Communication Subspaces for Local Field Potential Defined Network States

Ziyi Guo[12], Ryan A. Young[2], and Shantanu P. Jadhav[123]

[1]Department of Psychology, [2]Program in Neuroscience, [3]The Volen National Center for Complex Systems, Brandeis University, Waltham, MA

Scan for addenda and updates about the project!

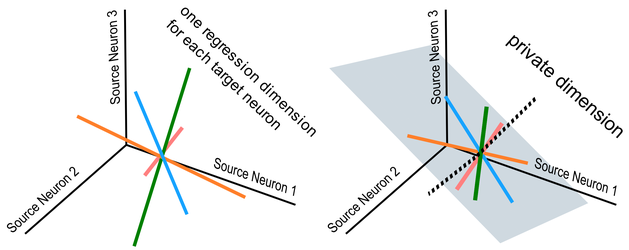
Introduction

- The hippocampus (HPC) and prefrontal cortex (PFC) work in an integrated fashion to support cognition and memory-guided behavior (e.g., Zielinski *et al*., 2020).
- The rhythmic fluctuations in the local field potentials of HPC and PFC have been shown to reveal broad behavioral states (e.g., movement) and periods of inter- and intra-regional communication.
- Do covarying HPC-PFC cellular ensembles differ during these oscillatory patterns? Do network patterns increase or decrease the directions of influence within an ensemble interaction space?

Methods

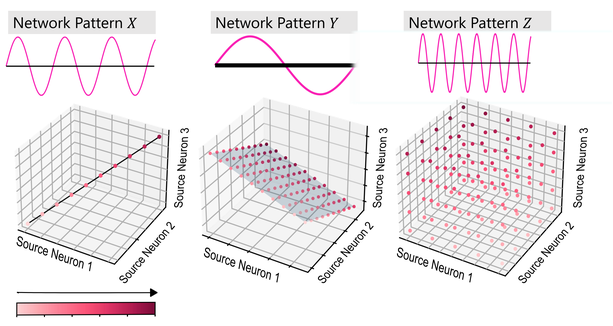
- 5 animals, 32-64 tetrode HPC (CA1)-PFC recordings
- Firing rate matched cellular partitions were created for source and target brain areas
- High and low activity periods of cell firing were extracted for theta (6-12Hz), delta (0.5-4Hz), and shape-wave ripples (150-200Hz)
- Spiking activities separately subjected to reduced-rank regression (Semedo *et al*. 2019):

$$\hat{Y}_{target} = X_{source}\, B_{rrr} = X_{source}\, B_{ols} V V^T$$



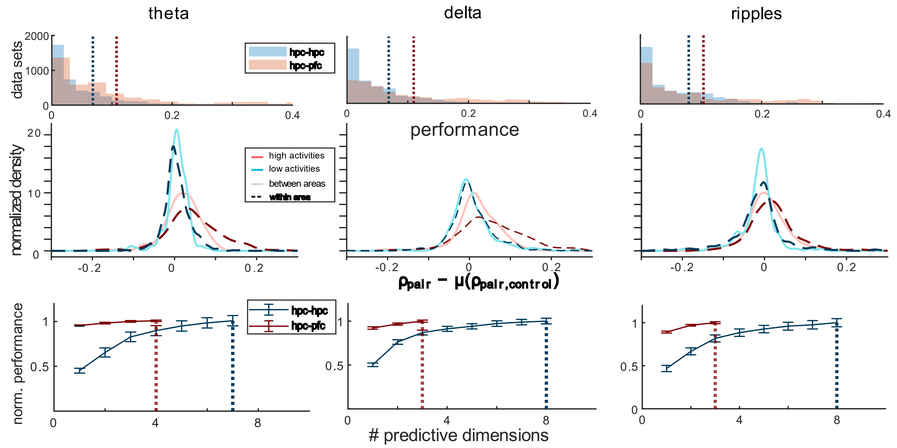
High vs. low dimensional interactions

Left: target activities span the whole source activity space.
Right: target activities span a subspace of the source activities. Dimensions outside such subspace is private to the target region.



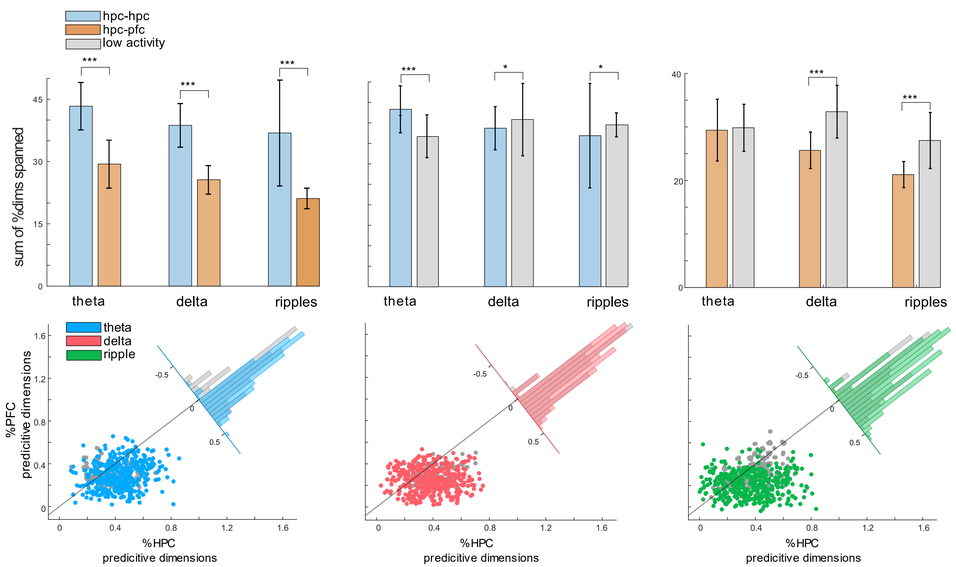
Dimensions of spiking interactions differ by network patterns

Results



Neuronal interaction strength is stronger during rhythmic network patterns, both within and between regions; Prediction performance can be captured with a few dimensions.

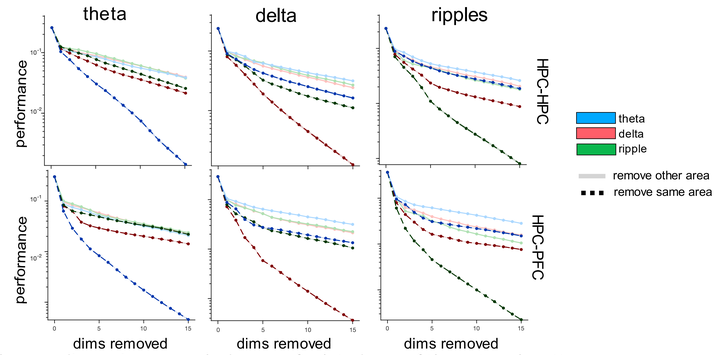
Top: variance explained through ordinary least square prediction matrices within(blue) and among(red) regions with significant differences (all p's <0.001), dashed lines showing the medians.
Middle: pairwise correlation of cell firing during oscillation activities of different strengths.
Bottom: normalized performance as predictive dimensions increase, dashed lines showing the optimal dimensions.



Predictive dimensions differentially modulated for high/low network pattern activity during inter- and intra-network interactions.

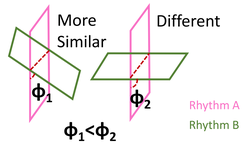
Top left: sum of %dimensions spanned in the target space during different patterns. ANOVA showed significant difference among the patterns and Wilcoxon paired t-tests showed significant difference among different regional interactions (all p's < 0.001). Top middle and right: sum of %dimensions spanned in the target space during periods of high vs. low activities.
Bottom: lower dimensional interactions between brain regions as compared with within brain regions.

Results (cont')

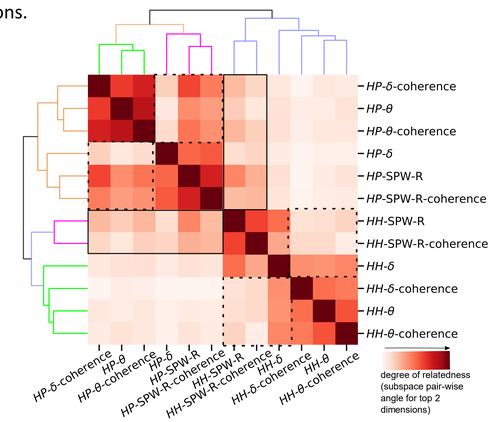


Removal of subspace dimensions reveals degree of relatedness of the network patterns.

Predictive performance of regression as dimensions of each rhythm are sequentially removed from each subspace of theta (left, blue), delta (middle, red), and sharp-wave-ripple (right, green) during HPC-HPC (top) and HPC-PFC (bottom) interactions.



Subspace similarity assessed by the degree to which their subspace content overlaps: the angle between spaces and degree to which removing the neural firing of one space affects another.



Conclusions

- Ensembles of co-fluctuating neurons in the HPC and PFC reveal a substructure of interaction during unique hippocampal activity patterns.
- Local-field network patterns have lower dimensional neuronal interaction between as opposed to within brain regions.
- Subspace distances suggest within and between brain area spaces cluster into hubs of overlap for inter and intra region interactions, respectively.
- Inter/intra region clusters potentially connected by SPW-R subspaces.

References & Acknowledgements

1. Semedo et al. *Neuron*, vol. 102, no. 1, pp. 249-259.e4, 2019.
2. Zielinski et al. *Hippocampus*, vol. 30, no. 1, pp. 60-72, 2020.

This research was conducted as a part of the Brandeis Computational Neuroscience Traineeship Program under NIH Training Grant 5R90DA033463-09. It was also supported by NIH Grant R01 MH112661. Many thanks to members of the Jadhav Lab and friends who helped and supported me in this project.