Towards Realistic Prosthetic Gait Simulations: Enhancing the Accuracy of OpenSim Analysis by Integrating the Transfemoral Prosthesis Model

Hyungseok Ryu*, Woolim Hong**, Pilwon Hur*†

Presentor : Hyungseok Ryu

* GIST, ** North Carolina State Univ., *† GIST

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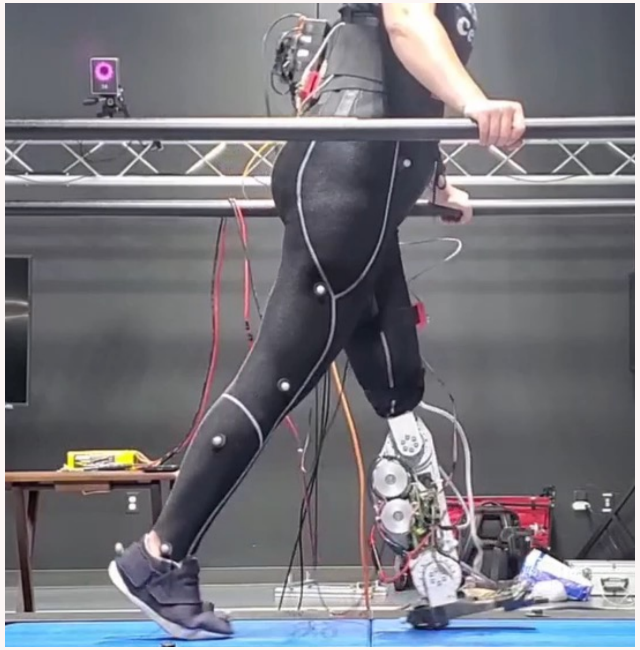
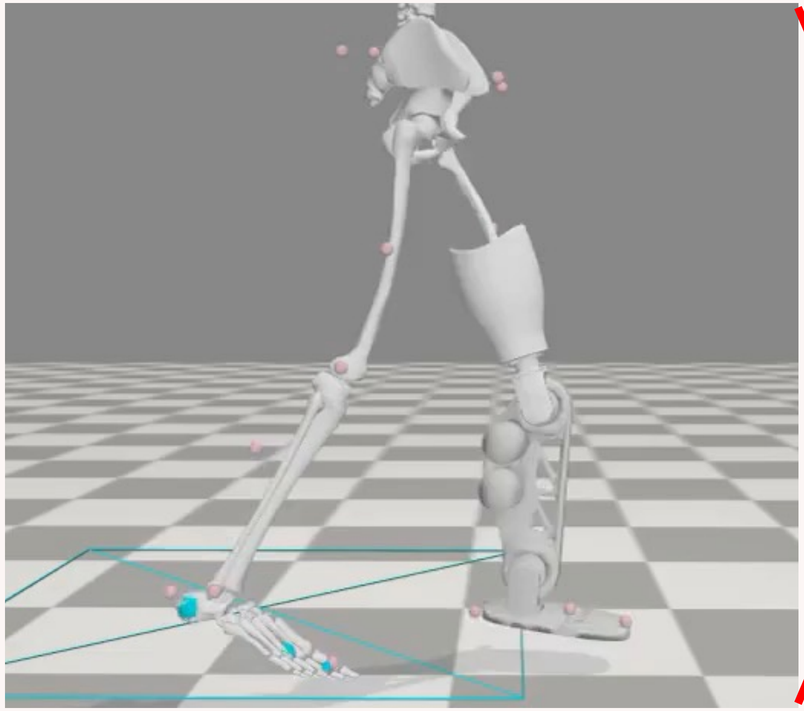
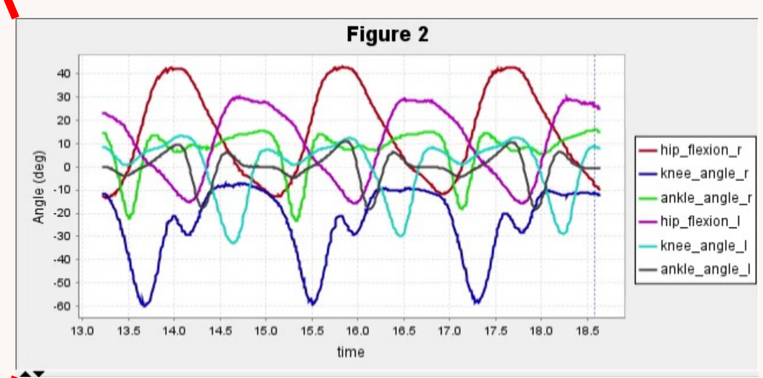
Introduction

❖ Background

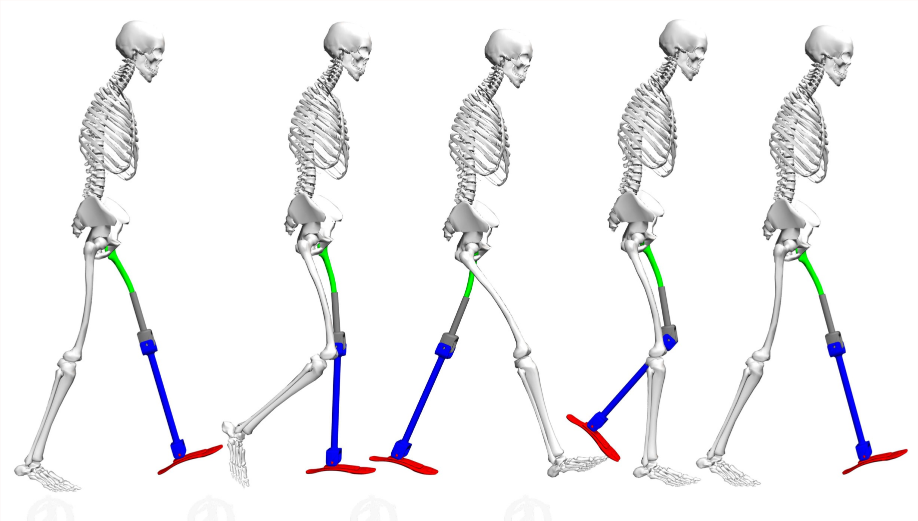




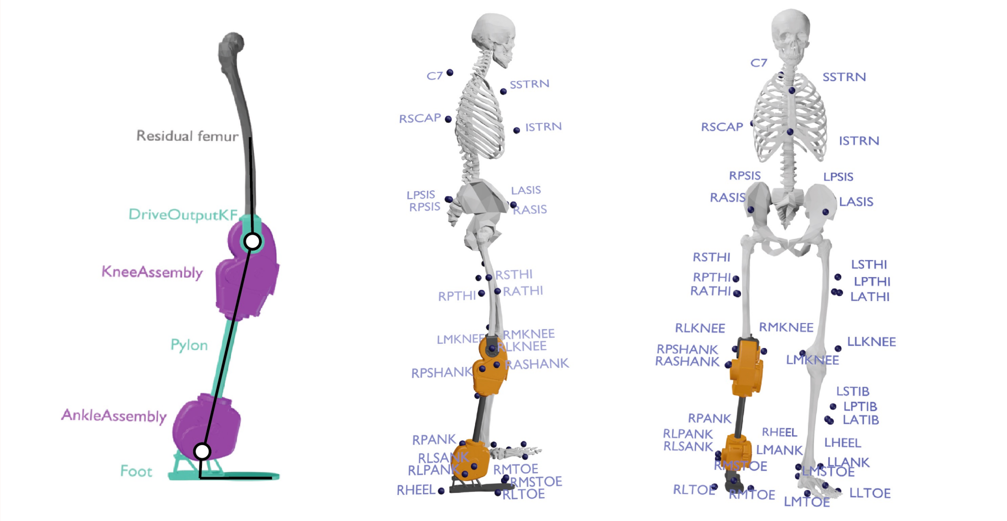


Introduction

❖ Related Research



- OpenSim model of osseoinegrated transfemoral amputee
- <u>**Passive prosthesis**</u>



- OpenSim model
- Powered prosthesis actuated in ankle and knee joints
- Using <u>**only kinematic factor**</u> for validation of model

1. *V. Raveendranathan and R. Carloni, "Musculoskeletal model of an osseointegrated transfemoral amputee in opensim" (2020)*
2. *J. Camargo, K. Bhakta, J. Maldonado-Contreras, S. Zhou, K. Herrin, and A. Young, "Opensim model for biomechanical analysis with the open-source bionic leg" (2022)*

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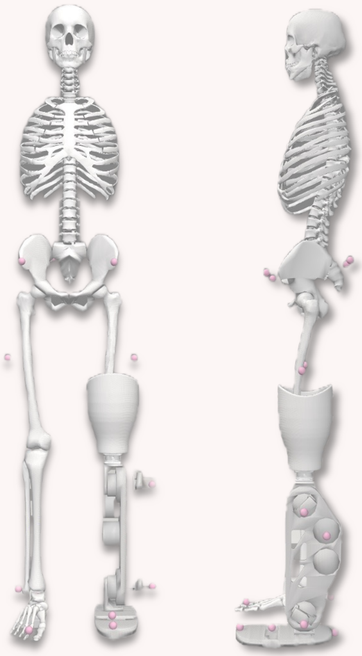
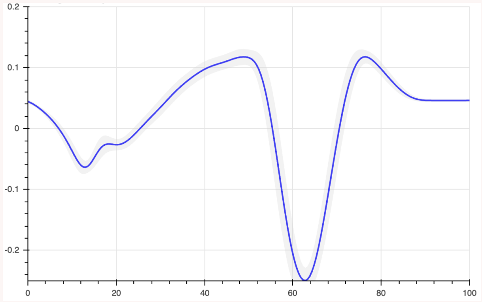
Introduction

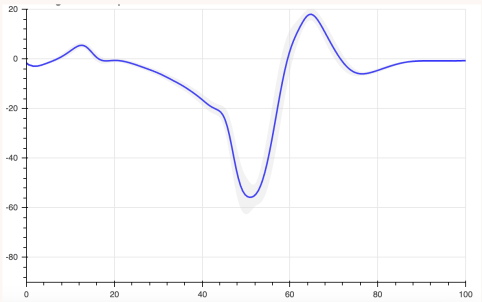
❖ Objective

- Development of an **OpenSim model wearing a powered prosthesis** actuated in ankle and knee joints.
- Comparing the **inverse kinematics** and **inverse dynamics** results with the encoder data from the knee and ankle actuators, which served as the ground truth.





Kinematics



Kinetics

Methods

❖ Framework

One subject with transfemoral amputation

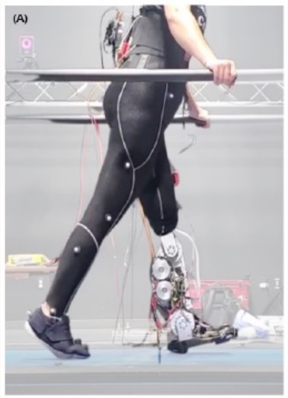
02

Convert data for OpenSim

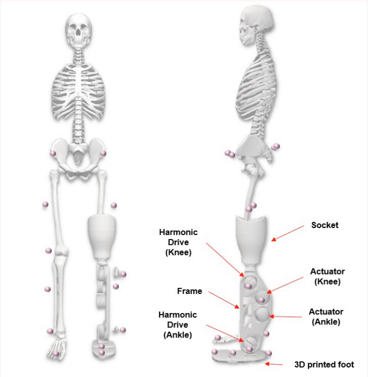
04

Experimental protocols | **OpenSim model** | **Data Processing** | **Data Analysis**

01



16 DOFs Model



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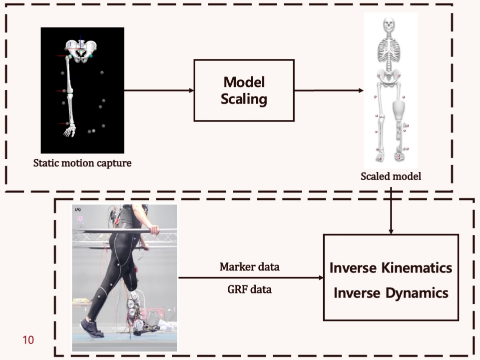


1. **RMSE**
2. **Paired t-test**

Methods

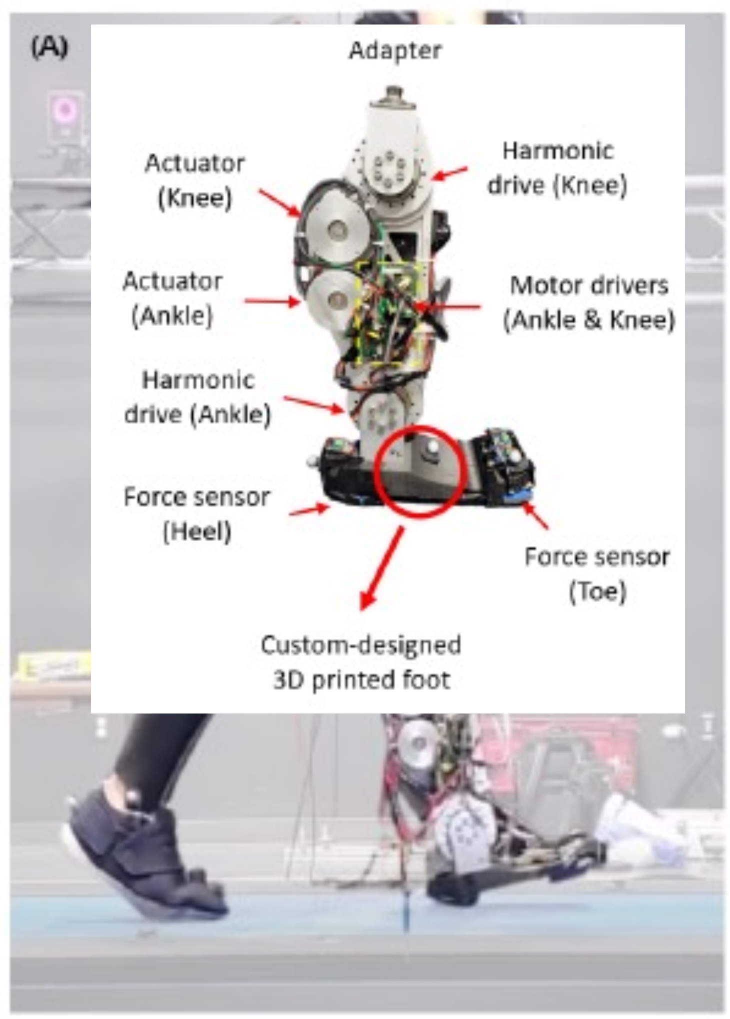
❖ Experimental Protocol

➢ Data collection

- One subject with unilateral transfemoral amputation
- Encoder data of ankle/knee joints (angles & torques)
- Motion Capture data (44-camera Vicon system)
- Force plate data (AMTI instrumented treadmill)
- Walking trials at fixed speed of 0.67 m/s
- Marker, encoder, GRF data: low-pass filter (6, 10, and 10 Hz)
- 13 gaits cycles

➢ Prosthesis

- Custom-built AMPRO II powered prosthesis actuated in ankle

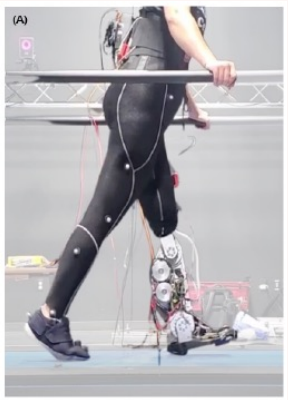


Methods

❖ Framework

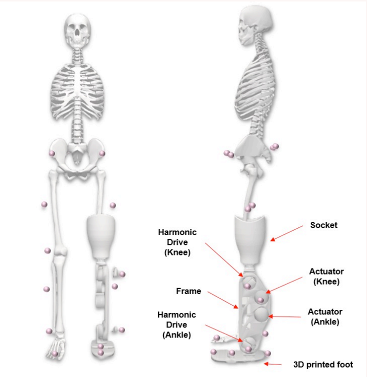
01 Experimental protocols

One subject with transfemoral amputation



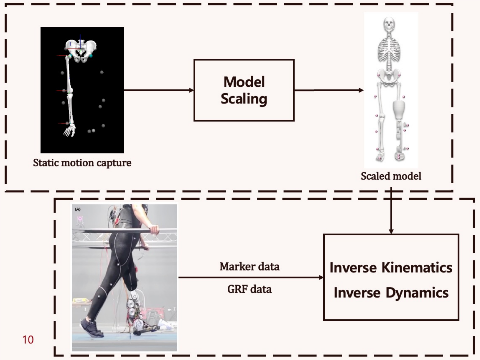
02 OpenSim model

16 DOFs Model



03 Data Processing

Convert data for OpenSim



04 Data Analysis

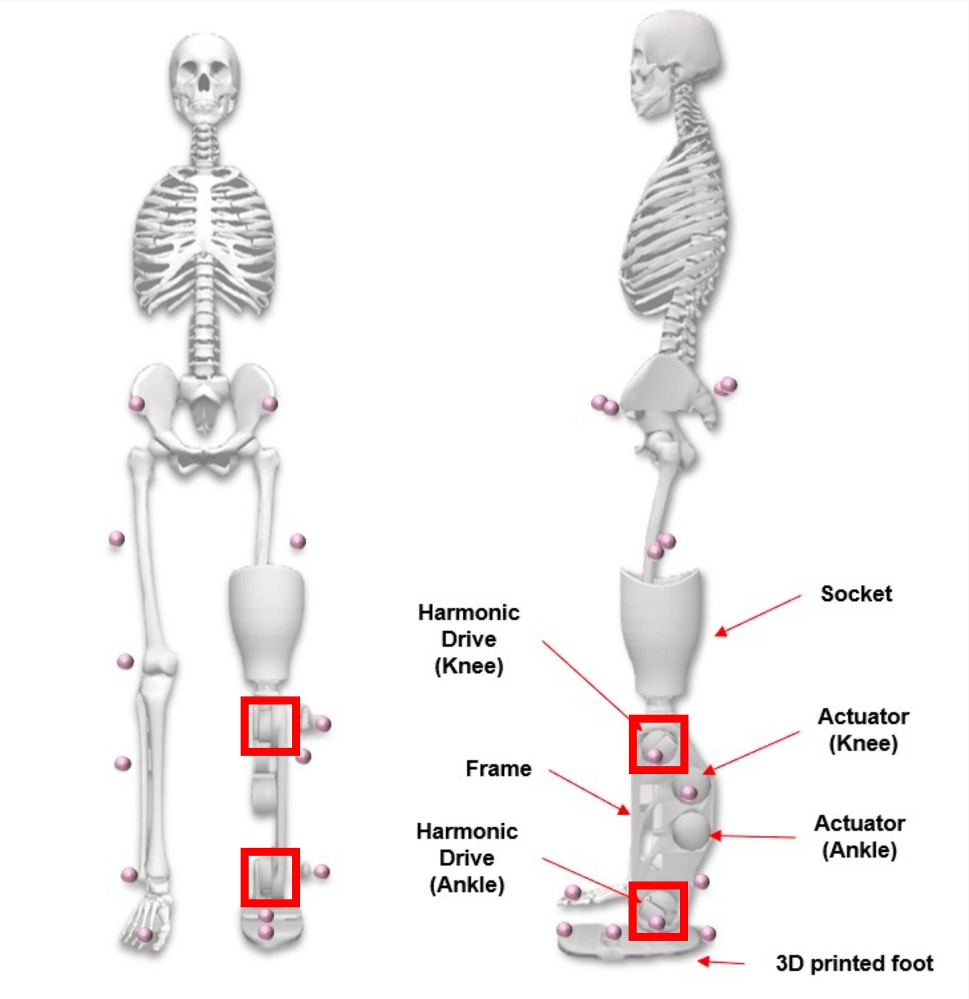
1. RMSE
2. Paired t-test

Methods

❖ OpenSim model

➢ Model adjustments

- Modified "Gait2354 Simbody" from OpenSim
- Set torso DOF to 0
- Removed muscles
- Removed joints in feet
- Actuators & harmonic drives in rotating parts
- Ankle & knee joints (flexion motion only)
- 16 DOFs in total



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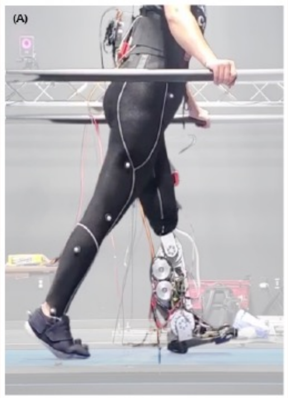
Methods

❖ Framework

01

Experimental protocols

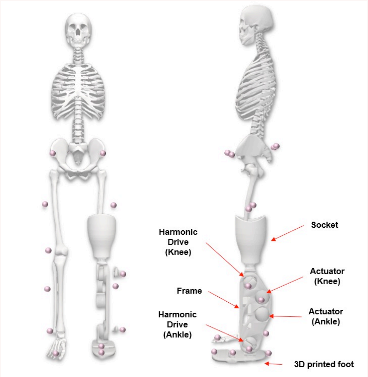
One subject with transfemoral amputation



02

OpenSim model

16 DOFs Model



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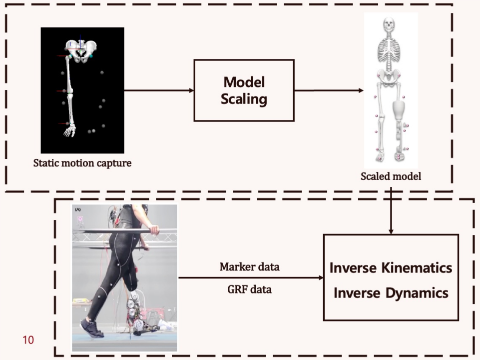
Data Processing

Convert data for OpenSim



04

Data Analysis

1. RMSE
2. Paired t-test

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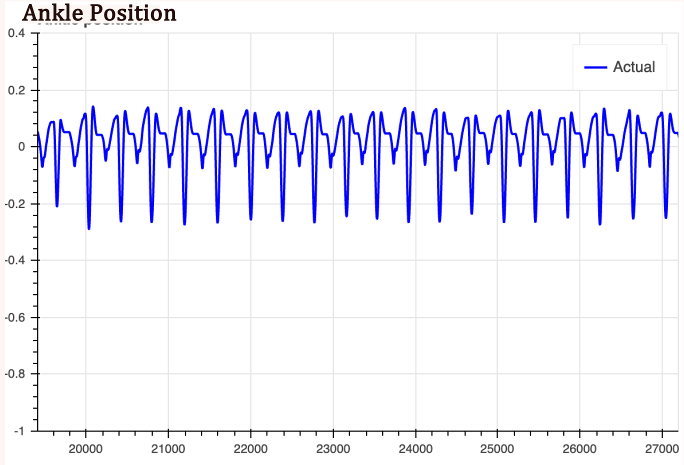
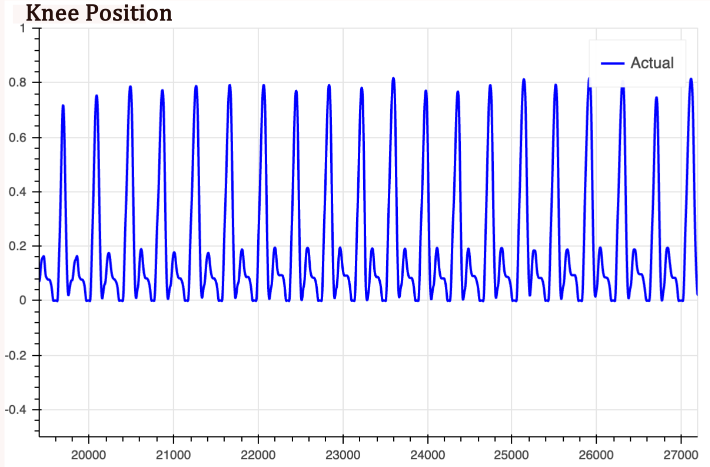
Methods – Data Processing

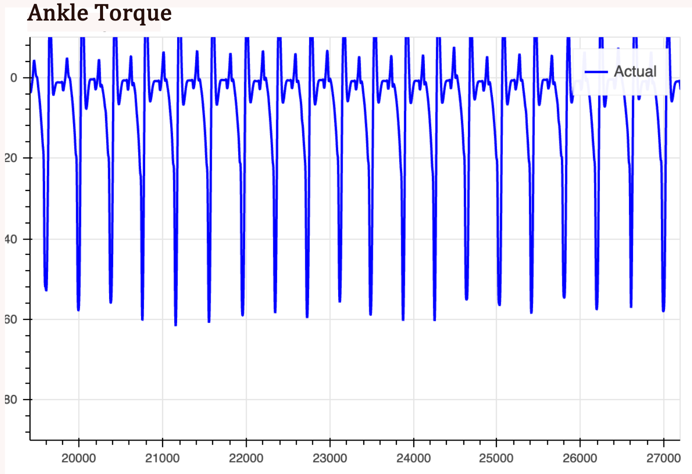
Encoder (US Digital, E5)

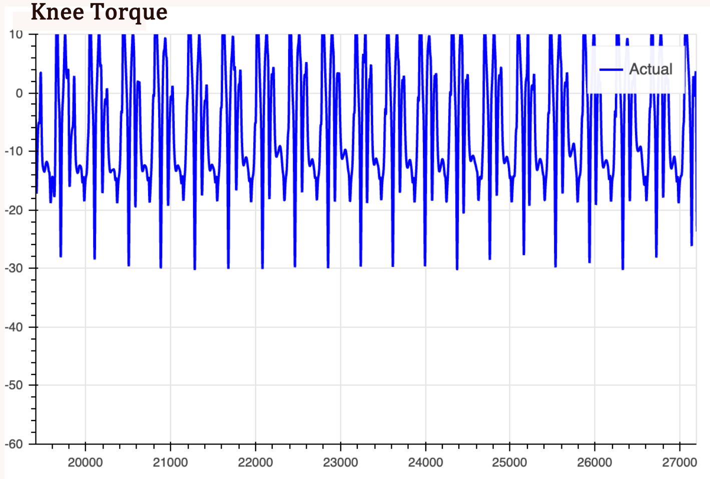
Position



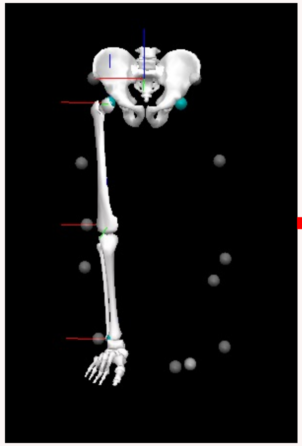


Current



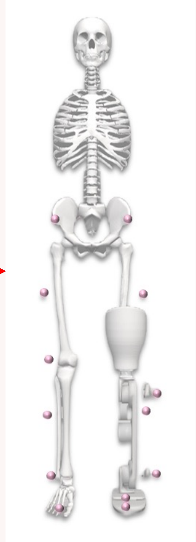


Methods – Data Processing

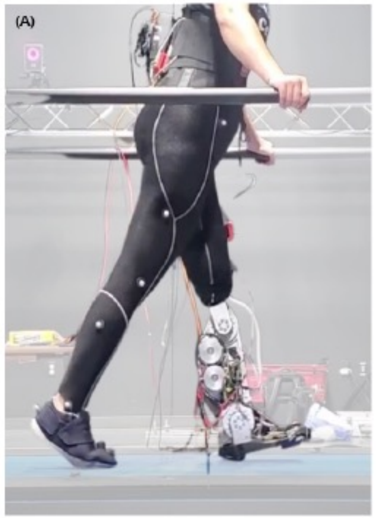


Static motion capture

Model Scaling



Scaled model

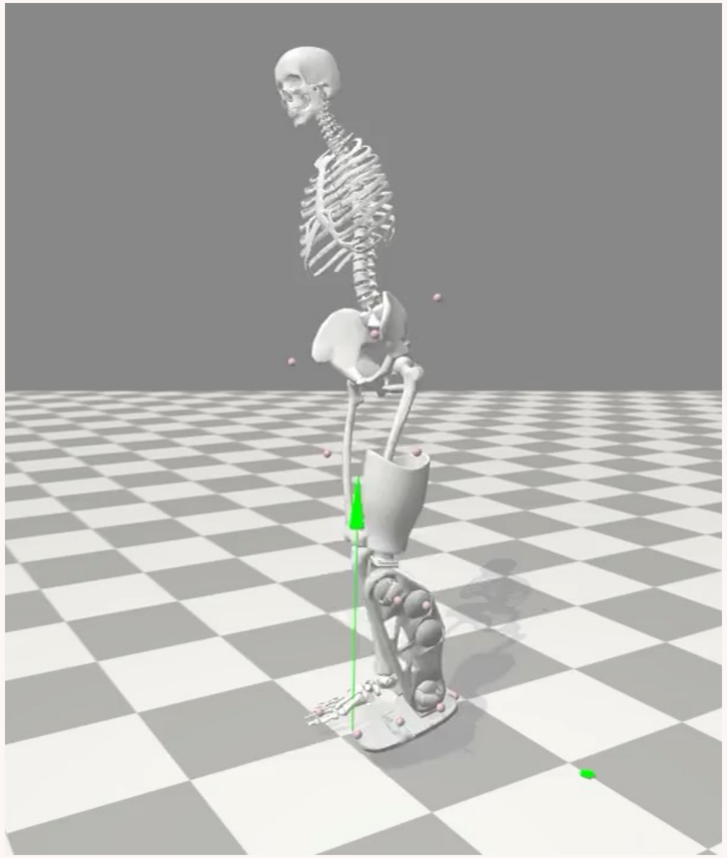


Marker data

GRF data

Inverse Kinematics

Inverse Dynamics



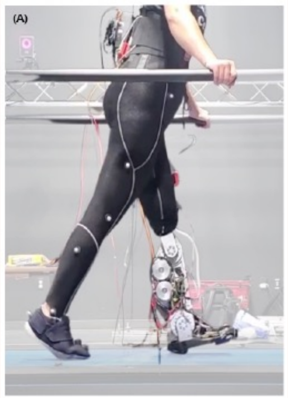
Methods

❖ Framework

01

Experimental protocols

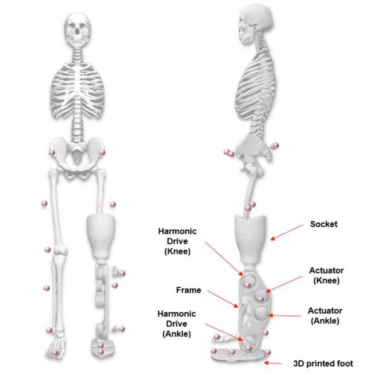
One subject with transfemoral amputation



02

OpenSim model

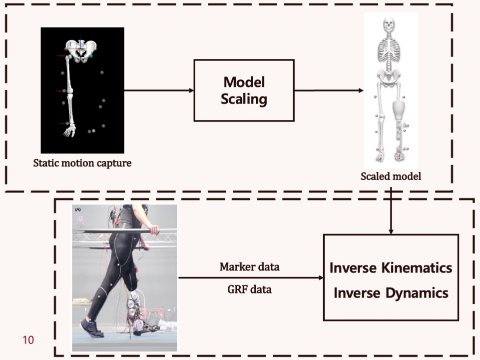
16 DOFs Model



03

Data Processing

Convert data for OpenSim



04

Data Analysis

1. **RMSE**
2. **Paired t-test**

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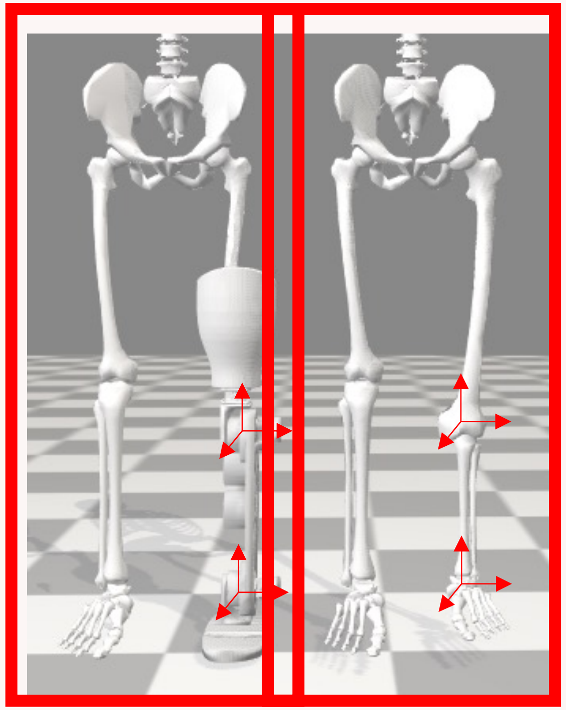
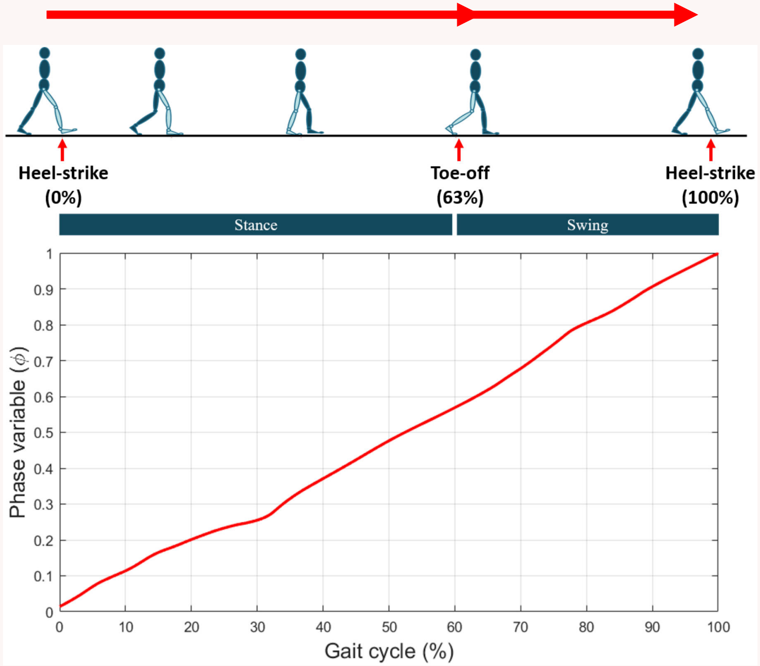
Methods

❖ Data analysis

- ➢ Ankle & knee joints angle and moment
  - Encoder data vs. Models with and without prosthesis (*RMSE*)
  - Full Phase & Stance Phase
  - Paired t-test(Scipy in Python) for RMSE values about models with and without prosthesis ($p < 0.01$)



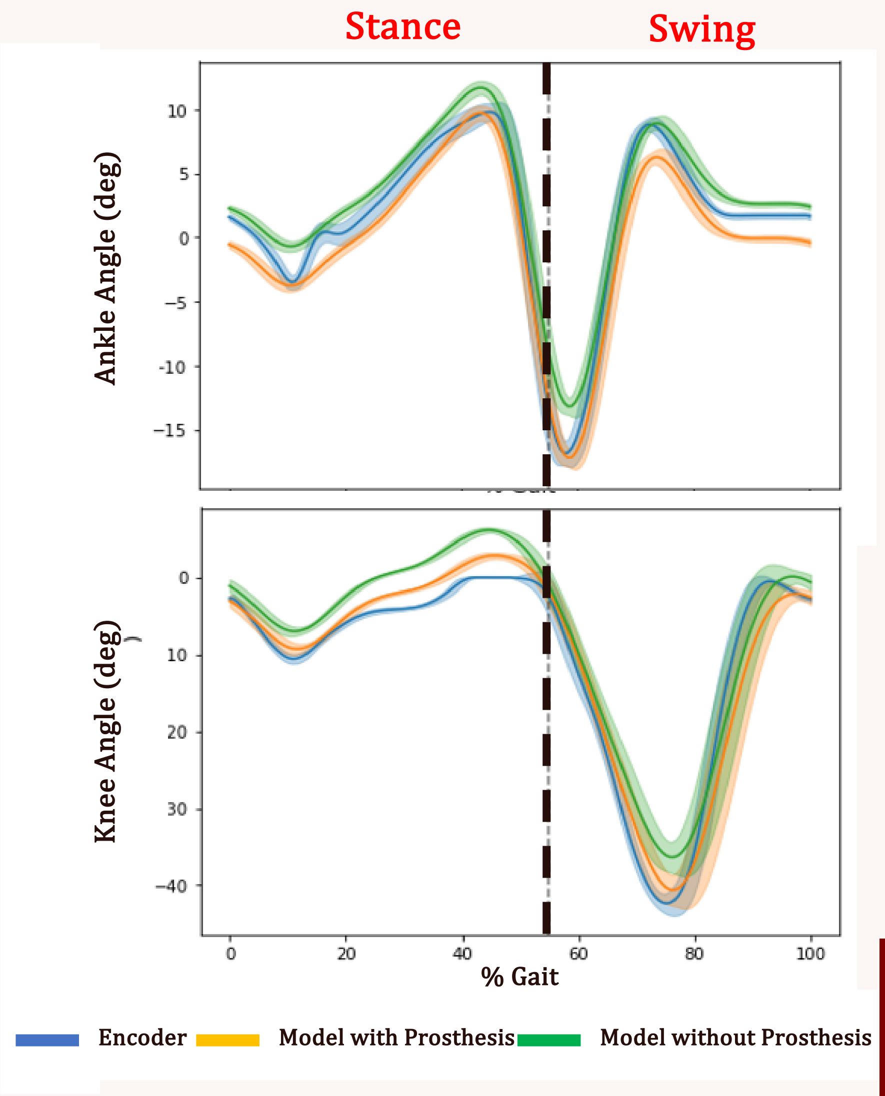


Results

❖ Kinematics Results

- Model with prosthesis is closer before reaching the peak value of the swing phase, but not after reaching the peak value.

RMSE		Ankle Angle	Knee Angle
Full Phase	Model with prosthesis	2.229 ± 0.569	4.236 ± 1.696
	Model without prosthesis	2.203 ± 0.458	5.306 ± 1.201
Stance Phase	Model with prosthesis	5.135 ± 0.242	1.824 ± 0.282
	Model without prosthesis	6.079 ± 0.265	4.362 ± 0.255

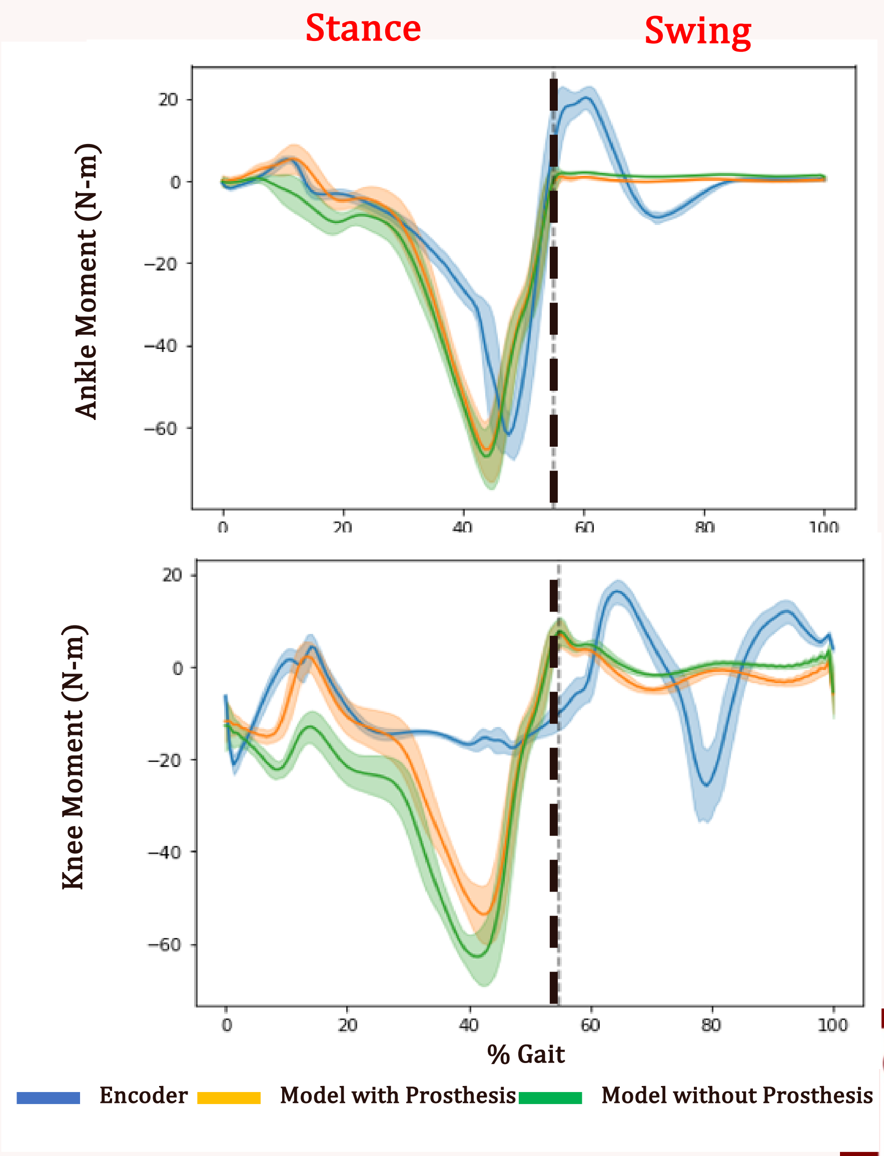


Results

❖ Kinetics Results

- ➢ Stance Phase
  - Model with prosthesis offers a closer match to actuator data during the stance phase.
  - Model with prosthesis better reflects the dynamics features of a real powered prosthesis during stance phase.

RMSE		Ankle Torque	Knee Torque
Full Phase	Model with prosthesis	11.425 ± 1.566	15.401 ± 0.911
	Model without prosthesis	12.103 ± 1.749	19.474 ± 1.187
Stance Phase	Model with prosthesis	12.548 ± 2.225	17.646 ± 1.457
	Model without prosthesis	13.761 ± 2.391	23.768 ± 1.849

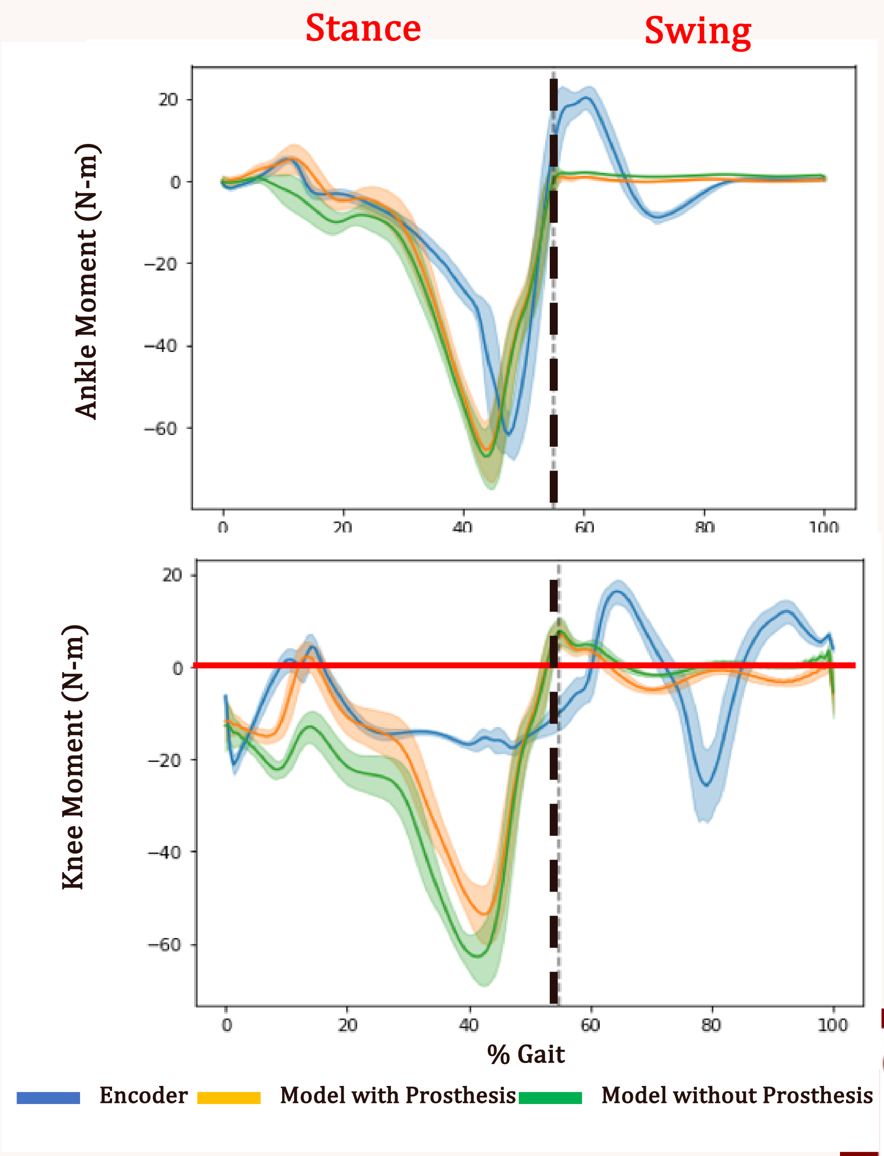


Results

❖ Kinetics Results

- ➢ Swing Phase
  - Both models show completely different results from the encoder data during the swing phase.
  - Model with prosthesis accurately captures a negative moment in the knee during the swing phase.

RMSE		Ankle Torque	Knee Torque
Full Phase	Model with prosthesis	11.425 ± 1.566	15.401 ± 0.911
	Model without prosthesis	12.103 ± 1.749	19.474 ± 1.187
Stance Phase	Model with prosthesis	12.548 ± 2.225	17.646 ± 1.457
	Model without prosthesis	13.761 ± 2.391	23.768 ± 1.849



Results

❖ Total RMSE

- RMSE values show better performance for the model with prosthesis except for ankle angle at the full phase.
- Statistically significant differences present for all variables except ankle angle for the full gait cycle.
- In conjunction with RMSE results, the model with prosthesis provides a more accurate representation of the kinematic and kinetic features of prosthesis side gait.

RMSE		Ankle Torque	Knee Torque	Ankle Angle	Knee Angle
Full Phase	Model with prosthesis	11.425 ± 1.566 *	15.401 ± 0.911 *	2.229 ± 0.569	4.236 ± 1.696 *
	Model without prosthesis	12.103 ± 1.749 *	19.474 ± 1.187 *	2.203 ± 0.458	5.306 ± 1.201 *
Stance Phase	Model with prosthesis	12.548 ± 2.225 *	17.646 ± 1.457 *	5.135 ± 0.242 *	1.824 ± 0.282 *
	Model without prosthesis	13.761 ± 2.391 *	23.768 ± 1.849 *	6.079 ± 0.265 *	4.362 ± 0.255 *

$p < 0.01$

Conclusion

❖ Limitation

- Prosthesis model may not capture all intricacies of real-world prosthetic devices, potentially affecting accuracy.
- Experiment conducted on only one subject.

❖ Future work

- To strengthen the generalizability of the results, future studies will involve a larger and more diverse group of participants, including individuals with varying levels of amputation.
- We will also consider the influence of external factors, such as varying walking surfaces, slopes, and environmental conditions, on prosthesis performance.
- We will apply this model to forward simulation.

Q&A