39^{th} Benelux Meeting

on

Systems and Control

March 10 – 12, 2020

Elspeet, The Netherlands

Book of Abstracts

Time-Varying Ankle Joint Stiffness Identification during Cyclic Movement

Ronald C. van 't Veld[1], Alejandro Moya Esteban[1] and Alfred C. Schouten[1,2]
[1] Department of Biomechanical Engineering, University of Twente, Enschede, The Netherlands
[2] Department of Biomechanical Engineering, Delft University of Technology, Delft, The Netherlands
Email: {r.c.vantveld,a.moyaesteban,a.c.schouten}@utwente.nl

1 Introduction

Human limb mechanical properties can be quantified using joint impedance, the dynamic relation between joint angle deviations and corresponding joint torque, with joint stiffness as its position-dependent component. Joint stiffness is key in postural control and movement and well understood within (quasi-)static conditions [1]. However, muscle and joint mechanics change during movement, consequently also the joint stiffness changes [2]. Monitoring and understanding the continuous modulation of joint stiffness during movement in able-bodied subjects has several technical and clinical applications. For example, it can be applied to the design of next-generation biomimetic prostheses and exoskeletons or to advance clinical assessment and decision making. The goal of this study is to develop an experimental protocol to assess how humans modulate ankle joint stiffness during cyclic movement.

2 Methods

Six healthy adults (5 male, 24.2±1.0y) participated in this study. Participants were seated with their right foot connected to a single axis actuator using a footplate. The experiment consisted of three conditions: a 5Nm amplitude sinusoidal torque tracking task against a rigid actuator (static posture), and a 0.15rad amplitude slow (0.3Hz) and fast (0.6Hz) sinusoidal position tracking task against a virtual spring resulting in a torque amplitude of approximately 9Nm (dynamic posture). Additionally, pseudo-random binary sequence (PRBS) perturbations were applied during the tasks (±0.015 rad, 0.15s switching time). System identification was performed using an ensemble-based, linear time-varying (LTV) algorithm, which produced ankle joint stiffness estimates by means of multiple short segments of the torque and angle recordings [2].

3 Results and Discussion

The results across subjects and conditions show two maximum stiffness peaks followed by periods of decreased stiffness, see Fig. 1. The two stiffness peaks correspond to the two phases with increased ankle deflection and increased voluntary torque exerted by the human. The average estimated joint stiffness magnitude across conditions ordered from low to high was: fast dynamic, static and slow dynamic posture. Our results highlight the variability in stiffness modulation strategies across conditions, especially across movement frequency.

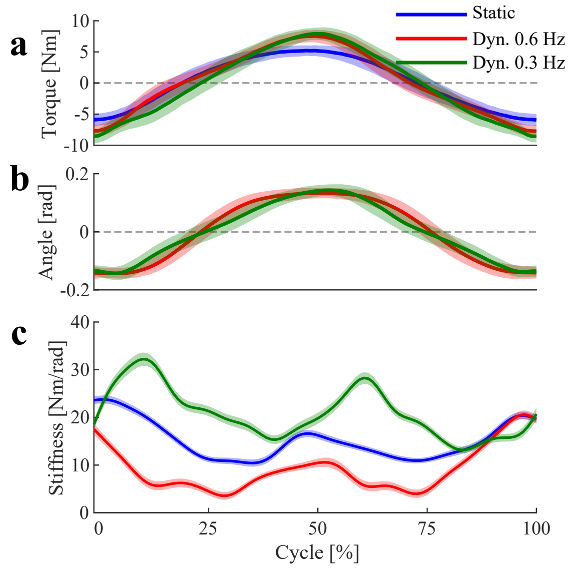

Figure 1: Ensemble mean ±1 sd of *(a)* measured ankle torque and *(b)* measured ankle angle around the neutral angle. *(c)* Mean ±1 sd of estimated ankle joint stiffness over 35 repetitions of MS algorithm. Data from representative subject, adapted from [3].

References

[1] R. E. Kearney and I. W. Hunter, "System Identification of Human Joint Dynamics," *Critical Reviews in Biomedical Engineering*, vol. 18, no. I, pp. 55–87, 1990.

[2] D. Ludvig, M. Plocharski, P. Plocharski, and E. J. Perreault, "Mechanisms Contributing to Reduced Knee Stiffness during Movement," *Experimental Brain Research*, vol. 235, no. 10, pp. 2959–2970, 2017.

[3] A. Moya Esteban, R. C. van 't Veld, C. P. Cop, G. Durandau, M. Sartori, and A. C. Schouten, "Estimation of Time-Varying Ankle Joint Stiffness Under Dynamic Conditions via System Identification Techniques," *41st Annual International Conference of the IEEE EMBC*, pp. 2119–2122, 2019.