Effects of Prosthetic Forefoot Stiffnesses on the External Mean Ankle Moment Arm (EMAMA) in Different Activities

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Summary

This study addressed the biomechanical effect of varying forefoot stiffness in a foot prosthesis during different ambulation tasks. The external mean ankle moment arm (EMAMA) outcome measure captures the mean dynamic effects of changes in center of pressure (CoP) that impact body dynamics. Findings show that EMAMA shifts in different tasks (up and down ramps and stairs) relative to level walking, and can be modulated by changes in forefoot stiffness. Control of prosthetic forefoot stiffness to match natural EMAMA changes may improve biomimetic behavior.

Introduction

Characterizing biomechanics of the human ankle during different movements is crucial to developing biomimetic prostheses. However, common measures used to design these devices, such as CoP or joint impedance, do not fully summarize the net dynamic effect of ankle mechanics [1]. The EMAMA measure summarizes the net relationship between ground reaction force and ankle moment throughout stance [2]. For example, EMAMA changes systematically across walking and running speeds [2]. This study calculates EMAMA across different prosthetic forefoot stiffness settings and ambulation tasks to understand how they affect movement. The measurement is made using a novel combination of wearable sensors. We hypothesized that EMAMA would shift forward with higher prosthetic forefoot stiffness, and also shift across tasks such as ramps and stairs.

Methods

Two subjects performed five ambulatory tasks using a variable stiffness prosthetic foot in three stiffness settings [3]. We collected data from a prosthesis-embedded six-degree-of-freedom load cell (iPecs, RTC Electronics) and an inertial measurement unit (IMU) wearable suit (MVN Awinda, Xsens). Tasks were level walking and ascending and descending ramps and stairs.

We used data from the load cell to measure leg forces and identify gait events. We combined load cell and IMU data to determine the moment produced about the ankle in the sagittal plane during stance phase. These measures were then used to calculate the EMAMA during stance phase across different stiffness settings and ambulatory tasks (Equation 1).

$$\text{EMAMA} = \frac{J}{I} = \frac{\int_{\text{HS}}^{\text{TO}} M dt}{\left\| \int_{\text{HS}}^{\text{TO}} \vec{F} dt \right\|} \qquad (1)$$

Results and Discussion

During level ground walking and ramp descent, EMAMA tended to increase with increased prosthesis stiffness. EMAMA also increased during ramp descent and decreased during ramp ascent in comparison to level walking. This was hypothesized, as the incline or decline impacts forward momentum and CoP shift during stance phase. EMAMA values found during stair ascent and descent were highly variable and did not show consistent trends across stiffness settings. However, EMAMA showed a large forward shift in CoP in the down stairs condition in comparison to other ambulatory tasks, while results from the up stairs condition were too variable to draw conclusions.

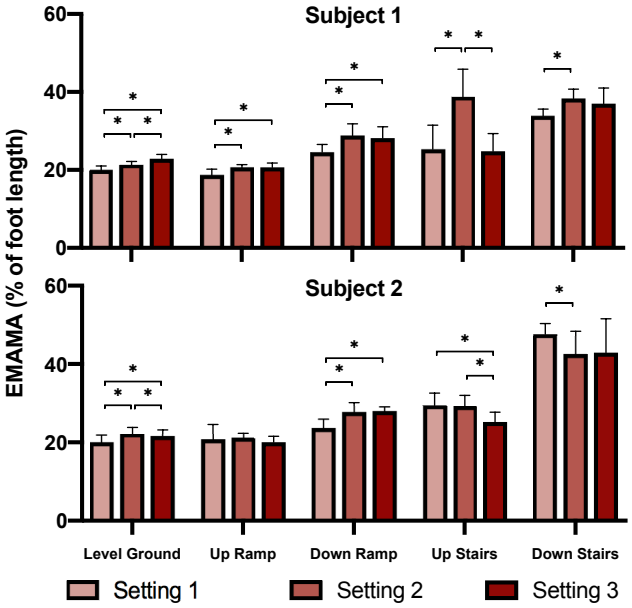

Figure 1: EMAMA values across tasks and forefoot stiffness settings. Asterisks indicate a significant difference (p<0.05).

These results suggest that EMAMA could be used to quantify changes in prosthesis stiffness and dynamic CoP during level ground walking and ramp descent. The study also provides a precedent for obtaining a novel biomechanical measure outside of the lab using portable data acquisition methods.

Conclusions

The EMAMA outcome measure is able to quantify dynamic changes in CoP during amputee ambulation. The results suggest that this outcome measure can quantify dynamic CoP across some varying stiffness parameters and ambulation tasks. Further testing will allow for more accurate inter-subject analysis.

Acknowledgments

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References

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