David Winter Young Investigator Award Nominee - Best Poster Presentation

SIMULATION OF A PASSIVE ASSISTIVE DEVICE TO REDUCE RUNNING EFFORT

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INTRODUCTION
Locomotion is a central part of our everyday lives and plays a huge role in physical and mental health. Because humans are very adept at locomotion as a result of evolution and learning, increasing gait efficiency has proven difficult. Although several groups have increased human walking efficiency using powered exoskeletons, only one unpowered device (an ankle exoskeleton) has increased walking efficiency [1]. However, no one has yet determined a way to increase running efficiency with an ungrounded, unpowered device.

Most of the energy required for running is used to support the body against gravity and propel the body forward. However, one study suggests that the cost associated with leg swing is approximately 20% of the total metabolic cost [2]. This finding suggests that a device used to assist leg swing could reduce the energetic cost of running, and we wondered if we could parametrize a passive device to do so.

METHODS
Using OpenSim 3.3 [3], a musculoskeletal model with 23 degrees-of-freedom and 92 musculotendon actuators was scaled to match subject data from Hamner *et al.* (1.83 m tall, 65.9 kg) [4]. A linear spring with a dead-zone (our passive assistance device) was added to the model as an object in the Pathspring class connecting the left and right legs and attached to various locations on the ankles, shanks, and knees. The optimal muscle activations were then computed using the computed muscle control (CMC) tool [5] and experimental running data from Hamner *et al.* (3.96 m/s) [4]. Running effort was computed as the sum of the squared muscle activations over the gait cycle [6].

In order to determine the device parameters, experimental joint torques were divided by the moment arm between each joint and the device's line of action. These normalized torques were plotted against the length of the linear spring to determine an ideal resting length and linear stiffness such that the device provided assistive torques with a magnitude equal to or smaller than experimental joint torques.

RESULTS AND DISCUSSION
Most of the various device attachment points reduced running effort, but because the most significant decreases were seen when the device was attached to the ankles, subsequent calculations were performed with this geometry path. Using the plots of normalized torque versus length of the linear spring, a resting length of 0.5 m was selected because it was the minimum length such that the band never resisted experimental joint torques. Additionally, a linear stiffness of 60 N/m ensured that the torque provided was less than the magnitude necessary for running.

Simulations performed with the chosen inputs for the parametrized spring attached at the ankle showed a total decrease in effort of 7.37%, with a 9.65% decrease for the right leg and a 4.96% decrease for the left leg over one gait cycle (see Figure 1). This difference between the two legs is likely due to asymmetric step lengths, which resulted in more assistive forces applied to the right leg in swing phase.

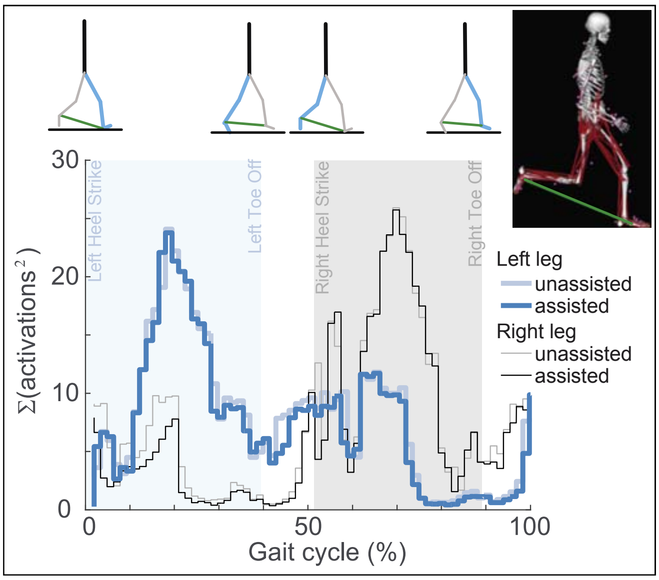

Figure 1: Sum of the muscle activations squared with and without the assistive device over one gait cycle.

This analysis assumes that our device does not change running kinematics and ground reaction forces. Because the selected parameters resulted in applied forces under 30 N, kinematic changes would likely be small and may even improve efficiency as the user learns how to best use the device.

CONCLUSIONS
Our simulations suggest that it is possible to create an assistive device to reduce running effort in the form of an elastic band attached between the two ankles, a simple and lightweight solution compared to other exoskeletons. Assuming a simple model of a linear spring with a dead-zone, an ideal resting length and linear stiffness of 0.5 m and 60 N/m, respectively, were calculated so the device would only assist the experimental knee and hip joint torques. Simulations with this implemented device reduced running effort by more than 7%.

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