Building a "cognitive map" of a reward-based motor skill learning

Yera Choi, Emily Yunha Shin, Hyeonjeong Lee, Sungshin Kim

Computational Learning & Memory Neuroscience Lab

Th647

Introduction

- In motor skill learning, new patterns of movements are acquired, with guidance of feedbacks such as reward.
- Many studies on motor skill learning adopted *motor sequence learning paradigms*, which generally incorporate rather familiar movements (e.g., pressing a button) in novel sequences.
- To investigate the neural correlates underlying the acquisition of a real "*de novo*" motor task, we designed a novel fMRI experiment, which adopted a high-dimensional *de novo* motor skill learning paradigm using a MR-compatible data-glove.
- "Cognitive map"
  - Represents one's cognitive map knowledge of spatial relationships (Behrens et al., 2018)
  - "Navigating" a 2D space by changing one's hand postures in a high-dimensional motor space may reveal a "cognitive map" of complex motor skill learning
  - (We initially assumed the involvement of the hippocampus and/or entorhinal cortex, due to the "spatial" component of the task)

Research questions

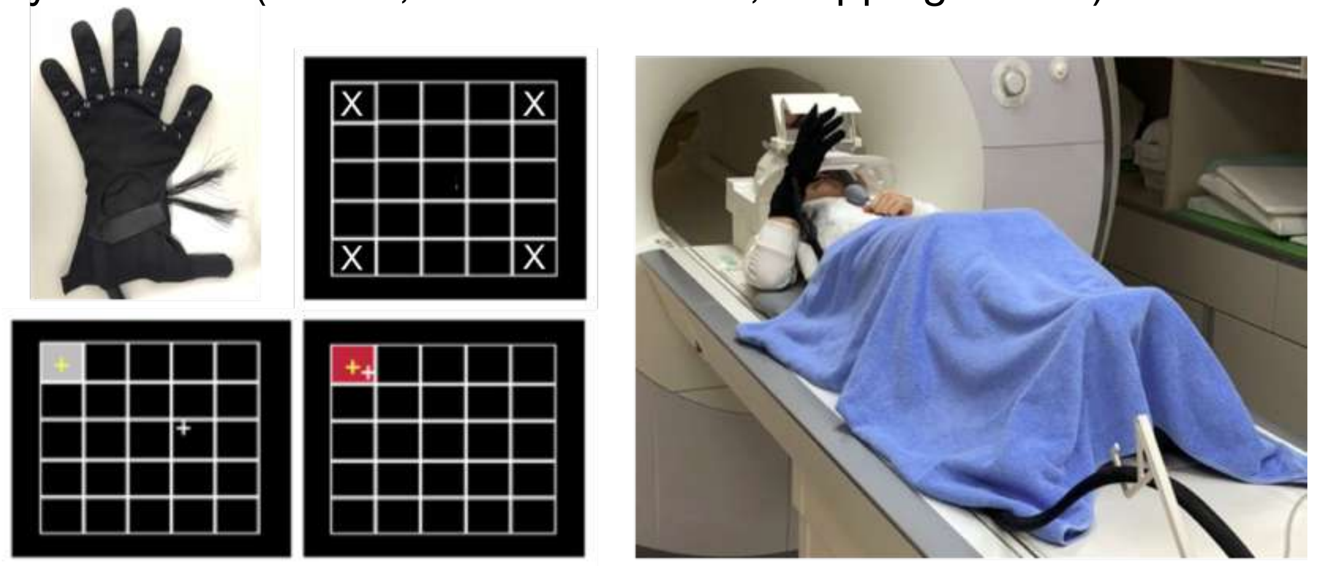
- How does "*de novo* motor skill learning" get represented in the brain?
- Can we find evidence of a "cognitive map" for complex motor skill learning?
  - How does extensive motor training change the representation of task states (e.g., target position, path from the previous target to the current target)?

Experimental design

- **Participants**: 30 young healthy right-handed participants (12 females)
- **Task**: To move cursor to reach targets on 5 x 5 grid, using an MR-compatible right-handed data glove with 14 sensors measuring hand joint angle
  - 14D vector (h) representing hand posture linearly mapped onto 2D cursor position (p) on screen, using principal component analysis (Ranganathan et al., 2013)

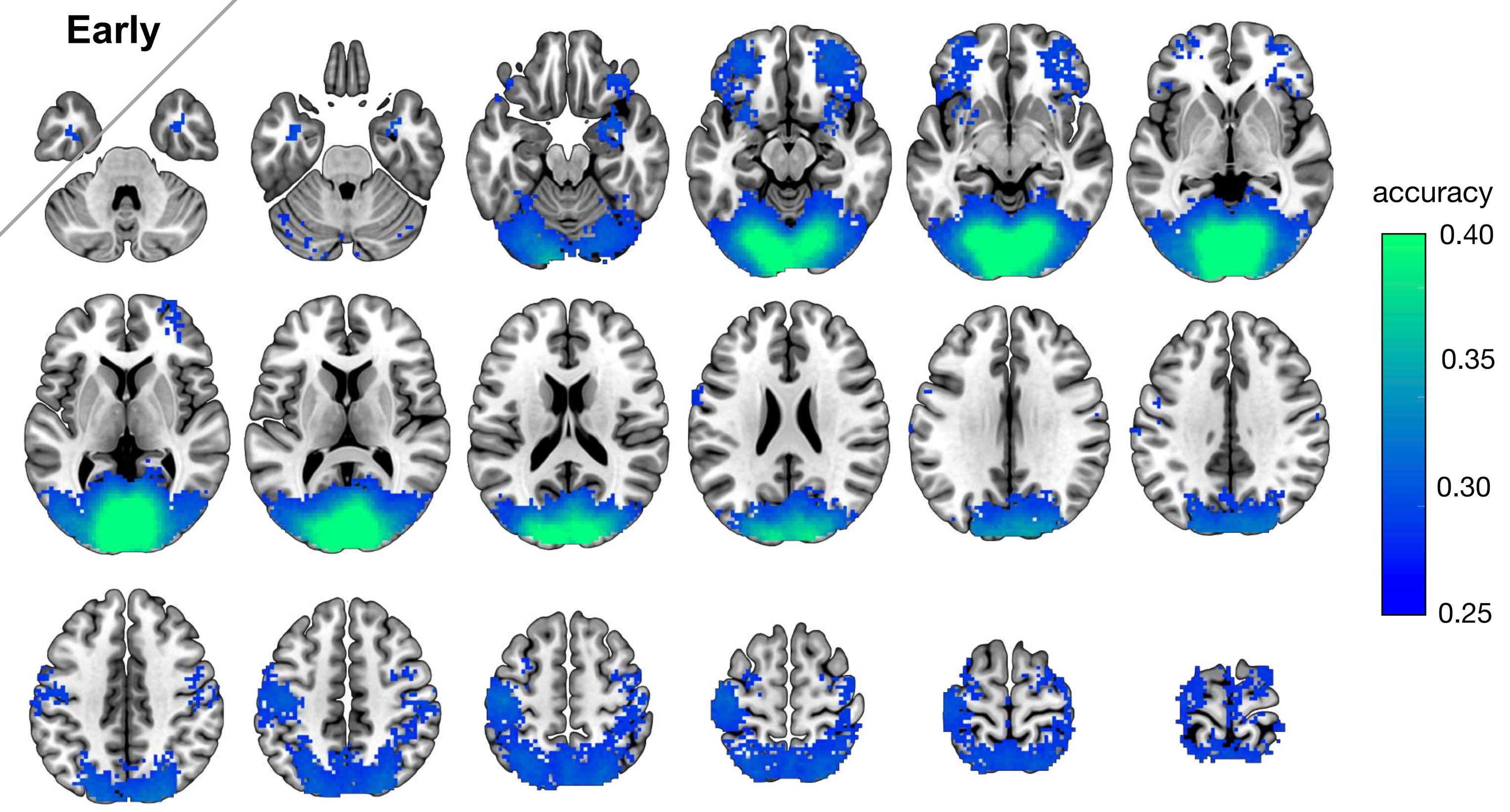
$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,13} & a_{1,14} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,13} & a_{2,14} \end{bmatrix} \times \begin{bmatrix} h_1 & h_2 & \ldots & h_{13} & h_{14} \end{bmatrix}^T + \begin{bmatrix} x_0 \\ y_0 \end{bmatrix}, \quad \text{i.e.,} \quad \mathbf{p} = \mathbf{Ah} + \mathbf{p_0}$$

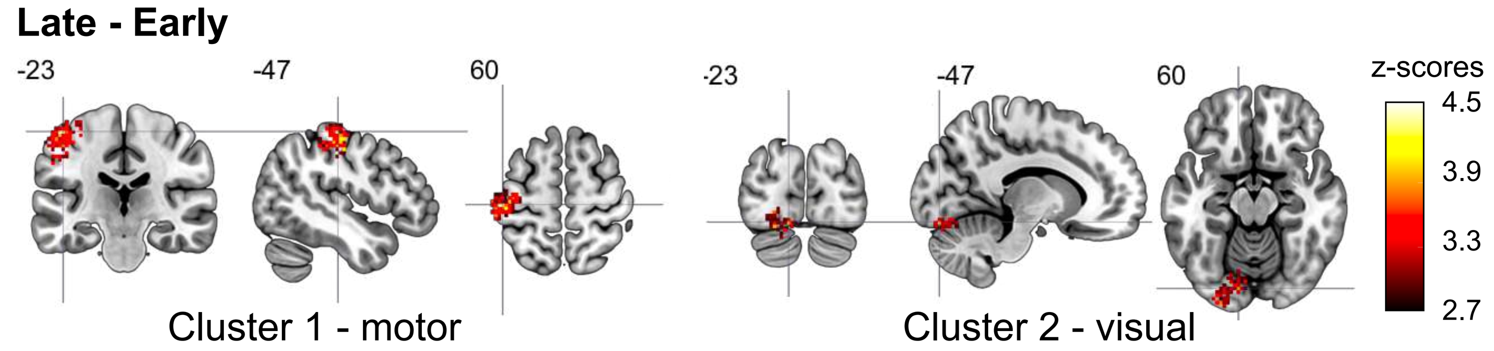
- **Targets**: Presented at one of 4 grid corners every 5 seconds
  - Sequence were designed such that 12 different paths between targets repeated
- **Mappings**
  - Mapping A **(Practiced):** X - 1st PC, Y - 2nd PC
  - Mapping B **(Unpracticed):** X - 2nd PC, Y - 1st PC, counterbalanced across participants
- **Learning schedule**
  - Day 1: Calibration, Pre-training, fMRI 1 (**"Early"**, 97 trials x 7 runs, Mappings A & B)
  - Days 2-6: Behavior Training 1-5 (Mapping A only)
  - Day 7: fMRI 2 (**"Late"**, 97 trials x 7 runs, Mappings A & B)



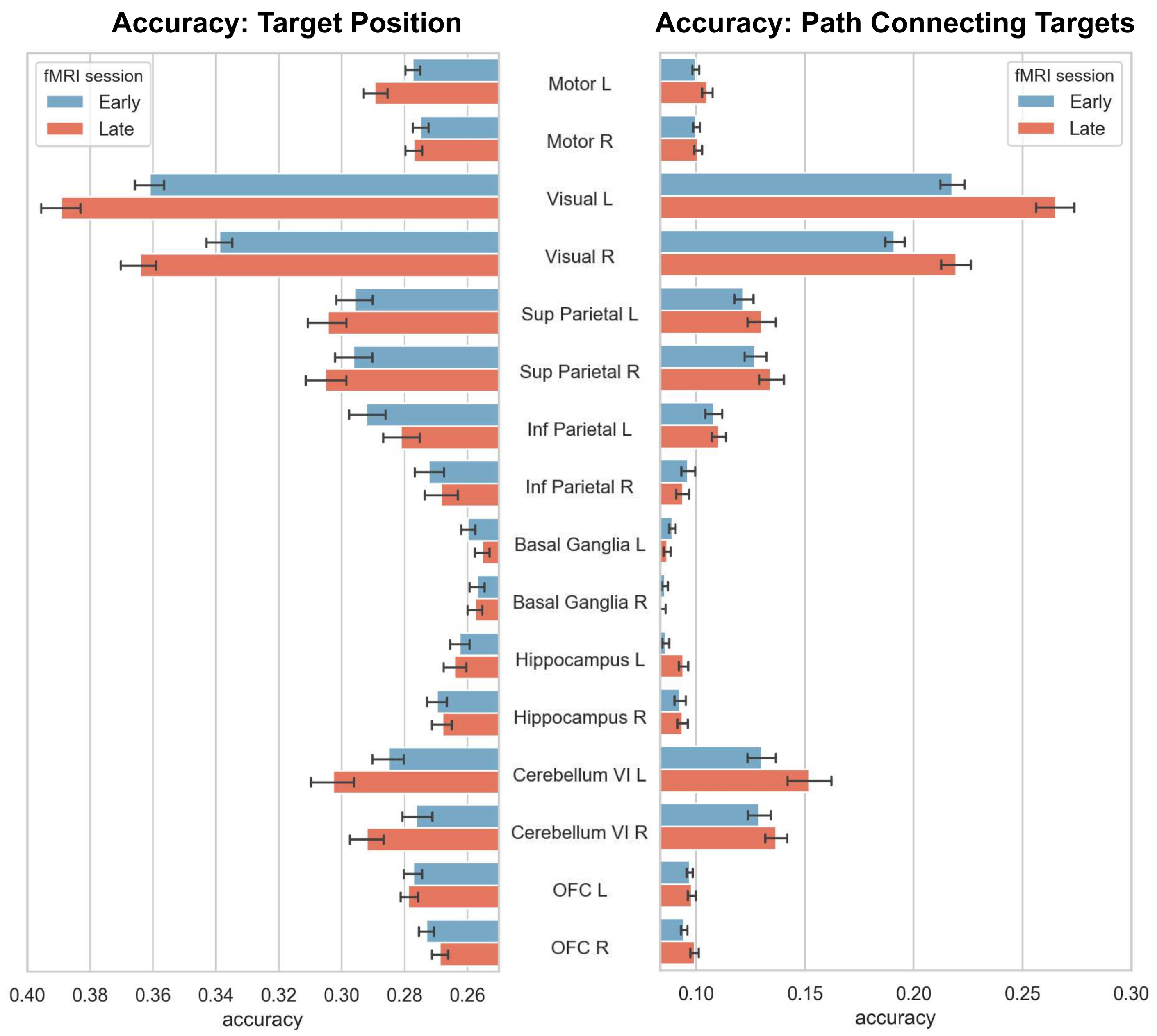
MVPA results

- Linear discriminant analysis (LDA) classifier, across-run cross-validation for all MVPA analyses
- Searchlight analysis
  - Radius = 6 mm





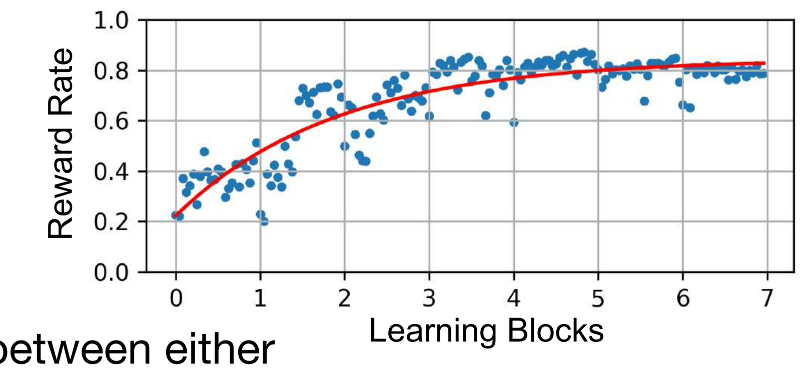
- ROI-based MVPA results
  - 120 ROIs from the AAL2 atlas
  - **Labels**: (1) 4 target positions, (2) 12 paths connecting pairs of targets
  - Among ROIs showing decoding accuracies significantly higher than the chance level, some ROIs in motor, visual, and cerebellar regions showed increased decoding accuracies after extensive training, even after controlling for the effect of total hand movement



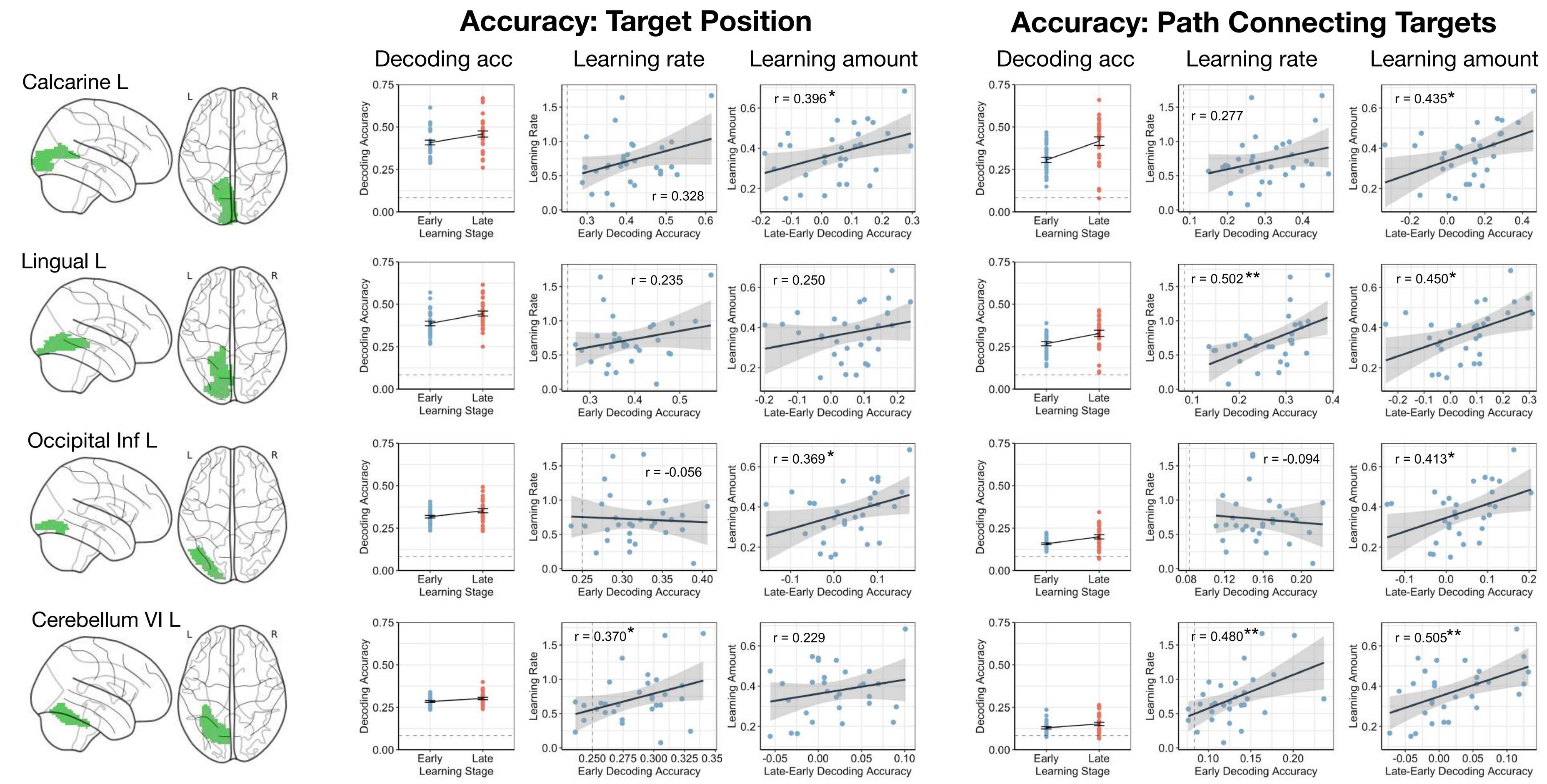
Combined analysis fo fMRI to behavioral data

- Exponential curve fitting of individual reward rate data, to explain individual variances in performance
- Calculated measures of performance, *R*
  - Learning amount: Late - Early reward rate
  - Learning rate: *b*

$$R = A(1 - e^{-bt}) + C$$



- Selected ROIs showing significant correlation between either
  - (1) **Late - Early Decoding Accuracy** and **Learning Amount**, or
  - (2) **Early Decoding Accuracy** and **Learning Rate**, separately for **Target Position** and/or **Path Connecting Targets**



Conclusion

- Information for task states are represented in ROIs of the visuomotor network and increased as learning proceeded
- Left Cerebellum Lobule VI
  - Has been reported as an important region for "slow state", with increased decoding accuracy with learning, while separating different motor tasks (Kim et al, 2015)
- However, we could not find significant decoding in the hippocampus/entorhinal cortex supporting initially hypothesized "cognitive map"

Future works

- Connectivity analysis
  - How does extensive motor training change patterns of interaction between networks?
    - Informational connectivity may be considered (Anzellotti & Coutanche, 2018)

References

- Kim, S., Ogawa, K., Lv, J., Schweighofer, N., & Imamizu, H. (2015). Neural substrates related to motor memory with multiple timescales in sensorimotor adaptation. *PLoS biology*, 13(12), e1002312.
- Behrens, T. E., Muller, T. H., Whittington, J. C., Mark, S., Baram, A. B., Stachenfeld, K. L., & Kurth-Nelson, Z. (2018). What is a cognitive map? Organizing knowledge for flexible behavior. *Neuron*, 100(2), 490-509.
- Ranganathan, R., Adewuyi, A., & Mussa-Ivaldi, F. A. (2013). Learning to be lazy: exploiting redundancy in a novel task to minimize movement-related effort. *Journal of Neuroscience*, 33(7), 2754-2760.
- Anzellotti, S., & Coutanche, M. N. (2018). Beyond functional connectivity: investigating networks of multivariate representations. *Trends in cognitive sciences*, 22(3), 258-269.

Acknowledgments

This study was supported by IBS-R015-D1 from the Institute for Basic Science., Neuroimaging was performed at the Center for Neuroscience Imaging Research, supported by the Institute for Basic Science and Sungkyunkwan University.

Contact | clmnlab@gmail.com