avoid pain?

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Net positive work must be done by muscles

<table>
<thead>
<tr>
<th>Net Positive Work</th>
<th>Active Muscles</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image.png" alt="Stair Climbing Icon" /></td>
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Negative work can be done by muscles

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<th>Net Negative Work</th>
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<tr>
<td>Active Muscles</td>
<td>![Image of a person ascending stairs]</td>
<td>![Image of a person descending stairs]</td>
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Negative work can also be done passively
People can choose how to distribute neg. work\(^1\)

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<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td><strong>Passive Soft Tissues</strong></td>
<td><img src="image3.png" alt="Image" /></td>
<td><img src="image4.png" alt="Image" /></td>
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\(^1\)Zatsiorsky & Prilutsky 1982
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<th>Cost</th>
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<td>Active Muscles</td>
<td><img src="image1.png" alt="Positive Work" /></td>
<td><img src="image2.png" alt="Negative Work" /></td>
<td>Metabolic Energy</td>
</tr>
<tr>
<td>Passive Soft Tissues</td>
<td><img src="image3.png" alt="Positive Work" /></td>
<td><img src="image4.png" alt="Negative Work" /></td>
<td>Pain Risk of Injury</td>
</tr>
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Preferred landing strategy is a compromise between these costs

Cost

- Metabolic Energy
- Pain Risk of Injury
How can we compare costs quantitatively?

Preferred landing strategy is a compromise between these costs
Distribution of work → how people value costs

Active Work

Passive Work

Cost

Metabolic Energy

Pain Risk of Injury

reduces
Distribution of work → how people value costs

- **Active Work**
- **Passive Work**

**Cost**
- Metabolic Energy
- Pain Risk of Injury

reduces
How do people choose to distribute work?
How do people choose to distribute work?

Jump-Landing Experiment
How do people choose to distribute work?

Estimating Active vs. Passive Contributions
How do people choose to distribute work?

People prefer to do more active work than necessary.
$N=8$
Collected ground reaction forces and full-body kinematics
Range of jump heights

Counter-Movement  Push-off  Aerial  Collision  Recovery

\[ mgh_{\text{jump}} \]
Stiff-legged landing minimizes negative work

Counter-Movement  Push-off  Aerial  Collision  Recovery

$mgh_{\text{jump}}$  passive negative work
Doing work actively increases total work done

Counter-Movement

Push-off

Aerial

Collision

Recovery

\[ mgh_1 \]

\[ mgh_{\text{jump}} \]

\[ mgh_2 \]
Hypothesis: people prefer to perform extra work

- Counter-Movement
- Push-off
- Aerial
- Collision (active & passive negative work)
- Recovery
Representative mechanical power
Preferred landing style

![Graph showing relationship between Total Work (J) and Jump Height (m)].

- **Normal Recovery**
- **Normal Collision**

**Axes**:
- **Y-axis**: Total Work (J)
- **X-axis**: Jump Height (m)

**Legend**:
- **Collision**
- **Recovery**
Theoretical minimum: only negative work

![Graph showing the relationship between total work and jump height. The graph includes lines for Normal Recovery, Minimum Collision Work ($mgh_{jump}$), Normal Collision, Collision, and Recovery.](graph.png)
People choose to do more work than necessary

![Graph showing the relationship between total work (J) and jump height (m). The graph includes two lines: one for normal recovery work (Extra Positive Work) and one for minimum collision work (Extra Negative Work). The graph also shows the work done during collision and recovery phases.](image-url)
Landing stiff-legged minimizes work

![Graph showing the relationship between Total Work (J) and Jump Height (m). The graph includes lines for Normal Recovery, Stiff Recovery, Minimum Collision Work (mg\(h_{\text{jump}}\)), Stiff Collision, and Normal Collision.]
Landing softly increases neg. & pos. work

![Graph showing the relationship between Total Work (J) and Jump Height (m) with different recovery and collision conditions.]
Landing softly increases neg. & pos. work
Mechanical work performed landing from 40cm

- theoretical minimum
- stiff-legged
- normal (preferred)
- soft
Trade-off between energy and pain

more metabolic energy

more painful

-600 -500 -400 -300 -200 -100 0 100
Total Work (J)

theoretical minimum

stiff-legged

normal (preferred)

soft
People prefer to do 37% more negative work
König's Theorem

Total Mechanical Power

Joint + Soft Tissue

Rotational power due to muscles/tendons

Everything else, notably power due to deformations of non-rigid bodies

Center-of-Mass + Peripheral

Power due to motion of the CoM

Power due to motion relative to the CoM
Center-of-Mass + Peripheral = Joint + Soft Tissue
\[
\sum_{\text{legs}} F_i \cdot v_{\text{COM}} \approx \frac{d}{dt} \sum_{\text{segments}} \frac{1}{2} m_s (v_s - v_{\text{COM}})^2 + \frac{1}{2} l_s \cdot \omega_s^2
\]

Center-of-Mass + Peripheral*

\[\approx\]

(inverse dynamics)

\[
\sum_{\text{joints}} M_j \cdot \omega_j
\]

Joint* + Soft Tissue

*rigid-body assumptions
Joint

indicator of active contributions

Center-of-Mass + Peripheral

indicator of passive contributions

Soft Tissue
Mechanical Power

Counter-Movement

Push-off

Aerial

Collision

Recovery

Time
Mechanical Power (Inverse-Dynamics-based)

Joint Power
\[(\text{Total} - \text{Joint}) \text{ Power} = \text{Soft Tissue Power}\]
Mechanical Power (Soft Tissue)

positive work (damped rebound?)

negative work (absorption)
Soft Tissue Collision work increases with Total
Soft Tissues perform 16% of Collision work
Passive contribution highest for small Collisions

Collision Work

Soft Tissue

Total

Soft Tissue Contribution to Collision

Collisions during walking at 1.25 m/s (Zelik and Kuo 2010)

Percent

16.0%
People prefer to distribute work between active & passive tissues, doing 37% more than needed

Collisions could be done for free, but it hurts to land passively,
So people will choose
Mostly muscles to use.
Comfort is worth energy.

Acknowledgements
Adrian Choy
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