Moving & Shaking: Soft Tissue Work in Human Walking
Mmmm... rigid-body dynamics
But >80% of the body is “soft”

More like Jello than rigid?
Walking has heelstrike collisions

Hypothesis: Soft tissue work during/after collisions Increasing with speed

Kuo 2002
Soft tissue work in walking? How much? When?

1) Method for estimating soft tissue power and work

2) Normal walking
“External” power, due to motion of the CoM

“Internal” power, due to motion of segments relative to the CoM

Center-of-Mass + Peripheral

König’s Theorem

Total Mechanical Power

Joint + Non-Joint ("Soft")

Rotational power due to muscles/tendons (inverse dynamics)

Everything else, notably power due to deformations of non-rigid bodies
Non-Joint ("Soft")

Center-of-Mass + Peripheral =

Joint + Non-Joint ("Soft")
Center-of-Mass $\rightarrow$ Peripheral

Joint $\rightarrow$ Non-Joint ("Soft")

no direct measure
\[ \sum F_i \cdot v_{\text{COM}} \quad \quad \quad \sum F_s \cdot v_{s/\text{COM}} + M_s \cdot \omega_s \]

Center-of-Mass + Peripheral

- Joint

\[ \sum M_j \cdot \omega_j \]

Non-Joint ("Soft")
Walking Experiment

- Young, healthy adults ($N=10$)
- Speeds 0.7 – 2.0 m/s
- Instrumented treadmill
- Collected forces & kinematics
1.25 m/s

Power (W/kg)

% Gait Cycle

Joint

Non-Joint ("Soft")
Non-Joint ("Soft")

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

1.25 m/s

Center-of-Mass

Peripheral

Knee

Ankle

Hip

% Gait Cycle
The graph shows the power (W/kg) as a function of the percentage of the gait cycle. The x-axis represents the percentage of the gait cycle, ranging from 0 to 100. The y-axis represents the power, ranging from -2 to 4 W/kg.

Three subplots are shown on the right side of the graph, indicating the power at different joints: Hip, Knee, and Ankle.

The graph highlights the summed Ankle-Knee-Hip power, which peaks at 1.25 m/s.

Mathematically, the sum of the moments for each joint over time is given by:

\[ \sum_{\text{joints}} M_j \cdot \omega_j \]
\[ \sum_{\text{legs}} F_i \cdot v_{\text{COM}} \]

Diagram: Power (W/kg) vs. % Gait Cycle with separate curves for Joint and Non-Joint ("Soft") categories.
Total Mechanical Power

- Joint
- Non-Joint (“Soft”)
Total Mechanical Power

[Diagram showing Total Mechanical Power across different stages of gait cycle: Collision, Rebound, Preload, and Push-off. The x-axis represents % Gait Cycle, and the y-axis represents Power (W/kg). The diagram also highlights the distinction between Joint and Non-Joint ("Soft").]
Total Mechanical Power

- **Joint**
- **Non-Joint ("Soft")**

![Graph showing power changes during gait cycle phases: Collision, Rebound, Preload, and Push-off. The graph illustrates the mechanical power output over time with distinct peaks and troughs.]
Total Mechanical Power

% Gait Cycle

Power (W/kg)

Collision

Rebound

Preload

Push-off

Swing

Joint

Non-Joint ("Soft")
Total Mechanical Power

integrate over time

Work

% Gait Cycle

Power (W/kg)

Collision

Joint

Non-Joint ("Soft")
Negative Collision Work

![Graph showing work vs. walking speed with joint and non-joint ("soft") sections.](image)
Negative Collision Work

dominated by non-joint work

[Graph showing work (J) vs. walking speed (m/s) with 60% of the data points indicating non-joint work significantly higher than joint work.]

Joint

Non-Joint ("Soft")
Positive Rebound Work

damped elastic rebound of soft tissues?

![Graph showing work (J) vs. walking speed (m/s)]

- **Work (J)**
  - Range: -10 to 30 J
- **Walking Speed (m/s)**
  - Range: 0.6 to 2.0 m/s

**Joint** and **Non-Joint (“Soft”)**
Limitations

- Indirect estimate
- Soft tissue work loosely defined as non-joint
- No indication of where work is done
Soft Tissue...

- Power estimated from GRFs and kinematics
- 60% of collision work in walking
- Not only dissipative, ~5-8 J elastic rebound
There is a collision in gait when the foot hits the ground and bears weight. Joint work measures miss three-fifths of the squish, which soft tissues perhaps dissipate.

Acknowledgements: NSF, DoD
There is a collision in gait when the foot hits the ground and bears weight. Joint work measures miss three-fifths of the squish, which soft tissues perhaps dissipate.

Acknowledgements: NSF, DoD