Double dissociation of fMRI activity in caudate nucleus supports human *de novo* motor skill learning

*Yera Choi, Emily Yunha Shin, Sungshin Kim**

Computational Learning & Memory Neuroscience Lab

696.09/AA37

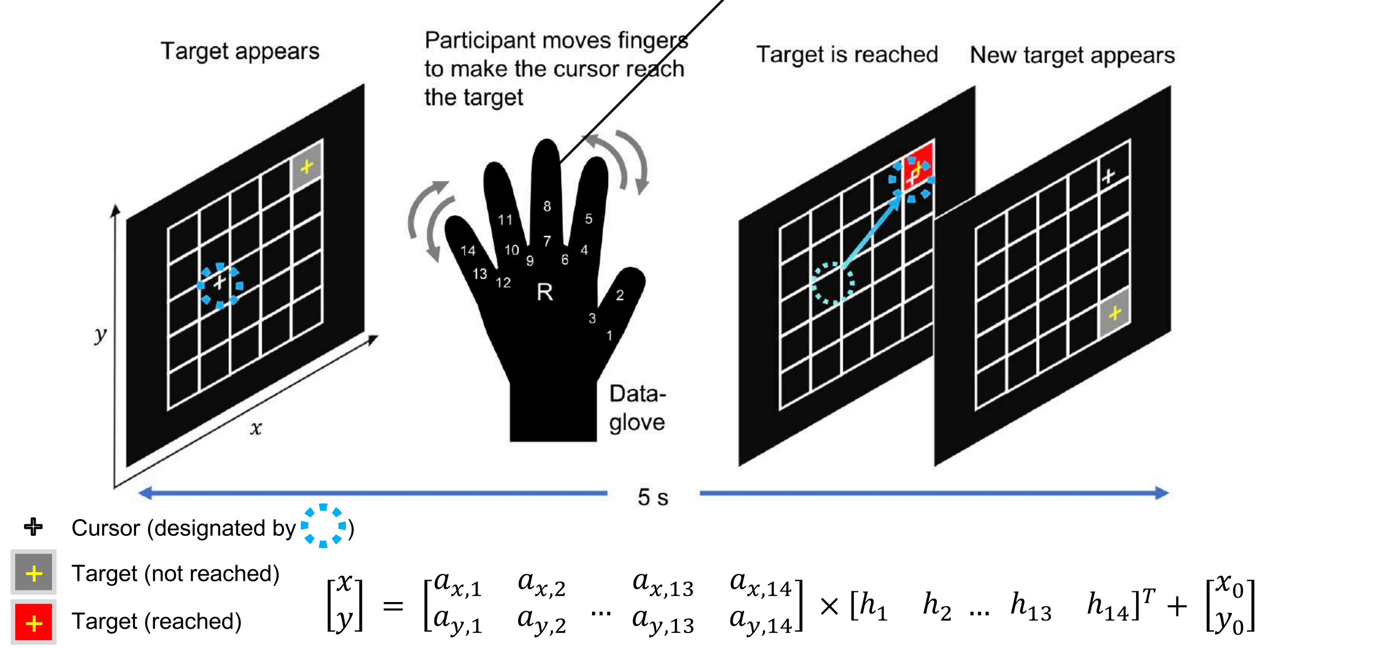
Introduction

- Motor skill learning is a complex process of generating new movement patterns reinforced by evaluative feedbacks to perform a motor task better, faster and more accurately
- The separate cognitive/sensorimotor loops of the basal ganglia (BG) play differential roles in learning motor skills
- Recent non-human primate studies suggest rostro-caudally separated circuits in the caudate nucleus for learning object-value association (object skill learning)
- In human *de novo* motor skill learning, little has been known about the exact role of BG, especially caudate nucleus, and its interaction with cortical regions during the course of learning

Research questions

- Is the human caudate nucleus functionally separated for the early and advanced stages of *de novo* motor skill learning, as suggested by previous non-human primate studies on object skill learning?
- How can the cortical-caudate interaction predict individual performance of motor skill learning?

Experimental design



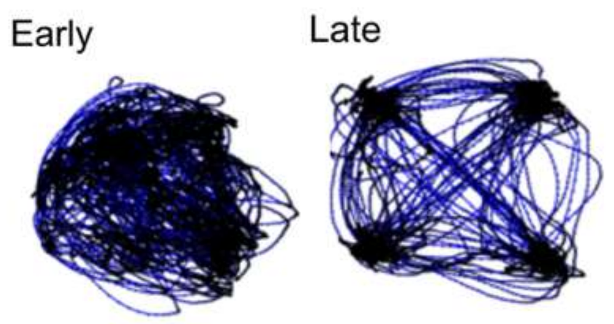
$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a_{x,1} & a_{x,2} & \cdots & a_{x,13} & a_{x,14} \\ a_{y,1} & a_{y,2} & \cdots & a_{y,13} & a_{y,14} \end{bmatrix} \times [h_1 \; h_2 \; \ldots \; h_{13} \; h_{14}]^T + \begin{bmatrix} x_0 \\ y_0 \end{bmatrix}$$

- **Participants**: 30 young healthy right-handed (12 females)
- **Task**: To move cursor to reach a target on 5 x 5 grid, using MR-compatible data glove with 14 sensors measuring hand joint angles
  - 14D vector (*h*) linearly mapped onto 2D cursor position (*p*) using PCA (Ranganathan et al., 2013)

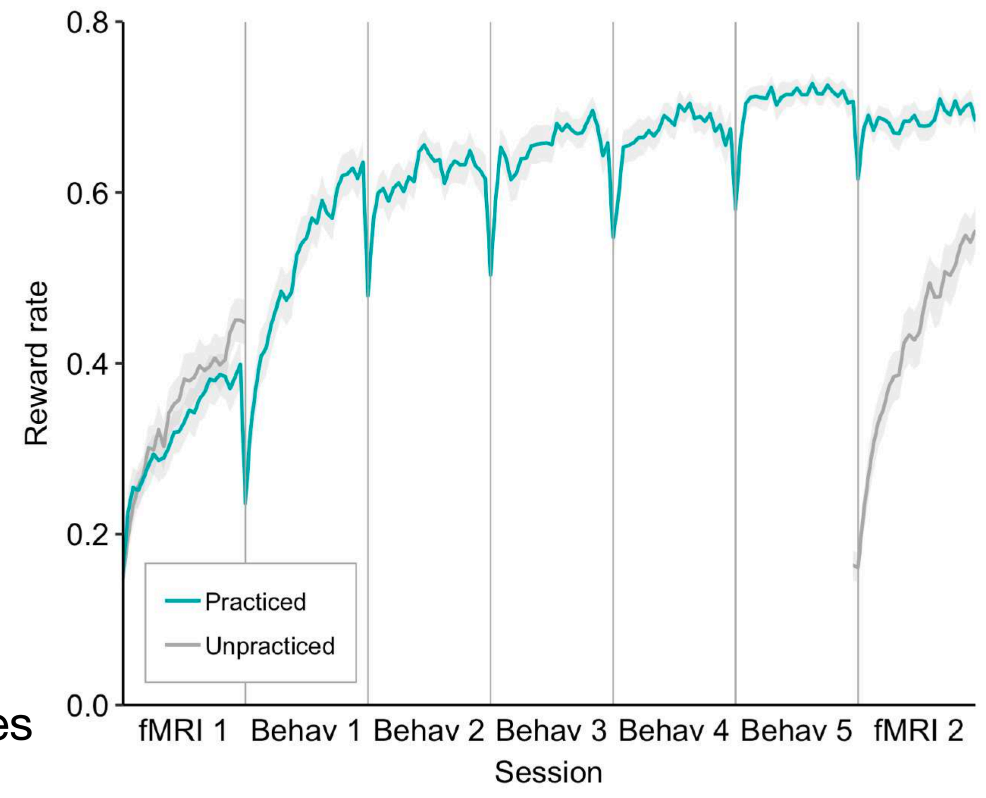
- **Targets**: Presented every 5 seconds at one of 4 grid corners
- **Mappings**: First 2 PCs used as either X or Y, with X-Y combinations switched for Practiced and Unpracticed mappings (counterbalanced)
  - e.g., Practiced (X: 1st, Y: 2nd PC), Unpracticed (X: 2nd, Y: 1st PC)
- **Learning schedule**
  - Day 1: Calibration, Pre-Training, rs-fMRI, **fMRI 1 ("Early"**, 97 trials x 7 runs, Practiced/Unpracticed)
  - Days 2-6: Behavior Training 1-5 (Practiced *only*)
  - Day 7: **fMRI 2 ("Late"**, 97 trials x 7 runs, Practiced/Unpracticed), rs-fMRI

Behavioral analysis

- Participants successfully acquired the skill to the plateau level
- Reward rate per block (12 trials): proportion of time rewarded (i.e., target in red)

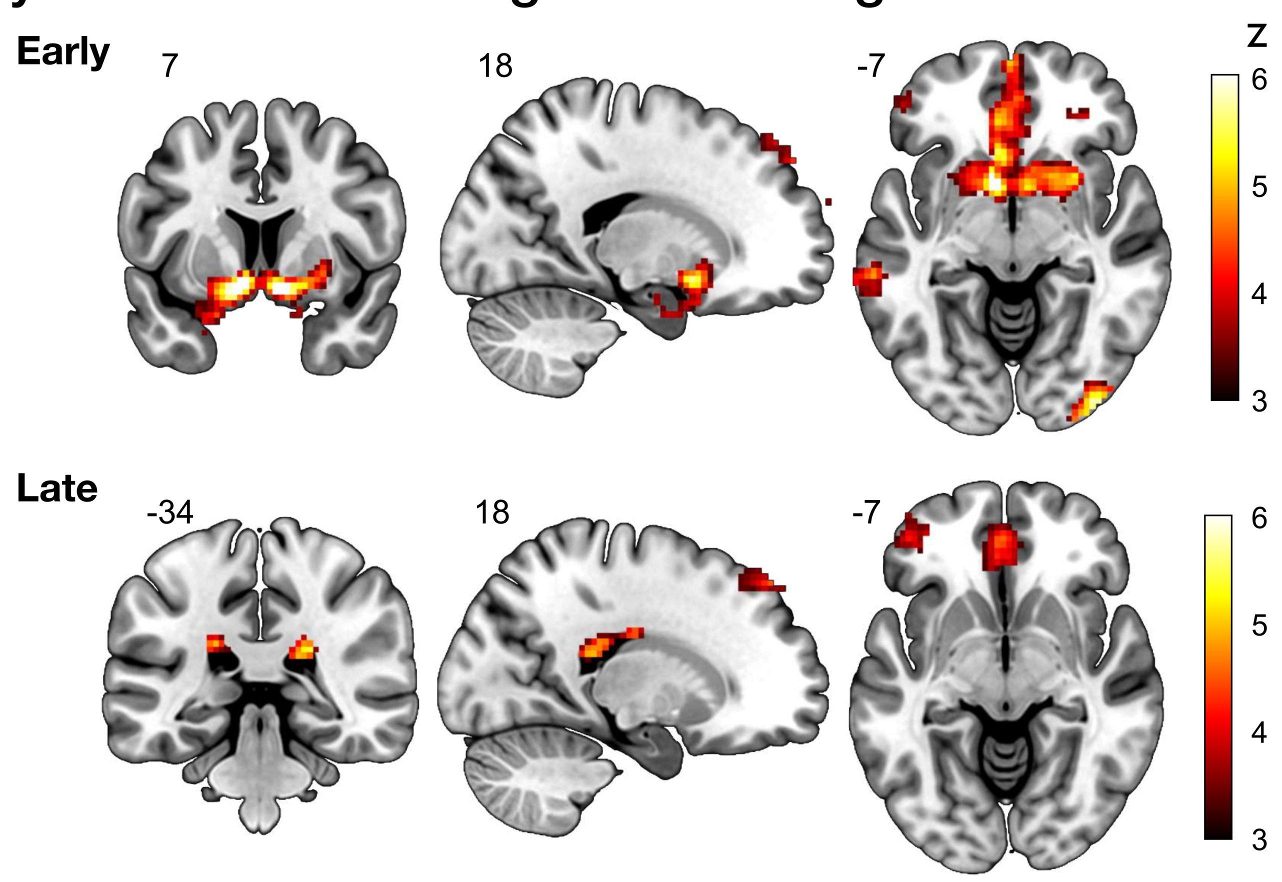


- Example of actual cursor trajectories



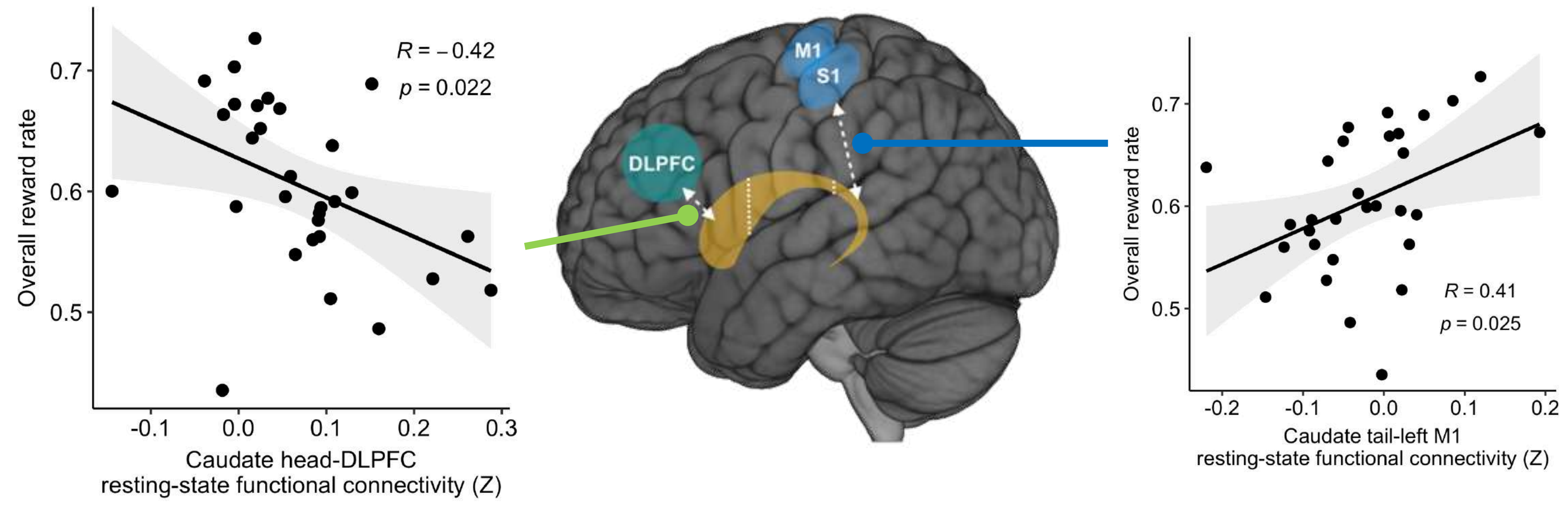
GLM analysis

❖ Neural correlates of reward modulation in early and advanced stages of learning



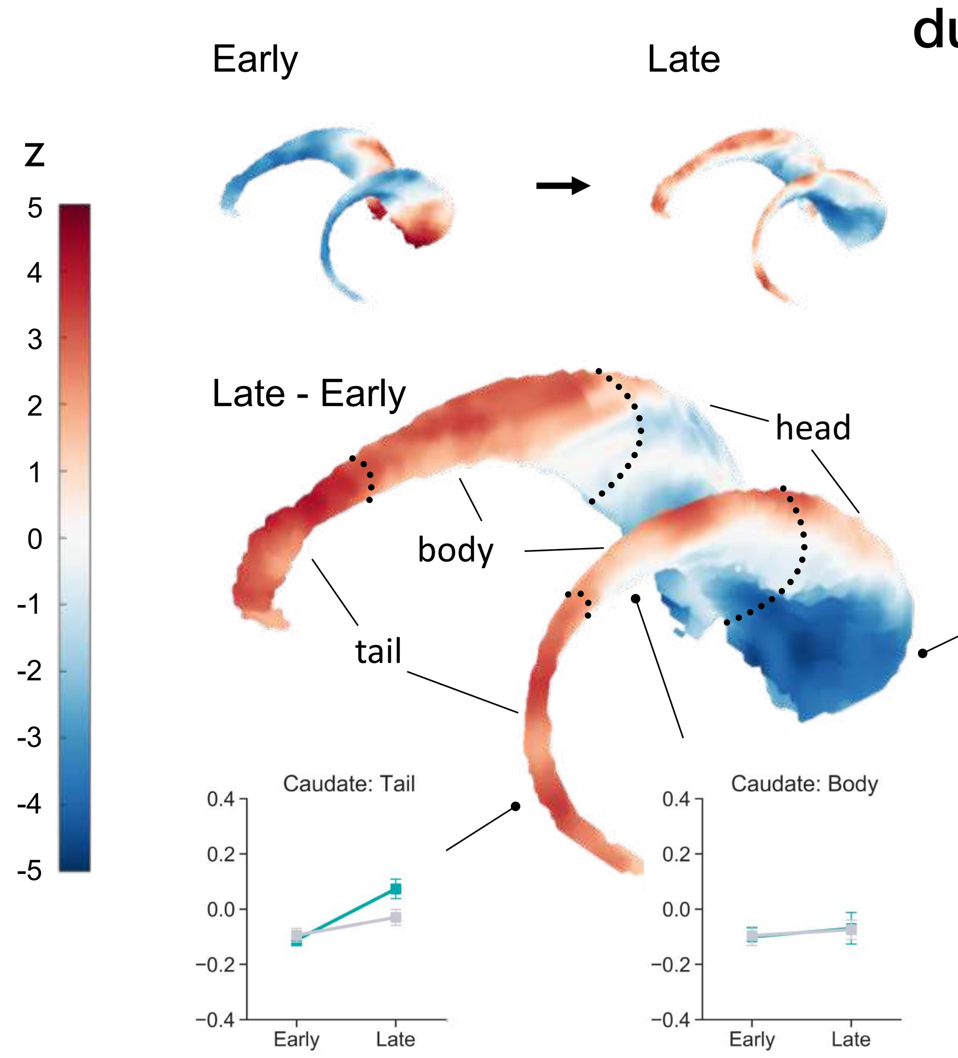
- Whole-brain voxel-wise GLM analysis with a parametric regressor modulating reward rate estimated every 1 second (uncorrected $p < 0.001$, cluster > 30 voxels)
- Regions showing positive reward modulation in Early and Late stages

Resting-state fMRI analysis

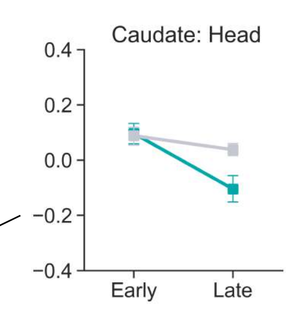


- Individual performance of motor skill learning (overall reward rate for Practiced mapping) is predicted by resting-state functional connectivity (FC) prior to learning
  - **Lower caudate head-DLPFC FC ↔ better performance**
  - **Higher caudate tail-left M1/S1 FC ↔ better performance**

❖ Gradual transition of reward modulation in the caudate nucleus during *de novo* motor skill learning



- Voxel-wise paired *t*-test, converted to *z*-scores
- **Higher reward modulation in Early (blue) vs. Late stage (red)**



- **Transition of reward modulation from rostral to caudal caudate nucleus**
- **Significant transition in caudate head/tail *only* for Practiced mapping**

Conclusion

- Double dissociation of responses to reward in caudate nucleus in early and advanced stages of learning (first demonstrated in human *de novo* motor skill learning using fMRI)
  - In line with studies reporting learning-related rostro-caudal transition of activities in BG including caudate nucleus (e.g., Kim et al., 2015)
- Better skill performance with (1) weaker FC between rostral "goal-directed" caudate head and PFC and (2) stronger FC between caudal "automatic" caudate tail and M1/S1
- **Future works**: TMS-fMRI study selectively targeting DLPFC in early and M1 in advanced stages of learning to perturb early skill acquisition and later skill consolidation

References

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.

Kim, H. F., & Hikosaka, O. (2015). Parallel basal ganglia circuits for voluntary and automatic behaviour to reach rewards. Brain, 138(7), 1776-1800.

Acknowledgments

This study was supported by IBS-R015-Y1 from the Institute for Basic Science. Neuroimaging was performed at the Center for Neuroscience Imaging Research and supported by the Institute for Basic Science and Sungkyunkwan University.

Contact | clmnlab@gmail.com