Exploring the Interaction of Ankle-Foot Orthoses and Gait in Children: Insights from Exoskeleton Emulator Experiments and Predictive Simulations

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Summary

We explored how different ankle-foot orthoses (AFOs) influence the gait pattern of children, in exoskeleton emulator experiments and predictive simulations. Simulations captured only some of the experimentally observed changes, indicating they are missing factors contributing to the effect of AFOs.

Introduction

AFOs have the potential to improve gait function in children with cerebral palsy, but the outcome is highly variable [1]. Outcomes can be improved by personalised AFO selection [2]. Exoskeleton emulators have accelerated orthosis design, but mechanistic insights into how musculoskeletal and AFO properties interact are still lacking. Predictive simulations based on personalised musculoskeletal models are a powerful tool to gain insight into how changes to the musculoskeletal system affect the gait pattern [3,4].

Methods

We collected data from 2 typically developing (TD) children (aged 8 and 6) walking on a treadmill at self-selected speed while wearing a unilateral ankle exoskeleton emulator (EXO-001, Humotech, USA). Each participant walked with shoes only and an exoskeleton with zero torque control as well as providing three levels of ankle stiffness (0.50, 0.95, 1.40 Nm/(rad·kg·m), multiplied by body mass and leg length). We scaled a musculoskeletal model (33 degrees of freedom, 94 muscles) [4] to the anthropometry of each subject. We modelled the exoskeleton by rigidly connecting its segments to the tibia and forefoot and adding rotational stiffness between them. We used PredSim [3,5] to predict their gait pattern for each condition. We calculated the total power distal to the right tibia [6] to quantify ankle-foot push-off.

Results and Discussion

Our simulations partially captured the experimentally observed effects (Figure 1). We focus our discussion on the gait characteristics that were influenced most by the exoskeleton. They captured the reduced stride frequency while walking with the exoskeleton but underestimated its magnitude for subject 2. For subject 1, simulations captured the decrease in peak power distal to the tibia when walking with the exoskeleton but missed the differences between the stiffness levels. For subject 2, they could predict that mid stiffness resulted in a higher peak power than low or high stiffness. All stiffnesses resulted in increased peak knee extension, but almost all simulations predicted the opposite. Simulations captured the changes in ankle range of motion for subject 2, but not for subject 1. In the *shoes* condition, the discrepancies between experimental and simulated kinematics were greater than what we found for adults [4]. We scaled muscle cross-sectional area proportionally to body mass to the power 2/3, but this may not hold for children [7]. We expect that modelling age-related differences in musculoskeletal properties will improve the accuracy of the simulations.

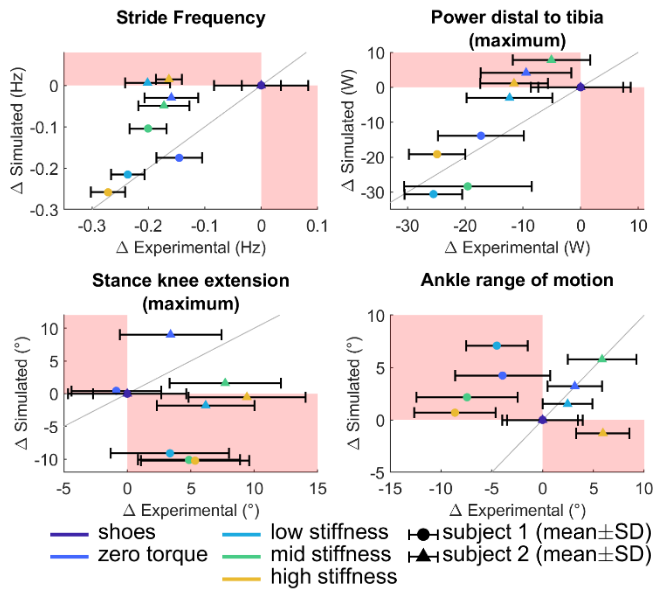

Figure 1: Comparison of experimental and simulated effects of ankle exoskeleton conditions. Red areas indicate experimental and simulated changes are in opposite direction.

Conclusions

Predictive simulations captured only a subset of the effects of an AFO on the gait pattern of children. The changes that were accurately predicted differed between subjects. Future work should aim to improve musculoskeletal modelling of children.

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