Relationship Between Dynamic Mean Ankle Moment Arm and Prosthetic Forefoot Stiffness on Level Ground, Ramps and Stairs

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***Abstract*— The goal of this research is to describe the biomechanical effect of forefoot stiffness in a foot prosthesis during different ambulatory tasks. This is accomplished by measuring the Dynamic Mean Moment Arm (DMAMA) of the prosthetic foot with data collected by a prosthesis-embedded load cell. Preliminary results suggest that both terrain (ramps and stairs) and prosthetic forefoot stiffness affects DMAMA.**

I. Introduction

Traditionally, the type and stiffness of a foot prosthesis is selected by a prosthetist based on the user's weight and activity level. However, a healthy ankle adapts and changes its biomechanical properties depending on its conditions and activities, such as going up and down stairs or walking on different terrains. Prosthetic feet with variable stiffness attempt to mimic this response [1].

In order to quantify the effects of the variable stiffness we calculated the Dynamic Mean Ankle Moment Arm (DMAMA) for different activities. The DMAMA metric is a summary of the net dynamic effect of a shift between hindfoot- and forefoot-dominated contact in running, walking and other activities [2]. As an example, DMAMA increases as a person transitions from walking to running as their gait becomes more forefoot dominant.

II. Methods

Six subjects used a variable stiffness prosthetic foot [1] in three stiffness settings (Soft, Mid, and Stiff) and performed five ambulatory tasks. We collected data from a six-degree-of-freedom load cell (iPecs, RTC Electronics) that was mounted between the pylon and the socket of subjects' prosthesis and an inertial measurement unit (IMU) wearable suit (MVN Awinda, Xsens). The ambulatory tasks were level walking and ascending and descending ramps and stairs. Prior to the tasks we collected motion capture (Optitrack Prime 13, NaturalPoint, Inc.) and force plate (Bertec, Inc.) data for calibration purposes.

$$DMAMA: d = \frac{J}{I} = \frac{\int_{HS}^{TO} M dt}{|| \int_{HS}^{TO} \vec{F} dt ||} = \frac{\bar{M}}{\bar{F}} \quad (1)$$

We combined the forces and moments measured by the prosthesis-embedded load cell with leg kinematics measured from the IMU suit to calculate the three dimensional-moments about the knee and ankle. We used the IMU data to distinguish the ambulatory tasks from one another. By dividing the mean sagittal ankle moment ($\bar{M}$) by the mean sagittal ground reaction force ($\bar{F}$) we calculated the DMAMA across the different stiffness settings (1).

III. Results & Discussion

Preliminary results confirm prior findings that walking on slopes and ramps affects ankle moment with all prostheses. The summary measure DMAMA summarizes this effect over the whole stance period: greater DMAMA indicates more forefoot-dominated gait. The DMAMA metric appears to increase during ramp descent compared to ramp ascent. Similarly, DMAMA appears to increase during stair descent when compared to stair ascent. There is little difference between level ground walking and ramp ascent. Soft vs. Mid stiffness has little effect on DMAMA, but the Stiff setting shows an overall decrease in DMAMA.

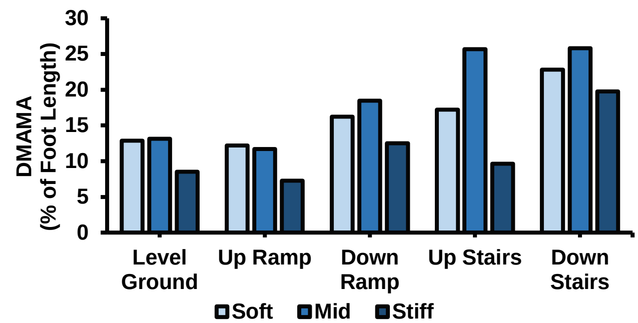

Fig. 1. DMAMA values across tasks and forefoot stiffness settings.

IV. Conclusions

We will present final results at the conference and discuss ways these field-based wearable analyses can be used to inspire the control of semi-active intelligent prostheses.

V. Acknowledgements

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VI. References

[1] E. M. Glanzer and P. G. Adamczyk, "Design and Validation of a Semi-Active Variable Stiffness Foot Prosthesis", IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 26, no. 12, pp. 2351-2359, Dec. 2018.

[2] P. G. Adamczyk, "Ankle control in walking and running: speed- and gait-related changes in Dynamic Mean Ankle Moment Arm (DMAMA)", J. Miomech. Eng., Dec 2019, doi: 10.1115/1.4045817