Leg Joint Function during Walking Maneuvers

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1 Introduction

Daily activities require frequent maneuvers of many types while maintaining stability. However, we have only started to characterize the mechanical and control mechanisms of unsteady locomotion (*1*). Walking maneuvers involve deviations from constant-average-velocity (CAV) movement, and often require accelerating or decelerating the center of mass (COM) using lower extremity joints. However, how lower-extremity joints are coordinated to change net COM mechanics is not well understood. Therefore, we studied the functions of the hip, knee, and ankle during walking maneuvers.

Based on observed anatomical, physiological, and functional differences among leg joints, we hypothesized that during walking 1) the hip functioned as motor to generate work, 2) the knee behaved as a strut to transfer energy, and 3) the ankle played a role as torsional spring to restore and return energy.

2 Methods

We recorded whole body kinematics and kinetics from 16 participants. Participants were asked to perform both steady state walking at a comfortable speed, and unsteady walking, specifically linear acceleration and deceleration. We used inverse dynamics to calculate net joint moments and powers from the hip, knee, and ankle during stance.

We decomposed leg and joint function into strut-, motor-, damper-, and spring-like function using non-dimensional indices. The strut index expressed total leg or joint power relative to net leg force or joint moment. The spring index expressed the possibility for energy storage during joint compression and return during thrust. The motor and damper indices reflected the amount of positive and negative joint work generation that was not associated with storage and return. The strut-, motor-, damper-, and spring- indices add up to 100%.

3 Results

Although the overall leg mechanics were primarily strut-like, joints did not act as struts during stance (Fig. 1). During CAV walking, the hip primarily acted as a power producing "motor" by generating mechanical work, and the ankle had the potential for spring-like behavior with little total mechanical work. Net knee work was also small, but the knee did not behave as a spring or solely as a strut, but showed phase-dependent motor-, damper-, and strut-like function.

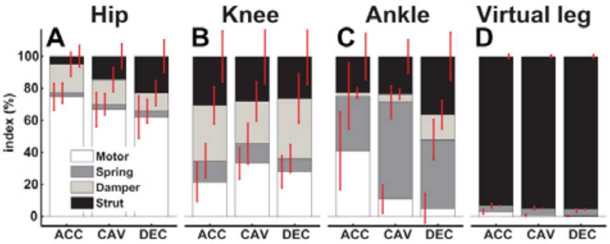

Figure 1. Functional indices for leg and leg joints. ACC, acceleration; DEC, deceleration

Acceleration and deceleration involved modest changes to joint function to produce large changes in COM kinetic energy. During acceleration the hip increased motor-like function, and the ankle changed from spring-like to more motor-like function compared to CAV walking. During deceleration the hip reduced motor-like function, the ankle reduced spring-like function, and the knee shifted from motor towards damper-like function compared to CAV walking. Changes to joint work in either acceleration or deceleration were primarily due to changes in movement excursions and not net moments.

4 Discussion

During acceleration and deceleration, hip behaves as motor; the knee acts as strut, motor, spring, and damper; and the ankle as an actuated spring. Overall, unsteady walking involved modifications of distinct functional roles of each joint. The motor function of the hip and the spring function of the ankle during walking also extend to running maneuvers (*2*). The functions of the hip, knee, and ankle are consistent with the muscle and tendon properties of proximal and distal joints.

Characterizing joint-level functions could contribute to designing the legs of humanoid robots, prosthetic limbs, or movement assisting devices for both CAV and unsteady locomotion.

References
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2. M. Qiao, D. L. Jindrich, Task-level Strategies for Human Sagittal-Plane Running Maneuvers are Consistent with Robotic Control Policies. *Plos One* **7**, e51888 (2012).