Reduced complexity and altered spatiotemporal coordination of fingertip forces after stroke

Department of Kinesiology
Mary Frances Early College of Education
Cognition and Dexterity Laboratory
UNIVERSITY OF GEORGIA

National Institute of Neurological Disorders and Stroke

Patrick Ihejirika[1], Michael Rosenberg PhD[2], Jing Xu PhD[1]
[1]Department of Kinesiology, University of Georgia, Athens, GA;
[2]Department of Biomedical Engineering, Emory University, Atlanta, GA

EMORY UNIVERSITY
Neuromechanics Lab

Introduction

The human hand movement is complex, dynamic and variable. The complexity of hand postures resides on much higher dimensions than previously thought[1]. Much of this complexity is lost after stroke[2], and spatiotemporal coordination is altered. However, how this coordination changes is yet to be elucidated. Here, we quantify and characterize post-stroke spatiotemporal finger coordiantion in isometric fingertip forces.

We hypothesize that paretic hands will have both reduced complexity in finger force coordination and altered coordination patterns compared to the healthy control dominant hands and non-paretic hands.

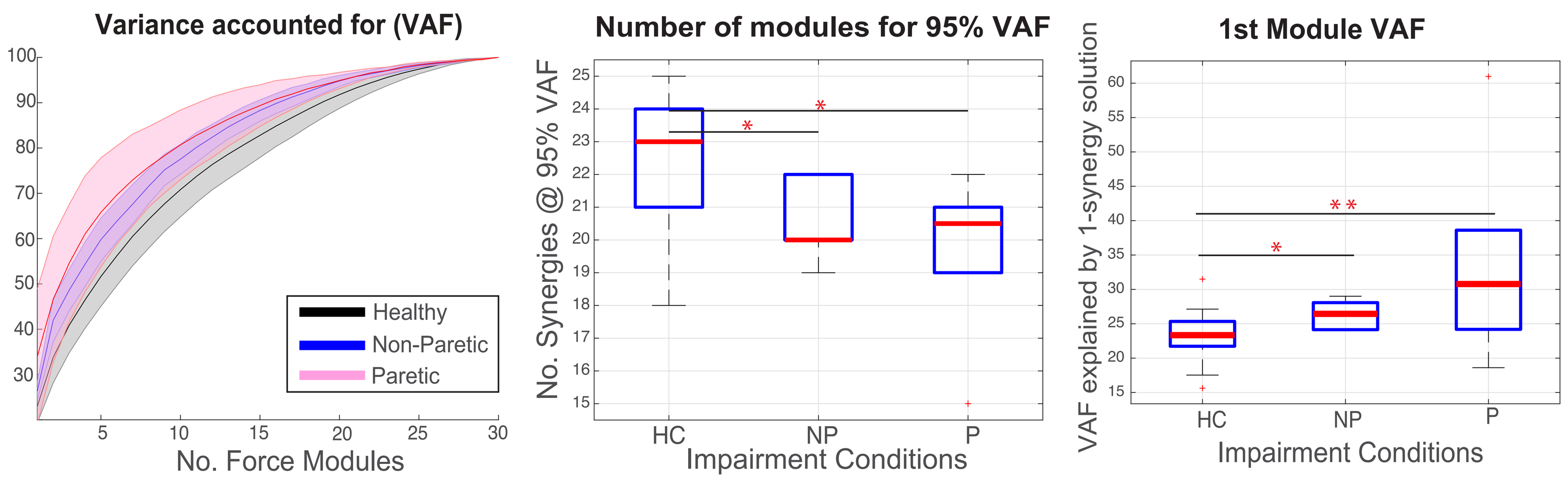
We predict that (1) fewer motor modules will be needed to explain the same amount of variance for paretic hands of the stroke survivors than healthy hands. (2) Modules extracted from paretic hands will poorly reconstruct isometric force trajectories of healthy control hands.

Finger force coordination in paretic and non-paretic hands has reduced complexity than healthy hands

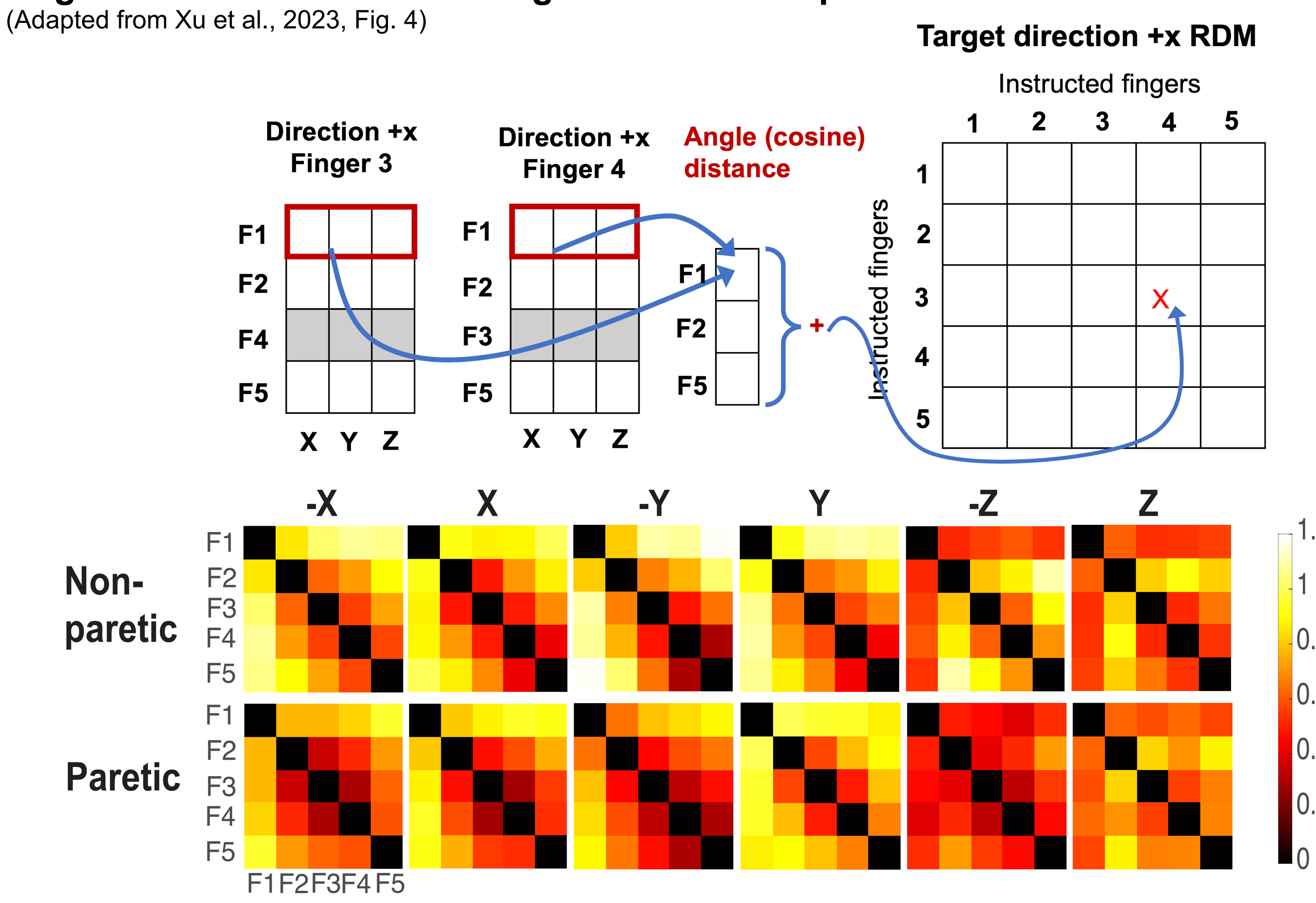
Prediction: Fewer force modules will be needed to explain the same amount of variance for paretic hands of the stroke survivors than healthy hands.

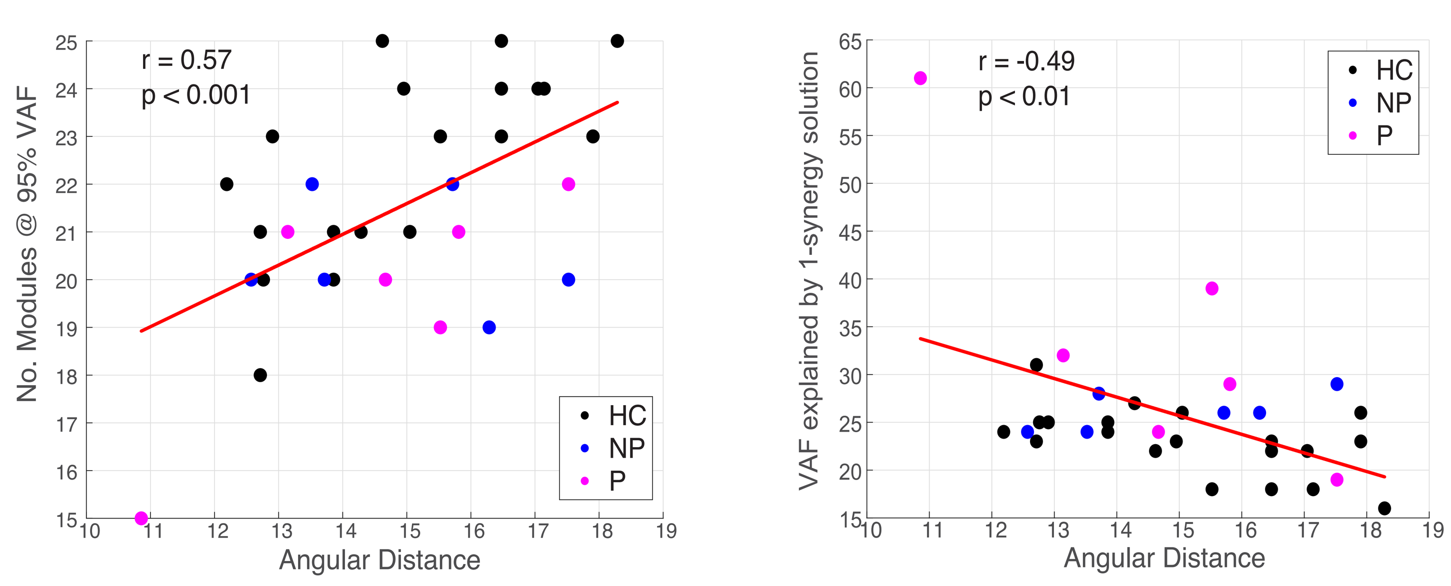
Takeaways:

- Healthy hands required more modules (Mean = 22.5; SD = 1.93) than non-paretic (Mean = 20.5; SD = 1.22; $p < 0.05$) and paretic hands (Mean = 20.5; SD = 1.22; $p < 0.05$) to explain 95% variance of force trajectory data, while non-paretic and paretic hands require similar number of modules.
- VAF for the first module solution for paretic (Mean = 34.0; SD = 14.87; $p < 0.01$) and non-paretic (Mean = 26.4; SD = 2.01; $p < 0.05$) hands were both larger than healthy hands (Mean = 23.0; SD = 3.70), indicating loss of complexity after stroke.
- Strong associations were found between complexity measures using NNMF and previously established Angular Distances between patterns of finger coactivation at end-point postures in the same task[2].



Angular Distances between finger coactivation patterns
(Adapted from Xu et al., 2023, Fig. 4)



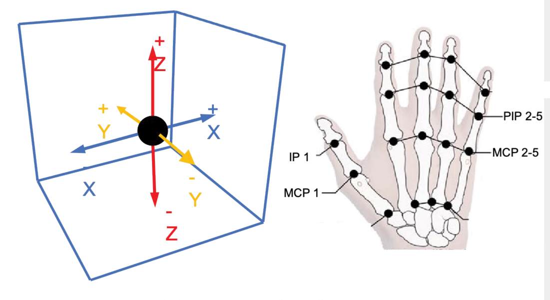


Methods

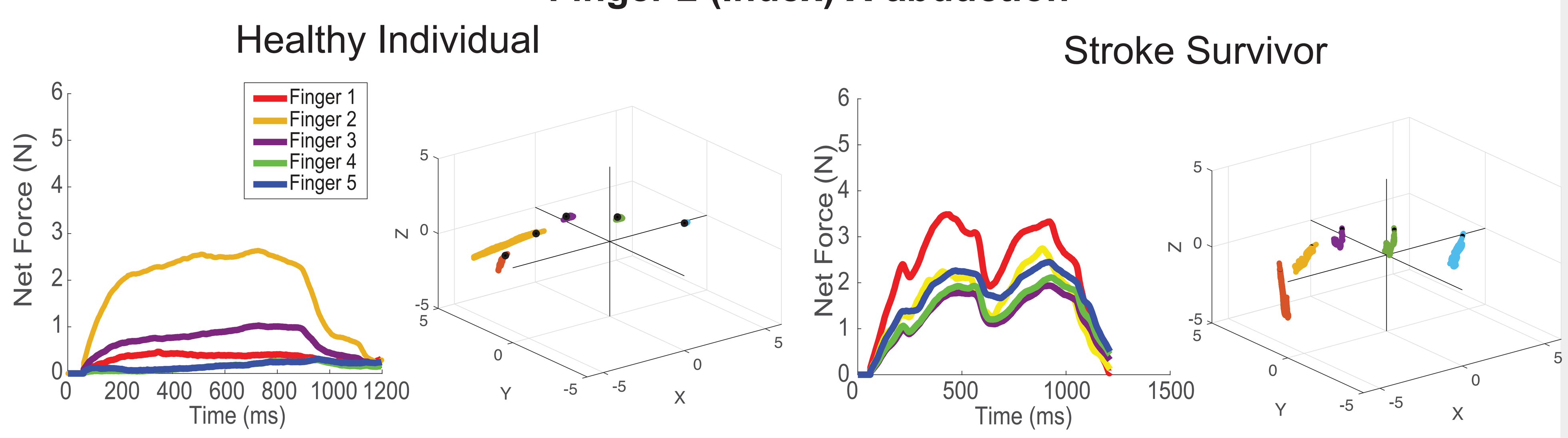
Participants: Healthy older adults (N=20) and individuals post stroke (N=6).

3D Isometric Fingertip Force Recording: Participants were instructed to control a dot in virtual space and move it towards a target in one of six possible directions (abd/adduction along the X axis and flexion/extension along the Y & Z axes) using one (instructed) finger at a time while keeping other fingers inactive. Fingers were kept stationary and the dot's trajectory in virual space was rendered from isometric fingertip forces recorded from the instructed finger. Forces across time from all five fingertips along the X,Y,Z axes were recorded simultaneously[2].

performance videos
healthy hand   paretic hand



Finger 2 (Index) X-abduction



Non-Negative Matrix Factorization (NNMF): Isometric fingertip force data were zero-centered, normalized and concatenated across all task conditions for each subject. Preprocessed data were ran through NNMF to extract force modules for each individual. NNMF has been shown to identify interpretable coordination patterns in movement[3,4]. Weights (W) specifies the isometric forces involved in synergy i. Recruitment of W over time is represented by coactivation (C). ε represents the error between the reconstructed and recorded force trajectories.

$$Force_i = W_i \times C_i + \in$$

Synergy Reconstruction Analysis: We used NNMF to extract spatiotemporal structures of non-impaired individuals' hands, non-paretic hands and paretic hands at 95th% VAF (j) to reconstruct other individuals' isometric finger force data (i). Similar reconstruction analysis was performed by Cheung et al. 2012[5].

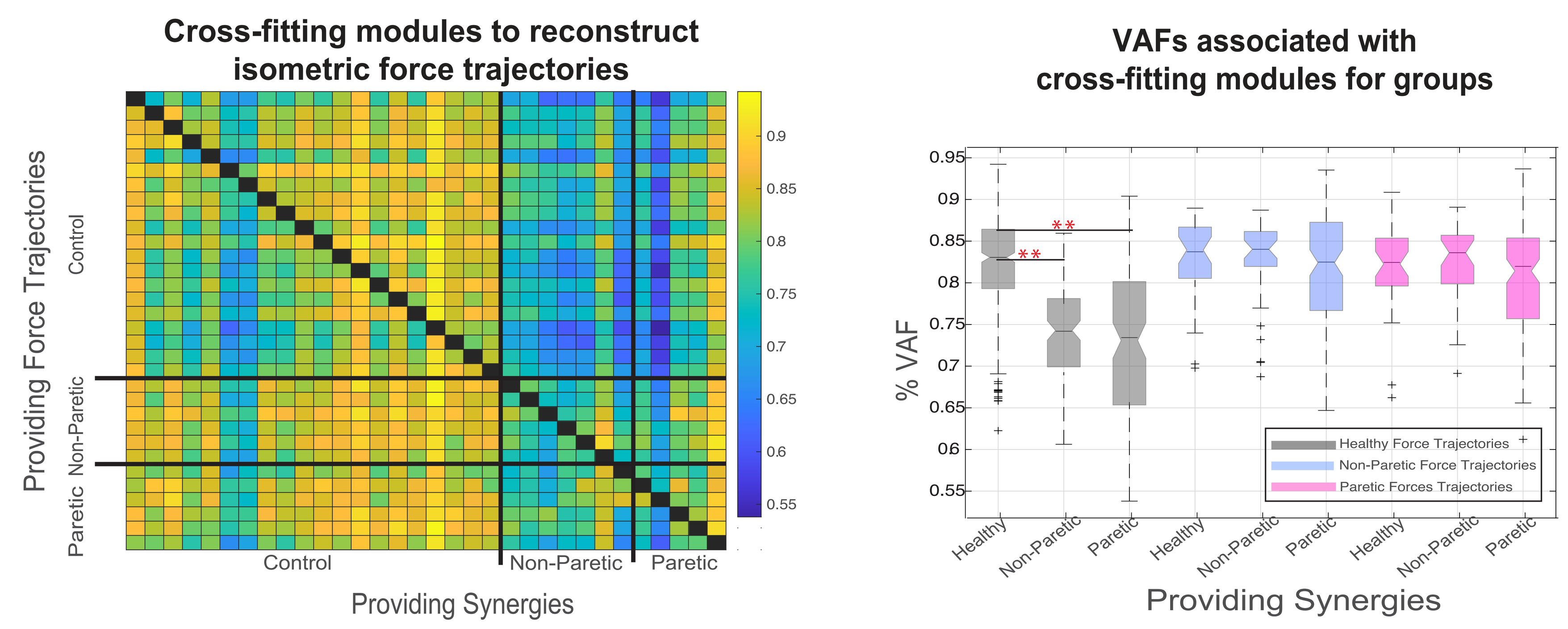
$$Force_i = W_i \times C_j + \in$$

Paretic and Non-paretic hand coordination is different from healthy hand coordination

Prediction: Modules extracted from paretic hands will poorly reconstruct isometric force trajectories of healthy control hands

Takeaways:

- Paretic (VAF Mean = 0.73; SD = 0.09, $p < 0.001$) and non-paretic (VAF Mean = 0.73; SD = 0.06, $p < 0.001$) hand force modules were less able to reconstruct healthy-hand force trajectories compared to healthy hand modules (VAF Mean = 0.82; SD = 0.06).
- Healthy hands were capable of reconstructing isometric finger force trajectories of paretic and non-paretic hands, but not vice versa.



Conclusion and Discussions

Our approach advances prior analyses of hand synergy complexity[1,2], traditionally focused on endpoint postural data, by using the full time series to extract spatiotemporal coordination patterns. We show that loss of complexity after stroke is also present in the spatiotemporal modules.

Beyond showing that post stroke fingertip force production complexity is reduced compared to healthy controls[2], our approach suggests that fingertip force production coordination is altered in paretic and non-paretic hands.

Future Directions...

- Expand the current analyses onto a larger sample size.
- Investigate how stroke affects finger coordination by merging the spatiotemporal coordination motor modules in the paretic and non-paretic hands (e.g., Cheung et al. 2012). This will allow further exploration of how the spatioremporal coordination is altered after stroke.

References

1. Yan, Y., Goodman, J. M., Moore, D. D., Solla, S. A., & Bensmaia, S. J. 2020. Nature Communications, 11(1), 3564.
2. Xu, J., Ma, T., Kumar, S., Olds, K., Brown, J., Carducci, J., Forrence, A., & Krakauer, J. 2023. eLife.91495.1
3. Lee, D. D., & Seung, H. S. 1999. Nature, 401(6755), 788–791.
4. Torres-Oviedo, G., Macpherson, J. M., & Ting, L. H. 2006. Journal of Neurophysiology, 96(3), 1530–1546.
5. Cheung, V. C. K., Turolla, A., Agostini, M., Silvoni, S., Bennis, C., Kasi, P., Paganoni, S., Bonato, P., & Bizzi, E. 2012. Proceedings of the National Academy of Sciences, 109(36), 14652–14656.

Acknowledgements

We thank Dr. Lena Ting for consultation on NNMF analyses.
This project is supported by by: NIH CTSA UL1 award 2UL1TR002378 and and NIH NINDS