Influence of Passive Ankle Foot Orthosis Stiffness and Varying Walking Speeds on Gait: A Case Study

Sara Chami[1], Ella Thomas[1], Pablo Ortega-Auriol[1], Thor Besier[12], Susan Stott[3], Julie Choisne[1]
[1]Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand
[2] Faculty of Engineering and Design, University of Auckland, Auckland, New Zealand
[3] Department of Surgery, University of Auckland, Auckland, New Zealand
Email: schb998@aucklanduni.ac.nz

Summary

This study investigated the interaction between walking speed and ankle-foot orthosis (AFO) stiffness and the effects on joint kinematics and kinetics. We designed a personalised, modular 3D-printed AFO and evaluated its effect across five walking speeds and two stiffness levels in a motion capture experiment with a healthy adult. As anticipated, ankle power was influenced by both walking speed and AFO stiffness. Our workflow will enable AFO stiffness to be tuned across a range of walking speeds to maximise ankle power and understand further gait adaptations.

Introduction

Personalising passive AFO stiffness to individual impairments is a promising approach to enhancing gait outcomes in cerebral palsy (CP) and individuals with calf muscle weakness [1,2]. Ankle power is a key determinant of walking speed and metabolic cost and a target for AFO personalisation. Existing studies have investigated the influence of AFO stiffness on ankle power at self-selected walking speed [1,2,3] but have neglected the tuning of AFO stiffness across variable walking speeds. We present a case study to investigate the influence of AFO stiffness on peak ankle plantarflexion power across variable walking speeds.

Methods

The right lower leg and foot plantar surface of a healthy adult female (22 years, 170cm, 60kg) was 3D scanned and imported into nTop (v5.8.2). A modular AFO was designed and 3D printed in carbon fibre nylon via FDM (Creality K1 Max). AFO stiffness was adjusted by swapping carbon fibre rods connecting the footplate and calf shell. Two stiffness levels (*low*: 537 N/m and *high*: 5037 N/m) were tested. The participant walked at speeds from 1.05 to 1.55 m/s (0.1 m/s increments) on an instrumented split-belt treadmill (Treadmetrix). Ground reaction forces and motion capture marker trajectories (Vicon) were collected and input to OpenSim to perform inverse kinematics and inverse dynamics. At least 15 gait cycles per condition (speed x AFO stiffness) were collected. Ankle plantar flexion power was calculated and normalised to body mass. We conducted a repeated measures ANOVA to assess the effects of walking speed and AFO stiffness on joint power, kinematics, and moments, including interaction effects between speed and stiffness.

Results and Discussion

Ankle power was strongly affected by both speed and AFO stiffness ($p < 0.0001$), with the effect of stiffness varying across different speeds. For low stiffness, ankle power at push-off remained unchanged across the lowest and highest speeds, while for high stiffness, it increased with speed ($p < 0.0001$). High stiffness generated lower ankle power than low stiffness across speeds (Figure 1). Ankle kinematics were influenced by both walking speed and AFO stiffness ($p < 0.0001$). Joint moments showed minimal variation across different speeds and stiffness conditions, with no significant effect of speed on the ankle. Stiffness had a small but significant effect on knee moments ($p < 0.0001$). Knee and hip power were influenced by speed ($p < 0.0001$) but not AFO stiffness ($p = 0.921$ and $p = 0.500$, respectively).

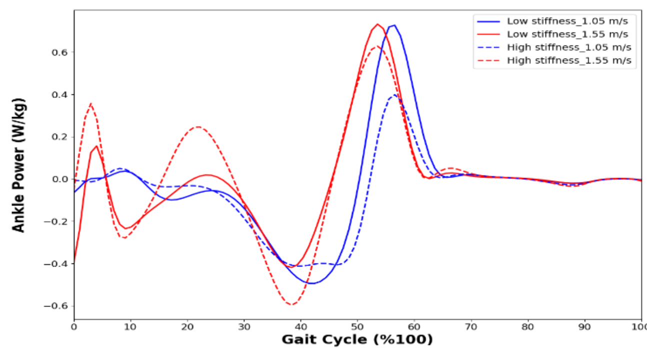

Figure 1: Average ankle power (W/kg) over the normalized gait cycle for low AFO stiffness (solid lines) and high AFO stiffness (dashed lines) at the lowest (blue) and highest (red) walking speeds.

Conclusions

Walking speed and AFO stiffness interact to influence gait biomechanics, with the strongest effects observed in ankle power. Therefore, AFO stiffness should not only be optimised for an individual's gait characteristics and impairments but also tailored to the various walking conditions in which the user intends to walk with the AFO.

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References

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