Do Switched Linear Dynamical Systems (SLDS) Provide Robust Kinematic Predictions of Healthy Treadmill Gait at Different Speeds?

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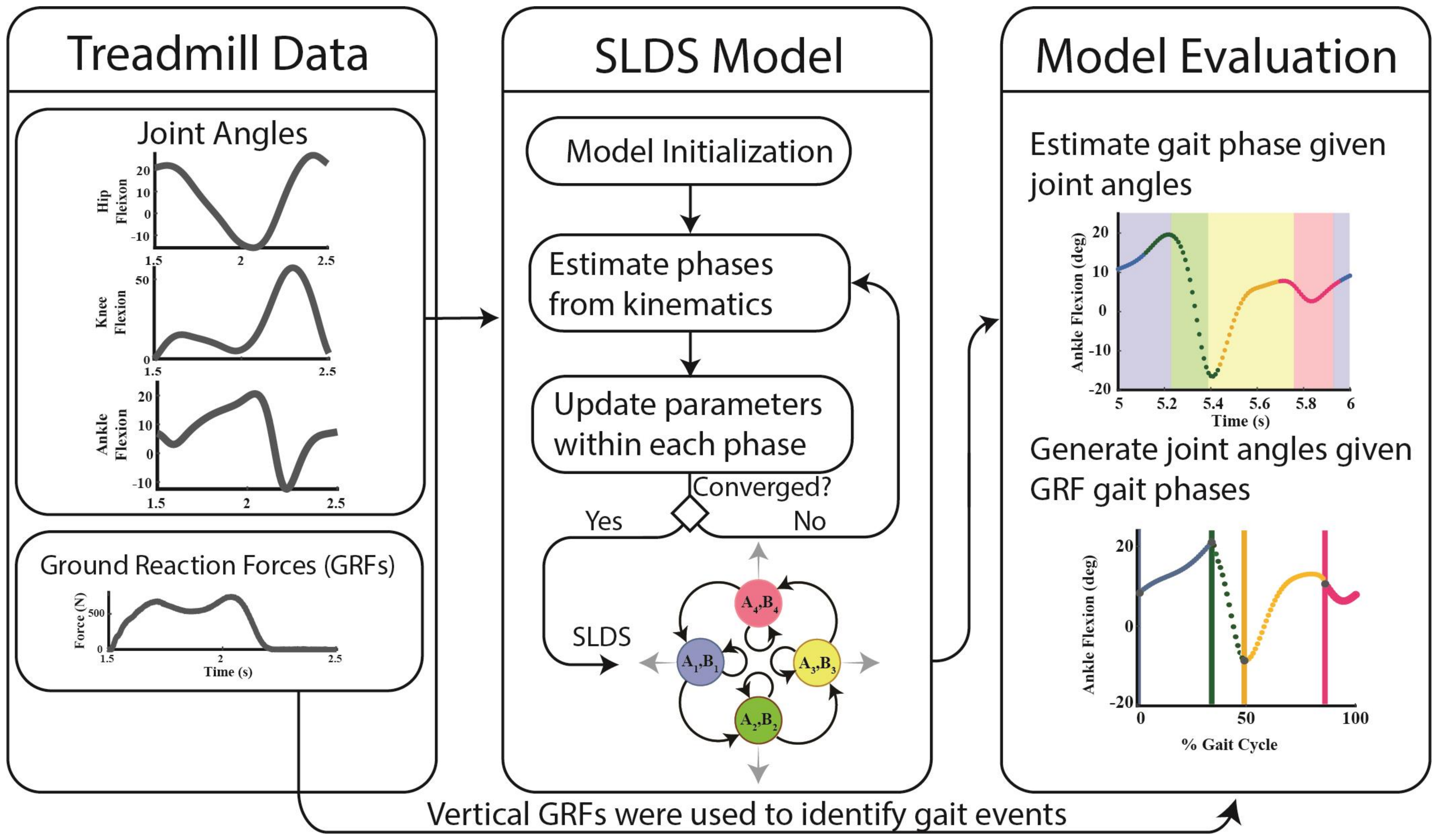
Subject-specific data-driven models can segment gait data into phases as well as predict gait kinematics.

- Recently, data-driven Switched Linear Dynamical Systems (SLDS) models have been used to both infer gait phases and to generate joint angle kinematics of treadmill gait [1].
- An SLDS is a set of linear dynamical systems with discrete modes that govern when to switch between the individual linear models using a Hidden Markovian model approach.
- In [1] four discrete modes were chosen which, after training, correspond closely to 4 interpretable gait phases (2 single support phases: right swing and left swing, and 2 double support phases), and the 4 generated linear models encoded gait kinematics.



- **The input treadmill data** consisted of 45 second trials of left and right sagittal hip, knee and ankle joint angles.
- **The SLDS model** associates each kinematic data point with one of the 4 modes and linear regression is performed on the data in each mode resulting in 4 linear models encoding the gait dynamics.
- **Model Evaluation:** Ground reaction forces used as a gold standard comparison or validation to the SLDS inferred gait phases. Given an initial condition and corresponding gait phase, the SLDS can generate future kinematics which are compared to test data.
- **Limitation:** It is unknown how the SLDS will perform on variable speed systems e.g. over ground walking. If models do not generalize across gait speed, then the capabilities of the SLDS are limited to controlled-speed systems e.g. treadmill walking.

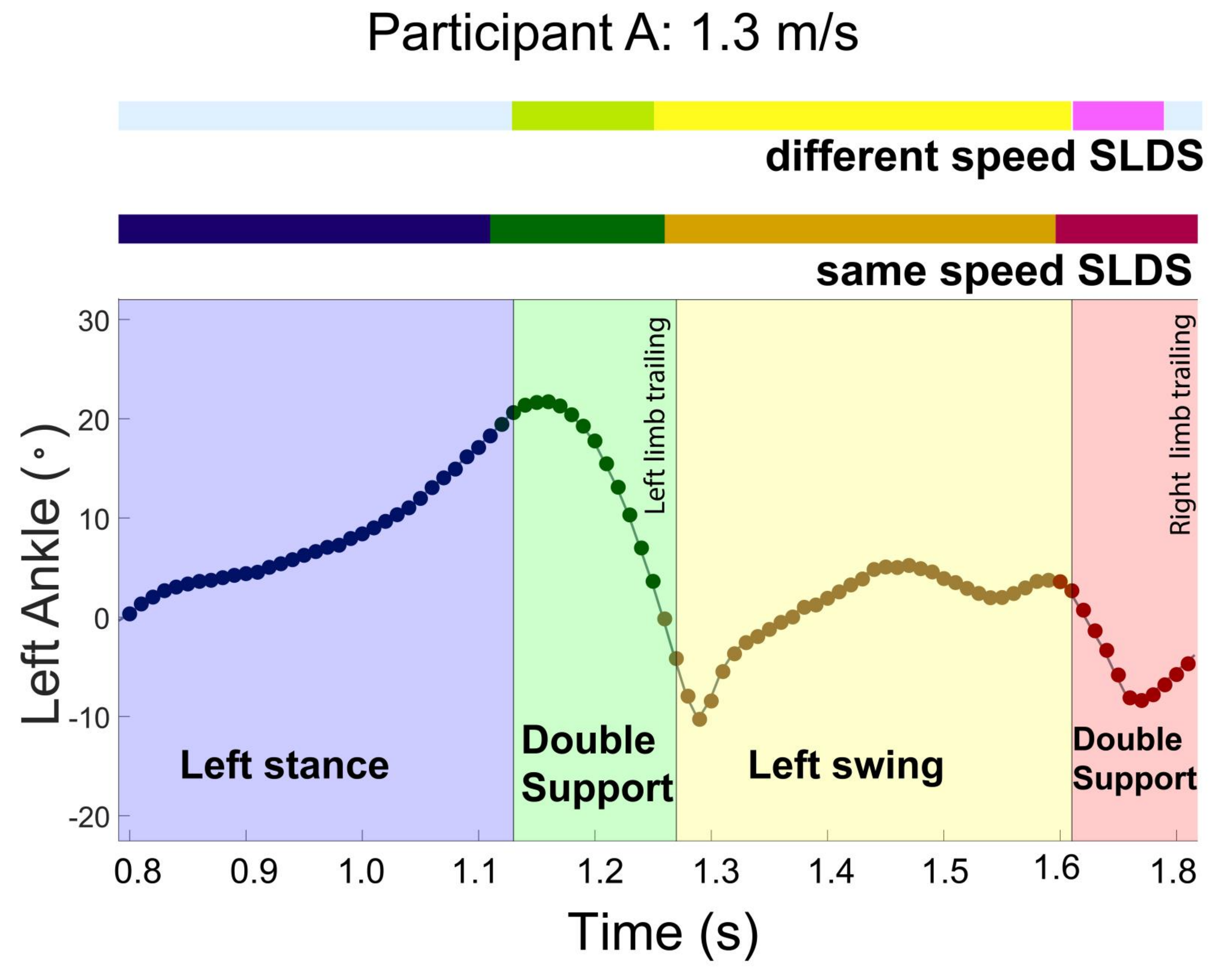
Question: Can SLDS models trained at one speed generalize to other speeds?

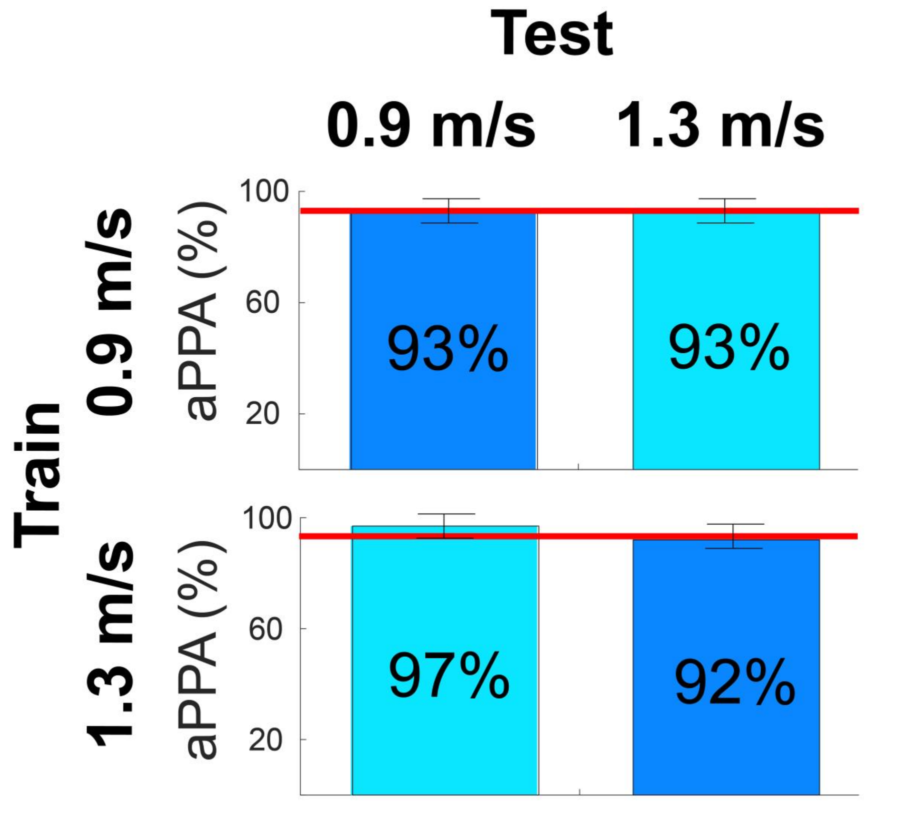
1. Can SLDS models trained at one speed infer gait phases at another speed?
2. Can SLDS models trained at one speed predict and generate kinematic trajectories at another speed?

Methods

- Dataset: two healthy individuals (1 male -28 years, 1 female -28 years) walking on a treadmill at a comfortable self-selected speed and at a fast speed.
- SLDS models were trained and tested on data of the same and different speed.
- Gait phase inference was evaluated by average phase prediction accuracy (aPPA).
- Gait kinematic predictions were evaluated by average root mean square error (aRMSE) across all joint angles.

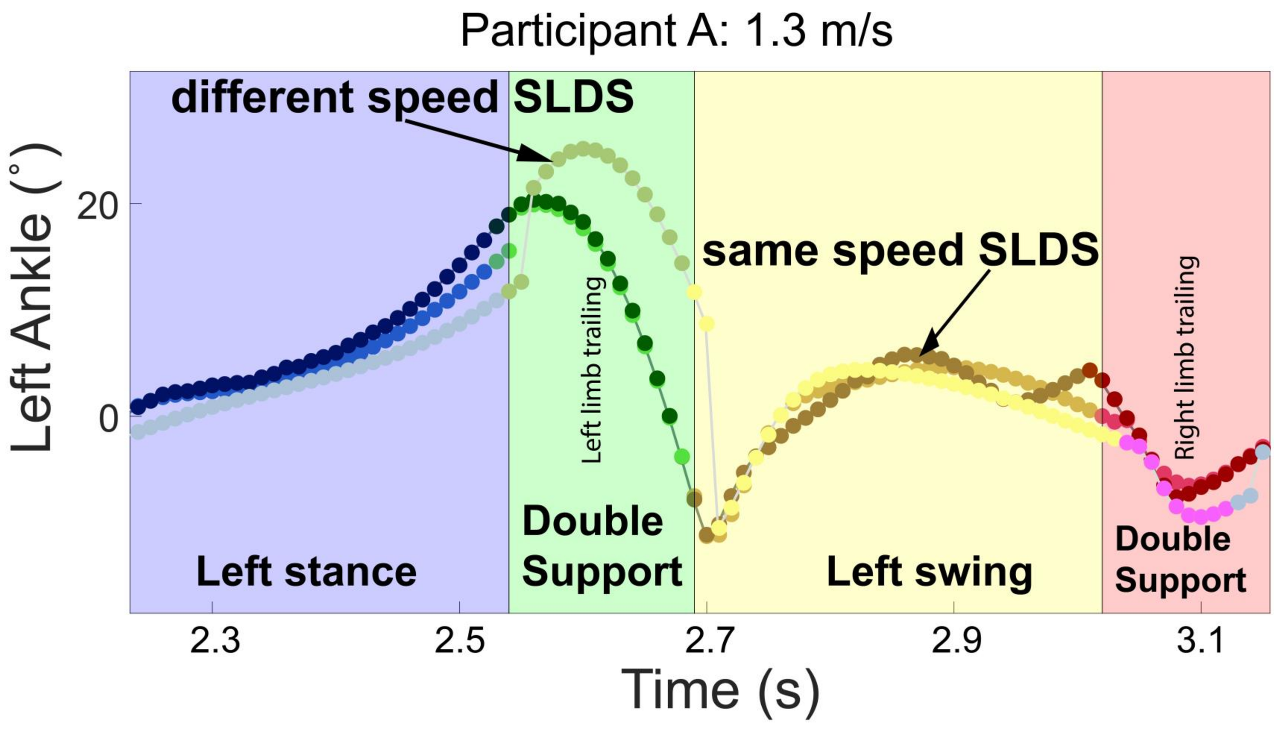
Gait phases were identified with similar accuracy across gait speeds.

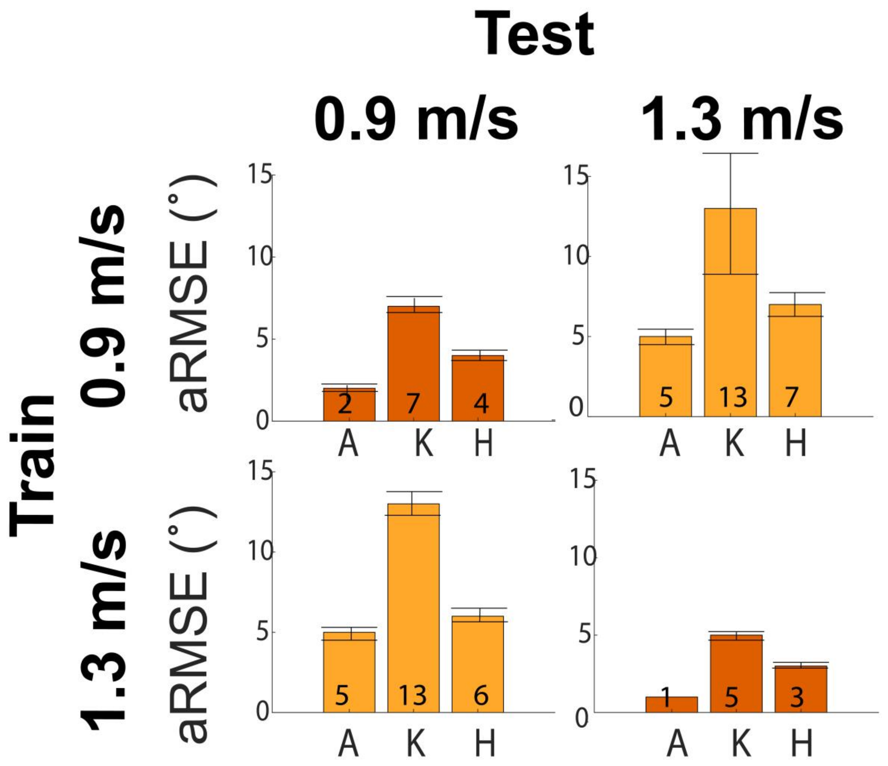


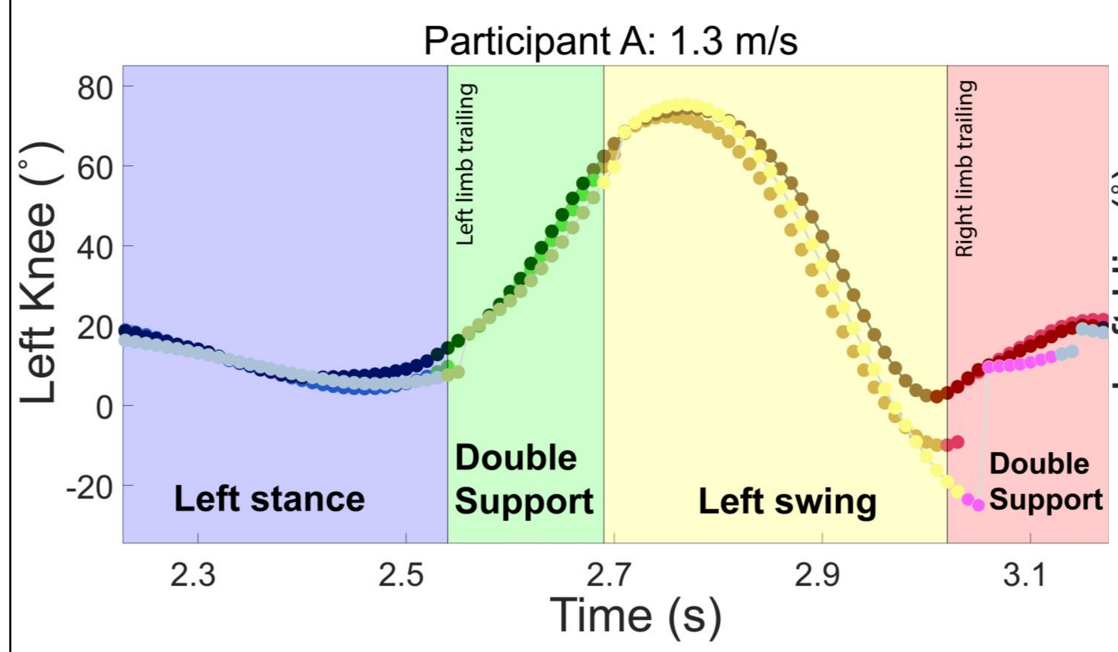


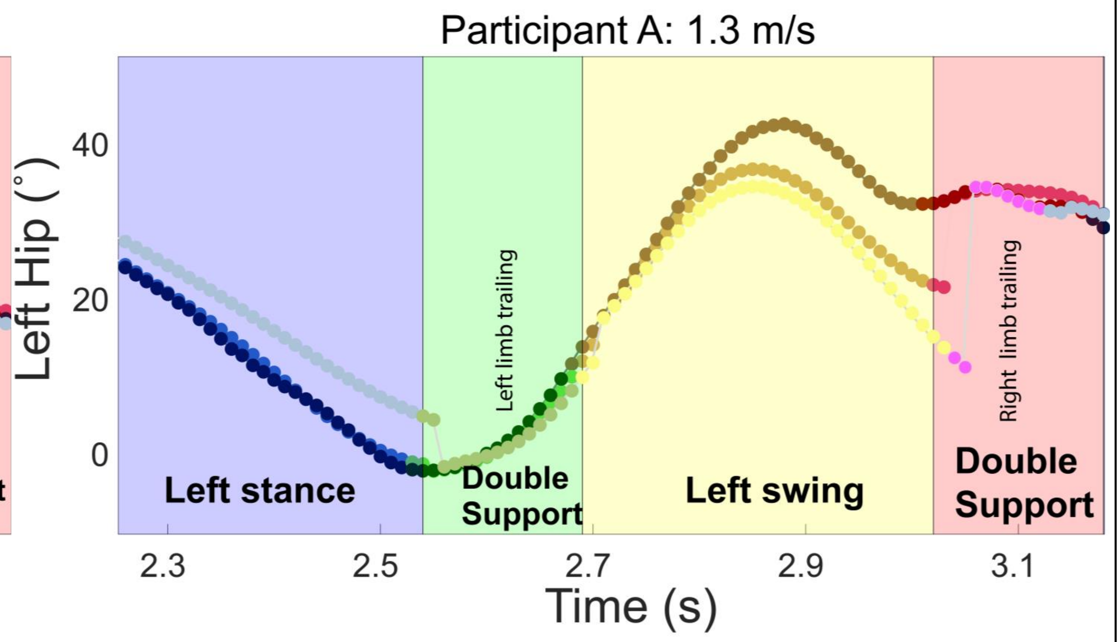
SLDS correctly identifies phases 92% of the time.

Same speed SLDS reconstructions are more closely aligned in gait phase and kinematic predictions than different speed SLDS reconstructions.









Conclusion

- SLDS can infer gait phases correctly 92% of the time for SLDS models trained with data of the same and different speeds. SLDS can be useful for applications where the post hoc determination of gait phase is necessary.
- Kinematic predictions demonstrated larger errors when the model used to generate predictions was trained on data of a different speed, thus accuracy decreases for applications where there are changes in gait speed.

Future Directions

- Further testing of SLDS' ability to generalize across speeds, gait types and gait impairments can potentially allow these individual-specific data-driven, generative models to improve human-robot interactions (HRI) for rehabilitative robotics.

References
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