Characterization of the Human Foot/Ankle System During Normal Walking Gait

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The Problem: We are attempting to characterize the function of the human foot/ankle system during a normal walking gait by developing a model that can adequately predict total ankle torque in the sagittal plane given angular position of the ankle during the stance phase and to identify how this model is tuned to adapt to changes in gait speed.

Motivation: A model that adequately characterizes the function of the human foot/ankle system during normal gait would provide valuable benefits to designers of robotic and prosthetic ankles. The ideal model could be used as an objective standard to measure the performance of artificial ankle designs and reduce the need for costly prototypes. At the same time, the process of developing a model of the human foot/ankle system could lead to a better understanding of the control strategies that humans use to adapt to changes in gait speed and terrain.

Previous Work: Other investigators have modeled the human foot/ankle system using an experimental setup intended to approximate conditions encountered in functional situations [2, 3, 4]. It was found that the passive and active mechanics of the ankle joint could be represented over a wide range of ankle dorsi/plantarflexion positions and levels of muscle activity by a simple linear mass/spring/damper model. This model can be represented by the following transfer function: $\frac{T(s)}{\theta(s)} = Is^2 + Bs + K$. Where T is the ankle torque, θ is the ankle angular position, I is an inertial parameter, B is a viscous parameter, K is an elastic parameter, and s is the Laplace variable. The inertial parameter was found to be constant, as would be expected, but the viscous parameter and the elastic parameter were found to be functions of both the ankle position and the level of muscle activity. Given the success of this simple model in characterizing the function of the human foot/ankle system in a setting where subjects were immobile, could a similar model comprised of dampers and springs be used to characterize ankle function during normal gait? The purpose of the present work is to begin to answer this question.

Approach: Dynamic gait data acquired from healthy, young subjects are used to provide ankle system inputs and outputs during the stance phase of a walking gait, and system identification techniques are applied to the data to find parameter values for an ankle system model. The data used for this study were collected as part of another independent study [1]. Consequently, the methods of data collection have been reported previously but are also briefly described here. Subjects walked barefoot at their self-selected normal speed on a 10 m walkway. The subjects were then asked to walk Afaster than you would normally walk.@ Finally they were asked to walk Aslower than you normally walk.@ For each subject, left and right lower limb data was collected for several trials at each speed. Dynamic gait data were acquired using a six-camera VICON 512 system (Oxford Metrics, Oxford, England) and two AMTI forceplates (AMTI, Newton, MA). The joint center positions, joint angular positions, and joint torques were subsequently calculated from the gait data using the VICON Clinical Manager.

Impact: Preliminary results indicate that, during controlled plantarflexion (from initial heel strike to when the foot is flat on the ground), the relationship between ankle torque and ankle position is linear and that, on average, the slope of this linear relationship increases with increasing gait speed (Fig. 1). This suggests that during the initial part of the stance phase of a walking gait, the human foot/ankle system can be characterized by a linear spring. Also, the system's adaptation to changes in gait speed can be characterized by tuning the stiffness of the spring. Furthermore, this suggests that an artificial ankle that is designed with the intent to function as a biological ankle must have the capability not only to be spring-like but also must be able to change the stiffness of that spring.

Future Work: The next step for this research will be to fill out and/or modify the model of the human foot/ankle system so that it is applicable to all parts of the stance phase of a walking gait. The model may then be used as a

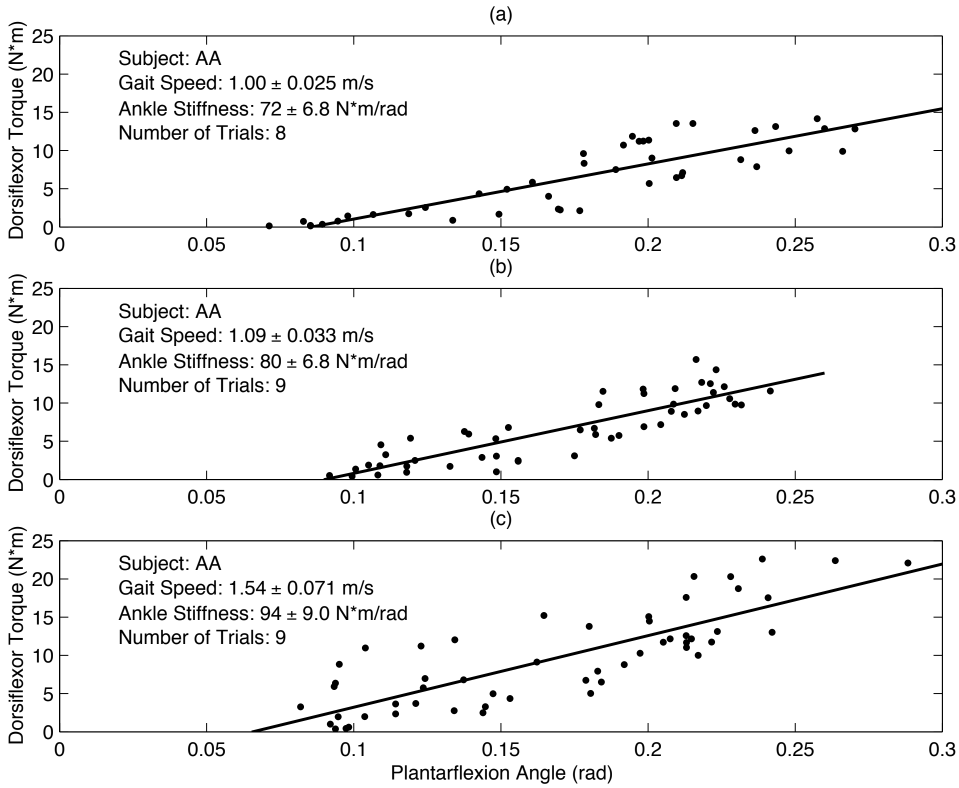

Figure 1: Ankle torque as a function of the angular position of the ankle for a single subject at the (a) slow, (b) normal, and (c) fast self-selected gait speeds. Positive torque corresponds to torque generated by active dorsiflexors. An increase in angle corresponds to a more plantarflexed position of the foot.

guide for the design of actively controlled prosthetic ankles and orthoses.

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