Functional Muscle Synergies: Interpretable Characterizations of Abnormal Neuromuscular Behavior from Trial Repetitions

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We demonstrate that **decomposing sEMG data** from repeated robot-mediated therapy tasks **using FPCA** can expose interpretable **differences in healthy and post-stroke** neuromotor behavior.

Problem

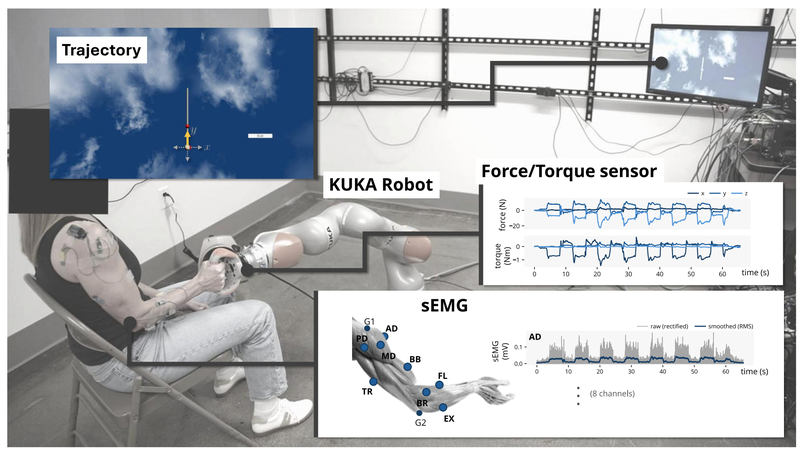
- Understanding whether robot-mediated therapy is effective requires **characterizing whether performed motions are unhealthy and intervening accordingly**.
- Standard synergy-based modeling methods are limited in two ways:
  - They may fail to **distinguish healthy and unhealthy behaviors** for users with milder impairments [1].
  - Their analysis does not **admit clear prescriptions** for how behavior should be modified to reach a healthier state.

Contributions

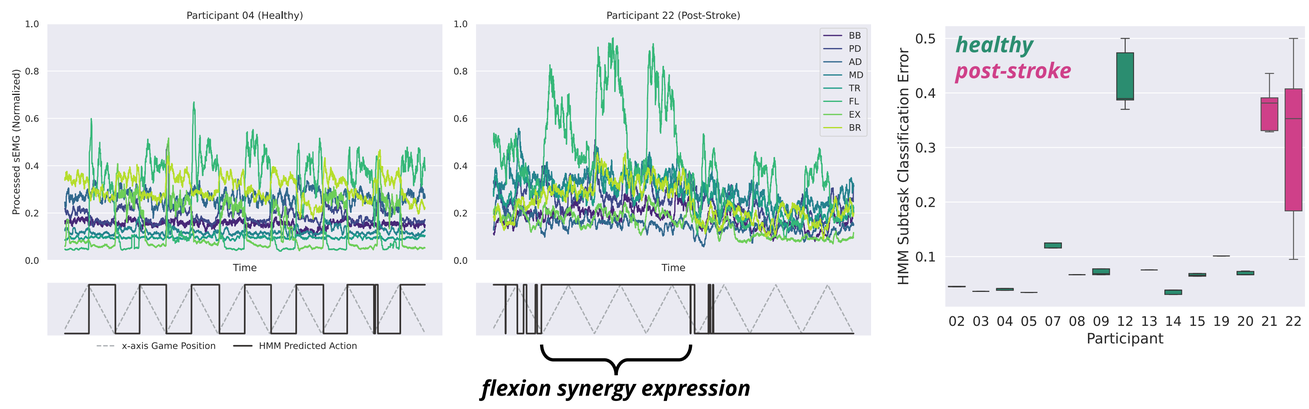
- A novel formulation of **functional principal component analysis (FPCA)** characterizing **the temporal behavior of surface electromyography (sEMG) data** collected during repeated therapy motions
- Proof-of-concept that this **formulation exposes differences between healthy and pathological neuromotor behavior**, even when synergy-based methods do not
- A theoretical framework for **leveraging this formulation to prescribe therapy tasks**

Prior Work: HMM-Based sEMG Analysis

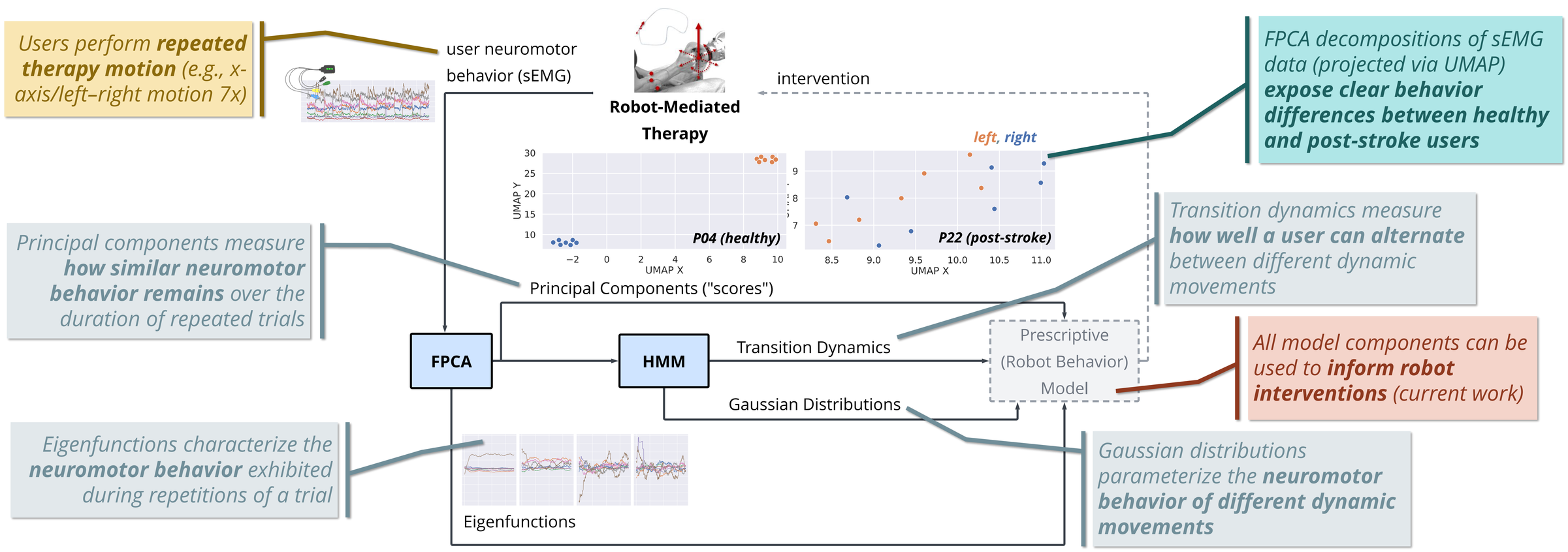
Data from 13 healthy and 2 post-stroke users were collected during isometric trajectory tracking tasks with repeated motions on the **OpenRobotRehab** [1] platform.



Hidden Markov Models (HMMs) were shown to expose temporal irregularities in post-stroke neuromotor behavior not detected via standard synergy analysis [2].



FPCA-Based Neuromotor Behavior Modeling



Significance

- We demonstrate that **our FPCA/HMM modeling method is capable of detecting and measuring temporal and behavioral sEMG patterns that differ between healthy and post-stroke populations** in a data set for which standard synergy methods failed to do so [1].
- We empirically show on a subset of our post-stroke trials that **repetitions misclassified by HMMs exhibit flexion synergy**. This synergy was previously not detected using standard synergy analysis techniques.

Future Work

- **Design prescriptive models** that optimize robot interventions to improve user transition dynamics and user muscle activation patterning
- Test this model's ability to perform on a **larger variety of dynamic tasks**

Acknowledgments / Sponsors / References

The authors would like to acknowledge Ajay Anand, Evan Falconer, Carson Wynn, Chad Berghoff, and Jono Jenkens for their contributions to the OpenRobotRehab system and data collection process.

This work was supported by the Department of Mechanical Engineering at the University of Utah.

[1] Anand et al. (2025) *ICORR*.
[2] Anand et al. (2026) *arXiv:2603.10173.*