Discrepancy Modeling of Ankle Exoskeleton Walking Can Improve Response Predictions

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Exoskeletons change gait, but predicting response is hard.

Ankle exoskeletons (exos) are prescribed to **assist walking** or **improve gait** following neurological injuries.

Changes in gait kinematics and muscle activity in **response** to exo properties are **highly heterogeneous** [1].

Data-driven modeling enables subject-specific dynamics to be estimated without detailed knowledge of an individual's physiology [2].

Identifying **interpretable dynamics** governing exo response may highlight individualized drivers of response.

However, if standard measurements (kinematics and muscle activity) can **encode** the dynamics of exo responses is **unclear**.

Driving Question

To what extent can **discrepancies** between walking dynamics in zero-stiffness and high-stiffness passive exos be identified using kinematic and myoelectric data?

Response as a Discrepancy

Discrepancies are mismatches between system and model dynamics.

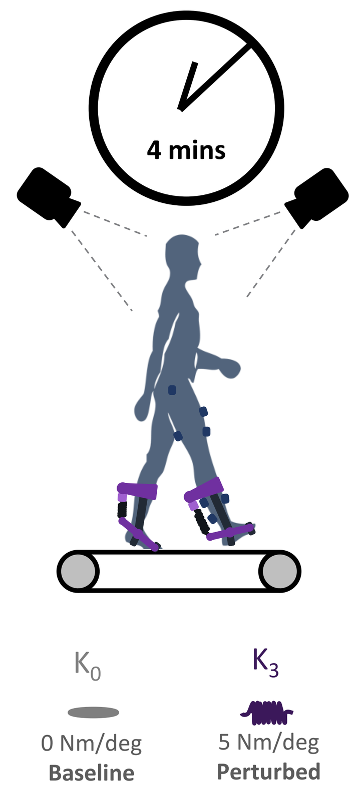
Discrepancy models **disambiguate** missing dynamics from noise and may quantify responses to exos.

For ankle exos:

An individual's response to exoskeleton properties, such as stiffness or torque, may be represented as a discrepancy between baseline dynamics (e.g., walking in a zero-stiffness exo) and the dynamics in a perturbed condition (e.g., walking in a high-stiffness exo)

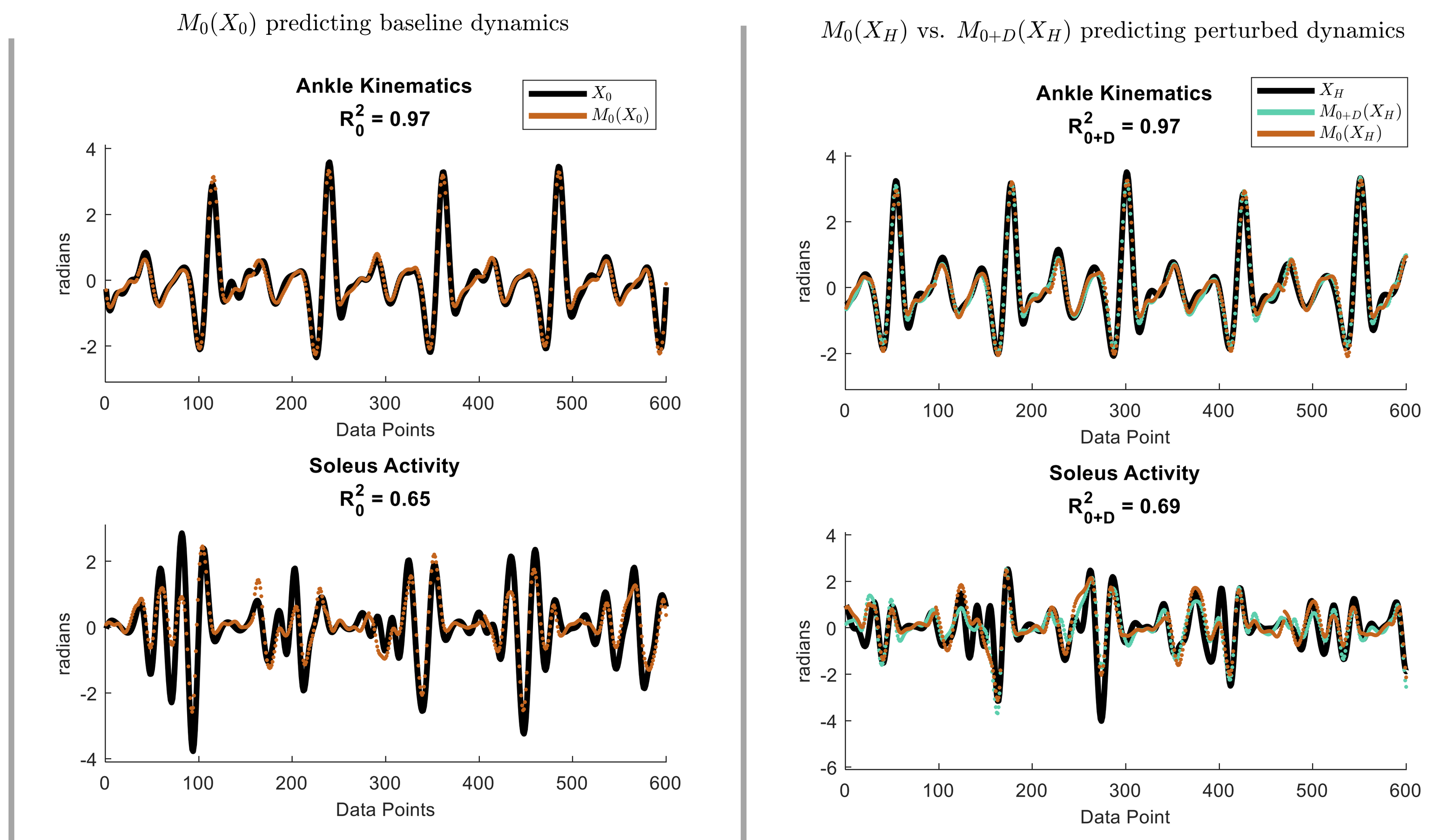
Methods & Results

Collect joint kinematics & muscle activity for zero-stiffness, X_0, & high-stiffness, X_H, exo walking for 11 subjects [2] → Train NN with baseline dynamics, $M_0(X_0)$ → Train NN with discrepancy dynamics with $M_D(X_H) = \dot{X}_H - M_0(X_H)$ → Compare perturbed dynamics to baseline & augmented dynamics, $M_{0+D}(X_H) = M_0(X_H) + M_D(X_H)$

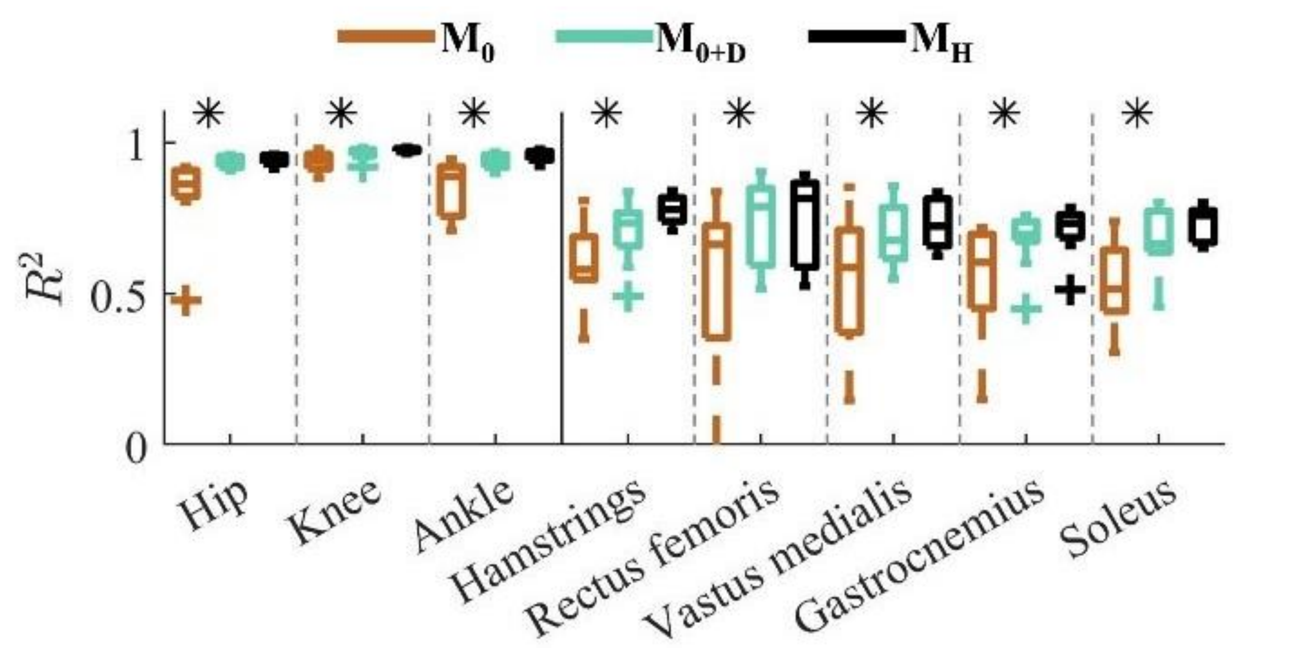


Neural network (NN) [3]

- 3 layer, 64 node
- Feed forward
- 3.5 min training, 30s test
- **Inputs** (49): gait phase, 10 lower-limb joint angles + derivatives, 14 myoelectric states + derivatives
- **Outputs** (8): second derivatives of right leg joint angles & muscle activity

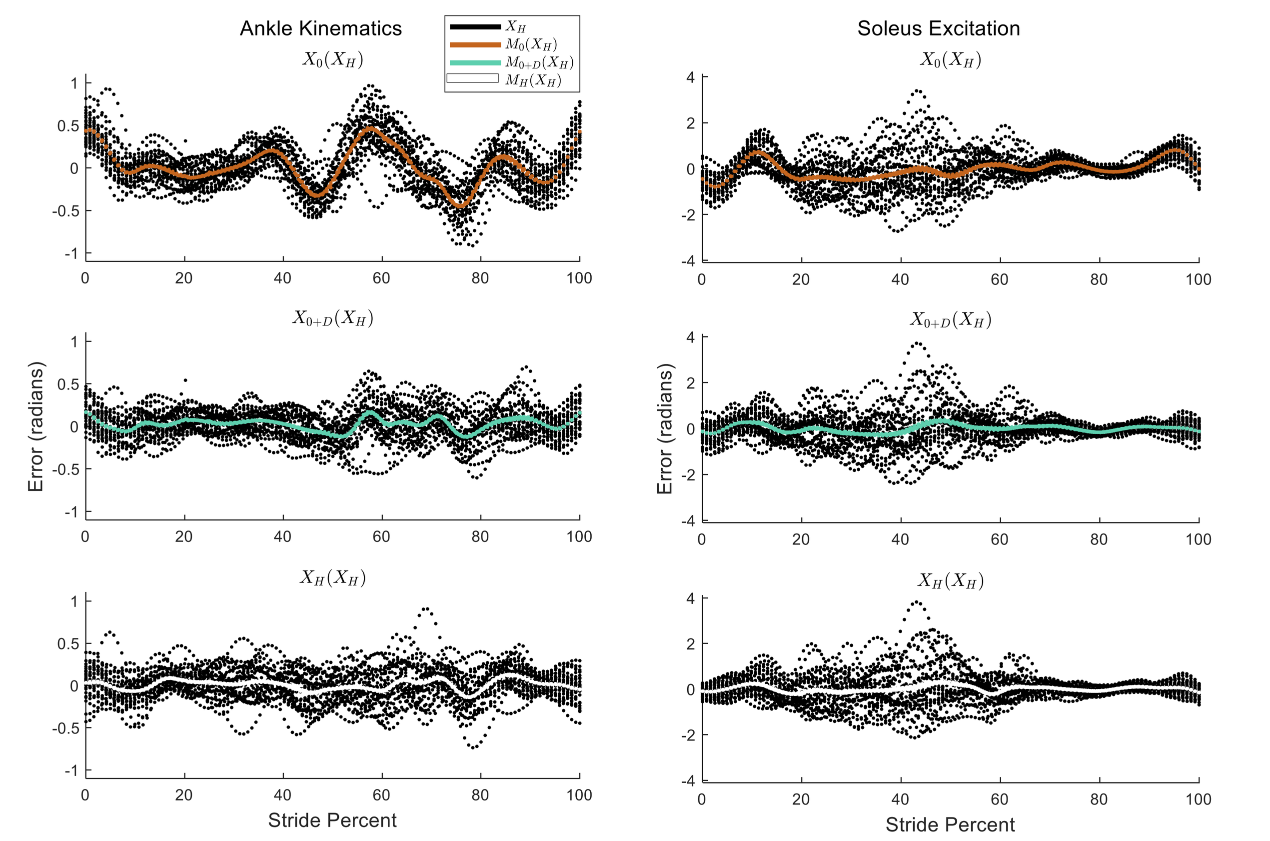


Augmented dynamics improved prediction accuracy of response to exoskeleton walking



Asterisks denote significant differences in accuracy between baseline (M_0) and augmented (M_{0+D}) models. M_H reflects the maximum expected prediction accuracy.

Bias analysis of model error suggests discrepancy modeling identifies missing dynamics



Non-zero mean = missing dynamics; zero mean = remaining variance is noise

Discussion

Discrepancy models **encode changes in dynamics** with ankle exos using kinematic and myoelectric measurements up to the limits imposed by measurements and noise.

Unexplained myoelectric variance suggests **additional measurements are needed** to encode myoelectric response dynamics to ankle exos (*e.g.*, ultrasound for MTU properties) [4].

Discrepancy structures identified from kinematics and muscle activity may still provide insight into different **mechanisms driving exo responses**.

Reducing model complexity and **identifying additional measurements** explaining responses represent important next steps to developing interpretable data-driven models of exo responses.

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References

[1] E. M. McCain, T. J. Dick, T. N. Giest, R. W. Nuckols, M. D. Lewek, K. R. Saul, et al., J Neuro Rehab, vol. 16, pp. 1-12, 2019.
[2] M. C. Rosenberg, B. S. Banjanin, S. A. Burden, and K. M. Steele, JRSI, vol. 17, p. 20200487, 2020.
[3] S. N. Kumpati and P. Kannan, TNNLS, vol. 1, pp. 4-27, 1990.
[4] R. W. Nuckols, T. J. Dick, O. N. Beck, and G. S. Sawicki, Scientific Reports, 10.1, pp. 1-15, 2020.