IoB Core Technology

Moonshot Research and Development Program Goal 1 Kanai Project

Technological Foundation for Transmitting Neural Activity Information Between Individuals and Information Transmission

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Overview

If technologies enabling the extraction of learned and stored information from one brain and its transfer to another could be developed, the "information transmission" portrayed in science fiction would become reality. Achieving this, however, requires a causal understanding of how local neural circuits encode information through cell-level spatiotemporal activity patterns. Such learning-related neural dynamics form the basis of cognition and memory, and are deeply implicated in brain disorders, including neurodevelopmental and psychiatric conditions.

Recent advances in optogenetics and in vivo imaging have begun to elucidate the minimal neuronal ensembles and connectivity motifs capable of artificially inducing sensory percepts [Dalgleish et al., 2020; Carrillo-Reid et al., 2019; Marshel et al., 2019]. Nonetheless, the field lacks methods for artificially generating the spatiotemporal activity patterns of neuronal populations themselves, representing a major unexplored frontier in understanding the principles of learning and memory.

In this study, we will utilize holographic microscopy to simultaneously record and manipulate single-cell activity. By extracting learning-related neural dynamics and reproducing them in naïve circuits, we aim to causally test the relationship between circuit-level plasticity and behavior. Furthermore, by integrating glial manipulation—including astrocytes—we will investigate how coordinated temporal sequences of activity across neurons and glia support flexible perceptual learning.

Research: Information Transmission Content (Left Column) and Research Approach (Right Column)

Results : Diverse neural responses in the barrel cortex encode learning-related information

Temporal activity of diverse learning-related neurons for information transmission

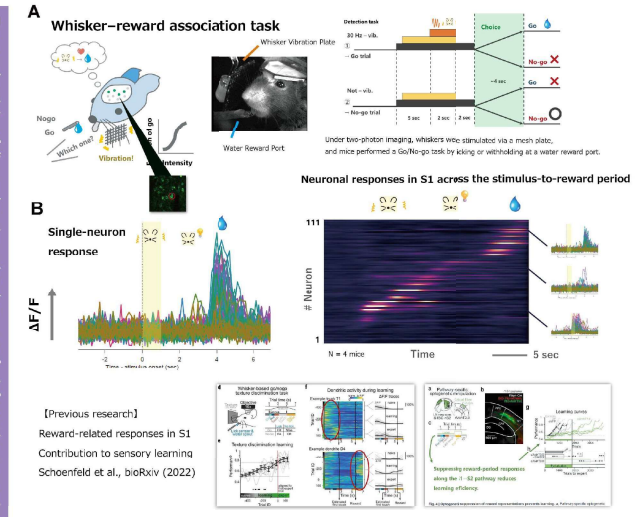
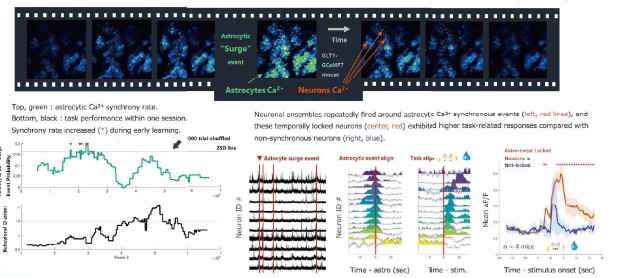


Fig1. A) Schematic of the whisker-reward association task under two-photon microscopy. B) Left: Example single-neuron Ca^{2+} activity and population response map. Task-related and decision-critical neurons exist in S1 barrel cortex, and manipulating them affects learning and behavior, indicating these circuits are essential for task performance.

Results : Astrocyte and neuronal activity correlated with learning rate increase

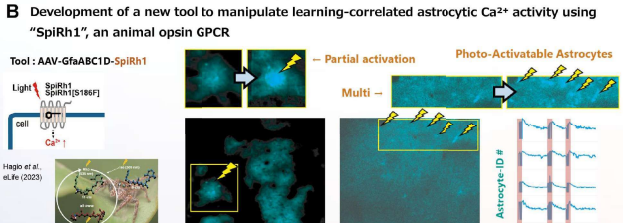
Findings on learning-correlated astrocytic activity that may facilitate information transmission

A During early learning, astrocytic Ca^{2+} shows increased synchronized activity ("surge"), and task-related neuronal ensembles tend to fire synchronously around these astrocytic surge events



Top, green : astrocytic Ca^{2+} synchrony rate.
Bottom, black : task performance within one session.
Synchrony rate increased (*) during early learning.

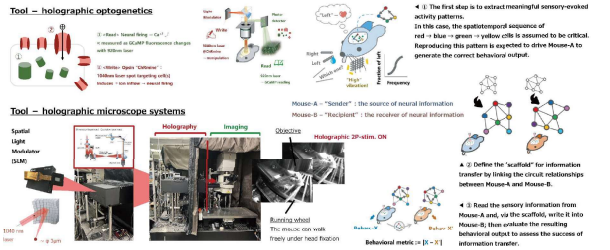
Neuronal ensembles repeatedly fired around astrocytic Ca^{2+} synchronous events (left, red lines), and these temporally locked neurons (center, red) exhibited higher task-related responses compared with non-synchronous neurons (right, blue).



B Development of a new tool to manipulate learning-correlated astrocytic Ca^{2+} activity using "SpiRh1", an animal opsin GPCR

Fig2. A) Top: Simultaneous astrocyte–neuron Ca^{2+} imaging in GLT1-GCaMP mice. Astrocytic surge events induce large-scale, dynamic changes across the field of view. Bottom: During early learning, surge event rates increased when performance first reached threshold (d-prime > 1.5). Neurons phase-locked to surge events carried higher task-related information than non-locked neurons. B) Astrocytic Ca^{2+} activity was optogenetically driven by expressing an animal opsin GPCR in astrocytes and stimulating single or multiple cells using two-photon holographic stimulation.

Highlights : Holographic microscopy-based information transfer between mice



Methods : Information-transfer protocol | ROI selection and linking circuits across mice

Information-transfer project using a holographic microscopy system

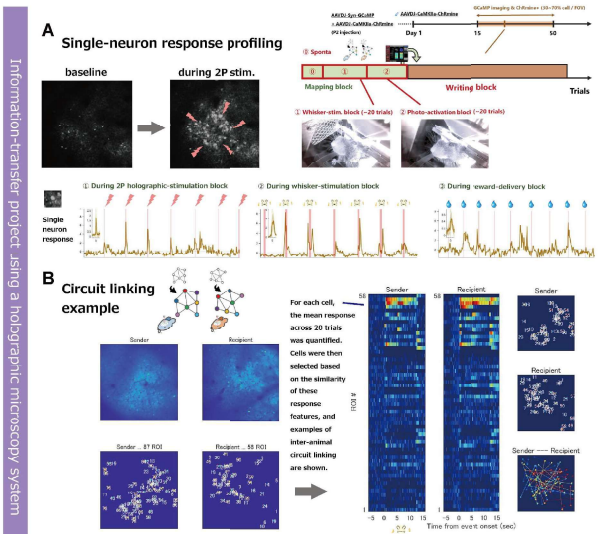


Fig3. A) In preparation for information transfer, barrel cortex neurons within the two-photon imaging field were labeled for light responsiveness using blocks that systematically stimulated all cells, and for whisker-evoked responses using blocks with passive sensory input. B) Based on the time-series features of these responses, corresponding neurons were linked across two animals.

Results : Information-transfer | compressed sender signals tended to shift behavior

Information-transfer project using a holographic microscopy system

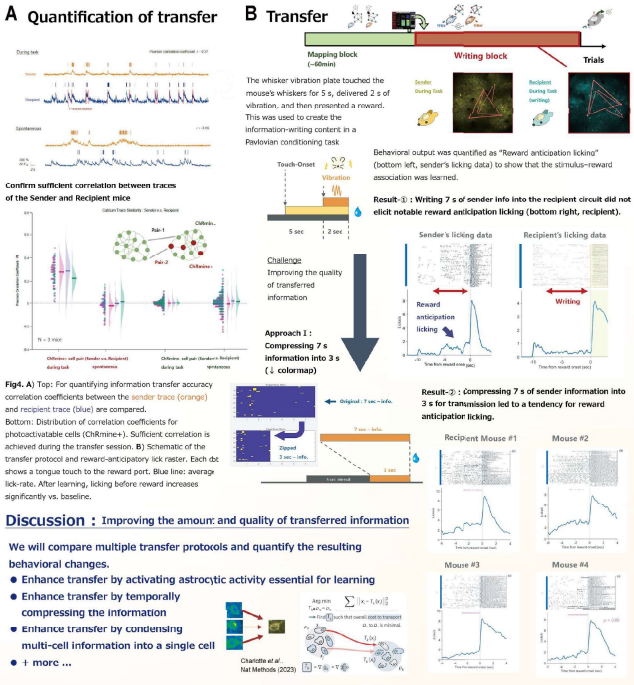


Fig4. A) Top: For quantifying information transfer accuracy correlation coefficients between the sender trace (orange) and recipient trace (blue) are compared. Bottom: Distribution of correlation coefficients for photoactivatable cells (ChRmine+). Sufficient correlation is achieved during the transfer session. B) Schematic of the transfer protocol and reward-anticipatory lick raster. Each dot shows a tongue touch to the reward port. Blue line: average lick-rate. After learning, licking before reward increases significantly vs. baseline.

Discussion : Improving the amount and quality of transferred information

We will compare multiple transfer protocols and quantify the resulting behavioral changes.

- Enhance transfer by activating astrocytic activity essential for learning
- Enhance transfer by temporally compressing the information
- Enhance transfer by condensing multi-cell information into a single cell
- + more ...

Charlotte et al. Nat Methods (2023)

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Future Prospects

By enabling information transmission, we aim to expand brain function using organoids and animal brains!

Internet of Brains