How does ankle impedance change as a function of age, muscle activation, and walking speed?

Varun Joshi
Mechanical Engineering
University of Michigan
Ann Arbor, United States
varunjos@umich.edu

Elliott Rouse
Mechanical Engineering
University of Michigan
Ann Arbor, United States
ejrouse@umich.edu

Chandramouli Krishnan
Physical Medicine and Rehabilitation,
University of Michigan
Ann Arbor, United States
mouli@umich.edu

***Abstract*—Ankle impedance governs how humans interact with the ground while walking and standing. Measuring this fundamental property of the neuromusculoskeletal system might allow us to better understand pathological gaits as well as the effects of various treatment techniques. As an initial step towards this, we measured ankle impedance of healthy human subjects walking at various speeds and standing at different levels of plantar flexor activation to better understand the effects of these possible confounding factors.**

***Keywords*— joint impedance, rehabilitation, neuromuscular biomechanics**

I. INTRODUCTION

Gait research on healthy human subjects suggests that the human nervous system tries to modulate the dynamic mechanical properties, i.e. the impedance (the collective term for stiffness, damping and inertia) of the limbs and joints to achieve stability in gait [1, 2]. Prior work in measurements of impedance for the ankle joint has mostly been focused on young healthy human subjects walking at their self-selected speed [3-5]. In order to extend the use of these measurement techniques to better understand pathological gait, we are studying the effects of walking speed and background muscle activation on ankle impedance in both young and older healthy participants. This abstract presents the initial results of these experiments.

II. METHODS

A. Experimental methods

Ankle impedance was measured both during walking and quiet standing. For the walking paradigm, subjects walked across a mechatronic platform, capable of inducing a small rotational perturbation [6], a hundred times at each of three different cadences – their self-selected, 25% slower and 50% slower, enforced using a metronome. For the standing paradigm, subjects stood with their right foot placed flat on the mechatronic platform, and the left foot rested on a stationary surface as they matched averaged plantar flexor activation to 5% and 10% of maximum muscle activation measured using M-wave.

While subjects walked, 12 motion capture cameras recorded the motion of 14 markers placed on the shank and foot, three EMG sensors (Delsys Trigno Avanti) recorded the activation of the Medial Gastrocnemius, Soleus and Tibialis Anterior muscles, and a six axis force plate recorded the ground reaction forces of the right leg in stance. In 50% of the recorded walking trials, the mechatronic platform elicited a small rotational perturbation of the stance foot about the ankle joint in the sagittal plane, randomized to occur at one of two possible time-points around 20% and 50% of the stance-phase for each subject. In the standing trials, the platform performed the same rotational perturbation 10 times, with each sequential perturbation timed to occur randomly between 10 and 15 seconds.

B. Data processing

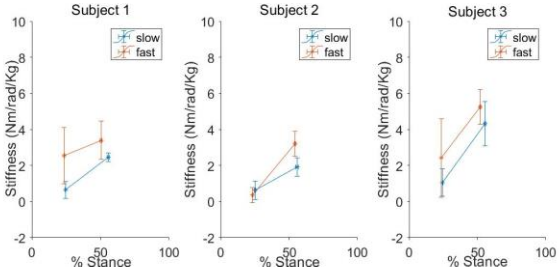
Using previously described methods [3-4], we fit a 2nd order parametric model to determine the impedance properties of the ankle joint:

$$T = I\ddot{\theta} + b\dot{\theta} + k\theta, \qquad (1)$$

where T is the ankle moment and θ is the ankle angle in the dorsi-plantar direction, *I* is the inertia, *b* is the damping, and *k* is the stiffness of the ankle joint.

III. RESULTS

Initial results for young healthy participants suggest that ankle joint stiffness increases with muscle activation in standing and that joint stiffness increases with increasing walking speed at the two time-points tested here.



References

[1] Hogan N. The mechanics of multi-joint posture and movement control. Biol Cybern. vol. 52, issue (5), pp. 315–331, September 1985

[2] Burdet E, Osu R, Franklin DW, Milner TE, Kawato M. The central nervous system stabilizes unstable dynamics by learning optimal impedance. Nature. 2001 Nov;414(6862):446–9.

[3] Rouse EJ, Hargrove LJ, Perreault EJ, Kuiken TA. Estimation of Human Ankle Impedance During the Stance Phase of Walking. IEEE Trans Neural Syst Rehabil Eng. 2014 Jul;22(4):870–8.

[4] Shorter AL, Rouse EJ. Mechanical Impedance of the Ankle During the Terminal Stance Phase of Walking. IEEE Trans Neural Syst Rehabil Eng. 2018 Jan;26(1):135–43.

[5] Lee H, Rouse EJ, Krebs HI. Summary of human ankle mechanical impedance during walking. IEEE journal of translational engineering in health and medicine. 2016 Aug 19;4:1-7.

[6] Rouse EJ, Hargrove LJ, Perreault EJ, Peshkin MA, Kuiken TA. Development of a Mechatronic Platform and Validation of Methods for Estimating Ankle Stiffness During the Stance Phase of Walking. J Biomech Eng. 2013 Jun 12;135(8).