Low rider: (what) are humans optimizing in reduced gravity?

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What are the priorities of the motor control system?

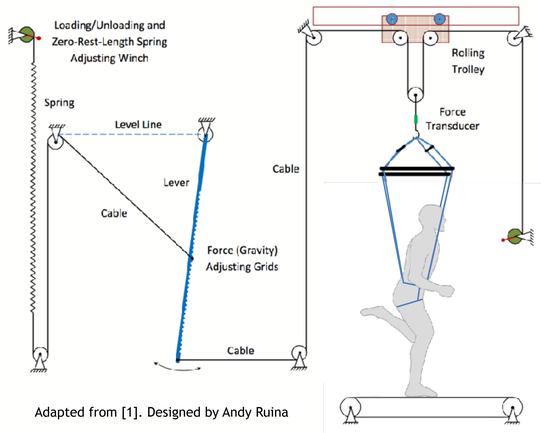
- Test: place subjects in novel circumstances, and observe changes in gait
- Reduced gravity apparatus offloads centre of mass during running [1]
- Humans tend to minimize metabolic energy expenditure in locomotion [2, 3]
- Simple model compares cost of redirecting centre of mass (E_{col}) to cost of rapid steps (E_{freq})

$$E_{tot} = \underbrace{\frac{mV^2}{2}}_{E_{col}} + \underbrace{A\left(\frac{g}{V}\right)^k}_{E_{freq}}$$

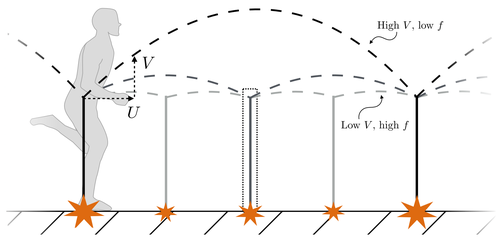
- Tradeoff in minimizing or maximizing V. Optimality yields:

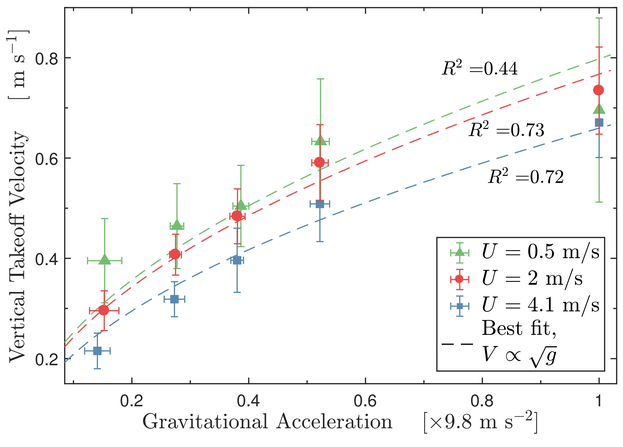
$$V^* \propto g^{k/(k+2)}$$

- k is unknown, but some good candidates are:
  - k = 1: a simple linear cost in step frequency
  - k = 2: ~ work based cost from swinging legs
  - k = 3: ~ a force/time cost [4, 5]



Adapted from [1]. Designed by Andy Ruina



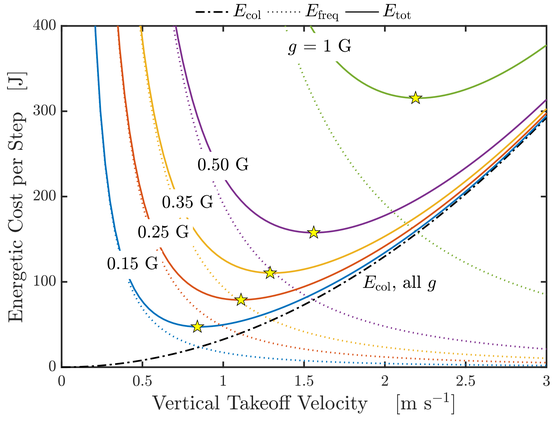


Experiment

- 10 subjects, 25 conditions:
  - g = [0.15, 0.25, 0.35, 0.5, 1] · G
  - Treadmill speed = 0.5, 1, 2, 3.1, 4.1 m/s
- As gravity increases, a pronounced increase in takeoff velocity occurs
  - For all speeds and all subjects
- k = 2 is a good predictor of trends, particularly at high speeds

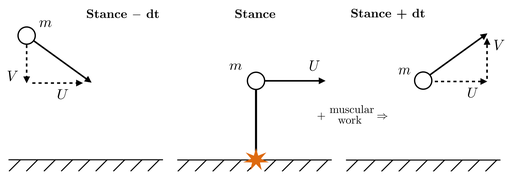
An energetic tradeoff

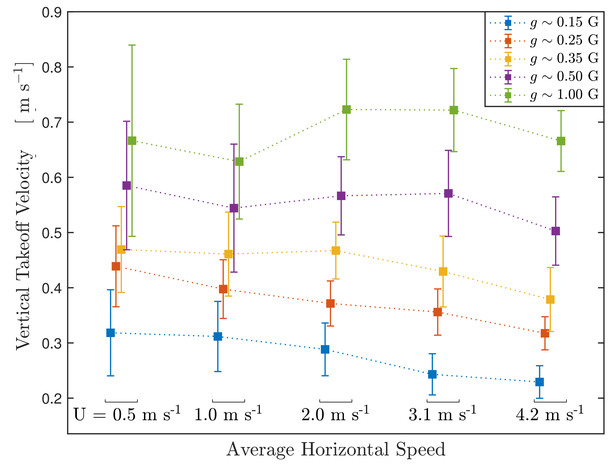
- Stance cost (E_{col}) as a function of V is independent of gravity
- Frequency cost is gravity dependent.
- As gravity decreases, frequency costs at a particular V go down, allowing runner to settle on a lower takeoff speed

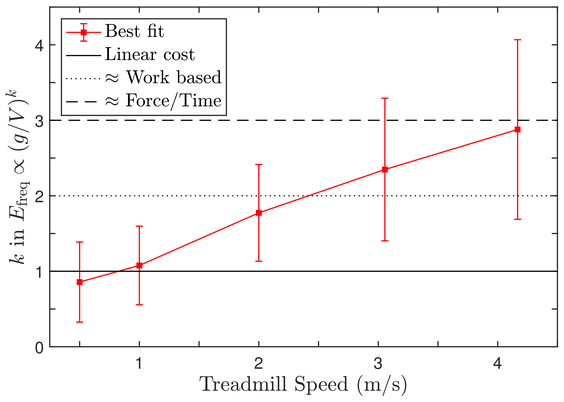


Limitations

- Anticipated no effect of treadmill speed
- In reality, vertical takeoff velocity decreases as treadmill speed increases
  - No flight phase at high g and low speed?
  - Add fore-aft accelerations to model?





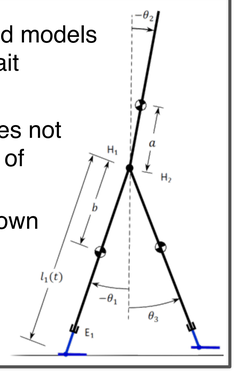


Changing costs?

- Assumed cost model independent of speed
- In reality, the best fit k increases as treadmill speed increases
- Does force/time cost dominate at high speeds?
  - Consistent with shorter stance time
  - Finite stance dynamics could be added to model

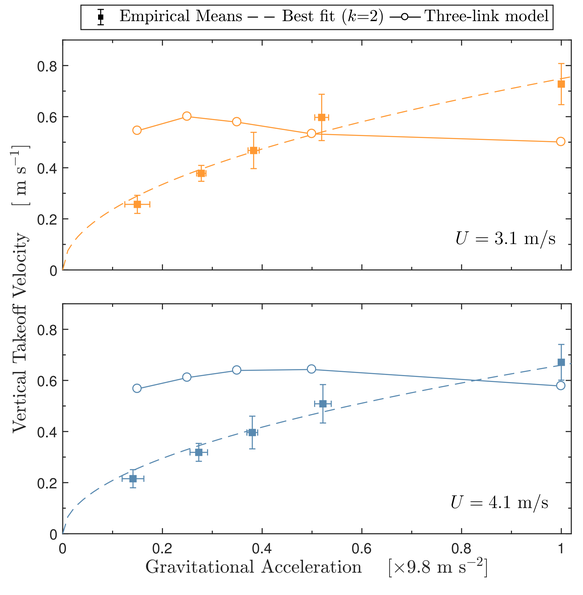
Next steps

- More realistic work-based models can predict aspects of gait selection in gravity [1]
- A similar model to [6] does not predict correct response of V to g
  - Add collisional touchdown map?
  - Add two-link legs?
  - Different g on links *vs* COM?



References

[1] Hasaneini *et al.* 2017. *bioRxiv* doi:10.1101/201319
[2] Long & Srinivasan 2013. *J. R. Soc. Interface* 10:20120980
[3] Selinger *et al.* 2015. *Curr. Biol.* 25:2452-56 **[4]** Kuo 2001. *J. Biotech. Eng.* 123:264-9 **[5]** Doke & Kuo 2007. *J. Exp. Biol.* 210:2390-8 **[6]** Hasaneini *et al.* 2013. *Adv. Robot.* 27:845-59



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