Spatiotemporal coordination of fingertip forces during isometric finger individuation reveals differences in complexity between healthy and stroke hands

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Introduction

The complex, dynamic and variable nature of the human hand movement contributes to difficulties in injury assessment and design of effective rehabilitation strategies. Investigating this coordination remains a challenge because it is difficult to quantify across individuals, diseases, and tasks. Previous research has extensively investigated hand posture using dimension-reduction approaches to extract hand synergies, especially principal component analysis (PCA)[1] and recent studies revealed that hand control is more complex and small-variance PCs contribute to the structure of everyday life hand postures[2] and that its complexity is lost after stroke[3]. The Spatiotemporal coordination of multi-finger control is yet to be explored.

Here we investigate the spatiotemporal coordination underlying healthy and paretic hand movement using data-driven approaches to analyze trajectories of isometric fingertip forces:

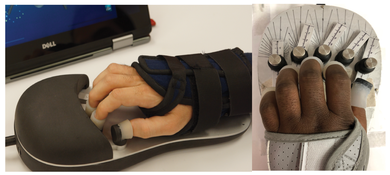
1. Principle component analysis (PCA)
2. Non-negative matrix factorization (NNMF) [4,5] with non-negative constraints and part-based representation potentially yielding more biologically interpretable results.

Hypothesis: Compared to the healthy hands, spatiotemporal coordination underlying **paretic finger control** will be less complex than those underlying the healthy hand, presenting less variances than those underlying healthy hand when performing different tasks, due to the loss of control repertoire.

Methods

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

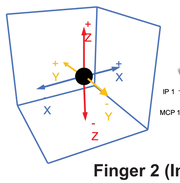
3D Isometric Fingertip Force: Participants were instructed to control a dot in virtual space and move towards a target in one of six possible directions (-X,+X,-Y,+Y,-Z,+Z) using one (instructed) finger at a time while keeping other fingers inactive. Fingers were kept stationary and the dot's trajectory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

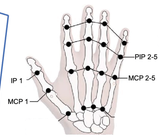


check out performance videos

healthy hand

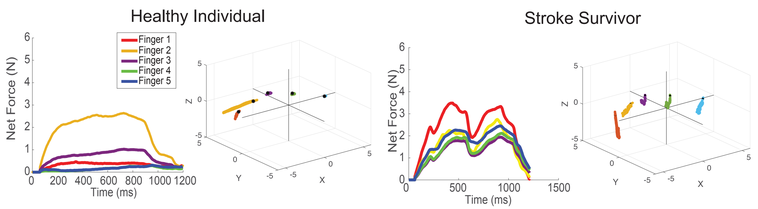
paretic hand





+X: adduction of MCP
-X: abduction of MCP
+Y: extension of PIP
-Y: flexion of PIP
+Z: extension of MCP
-Z: flexion of MCP

Finger 2 (Index) Moving toward X-



NNMF & PCA analysis: Isometric fingertip force data were zero-centered and normalized, and concatenated across all task conditions for each subject. Preprocessed data were ran through NNMF and PCA to extract force modules for each individual.

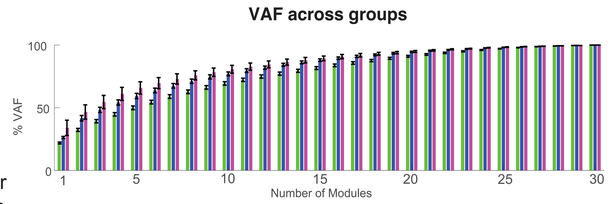
NNMF

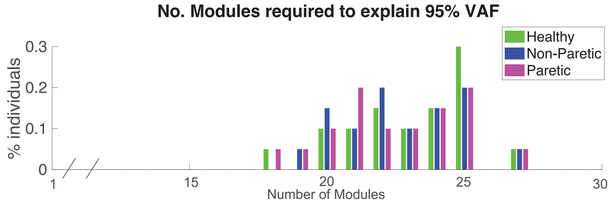
Prediction:

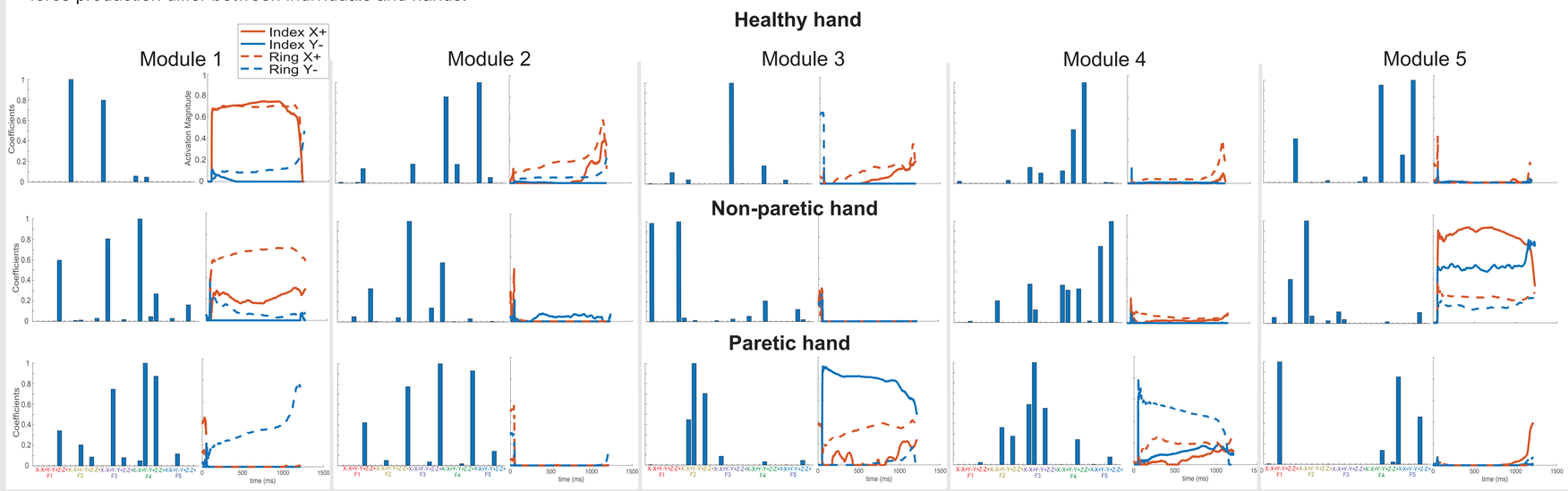
Less motor modules will be needed to explain the same amount of variance for paretic hands of the stroke survivors than healthy hands.

Takeaways:

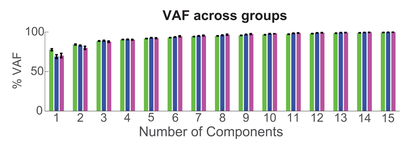
- Force production complexity is likely lower in paretic than non-paretic hands.
- The synergies that explain the most variance in finger force production differ between individuals and hands.

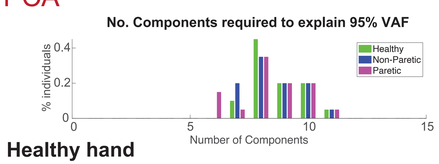


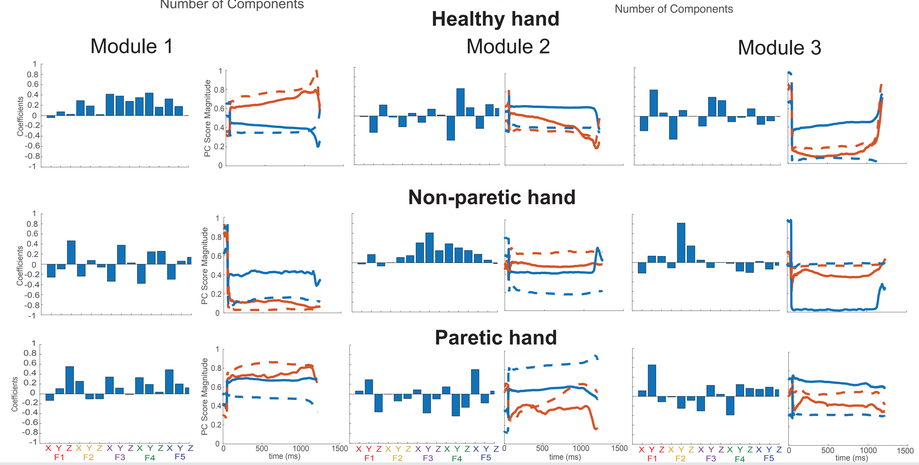




PCA







Discussion

We used data-driven approaches (NNMF and PCA) to reveal underlying spatiotemporal complexity of 3D finger coordinating in a finger-individuation task between healthy and stroke hands.

Our results suggest that similar to previous findings in static posture[3], loss of complexity may also generalize to spatiotemporal coordination in the paretic hands compared to control/non-paretic hands.

However, NNMF and PCA analysis offer different interpretations; PCA results suggests less complex control of force production for control hands while NNMF results suggests lower complexity for paretic hands.

Future analysis will characterize differences in inter- and intra-individual variability in finger coordination during isometric force production between non-disabled controls and stroke survivors.

References

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Acknowledgements

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