# Predicting Metabolic Cost Reduction under Hip Assistive Torque with Forward Dynamics Gait Controller

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## Summary

Forward dynamics simulation with artificial neural network (ANN)-based controller could simulate three-dimensional human walking with hip-assist torque and reproduce the experimental data. The simulation identified the experimentally determined optimal assistance level and reproduced the kinematics changes by the assistive torque level.

## Introduction

Net metabolic cost reduction is a widely adopted metric in evaluating performance of wearable assistive devices. However, its quantification through respiratory gas analysis is time-consuming, making it challenging to evaluate various combinations of assistive forces. Previous studies have utilized musculoskeletal simulations to understand changes of joint kinematics and metabolic costs by external assistance [1,2,3]. However, previous approaches had limitations in gait kinematics reproduction accuracy [1] and kinematics changes due to external force [3]. We aimed to predict kinematic and metabolic changes under external assistance through forward dynamics simulation with an ANN-based controller [4] and validated these predictions against human experiments.

## Methods

This study was approved by the Institutional Review Board (IRB) of KAIST. Full-body gait motion data were collected from a healthy male participant (height: 173cm, weight: 71.3kg). A 25-degree-of-freedom human skeletal model was controlled by ANN trained through deep reinforcement learning to mimic the subject's gait kinematics [4]. The gait controller was further trained with a reward function designed to minimize ground reaction forces, mechanical joint power, torque and jerk. To ensure the robustness of the gait controller, additional training was performed across various walking speeds and cadences (±10% from the reference motion).

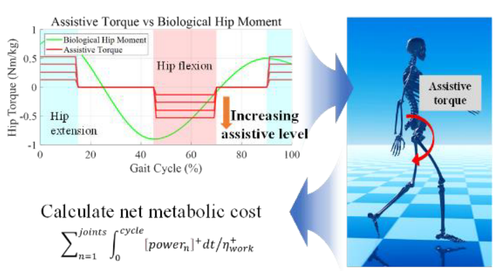


**Figure 1**: Prediction of net metabolic costs at various assistive torque levels. Assistive torque profile from [5]

Assistive torques were applied to both hip joints during gait. The level of assistive torque increased from 13% to 53% of the maximum hip moment, as presented in a previous study [5]. Net metabolic cost was estimated using positive joint power, calculated by multiplying joint torque and angular velocity, with mechanical work efficiency ($\eta_{work}^{+}$) adopted from [6] (Figure 1). The net metabolic cost was calculated over 12 gait cycles for each assistive torque condition and compared with previous human experimental data [5].

## Results and Discussion

We confirmed that external torques could modify not only joint torques but also gait parameters. As assistance level increased, velocity remained relatively constant while cadence increased by 2.8%. Previous Studies have reported that cadence increases with rising power transfer [7].

The experiment and simulation consumed 2.51 J/kg·m and 2.69 J/kg·m of metabolic energy, respectively, in baseline conditions. Both showed the lowest net metabolic cost at around 26% assistance level, with simulation showing 0.3 J/kg·m reduction compared to 0.11 J/kg·m in experiments. In ours, there was no energy consumption from soft tissues such as skin and muscles; all energy was transferred to rigid bodies.

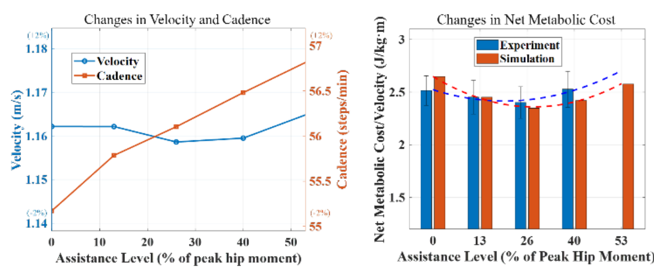


**Figure 2**: Walking velocity and cadence (left) and net metabolic cost [5] were changed according to hip assistive torque level.

## Conclusions

Our simulations replicated experimental metabolic cost patterns, identifying optimal assistance levels. It also showed that gait kinematics changed depending on assistance levels [7]. These suggest that our model can be used to predict human response to external assistive torques.

## Acknowledgments

This research was supported by the NRF (2022M3C1A3080598) and by IITP (2022-0-00025) funded by the Korea government.

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