

# Forecasting Gait Kinetics and Kinematics for Biological Joint Impedance Estimation Using Machine Learning

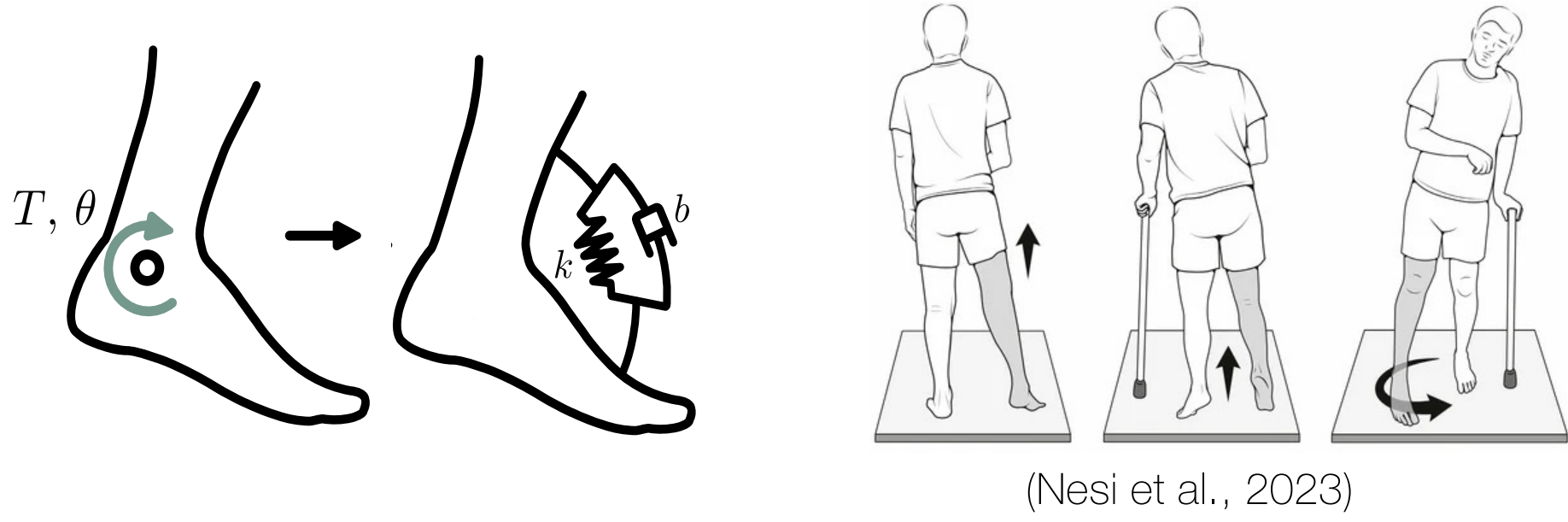
Nana Porter-Honicky, Elliott Rouse



## What is biological joint impedance?

$$T_p = I\ddot{\theta}_p + b\dot{\theta}_p + k\theta_p$$

- A mechanical model of the **inertia  $I$ , damping  $b$ , and stiffness  $k$**  of a joint [1,2]



- Impedance is useful tool in understanding **hypertonia, spasticity, and paresis** [3]

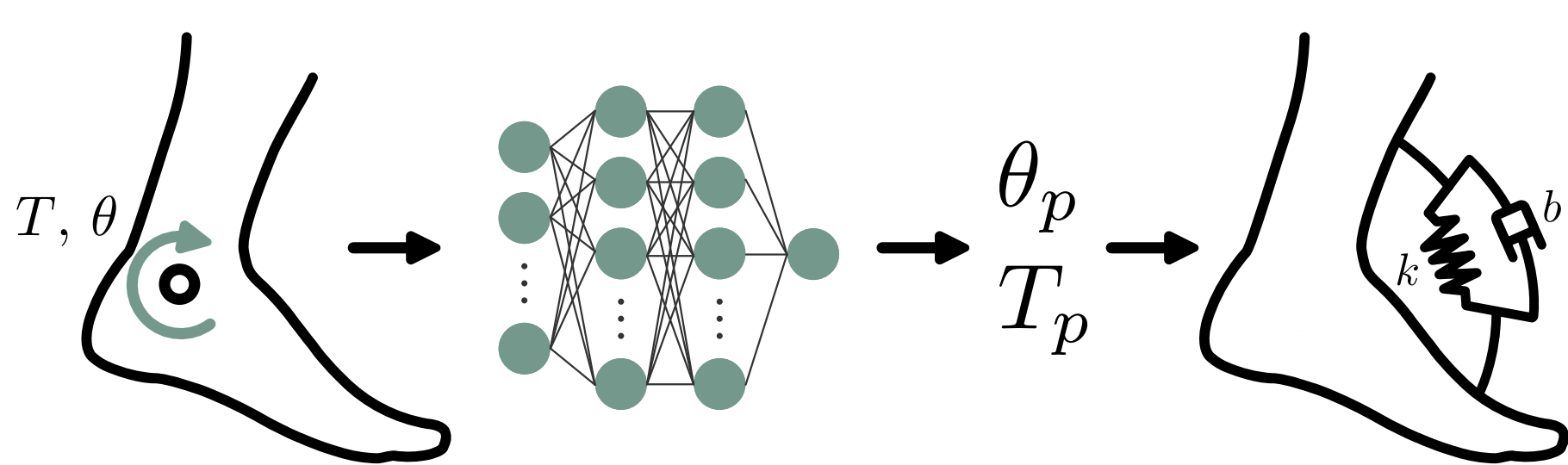
## Why is it so hard to measure?

- Impedance is **task and phase dependent** [2]
- Requires a **perturbation** [1]
- Requires **hundreds of trials** for both perturbed and unperturbed gait [2]

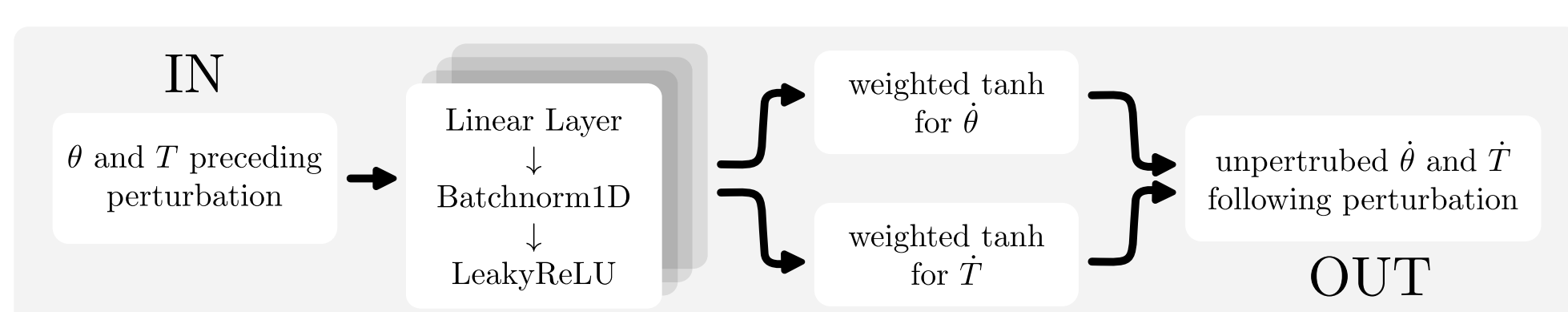
$$\begin{aligned} \sum \theta(t) - \sum \theta_p(t) &= \theta_p(t) \\ \sum T(t) - \sum T_p(t) &= T_p(t) \end{aligned} \rightarrow T_p = I\ddot{\theta}_p + b\dot{\theta}_p + k\theta_p$$

- Currently estimated using a **bootstrap sampling method**

## How do we get around this?



## Designing the model



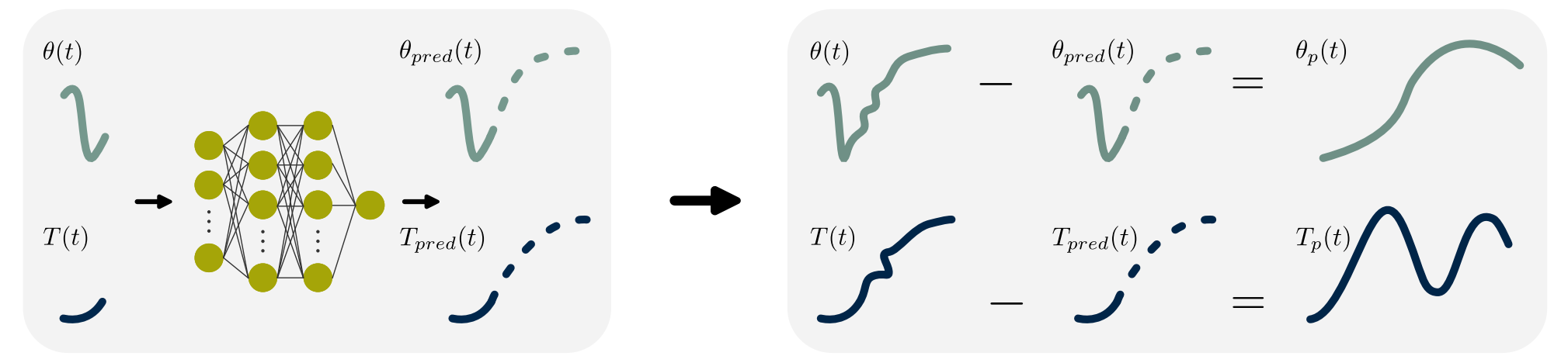
- Models trained on kinematic and kinetic **data from previous studies** [2,3]
- Simple **feed-forward neural network** structure

$$\mathcal{L}^{\text{train}}(\theta, \hat{\theta}, T, \hat{T}) := \alpha_T \ell_\delta(\hat{T}, T) + \alpha_{\dot{\theta}} \ell_\delta(\hat{\theta}, \dot{\theta}) + \alpha_{\dot{T}} \ell_\delta(\hat{T}, \dot{T}) + \alpha_\theta \ell_\delta(\hat{\theta}, \theta)$$

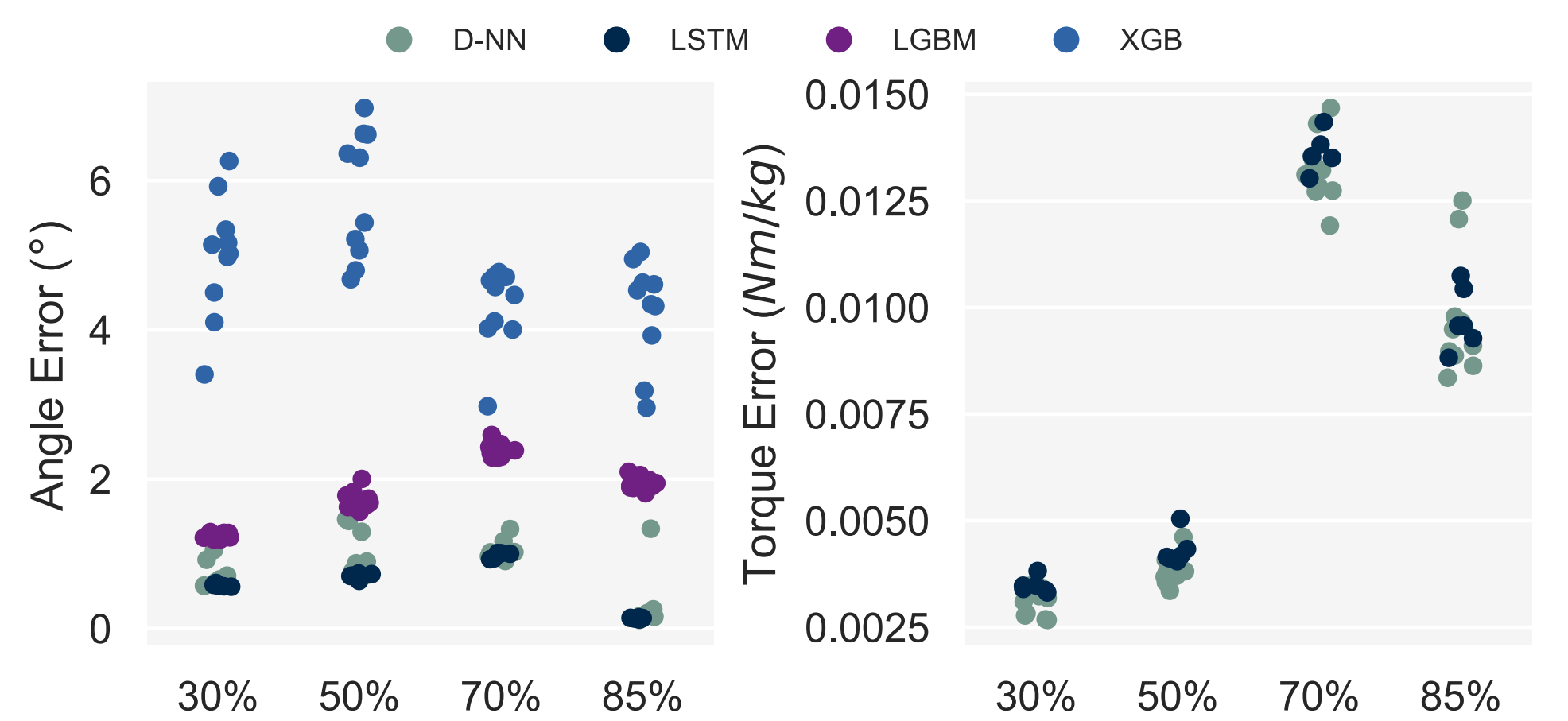
$$T_p = I\ddot{\theta}_p + b\dot{\theta}_p + k\theta_p$$

- Loss function designed to look like the **governing impedance equation**

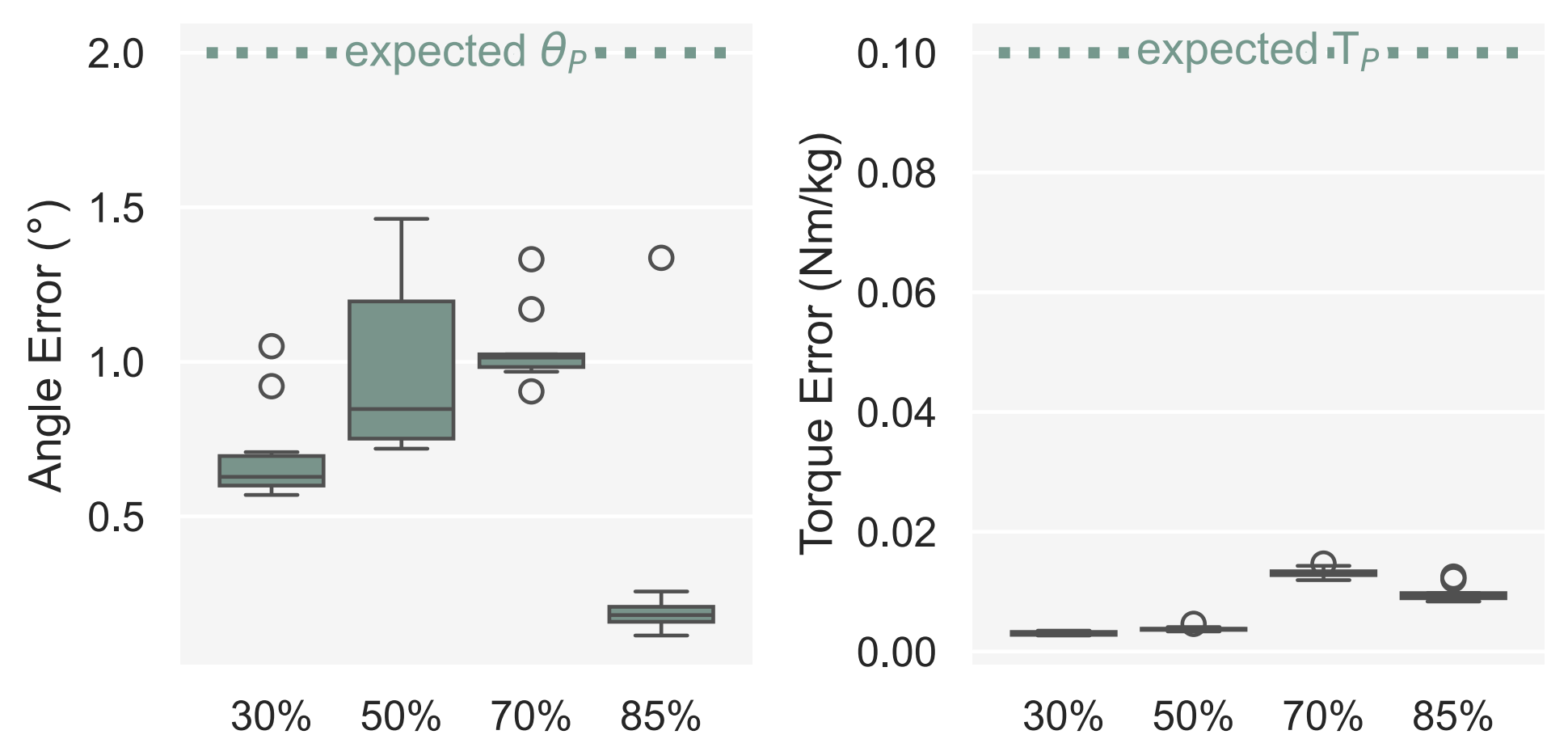
## Using our model to estimate impedance



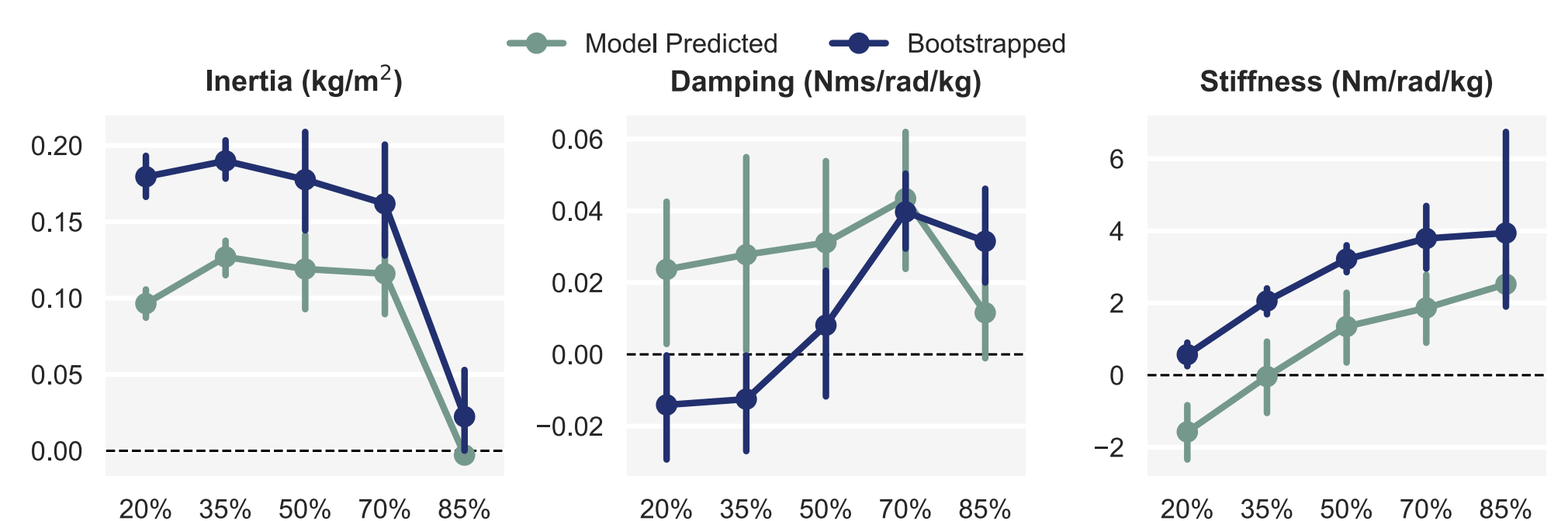
## Preliminary Results



- Out-performs other model types** on kinematic and kinetic predictions across stance phase



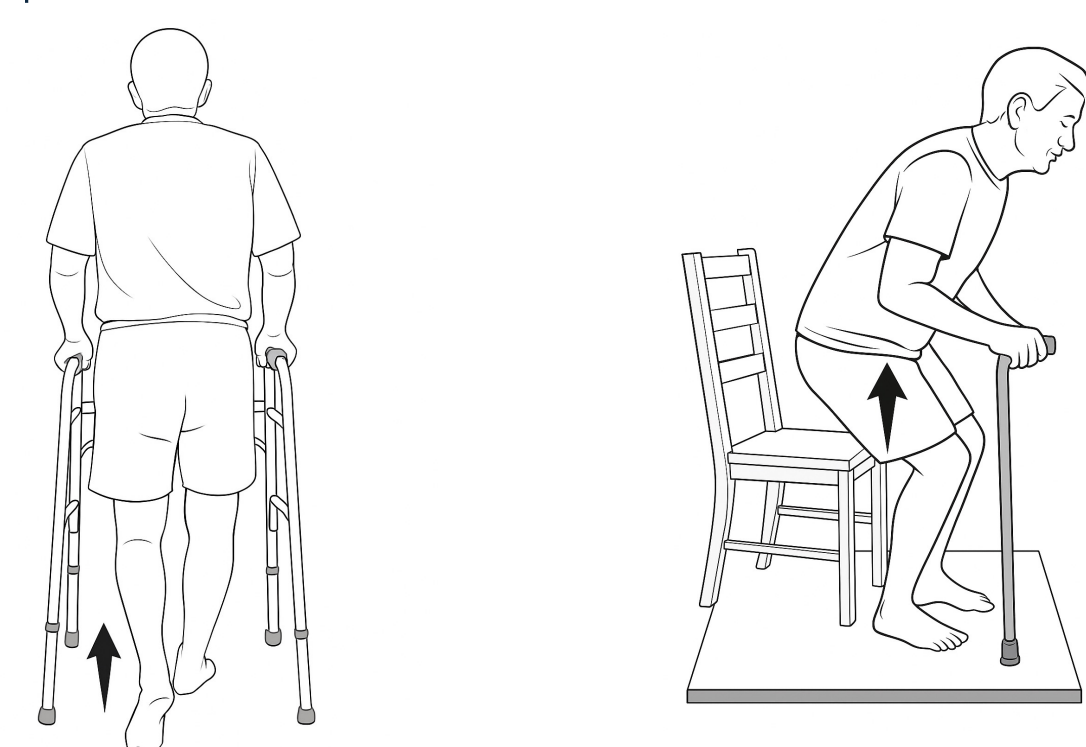
- Prediction errors **below expected perturbation magnitudes** across stance phase



- Impedance **estimates follow published trends**

## Implications

- Reduced data needs allow for **impedance estimates on more tasks and populations** (e.g. hemiparetic stroke and/or sit-to-stand)



## References

[1] E. J. Rouse, L. J. Hargrove, E. J. Perreault, and T. A. Kuiken, "Estimation of Human Ankle Impedance During the Stance Phase of Walking," *IEEE Trans Neural Syst Rehabil Eng*, vol. 22, no. 4, pp. 870–878, Jul. 2014

[2] R. Kearney and I. Hunter, "System Identification of Human Joint Dynamics," *ResearchGate*, 1990

[3] A. L. Shorter, J. K. Richardson, S. B. Finucane, V. Joshi, K. Gordon, and E. J. Rouse, "Characterization and clinical implications of ankle impedance during walking in chronic stroke," *Sci Rep*, vol. 11, Aug. 2021

[4] B. Nesi et al., "The Relationship between Gait Velocity and Walking Pattern in Hemiplegic Patients," *Applied Sciences*, vol. 13, no. 2, Art. no. 2, Jan. 2023