Forward Dynamics-Based Soft Suit Hip Assist Simulation: Comparison with Human Walking Data

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Summary

This study implemented a forward dynamics-based soft suit hip assist simulation using a neural network gait controller. The simulation closely matched experimental data, with a joint angle RMSE of 2.96°. Hip extensor activation decreased, while hip flexor activation slightly increased, effectively replicating human neuromuscular responses to assistance. These findings highlight the potential of simulations for assistive device development.

Introduction

A human-in-the-loop method efficiently customizes assistive devices with real-time physiological feedback [1]. Yet, repeated testing is time-intensive and burdensome, especially for older or clinical populations. Forward dynamics simulations with NN-based controllers show promise for reducing trials and speeding development [2], but they omit critical neurophysiological responses essential for safe functionality and efficacy. The objective of this study was to develop an NN-based gait controller that applies hip assist forces during walking and compare its simulated muscle activation and joint kinematics with human experimental data, aiming to evaluate how effectively the simulation replicates actual neuromuscular behavior.

Methods

IRB approval and informed consent were obtained prior to testing. Eleven healthy male participants (24.8 ± 1.4 years, 65.8 ± 5.8 kg, 174.1 ± 2.3 cm) performed three treadmill walking trials at 4 km/h: 5 minutes of baseline walking, 5 minutes with the soft suit worn but no assist, and 20 minutes with hip assist. Motion capture and EMG data from 12 right-leg muscles were recorded at sampling rates of 100 Hz and 2000 Hz, respectively. A musculoskeletal model with 25 degrees of freedom was developed in MuJoCo to replicate these trials, with the soft suit applying forces matching the real device (Figure 1) [3]. A neural network-based gait controller was trained via deep reinforcement learning to track participants' kinematics and EMG patterns. Simulation outputs were compared with human data across conditions to assess how closely the model captured actual neuromuscular responses.

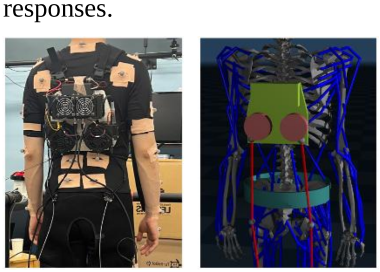

Figure 1: A participant wearing the soft suit (left) and the musculoskeletal model with the simulated soft suit (right).

Results and Discussion

The forward dynamics simulation demonstrated high agreement with experimental data, with a joint angle RMSE of 2.96° in lower limbs, confirming its accuracy in replicating human movement. Muscle activation trends were also consistent between simulation and EMG measurements. Hip extensor muscles, such as gluteus medius and gluteus maximus, exhibited reduced activation under assist conditions in both experimental EMG and simulation (Figure 2). Similarly, hip flexors, such as the rectus femoris and psoas, showed a slight increase in activation, reflecting shared neuromuscular adaptation mechanisms.

The consistent activation trends suggest that human adaptation to hip assist can be reliably reproduced in simulation. However, discrepancies in specific muscle activation levels highlight the need for further refinement in muscle dynamics modeling.

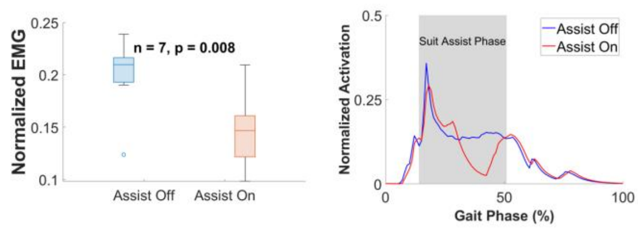

Figure 2: Experimental EMG (left) and simulated activation (right) for Gluteus Medius under assist-on and assist-off conditions.

Conclusions

This study demonstrated that the NN-based gait controller effectively replicates human neuromuscular responses to hip assist. The simulation showed consistent trends with experimental data in muscle activation and joint kinematics, addressing key limitations in capturing neurophysiological processes. These findings highlight the potential of forward dynamics simulations for developing safe and functional assistive devices.

Acknowledgments

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References

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