

Vertical Stiffness During the Double Support Period of Walking

John R Rebula, Shawn M. O'Connor, Arthur D. Kuo

Dept. Mechanical Engineering, University of Michigan, Ann Arbor, MI, USA

Introduction

- Bipedal walking often modeled with an inverted pendulum, running as a mass spring system
- Vertical spring stiffness determines redirection COM during running (Farley et. al., 1993)
- Walking double support period also redirects COM
- Double support period in human walking redirects COM in a spring-like manner

3 Experiment: Split belt Instrumented Treadmill Walking

- Healthy human subjects (N=5)
- Walking at 6 speeds, 0.75 to 2.0 m/s
- Running at 3 speeds, 2.0 to 2.6 m/s
- Ground reaction forces of each leg are measured
- Acceleration is integrated twice and drift corrected to produce COM displacement



6 Method: Relationship between time of contact and vertical stiffness

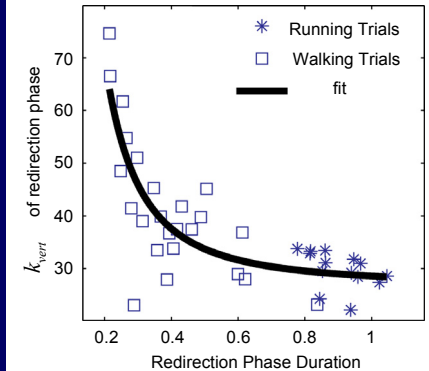
- Previous work (McMahon and Cheng, 1990) defines a relationship between vertical stiffness and time of contact of running:

$$k_{\text{vert}} \propto \frac{1}{t_c^2} \quad (1)$$

- We apply this relationship to both the contact phase of running and the double support period of walking

8 Results: Vertical Stiffness Over a Range of Redirection Times

- Equation 1, with an additional stiffness offset term, is fit to both the walking and running data:
- Both walking and running exhibit an inverse relationship between redirection phase duration and vertical stiffness

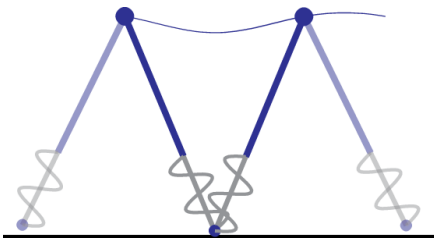


$$k_{\text{vert}} = \frac{4\pi^2 Q^2}{t_c^2}$$

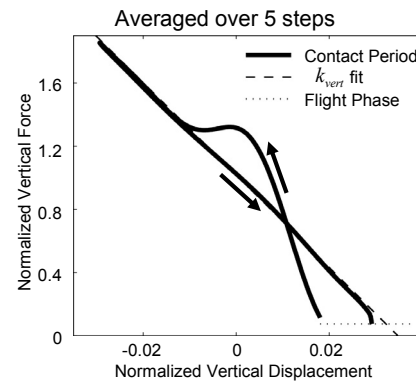
- Q : fraction of theoretical vertical oscillation period spent in redirection phase, Q^2 best fit = 0.043, 95% confidence interval: 0.034 to 0.053
- R^2 : 0.701

1 Running Dynamics

- Gravity driven ballistic phase
- Stance phase redirects the COM velocity

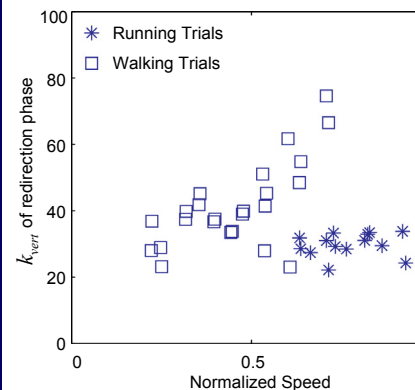


4 Method: Running Support Period Stiffness



7 Results: Vertical Stiffness over a Range of Walking and Running Speeds

- At similar speeds, walking redirection is stiffer than running
- Stiffness increases \propto with walking speed



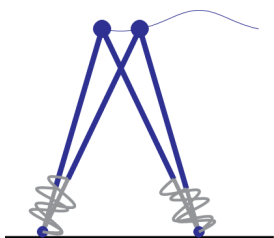
9 Conclusions

Both walking and running can be thought of as having a bouncy COM redirection phase.

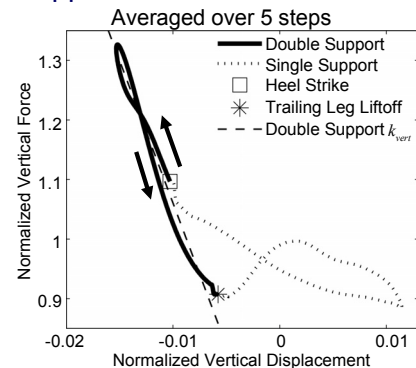
A single measure of vertical stiffness during redirection phase can be used to characterize both walking and running

2 Walking Dynamics

- Gravity driven pendular phase (single support)
- Double support phase redirects the COM velocity



5 Method: Walking Double Support Period Stiffness



References

- McMahon, T.A. and Cheng, G.C. (1990). *J. Biomechanics*, 23:65-78
- Farley, C.T., Glasheen, J., McMahon, T.A. (1993). *J. Experimental Biology*, 185:71-86