Mechanics and energetics of walking with restricted ankle plantarflexion

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1 Motivation

The ankle accounts for the largest burst of joint power of human walking, occurring at push-off near the end of stance. The ability to produce ankle push-off can be impeded by neurological and muscular pathologies or because of injury [1], and is accompanied by greater metabolic energy expenditure [2]. It is unclear whether greater expenditure is due to the decrease in push-off or to other aspects of the pathology. Dynamic walking models suggest that reduced push-off may result in greater collision losses, explaining why walking might then be uneconomical, regardless of other aspects of a pathology. This suggests that even healthy persons may experience greater collisions and expend more energy to walk when ankle motion is restricted.

2 State of the Art

A number of studies have demonstrated that gait pathologies lead to increased energy expenditure [2]. It is not, however, straightforward why muscle weakness or limited ankle joint motion need cause that increase. There is need for a mechanistic explanation for the energy penalty associated with restricted ankle motion..

3 Own Approach

We use dynamic walking models to explain a possible mechanism for poor walking economy. We test the predicted effects by measuring the mechanics and energetics of walking in healthy adults with artificially restricted ankle motion.

In simple dynamic walking models, the legs behave like pendulums and energy is dissipated when the swing leg collides with the ground. That loss normally appears to be reduced by pushing off with the trailing leg just prior to heel strike, Fig 1.a (left side) [3]. A reduced push-off at the trailing leg (Fig 1.a, smaller blue arrow) is expected to result in a larger-than-normal collision at the leading leg (Fig 1.a, larger red arrow). The models predict that gait with reduced push-off will require more total positive work to walk at the same speed. That work should in turn lead to a higher energetic cost.

We hypothesize that (1) Reduced ankle plantarflexion motion will result in less positive push-off work and more negative collision work. (2) The resulting gait will require more positive work with each step, and require greater energy expenditure.

We modified a commercially available ankle-foot-orthosis (AFO; Bledsoe) to constrain ankle plantarflexion range of motion. We measured the joint mechanics and metabolic energetics of walking with varying amounts of restriction to the ankle (Figure 1.b). The ankles were constrained by a steel cable attached to the AFOs, which were worn bilaterally (Figure 1). Gait was examined during six walking conditions: four with reduced ankle motion with the AFO, onewith the unrestricted AFO, and one with normal shod walking. Eight healthy adults participated as subjects (6 males and 2 females, age 18-33, weight 76.6±8.8 kg). All trials were conducted on an instrumented treadmill (Bertec, Instrumented treadmill) at 1.4 m/s walking speed (Fig 1.b). In addition to the ground reaction forces captured by the treadmill, we measured kinematic data, from which we calculated ankle knee and hip joint angles, moments, powers, and joint work. To characterize the effect of the constraint we have defined plantarflexion (PF) reduction as the reduction of peak plantarflexion relative to that observed for the same subject walking in the unconstrained condition.

4 Current Results

We found artificially reduced ankle motion to result in greater metabolic energy expenditure of healthy subjects. Net metabolic rate (gross rate minus standing rate) increased approximately linearly with PF reduction. Ankle restriction resulted in reduced push-off work and greater negative collision work, which may account for the energetic difference.

5 Best Possible Outcome

This study could also explain why people who have less ankle push-off due to ankle-foot injuries or pathologies expend more energy in walking. This study also support the notion that push-off is important for walking economy.

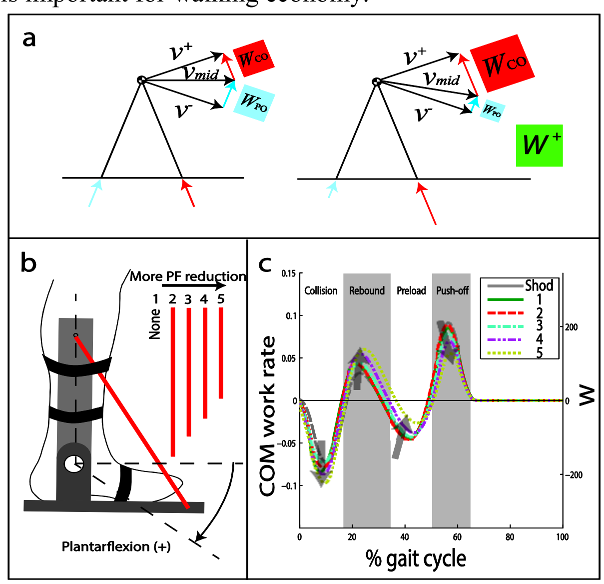

Figure 1: (a) Simple model of walking with push-off and collision impulses work-speed relationship. Velocity of the body center of mass (COM) is redirected by a push-off impulse (blue) by the trailing leg, and acollision impulse by the leading leg (red). Represented by a square is the work performed during a step of normal walking. (b) Modified ankle-foot-orthosis (AFO) for restricting ankle plantarflexion. Steel cable (line segments) attached to AFO restricts range of motion. (c) Average rate of COM work vs. stride time.

Reference

1. A. Danielsson et al, *Journal of rehabilitation medicine*, **36**, 2004
2. R. L. Waters. *Gait & Posture*, **9** 1999
3. A. D. Kuo, *Journal of Biomechanics*, **123**, 2001.

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