Can we explain reduced gravity trends without springs?

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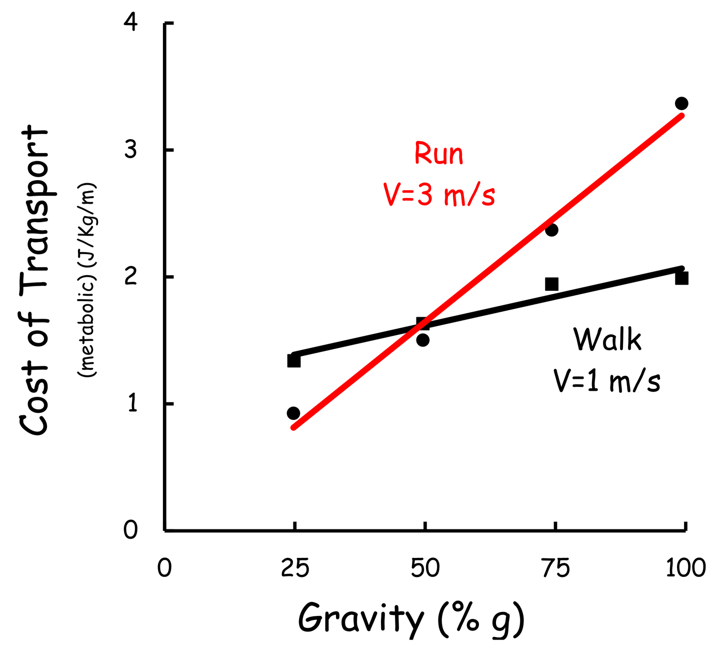
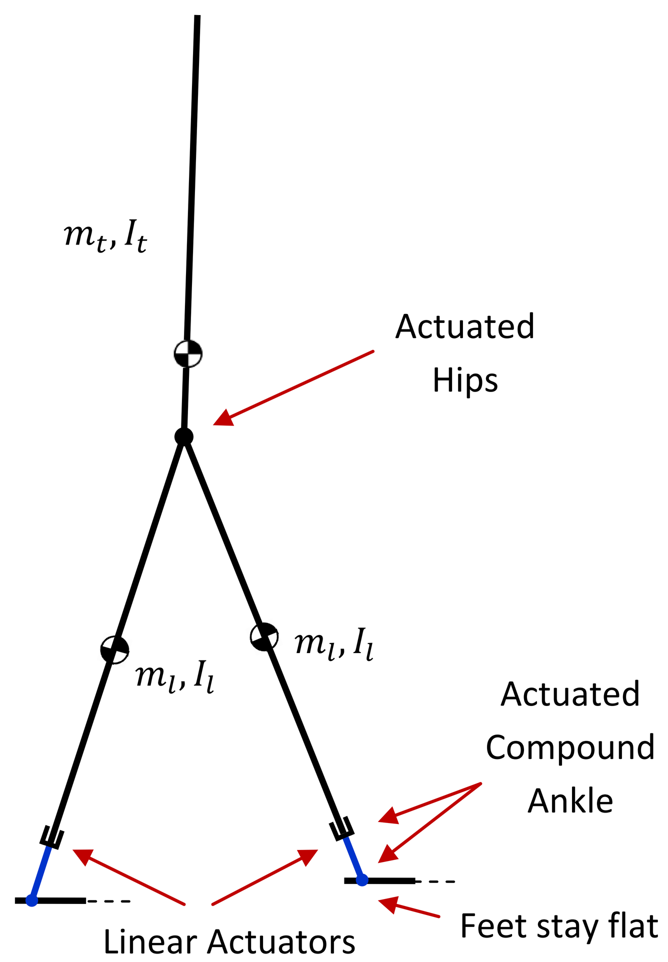
Observations

- Metabolic power in running decreases with gravity faster than in walking.
- Previous explanation (Farley and McMahon [1]) based on elasticity in running vs. potential/kinetic energy exchanges in walking



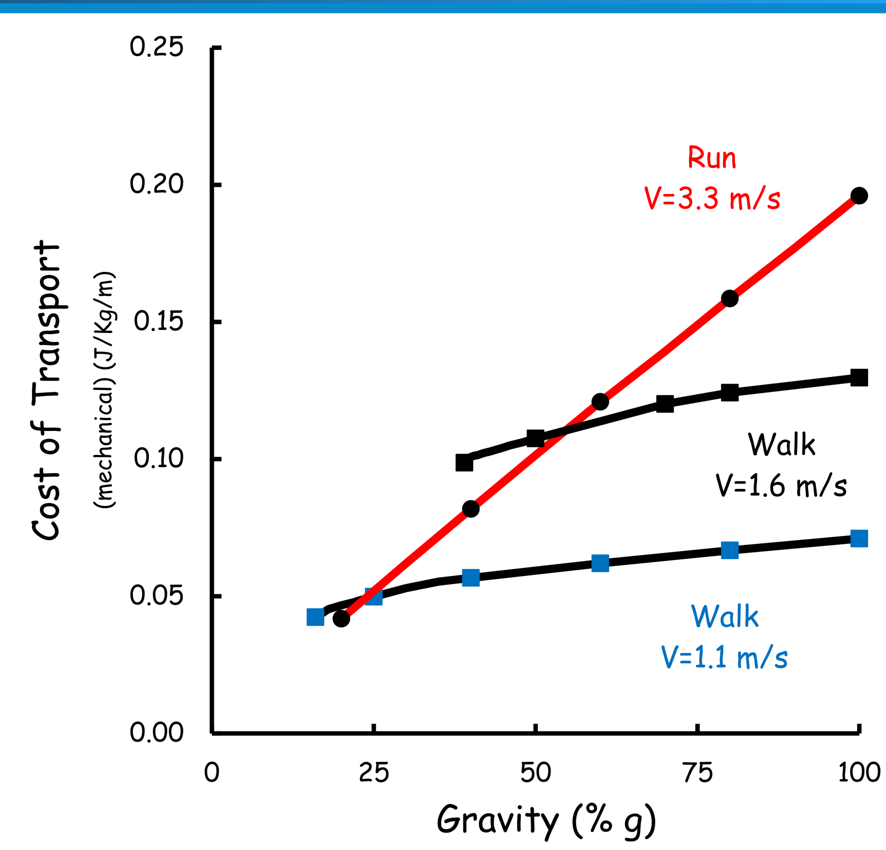
Biped Model Without Springs

- Realistic mass distribution
- Periodic gaits: walking, and running
- Extended double support is allowed in walking
- Dynamic optimization finds the gaits
- Cost function: mechanical COT = $\frac{\text{positive work}}{\text{step length} \times \text{body mass}}$
- Step length and step frequency are free
- Optimizations simulate reduced gravity in two ways:
  - 'hip-lift' (constant upward force, like experiment)
  - 'reduced-g' (reduced g on all body parts)



Model Predictions (Energetic Cost)

- Model predictions consistent with observations
- Cost cross-overs even without springs
- The energetics is determined by the balance between the stance and swing leg works for minimum net cost.
- 'Hip-lift' and reduced-g optimizations give almost identical results.
- Springs decrease the cost of running, improving the estimates of cross-over gravity levels.



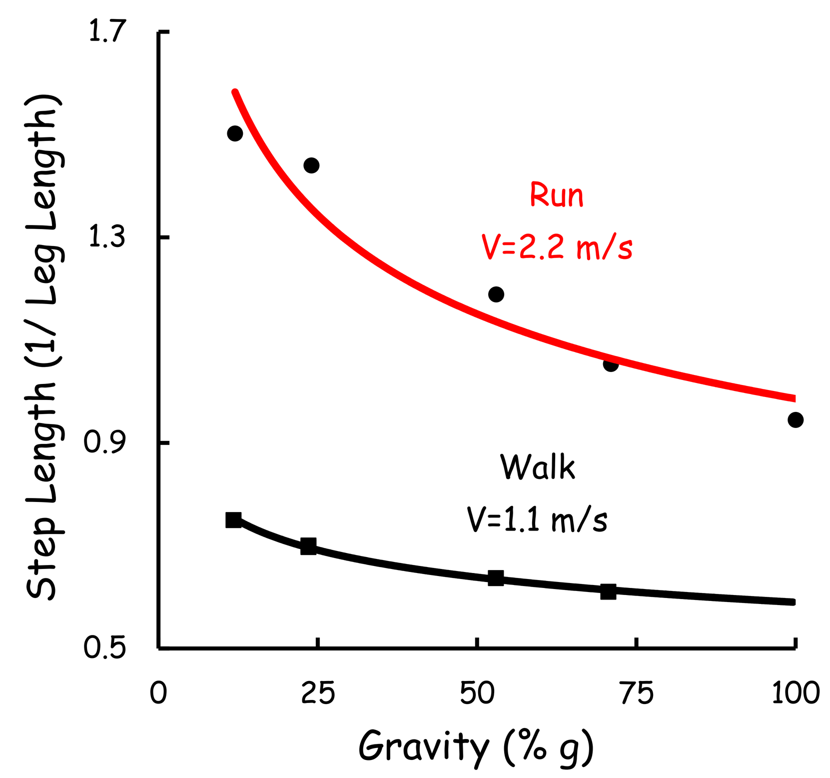
References

[1] C.T. Farley, and T.A. McMahon, "Energetics of walking and running: insights from simulated reduced-gravity experiments," J. Appl. Physiol., 73(6): 2709-2712, 1992.

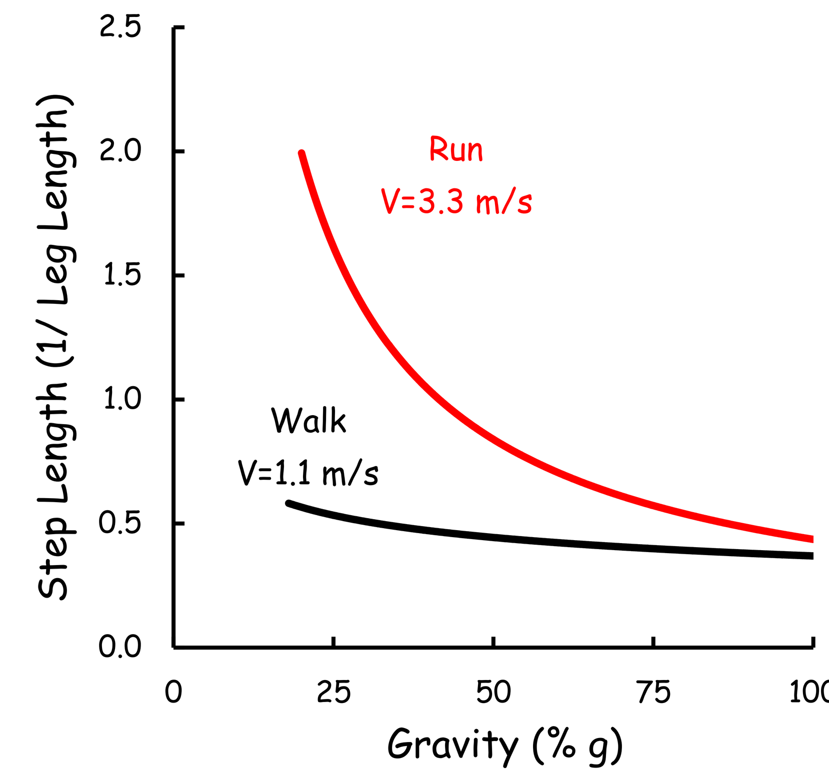
[2] A.D. Kuo, "A simple model of bipedal walking predicts the preferred speed-step length relationship," J. Biomech. Eng., 123(3): 264-269, 2001.

Kinematics

Experiment



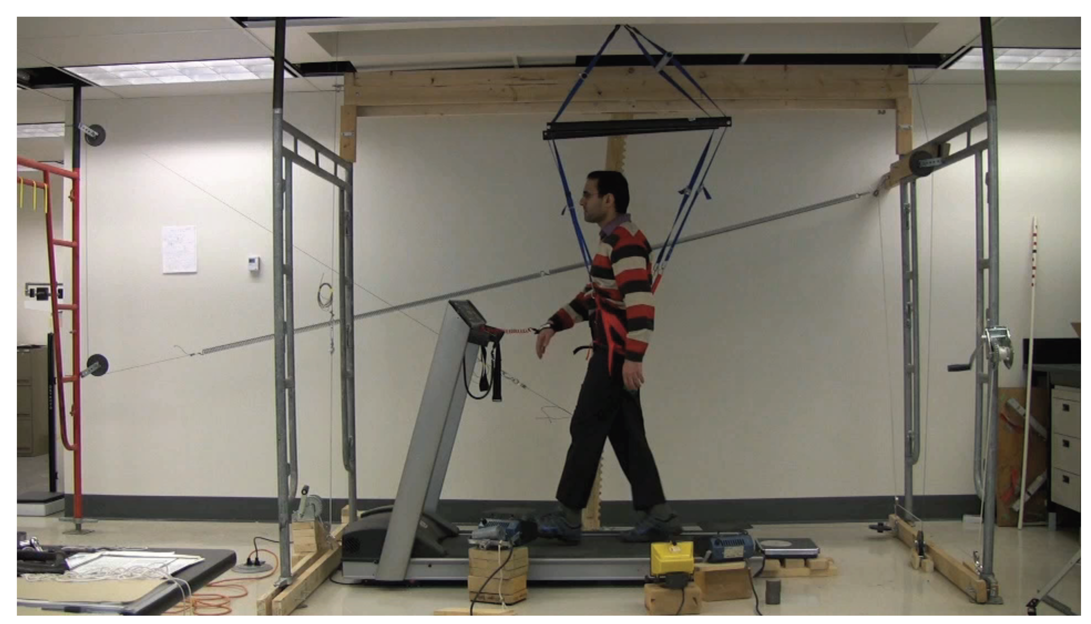
Model Prediction

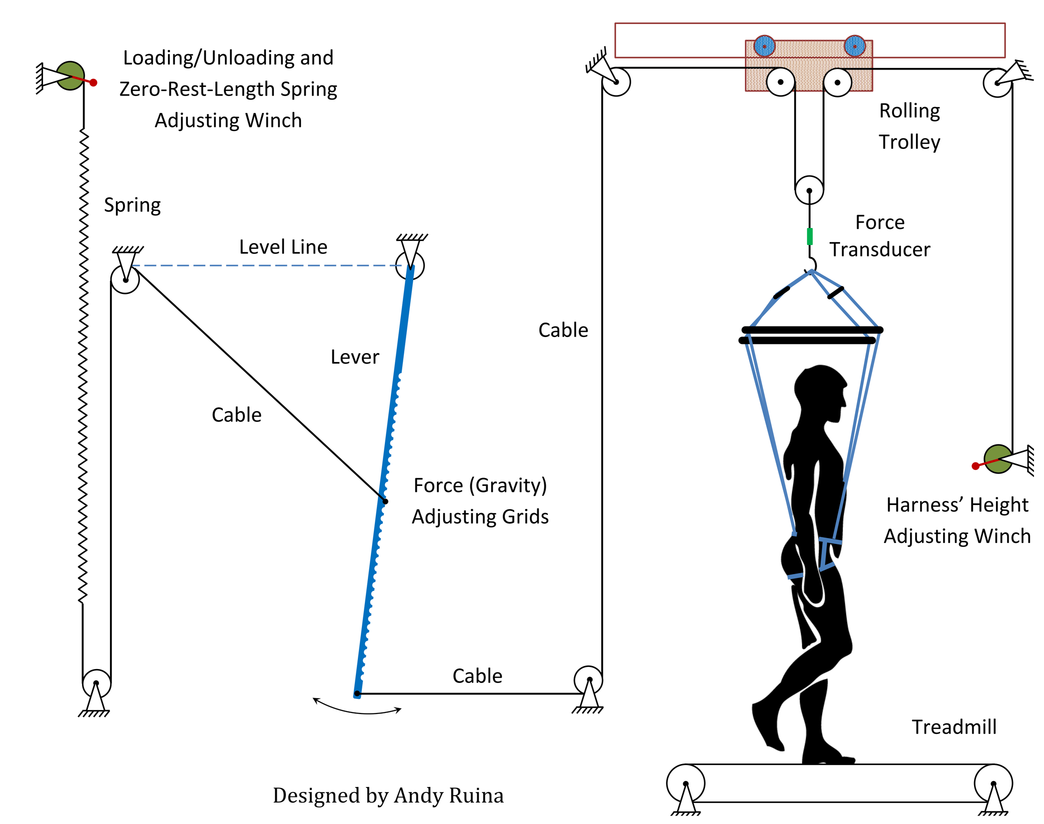


- For walking and running: decreased g results in increased step length.
- Step length predictions for 'hip-lift' are slightly shorter than for reduced-g.
- Optimizations under-estimate step length.
- An extra cost term for fast leg swing (*e.g.* force/time) improves step length estimates [2].

Reduced Gravity Simulator (constant upward force)

The reduced gravity apparatus based on zero-rest-length springs:





Final Comments

- Experimental results support model predictions
- The optimization here predicts energetic and kinemaytic trends without using springs: running more affected by gravity than walking
- Main determinant in optimization: trade offs between leg swing and stance costs.
- Some optimization details:
  - Some trends are explicable with collision angles.
  - Optimization in running shows constant cost per step as gravity is reduced $\Longrightarrow$ COT $\propto$ g.

Open Questions

- How would springs change these results?
- Besides energy efficiency, what is the role of passive compliance in biological locomotion?

Acknowledgment

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