Initiation of Walking: Passive or Active?

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Introduction: Some studies analyzing initiation of walking have indicated that the first step is a dynamic process with active "push" from the ankle and hip (Nissan and Whittle, 1990; Cook and Cozzens, 1976; Rossi, et al., 1995). Our paper examines the kinetic characteristics of the first step of initiation in trans-tibial amputees and able-bodied subjects. Our results suggest that the initial step may be a passive forward "fall". A rocker-based inverted pendulum model of what appears to be an initial fall into walking has been developed.

Statement of Clinical Significance: The skills needed to maintain stability, weight transfer, and foot clearance necessary for efficient walking become more critical during the transition from stationary standing to walking since the body needs to accelerate. These requirements become even more significant for people with lower limb amputations, where one or multiple joints are missing. Therefore, it is important to better understand the kinetic and kinematic requirements of initiation in order to design better and more efficient prosthetic and orthotic components.

Methodology: We measured the fore-aft ground reaction forces from the start of forward acceleration to first heel strike (HS1) in three persons with unilateral, trans-tibial amputations and three able-bodied subjects who signed consent forms approved by Northwestern University Institutional Review Board. The subjects stood with their feet on side-by-side individual force plates and were instructed to walk at slow, normal, or fast speeds. Each subject initiated walking with his or her self-selected leg. In subsequent trials, the subjects were instructed to initiate gait with the opposite foot. Kinematic data was calculated from marker position data that was collected at 120 Hz using an 8-camera Motion Analysis™ system, while kinetic data was recorded from six AMTI force platforms at 960 Hz.

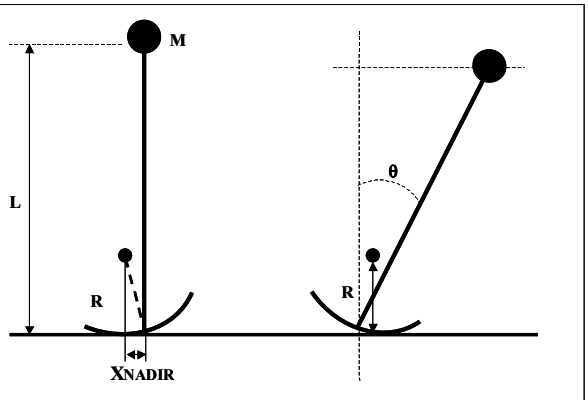

Figure 1. Rocker based inverted pendulum model.

In addition, a rocker-based inverted pendulum model was used to model the first step of initiation of walking (Figure 1). The pendulum mass (M), length (L), rocker radius (R), and rocker center (X_{NADIR}) were matched to individual subjects. Initial and terminal conditions for the angle between the pendulum and the vertical axis (θ) were approximated using the angles created by the BCOM-COP vector with the vertical axis in the walking trials. For each simulation the following initial conditions were used: θ_o = 0.036 rad, R/H = 0.275, and X_{NADIR} /H = -0.02 to -0.04, where H is the subject height. The rocker radius and rocker center were obtained from a circular fit of the knee-ankle-foot roll-over-shape during the initial step (Hansen, 2002). The angle at first heel strike was used as the angle at which the magnitudes of

the fore-aft forces of the falling pendulum were calculated during each simulation (θ_{HS1}). Lagrangian mechanics was used to derive the trajectory of the pendulum mass and the magnitude of the fore-aft ground reaction force. Results from our theoretical simulations were compared with the empirical measurements obtained from the subjects tested.

Results: Figure 2 shows a representative fore-aft force generated by a healthy subject during freely selected initiation (bottom) and the corresponding fore-aft force generated by the falling inverted pendulum model (top). Figure 3 compares the experimental values of the fore-aft forces at HS1 collected from the amputee and the able-bodied subjects with the forces generated by the falling pendulum. There is no significant statistical difference between forces generated by the amputees when initiating with either the healthy leg or the prosthetic leg, nor are there any differences from the forces generated by the pendulum model. Further, there are no statistical differences between able-bodied subjects, the amputee subjects, or the model (t-tests, $p<0.05$).

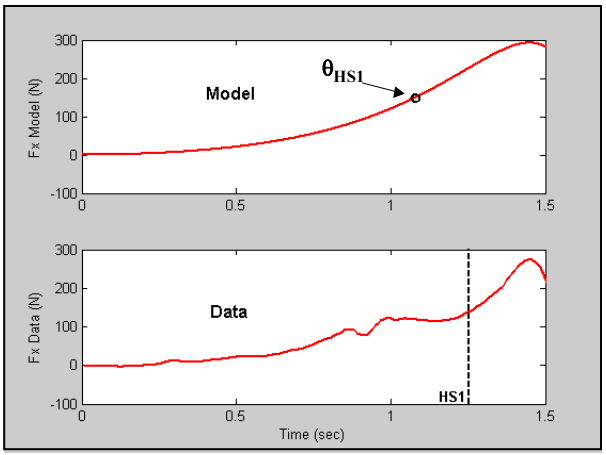

Figure 2. Fore-aft GRF for model and data.

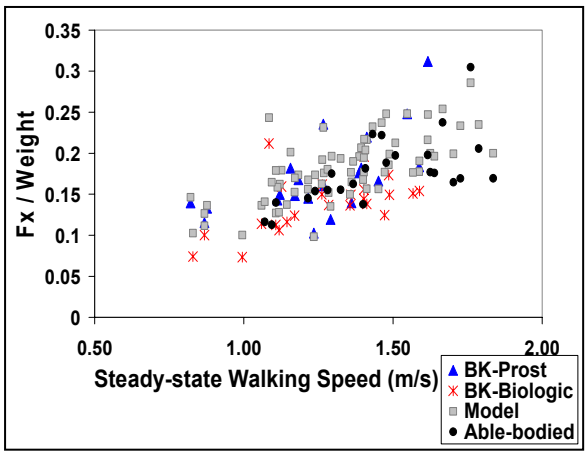

Figure 3. Fore-aft GRFs at HS1

Discussion: The results from the pendulum model together with the experimental results suggest that the first step of initiation of walking may be a passive forward fall, with little or no significant push at the ankle. The similar fore-aft forces generated by the amputee subjects when they started with either the prosthetic or the healthy foot further supports this concept. Greater forward velocity at first heel contact results from larger and longer forward fall. Input at the ankle and hip are expected to contribute towards forward momentum generation after the first heel contact.

References:

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