Estimation of Knee Impedance During Exoskeleton Assisted Gait

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I. Introduction

Knowledge of joint mechanical impedance is important for understanding how the human body responds to disturbances and the regulation of this property is an integral aspect of locomotion. Joint impedance can be well parameterized by three components: stiffness, damping, and inertia. To measure impedance, one must perturb the joint being examined and measure the torques and positions that result from the applied perturbation [1]. During locomotion, the impedance of the joints of the lower limb (hip, knee, and ankle) changes dynamically over the duration of one gait cycle. Currently, how impedance varies at the ankle joint over a gait cycle is fully characterized. However, how the impedance of the knee joint varies over this same span is still unknown [2]. This work characterizes how knee impedance varies over the entire gait cycle for one subject.

II. Methods

One unimpaired, adult male participated in this study. The subject walked on a consumer treadmill (Schwinn 870, Nautilus Inc., USA) at a speed of 2.3 MPH while donning a knee exoskeleton. Subject data was collected under two conditions. The exo no perturbation (ENP) condition occurred first, where the subject participated in exoskeleton assisted walking without perturbations being applied during gait. After, the exo with perturbation (EWP) condition took place where the exoskeleton applied torque perturbations at eight different points in the subject's gait cycle. During both conditions, knee joint angle measurement resulted from use of an electrogoniometer (S700, Measurand Inc., Canada). Measurement of the torques applied to the knee joint during walking resulted from use of a torque sensing mechanism in the exoskeleton. Subtraction of the position and torque trajectories collected during the ENP condition from the corresponding position and torque trajectories of the EWP condition resulted in isolation of the applied perturbations. Impedance parameter estimation transpired from a bounded least squares optimization on a 100 ms window of the isolated position and torque perturbations. The 100 ms window started after the onset of the isolated perturbations.

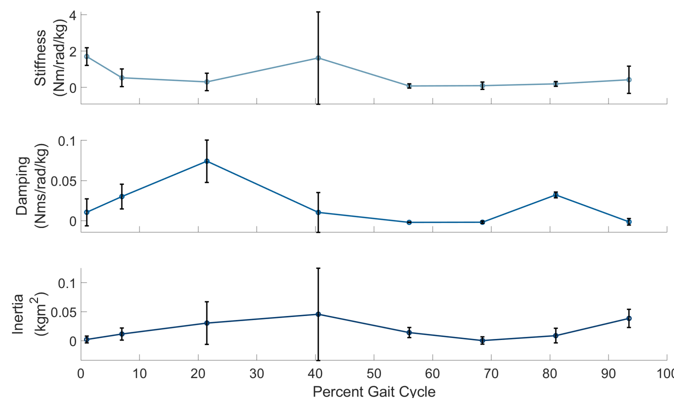

Fig. 1. Estimated stiffness, damping, and inertia values for a single subject during the gait cycle. Stiffness and damping values are normalized by subject weight while inertia is not.

III. Results & Discussion

The maximum stiffness, damping, and inertia values occurred at the first, third, and fourth timing points respectively (Fig. 1). The sharp rise in knee stiffness at timing point 4 coincides with the timing point where maximum ankle stiffness has been shown in literature [2]. This increase in stiffness at both the knee and the ankle at the same time could suggest that the body is preparing to store large quantities of energy in preparation for the push-off portion of walking.

IV. Conclusion

The impedance parameters of stiffness, damping, and inertia were estimated for one subject during the entirety of their gait cycle. These results could help inform how the body stores energy during the gait cycle. Future studies will conduct a similar methodology with a larger sample size to elucidate if the trends observed in this initial study remain.

References

[1] R. E. Kearney and I. W. Hunter, "System Identification of Human Joint Impedance," *Journal of the American Society for Information Science*, 1990.

[2] A. L. Shorter and E. J. Rouse, "Mechanical Impedance of the Ankle during the Terminal Stance Phase of Walking," *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 26, no. 1, pp. 135–143, 2018.