Linear Power Flow in Voluntary Toe-Walking

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Introduction

Toe walking is common among patients with upper motor neuron pathologies such as stroke and cerebral palsy. A variety of surgical and orthotic interventions is employed to eliminate toe-walking. Toe-walking is believed to impair the mechanics of gait. This belief stems primarily from the analysis of joint powers. Joint powers, as measured in clinical gait analysis, are the product of the net joint moment and angular velocity about the flexion/extension axis. Ankle joint power at push-off is significantly reduced in toe-walking (Olney, MacPhail et al. 1990).

As toe-walking is quite common in nature, far more common than heel-toe walking, even among bipeds, it seems unlikely that it is inherently mechanically disadvantageous. We chose to study the kinetics of toe-walking by comparing the linear power transmitted to the upper-body at the hip joint in heel-toe and toe-walking gait. Further, we employed a novel form of power analysis that allows us to determine the contribution of each joint’s moment to the total linear power at the hip.

Procedures

We evaluated the heel-toe and toe-walking gait of 10 healthy young adults (27±5yrs, 60±10kg, 1.7±0.1m). Informed consent was obtained and the protocol was approved by the hospital IRB. Gait laboratory kinematic and kinetic data were obtained for the subjects walking at their chosen speed (1.2±0.1m/s) and toe-walking at nearly the same speed (1.1±0.1m/s). Individual models of each subject’s right lower extremity were developed using SIMM/Dynamic Pipeline (Musculo-Graphics, Evanston, IL). Inverse dynamic analysis was then performed using SD/Fast (Symbolic Dynamics, Mountain View, CA). At each instant, the net joint moments were calculated and the instantaneous velocity and contact force at the hip joint were determined. Each net joint moment was then applied individually and the resulting joint velocity and contact force were determined. This permitted us to determine the total hip joint linear power throughout the gait cycle and each joint torque’s contribution to the total power. Three trials of each form of gait were analyzed for each subject.

Results

Throughout the gait cycle the net linear power at the hip joint in toe-walking was similar to that in heel-toe walking (Figure 1). There is a large positive component just after heel strike and a smaller component just before toe-off in stance. The average peak hip linear power in toe-walking was 99.3(28.5) watts and 100.1(33.9) watts for heel-toe walking. In late swing, there is also a large positive power flow from the leg to the upper-body.
The ankle moment contribution to the total power showed two positive peaks in stance. The first peak occurred in early stance. The peak ankle moment contribution (the second peak for toe-walking) occurred prior to toe-off in both cases and was not significantly different in magnitude. The first ankle moment associated positive power peak was offset by compensations in the knee moment associated induce power. Knee moment associated linear power becomes positive in early stance in heel-toe gait. In toe-walking, it remains negative throughout stance.

The ankle moment makes no significant contribution in swing. In late swing, the hip moment (extending the thigh) produces a positive power contribution that is precisely offset by the knee moment, which is extending the knee at this stage. Thus, the net positive power flow at the hip in late swing is not due to the action of any joint moment. Rather it is energy flowing from the slowing lower limb to the upper-body.

**Discussion**

Linear power analysis reveals that only a small portion of ankle push-off power directly propels or supports the upper-body. The majority of the power generated by the ankle moment is absorbed in the segments of the lower limb. A portion of the energy absorbed by the lower limb is passively transferred to the upper-body in late stance. This result is consistent with the findings of Meinders et al. (Meinders, Gitter et al. 1998). Thus, calculations of linear power and power flow analyses based on joint powers yield consistent results, as they should.

Calculation of the contribution of each joint moment to the total linear power provides valuable insight into inter-segmental coordination. Toe-walking requires increased knee compliance in early stance.

In healthy young subjects, this is provided by precise modulation of the knee moments. Among patients with neuromuscular pathologies, we would expect to see different compensating mechanisms or failure to compensate, compromising upper-body propulsion or support.

**References**
