Identifying subject-specific hybrid dynamic signatures during walking

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Identifying dynamics of intervention response

Responses to clinical interventions for individuals with motor impairments are highly variable[1].

Identifying mechanisms underlying individual responses may inform predictions of intervention responses.

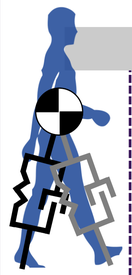
Control of center-of-mass (COM) motion is fundamental to locomotion and may reflect the **complex interactions of altered physiological and neural mechanisms**[2,3].

Quantifying inter-individual **differences in the dynamics describing COM control** provides a step towards mechanism identification.

We identified subject-specific **dynamic signatures: lumped-parameter hybrid dynamics describing COM control** during walking. We expected dynamic signatures to differ between unimpaired individuals and a stroke survivor.

Identifying dynamics of COM control with Hybrid-SINDy[4]

SINDy: Sparse identification of nonlinear dynamics[5]



Collect walking data

7 unimpaired adults [*5 female / 2 male*]

1 female adult stroke survivor with chronic left-leg hemiparesis

Treadmill walking

Generate nonlinear dynamics library

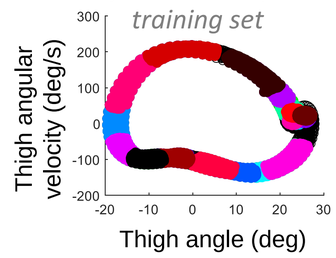
Based on knowledge of the system dynamics for a bipedal spring-loaded inverted pendulum[6]

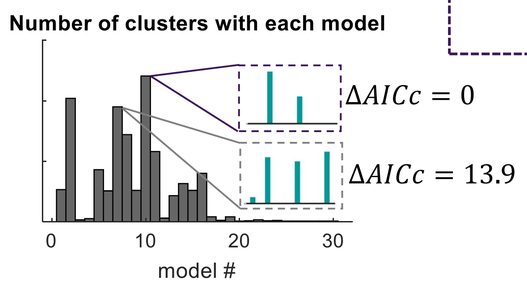
$$\ddot{Q} = f(q,\dot{q}) = A\begin{bmatrix}1 & q_j & \frac{q_j}{L_j} & \frac{q_j}{L_j}\dot{L}_j\end{bmatrix}^{\mathrm{T}}$$
$$j = \{R, L\}$$

$\ddot{Q} = ground\ reaction\ forces\ (proxy\ for\ COM\ acceleration)$
$q = COM\ position\ w.r.t.\ foot$
$\dot{q} = COM\ velocity\ w.r.t.\ foot$
$L = leg\ length$
$\dot{L} = leg\ length\ velocity$

Cluster gait data by kinematic similarity

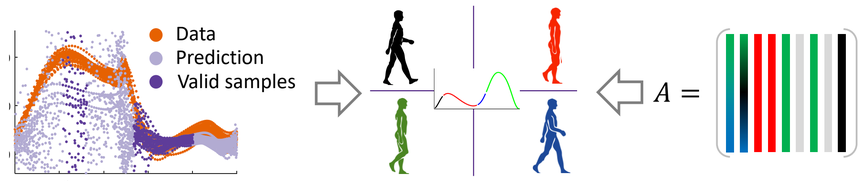
Cluster for each sample in the training set





Select plausible dynamic signatures[4,7]

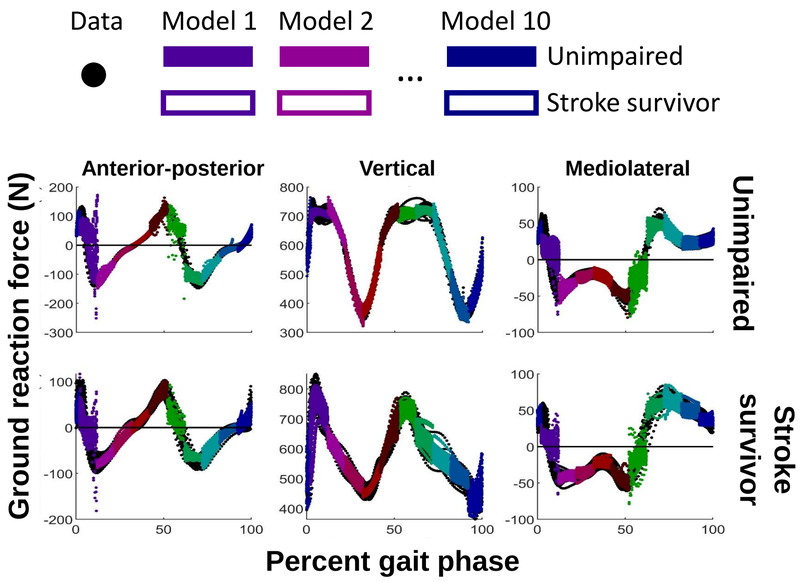
Frequently-identified dynamics that are supported by the relative Akaike Information Criterion ($\Delta AICc$)



Identify sparse hybrid dynamics[4]

For each cluster, fit multiple models of different complexity
Identify gait phases where each model is valid using held-out data

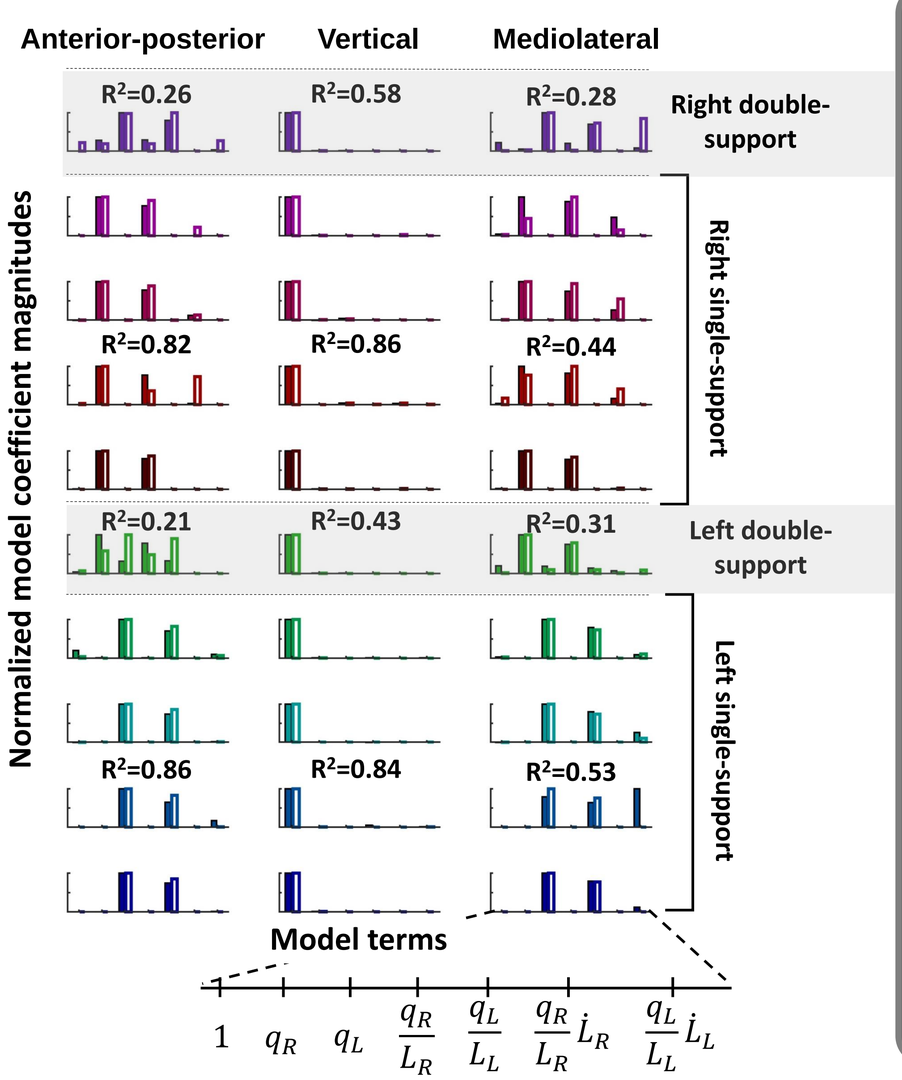
Predictions and dynamic signatures



Unimpaired plausible dynamics were symmetric and predominantly elastic during single-support

The stroke survivor exhibited asymmetric and **viscous dynamics** during single-limb support

Plausible **mediolateral dynamics** during stance were not well identified for all participants (R^2<0.53 ± 0.22)



Implications of identified dynamic signatures

The Hybrid-SINDy algorithm **successfully identified dynamic signatures** in unimpaired individuals and a stroke survivor

- Unimpaired dynamics were consistent with physics-based models of gait[6, 8]
- Asymmetries in the stroke-survivor's plausible dynamics were **consistent with her impairment** and with **post-stroke limb energetics**[3]

Variables reflecting leg angle did not explain mediolateral dynamics across participants[8]

- **Additional input variables may be needed** to determine if (e.g.) an ankle strategy describes mediolateral COM control for some individuals

Identifying nonlinear dynamic signatures may inform experiments to validate potential mechanisms of intervention responses

References

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