Neural Manifolds Underlying Naturalistic Human Movements in Electrocorticography

Zoe Steine-Hanson[1], Rajesh P. N. Rao[1], Bing Brunton[2]
[1] Paul G. Allen School of Computer Science and Engineering, University of Washington; [2] Department of Biology, University of Washington

Introduction

- There has been increasing interest in analysis of low-dimensional neural manifolds, with most studies analyzing neural manifolds during experimentally driven movement tasks in non-human primates [1].
- Recent work on neural manifolds has also explored manifolds in human ECoG data, and found that manifolds in ECoG were aligned across different hand gestures [2].
- However, it remains unknown whether low-dimensional neural manifolds persist during natural movements, or if they are just a by-product of simple experimental tasks [1].

Question: Do low-dimensional neural manifolds exist during natural movements?

Our Approach: We analyzed the alignment of neural manifolds from human ECoG data recorded during free-form natural movements using PCA (Principal Components Analysis) and PAA (Principal Angles Analysis).

TL-DR

> We analyze neural manifolds of human electrocorticography data during natural reaching events using Principal Angles Analysis

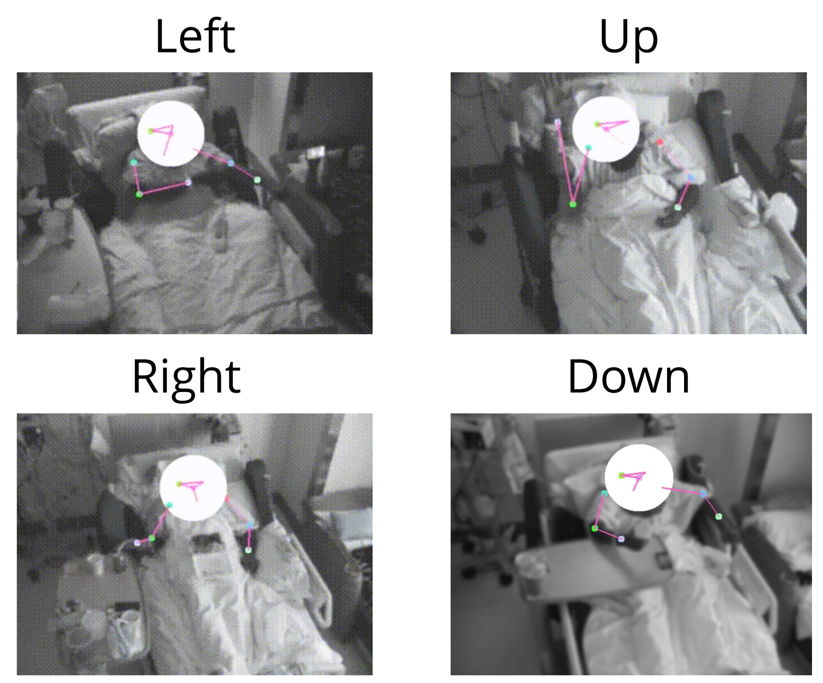
> We find that manifolds across movements, across days and across participants are all more aligned than chance

> These results provide initial evidence for the existence of neural manifolds for the control of naturalistic movements

References
[1] Gallego, J., Perich, M. G., Miller, L. E., & Solla S. A. (2017). Neuron
[2] Natraj, N., Silversmith, D. B., Chang, E. F., Ganguly, K. (2022). Neuron
[3] Singh, S. H., Peterson, S. M., Rao, R. P., Brunton, B. W. (2021). J. of Neurosci. Meth.
[4] Peterson, S. M., Steine-Hanson, Z., Davis, N., Rao, R. P., Brunton, B. W. (2021). J. Neural Eng.

Methods

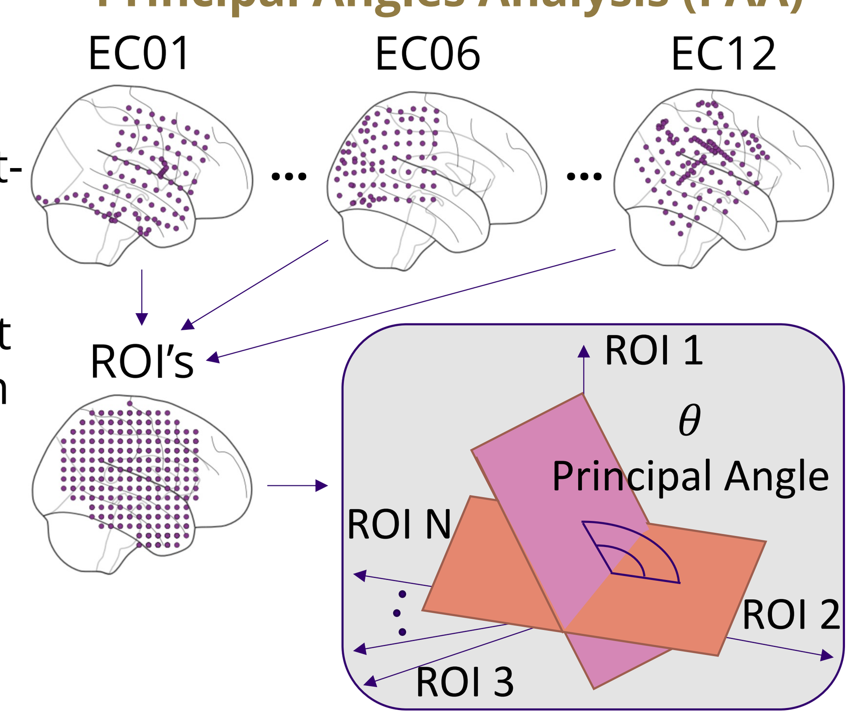
Examples of Movements



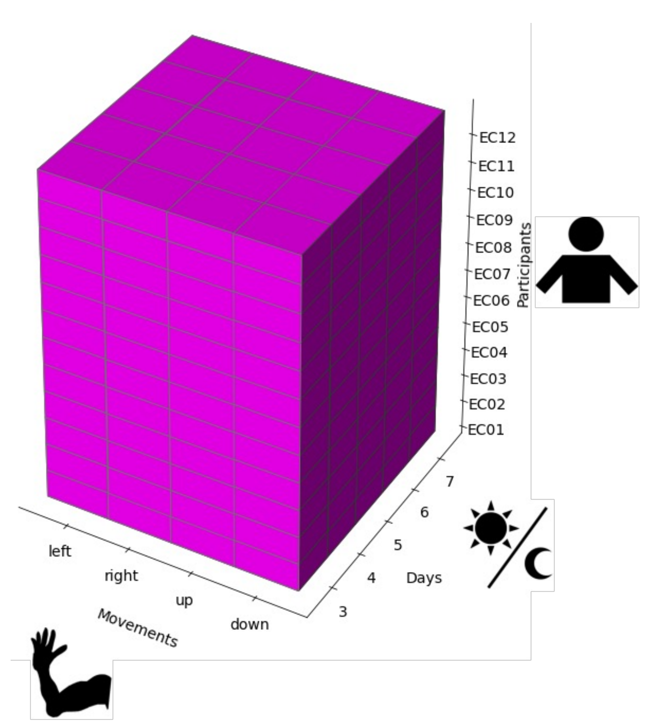
Human ECoG data from 12 participants during their 5 days in epilepsy monitoring. Previous work [3] used computer vision to get the joint poses of participants from video.

Principal Angles Analysis (PAA)

Electrodes were placed by clinical need, so we weight-averaged electrodes onto Regions of Interest (ROIs) [4]. We then filtered down to Low Frequency Oscillations (LFO) (0.5-4Hz) [2] and ran PCA.



Dimensions of the Data



Neural Dissimilarity: We analyzed the pairwise comparisons of the manifolds using PAA, such that small principal angles indicate less dissimilarity between manifolds. We sum all angles and normalize to create our neural dissimilarity metric.

Null Comparison: We generate a distribution of null data to confirm the significance of the manifold alignment using Tensor Maximum Entropy (TME), which generates surrogate data with the same first and second order moments as the ECoG data [2].

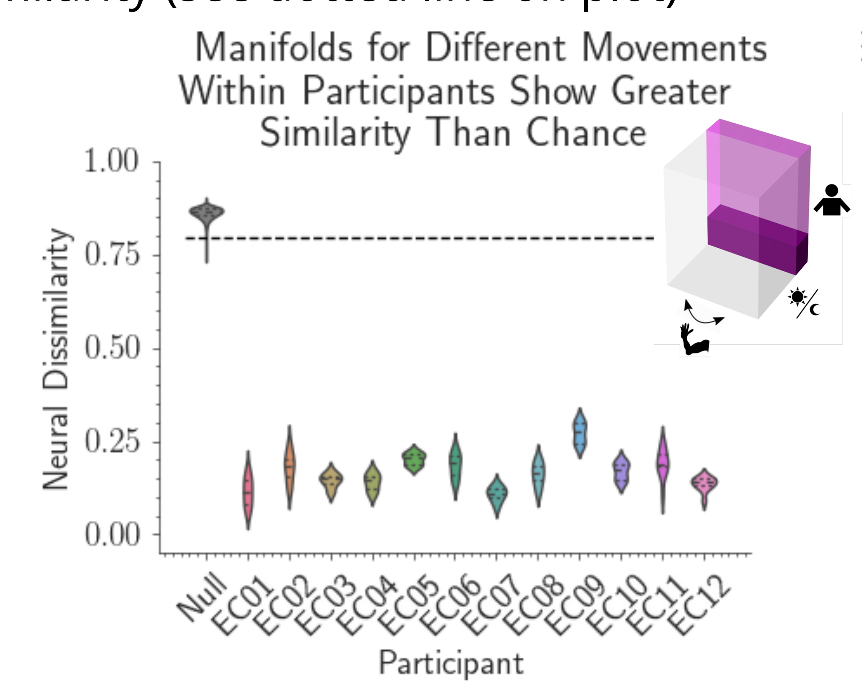
Cross-Movement Manifolds

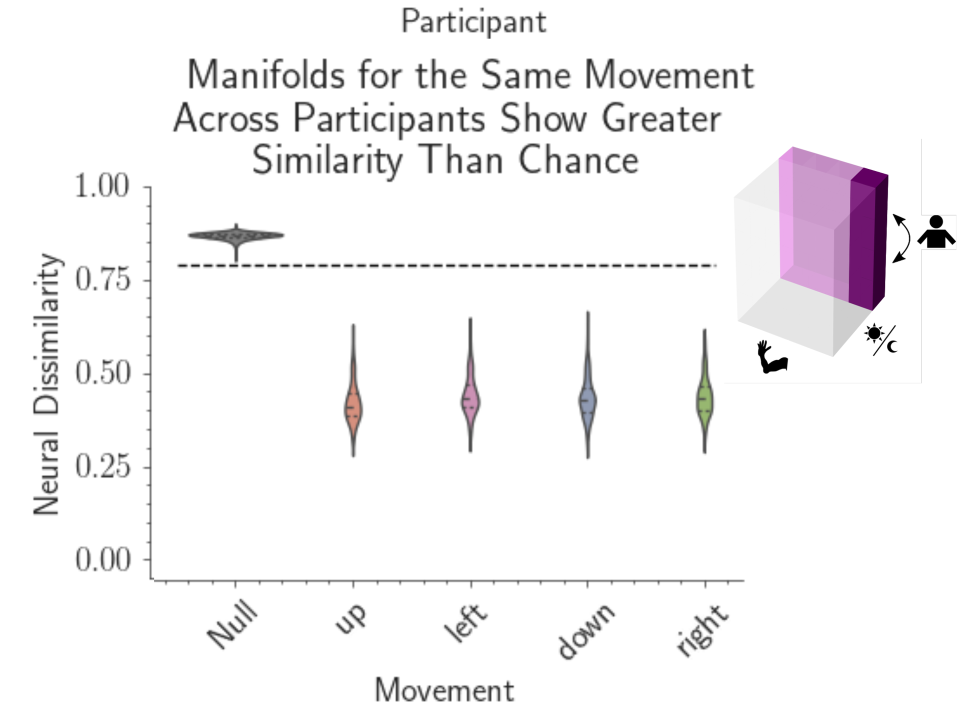
We compare the dissimilarity of the manifolds of 4 different movement types from one day

> The manifolds occupy a low dimensional subspace, with 80% variance accounted for by 9 PC's

> The average neural dissimilarity across movements for all participants was 0.17

> The 1% significance level, as defined by the null data generated with TME, had 0.79 neural dissimilarity (see dotted line on plot)



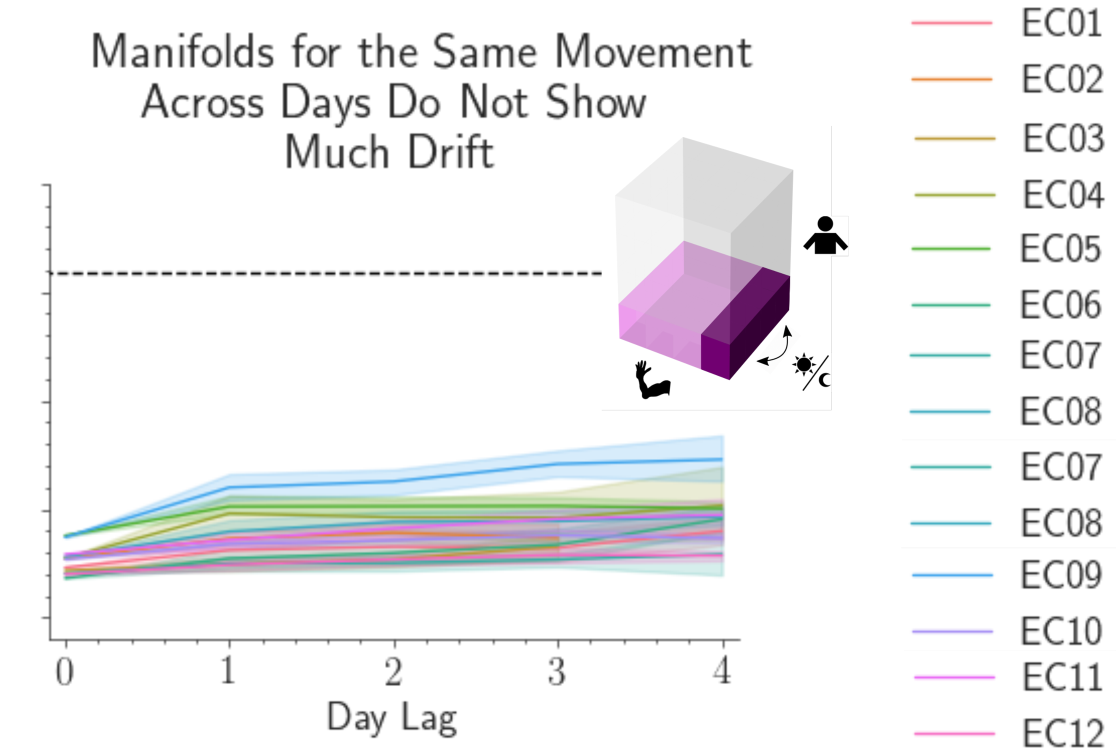


Cross-Participant Manifolds

We compare the dissimilarity of manifolds on the same movement type across all participants and days.

> The average neural dissimilarity across participants for all movement types was 0.43

> Participants with lower electrode overlap in their original electrode coverage had higher dissimilarity between participants (r-squared of -0.51)



Cross-Days Manifolds

We compare the similarity of the manifolds of the same movement type across days for the same participant.

> Neural manifolds of the same movement did not drift significantly over the course of the 5 day hospital stay

> The average neural dissimilarity across days for each type of movement and participant was 0.16

Discussion

Overall, our results provide initial evidence for the existence of neural manifolds for the control of naturalistic movements.

> Further analysis of the dynamic trajectories within these manifolds could reveal insights into the control of natural movement

> Future work could explore non-linear methods to uncover these manifolds

> Future work could explore a more fine grained analysis of the movements, rather than breaking reaches into 4 categories

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