Probing the neural codes for spatial memories

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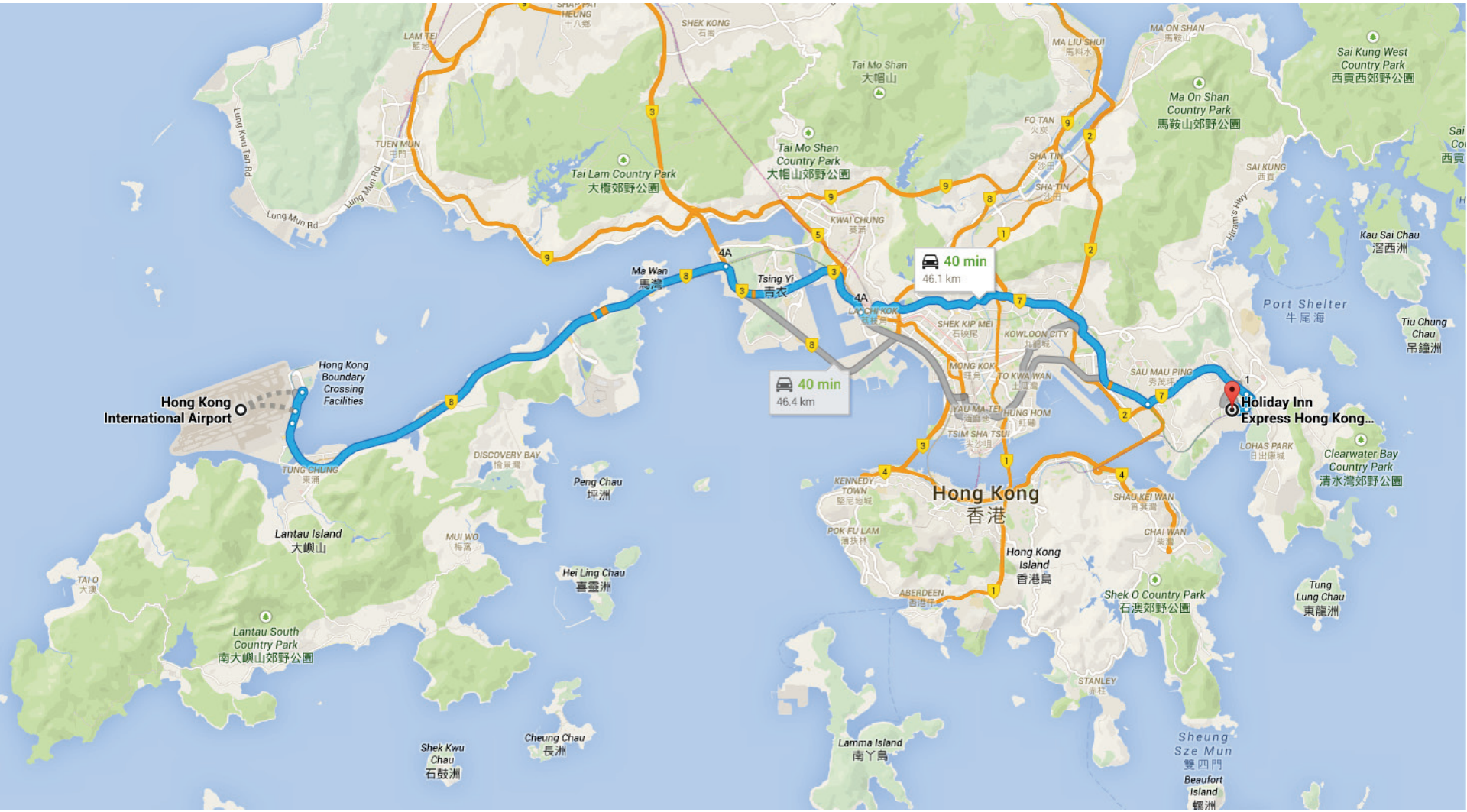
Spatial navigation



The Brain GPS system: hippocampal place cells and entorinal cortical grid cells

The Nobel Prize in Physiology or Medicine 2014

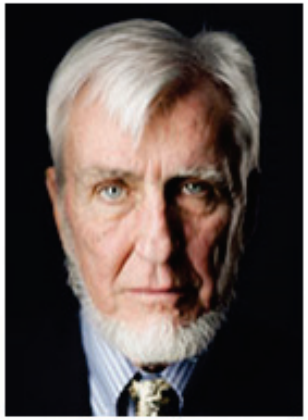


Photo: A. Mahmoud

John O'Keefe

Prize share: 1/2

Photo: A. Mahmoud

May-Britt Moser

Prize share: 1/4

Photo: A. Mahmoud

Edvard I. Moser

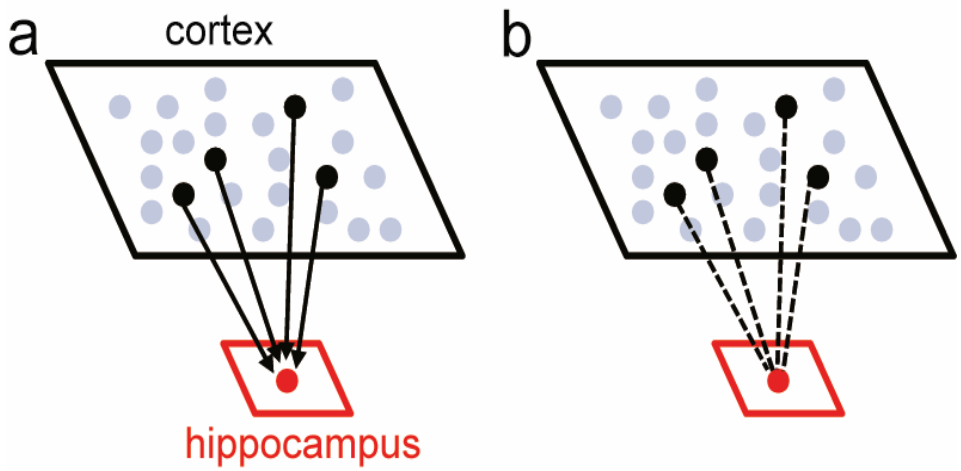
Prize share: 1/4

The Nobel Prize in Physiology or Medicine 2014 was divided, one half awarded to John O'Keefe, the other half jointly to May-Britt Moser and Edvard I. Moser *"for their discoveries of cells that constitute a positioning system in the brain"*.

Spatial memory

Index theory of spatial memory

Memory encoding /formation

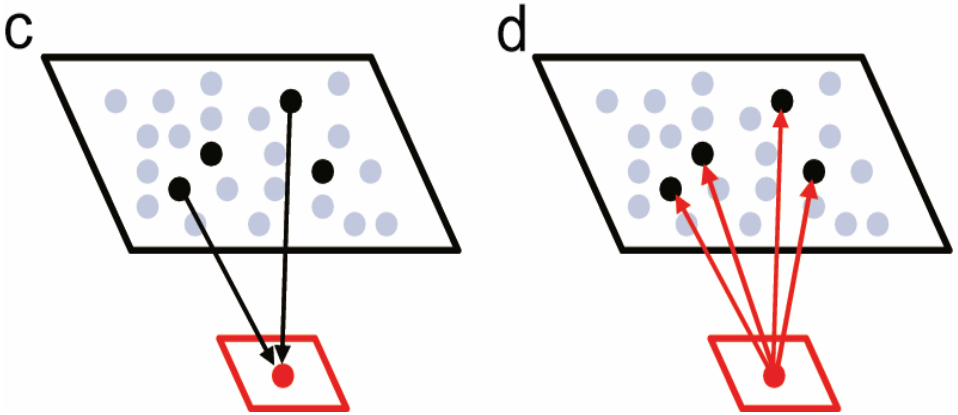


Cortical memory code

↓

Hippocampal memory code

Memory retrieval /consolidation



Cortical memory code

↑

Hippocampal memory code

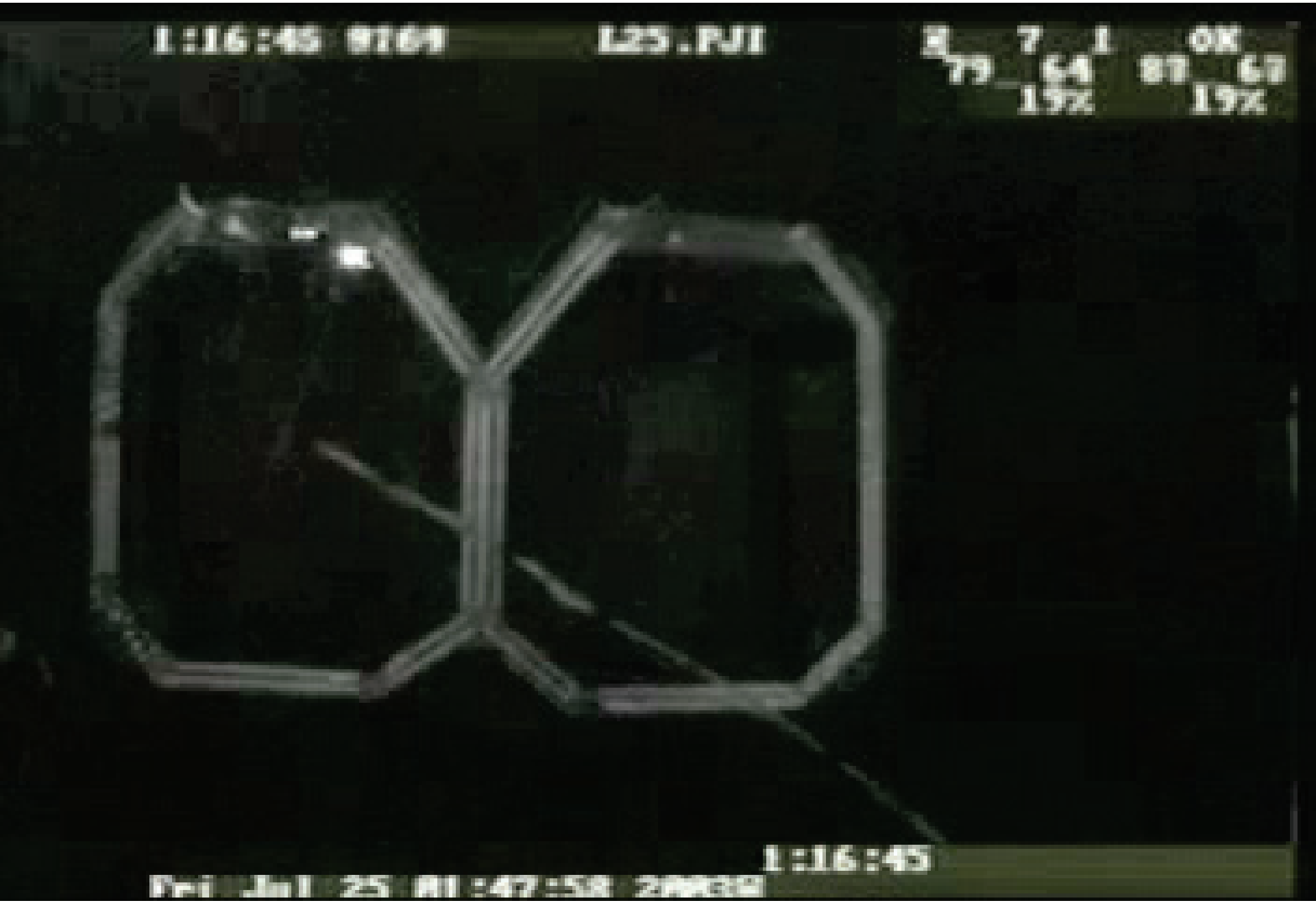
Objective

Experimental evidence for neocortical-hippocampal interactions

(Breakdown of the interaction in disease models)

Outline

- Recording techniques
- Memory encoding: V1 and hippocampal neurons during active behavior
- Memory consolidation: V1 and hippocampal neurons during sleep
- Summary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L25.PJI
7 1 OK
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19% 19%
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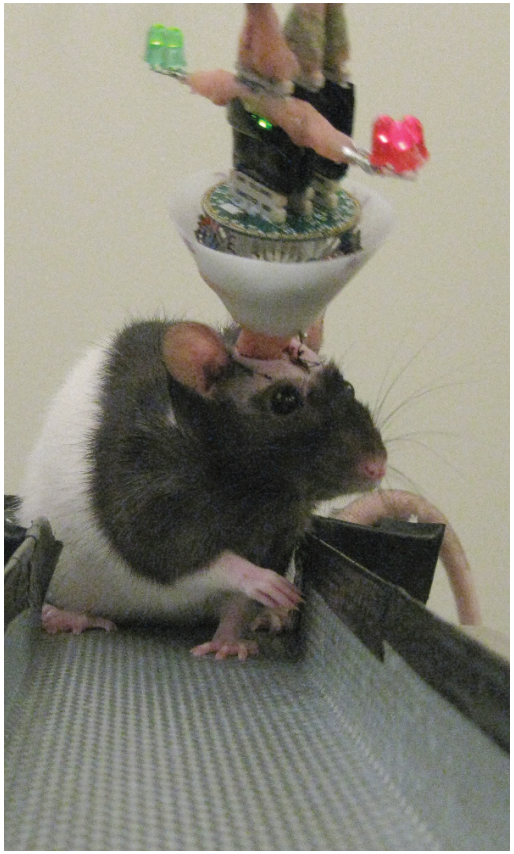
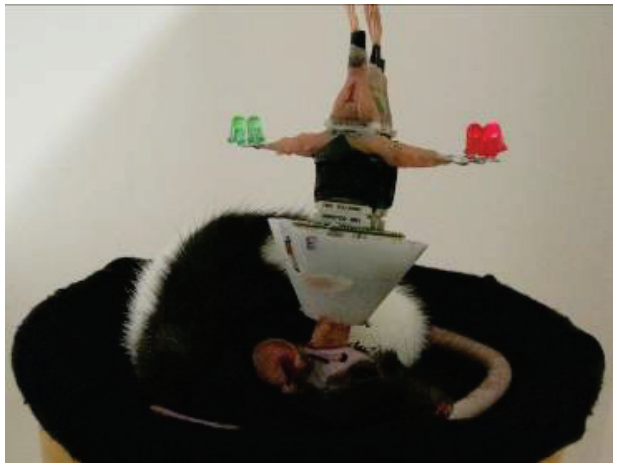
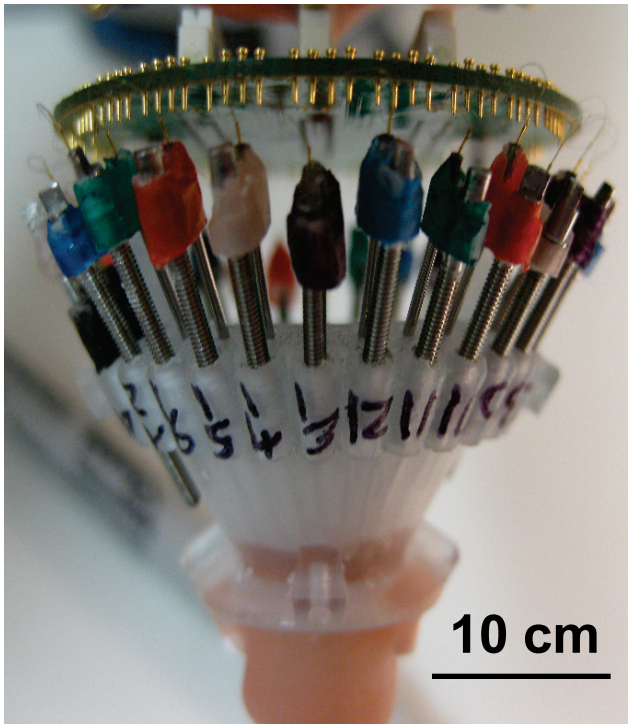
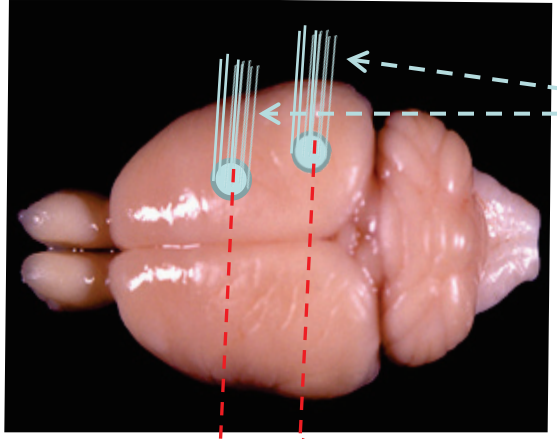




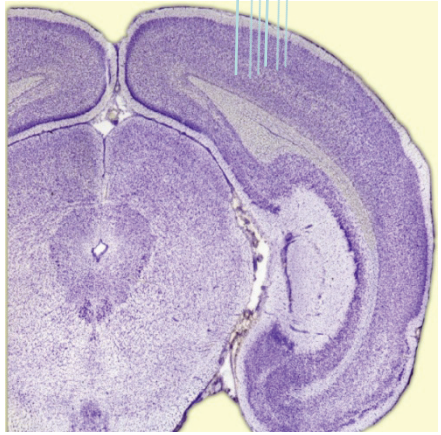

10 cm



Electrodes (tetrodes)

Hippocampus

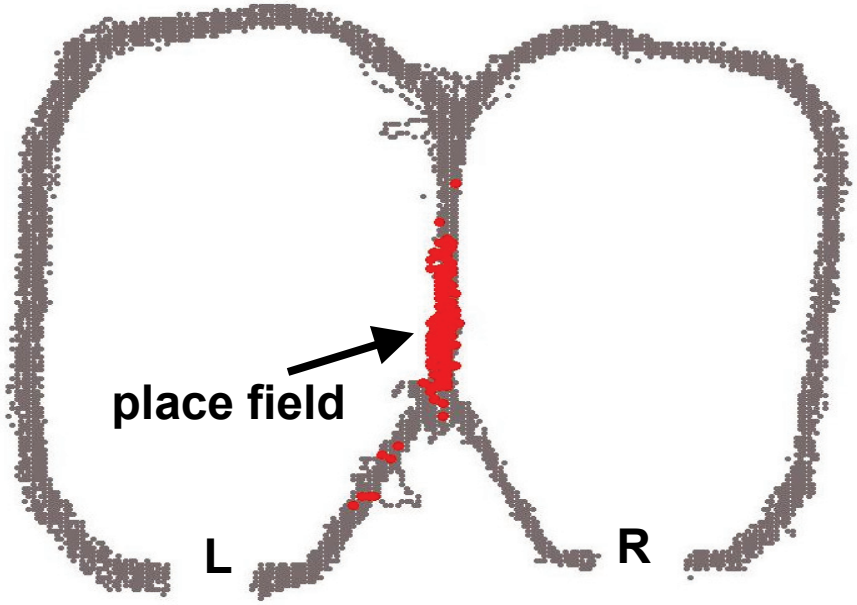
Visual cortex (V1)



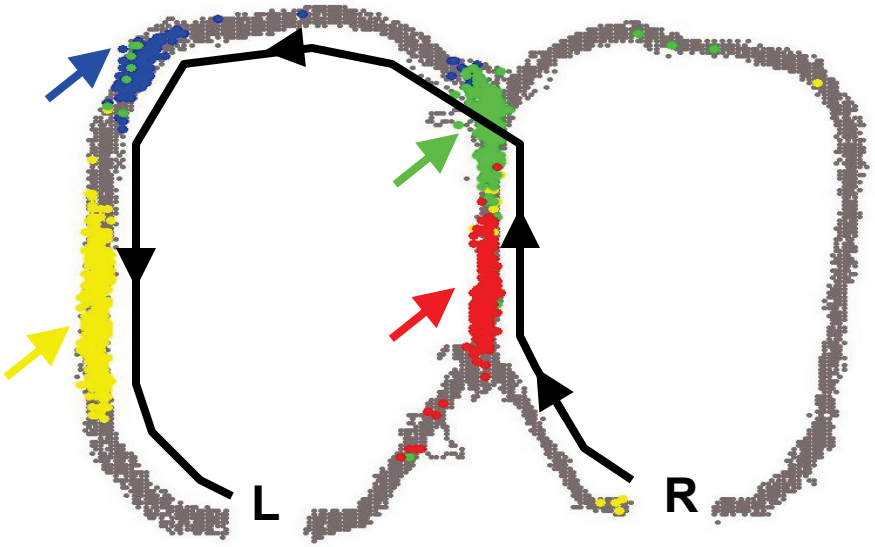
Output data:

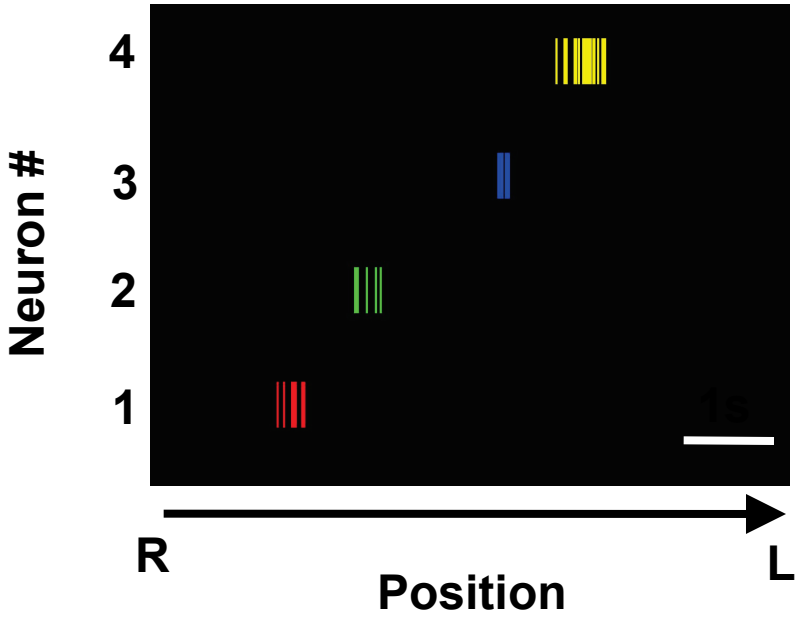
- **Spikes of a large number of single neurons**
- **Spikes of multi-unit activities (MUA)**
- **Local field potentials (LFPs)**

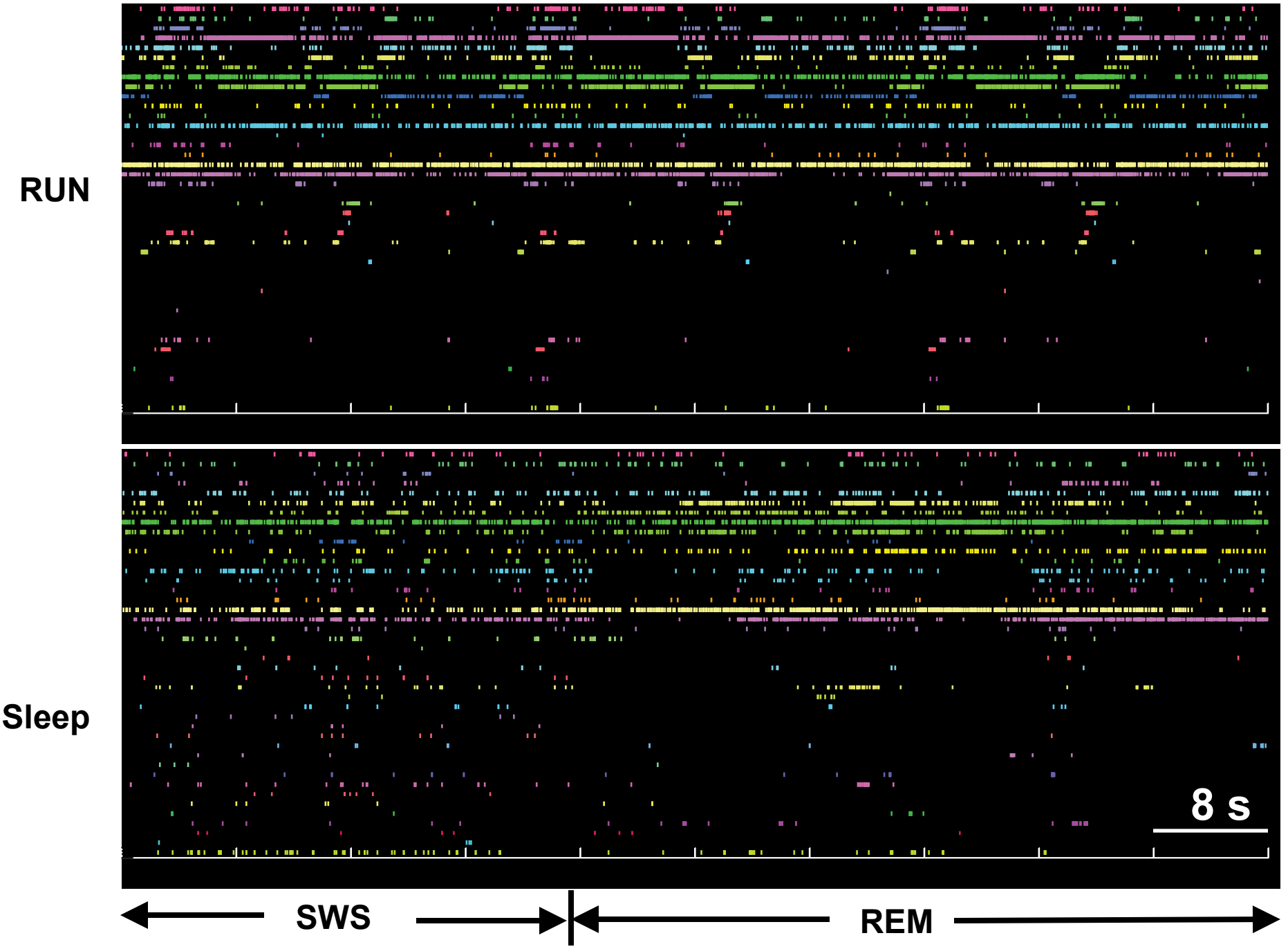
Rat hippocampal neurons (place cells)



The memory codes for spatial trajectories: firing sequences of multiple hippocampal neurons







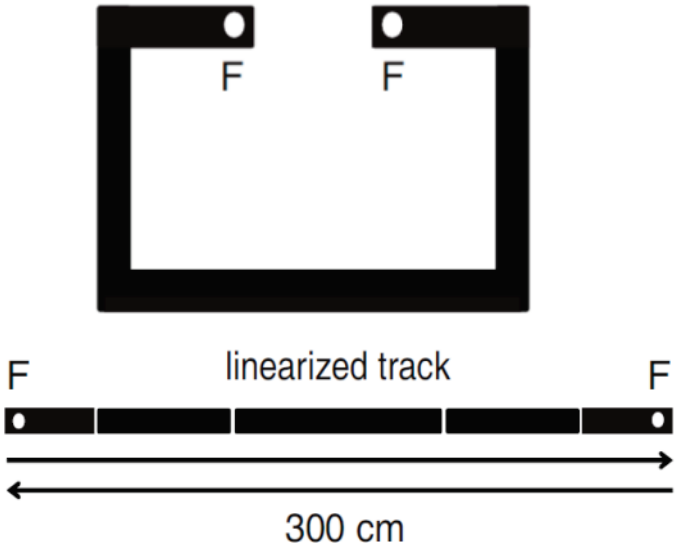
Owen_7_12, leftright_ordered

Outline

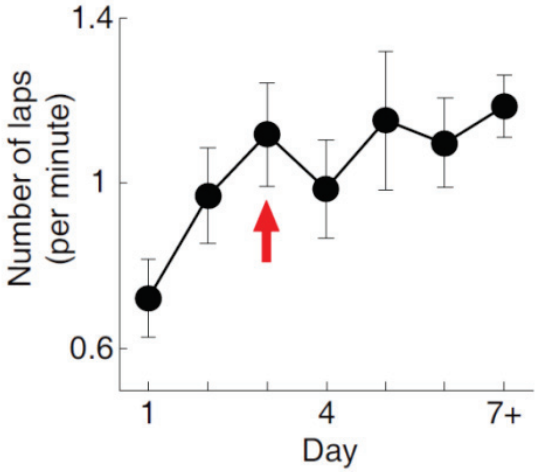
- Recording techniques
- **Memory encoding: V1 and hippocampal neurons during active behavior**
- Memory consolidation: V1 and hippocampal neurons during sleep
- Abnormal memory encoding: hippocampal neurons in a mouse model
- Summary

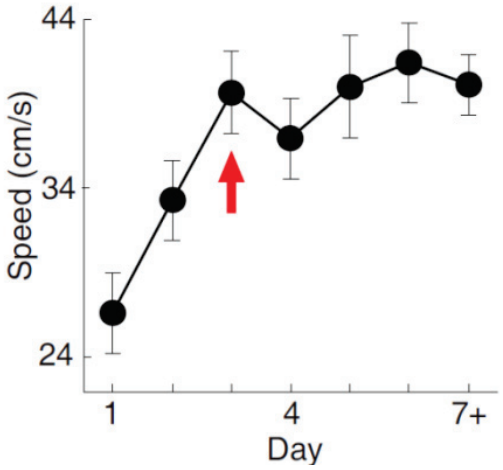
Experimental design

Task: running on a novel track

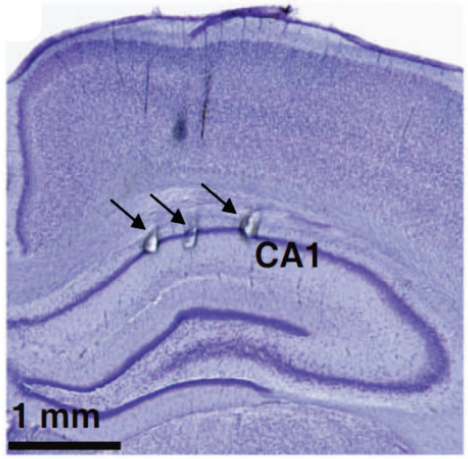


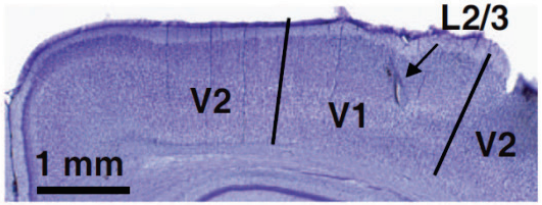
Performance

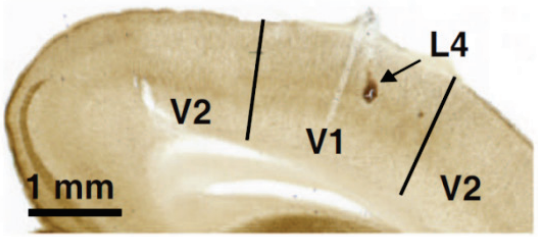


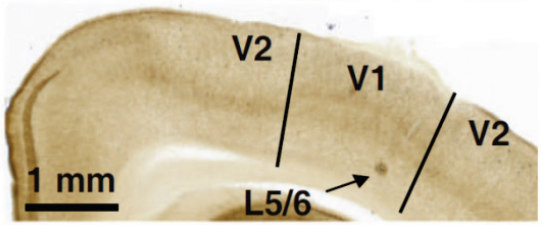


Recording sites

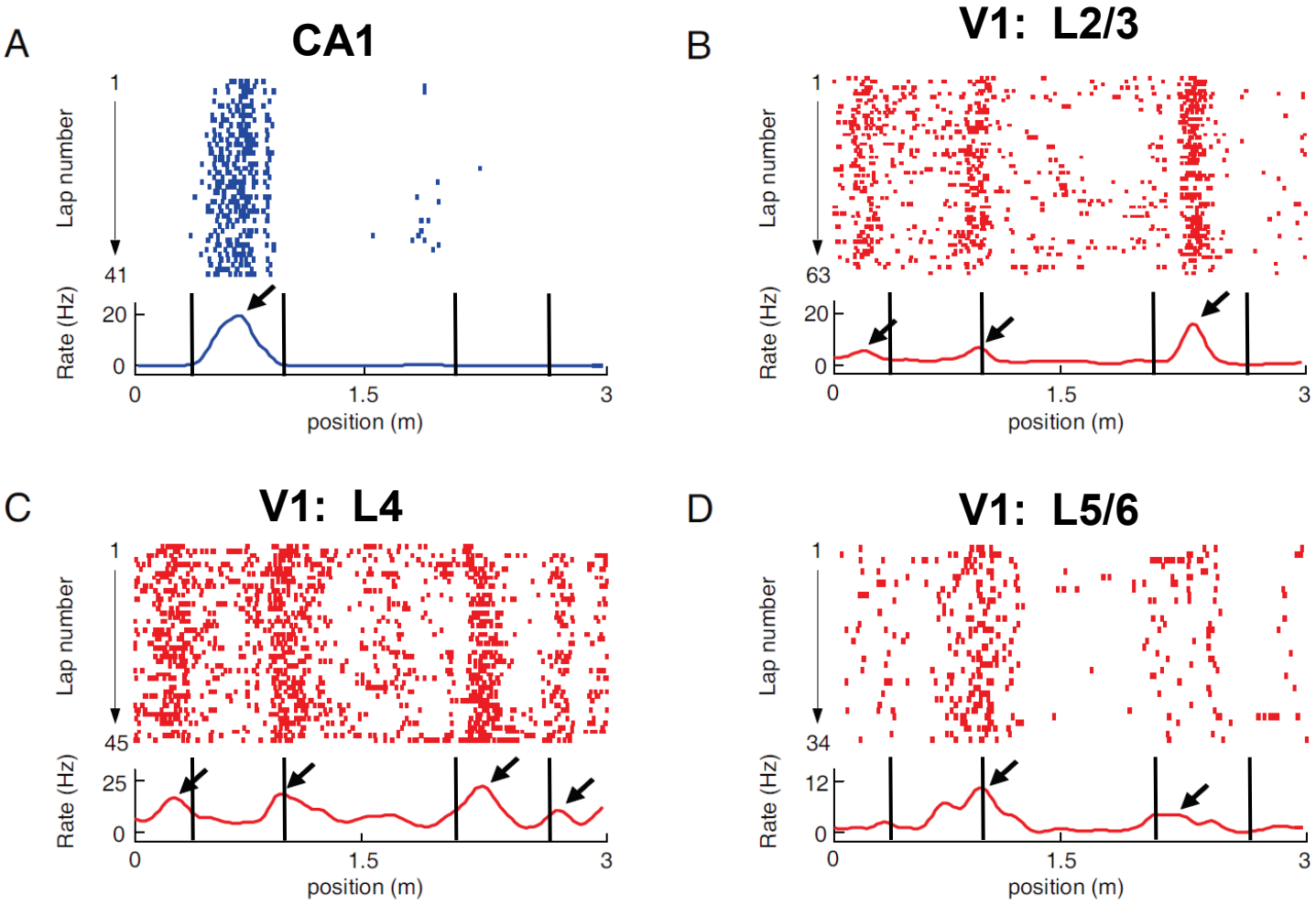




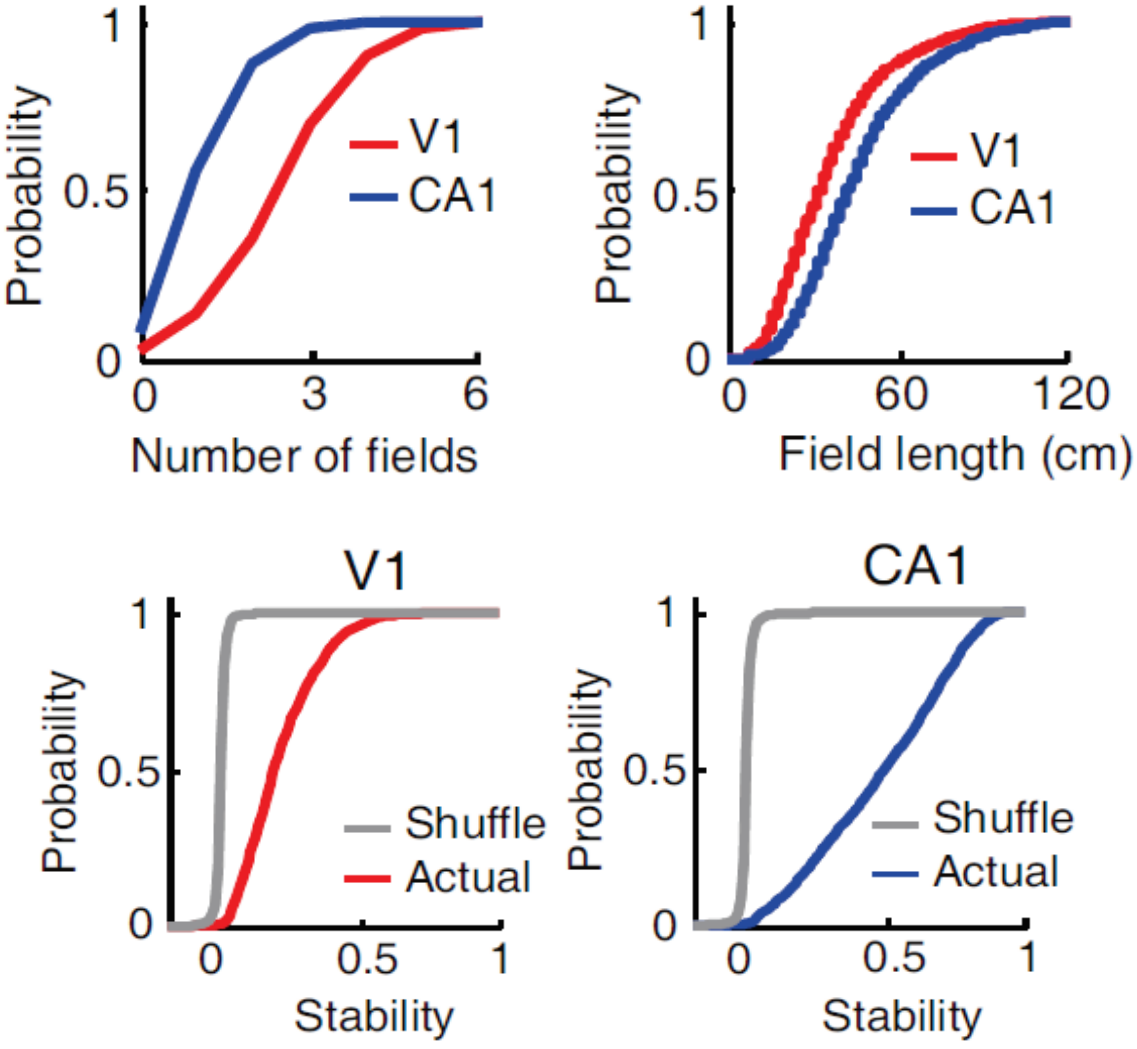




Responses of CA1 and V1 neurons



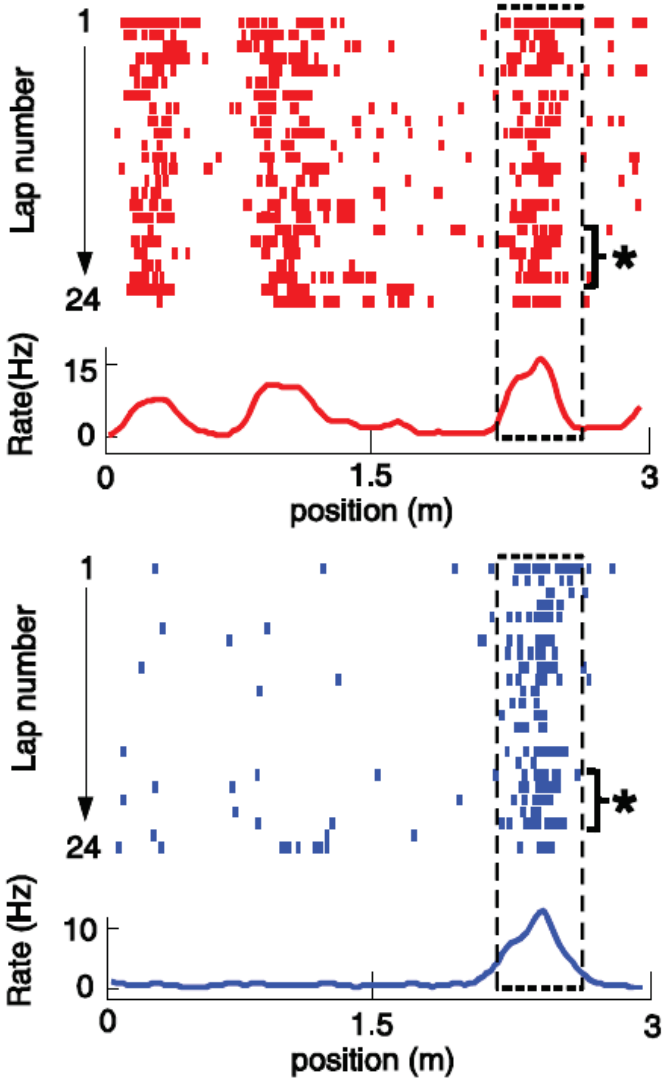
Quantifications of V1 (and CA1) responses

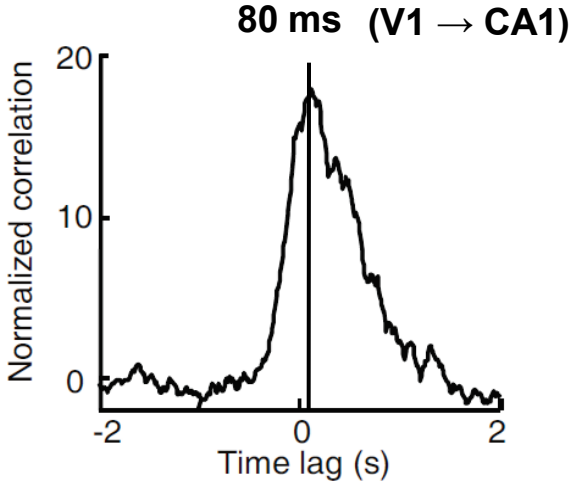


Cross-correlation of a pair of overlapping V1-CA1 cells

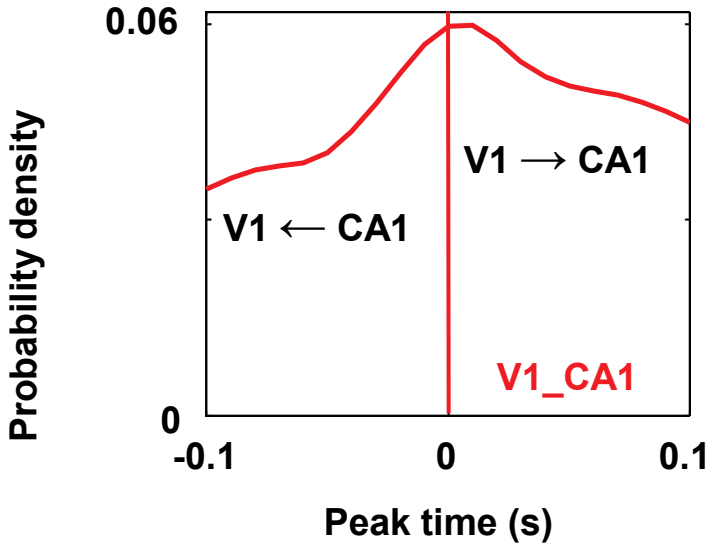
V1

CA1

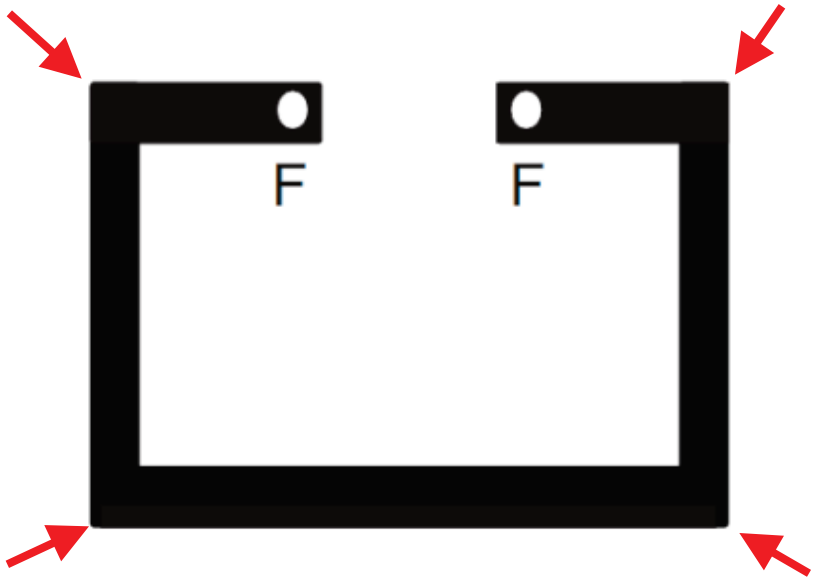


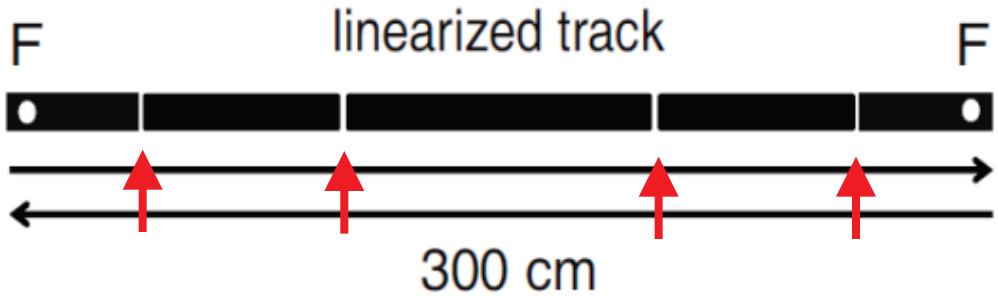


Cross-correlation peak times of overlapping cell pairs

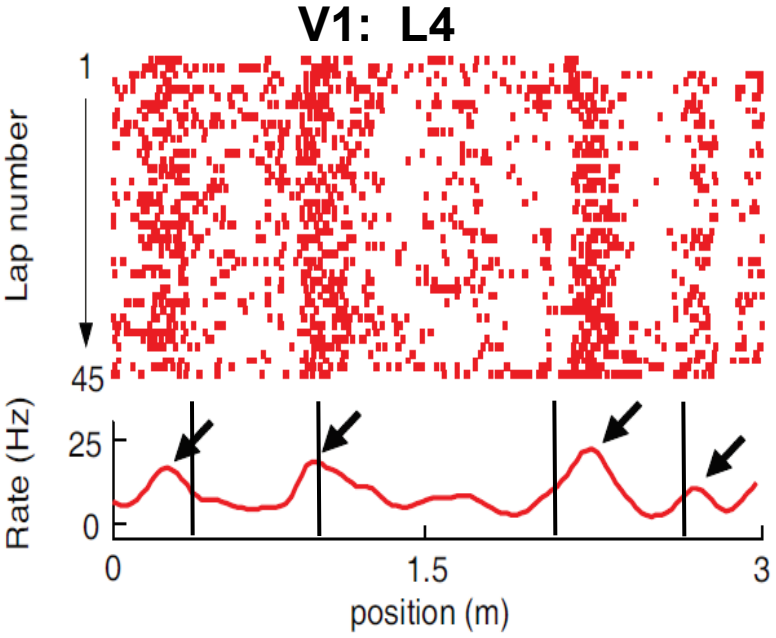


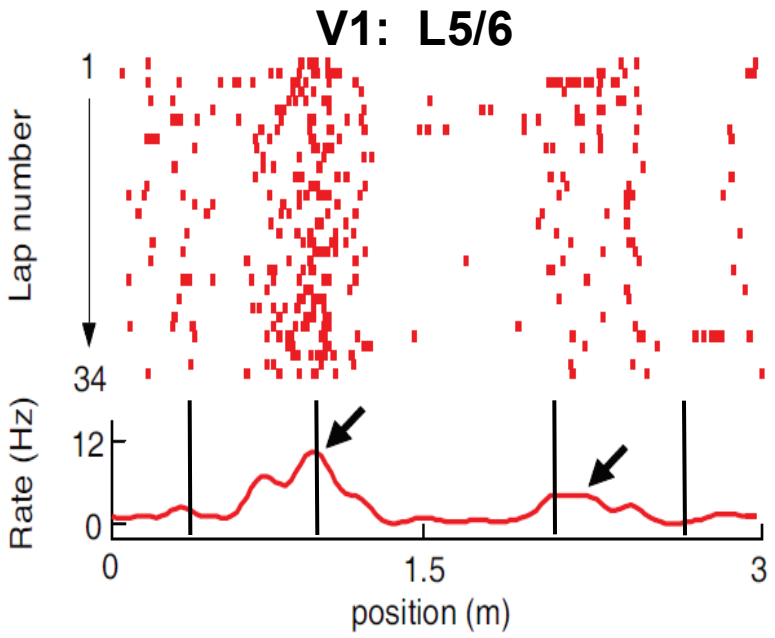
Landmarks



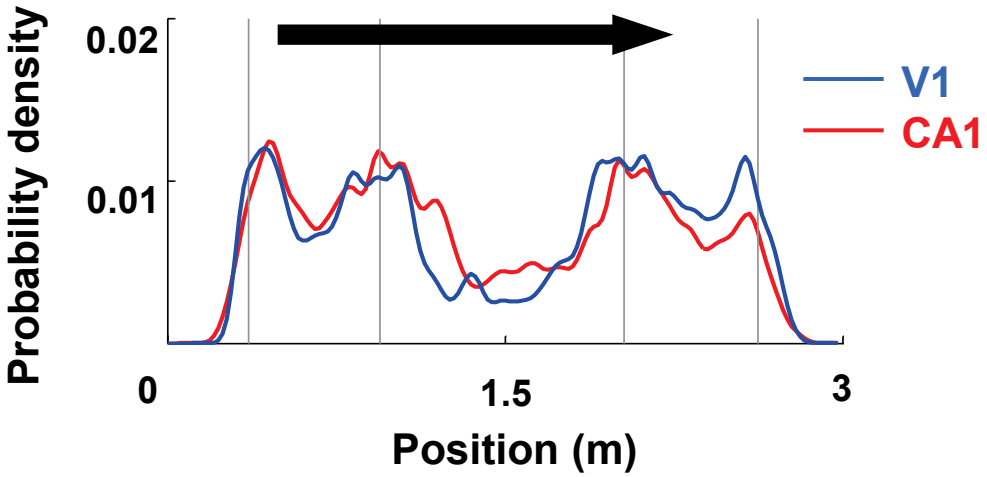


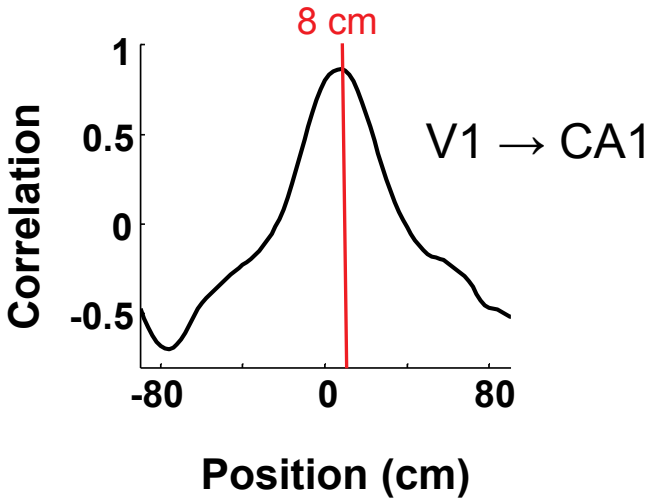
Fields around landmarks

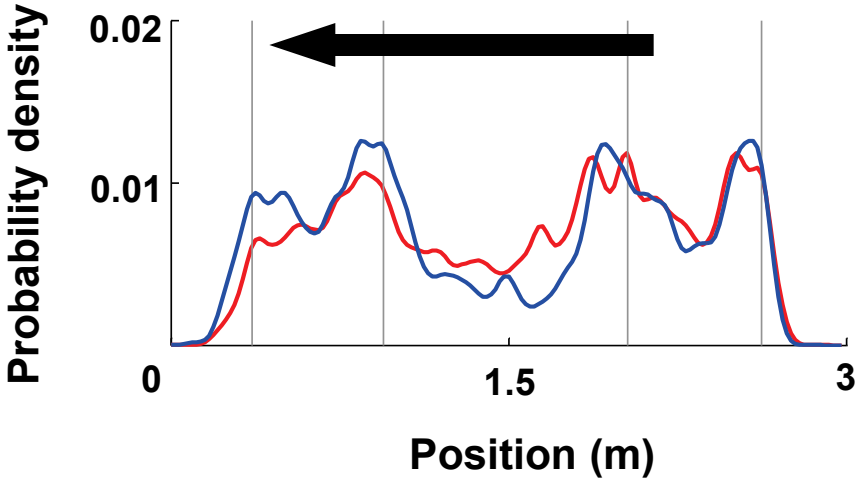


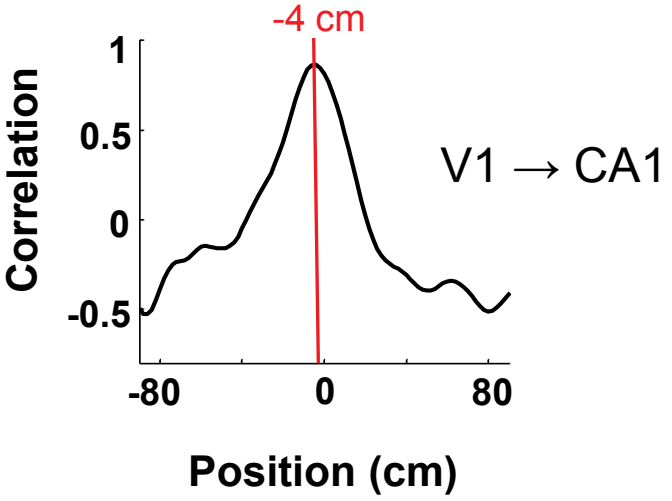


Field distributions of V1 and CA1 cells

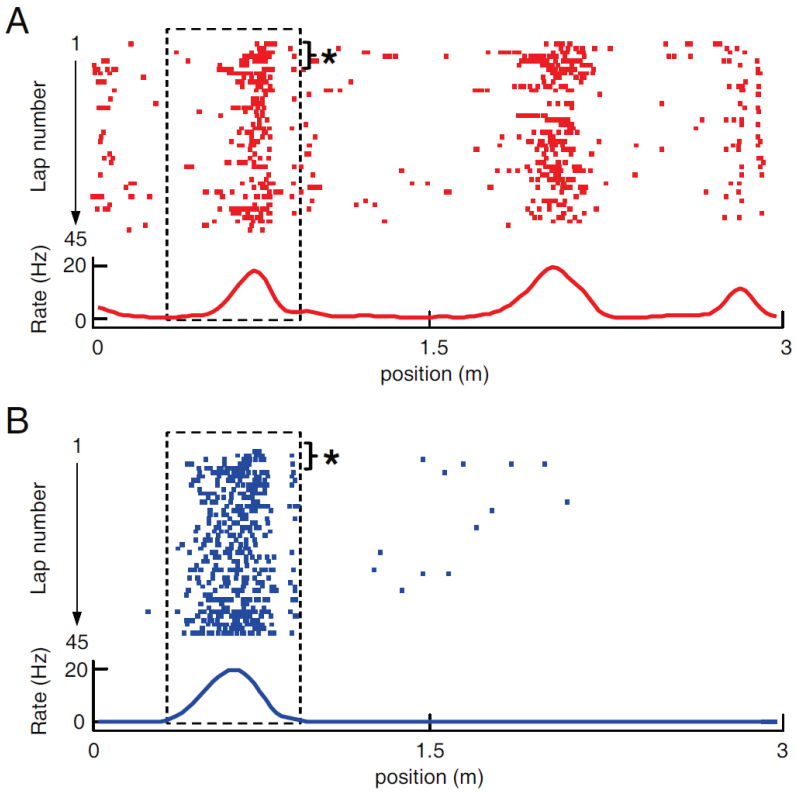


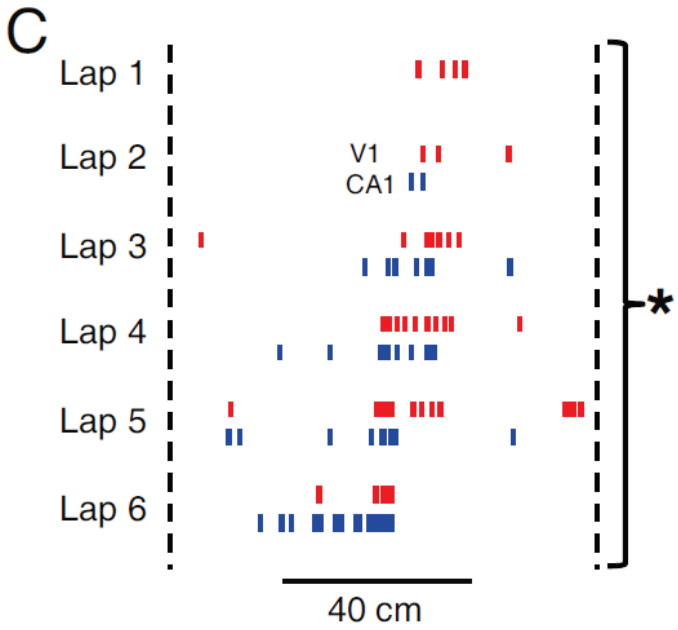


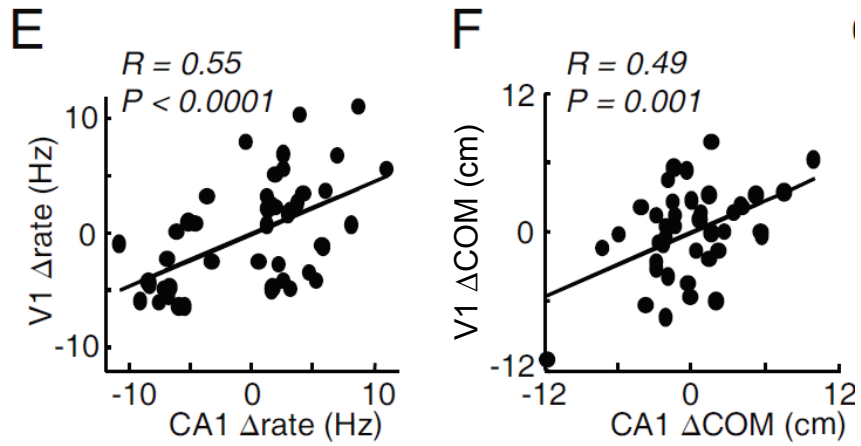




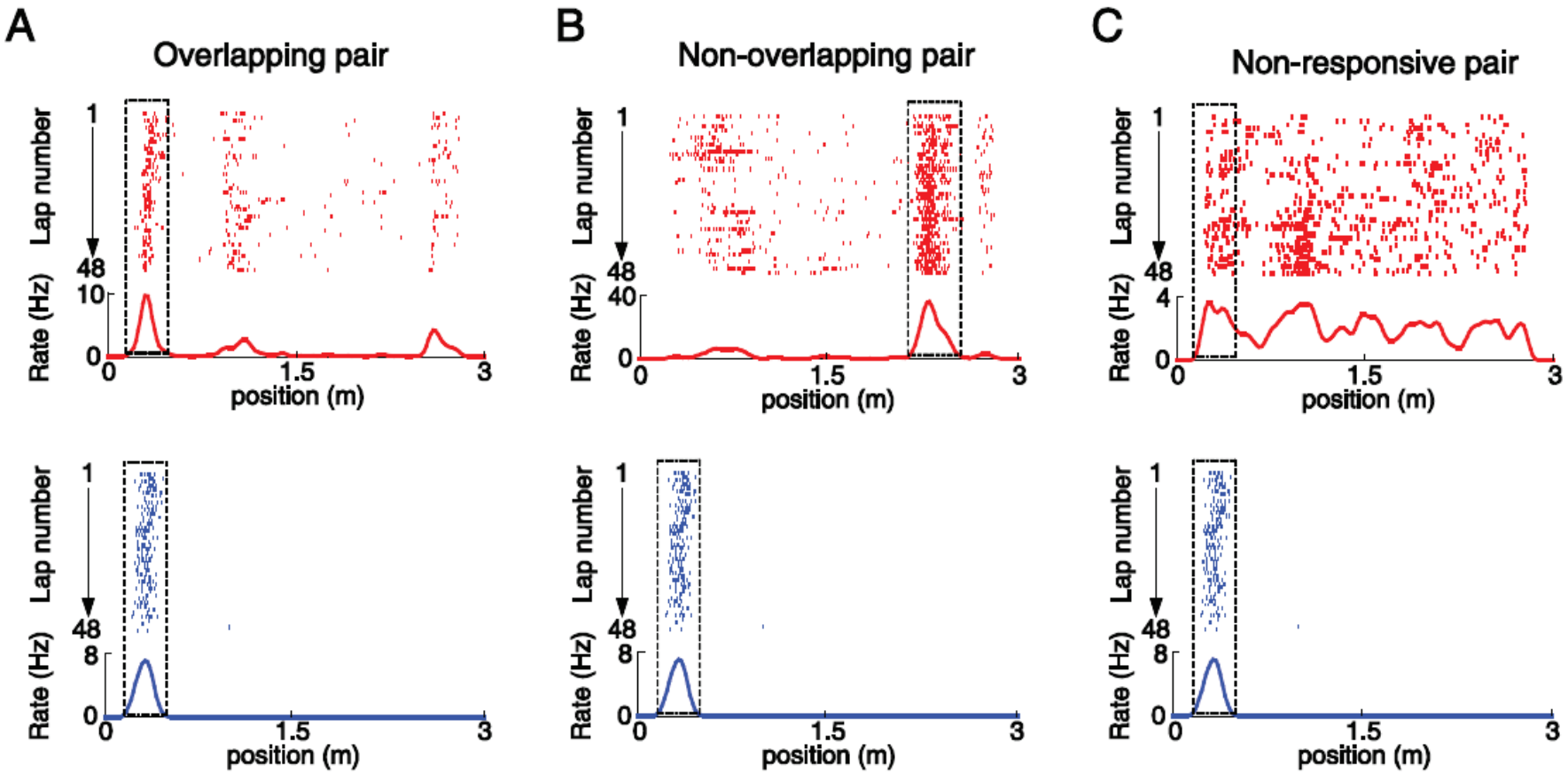
“Noise” correlation of a pair of overlapping V1-CA1 cells



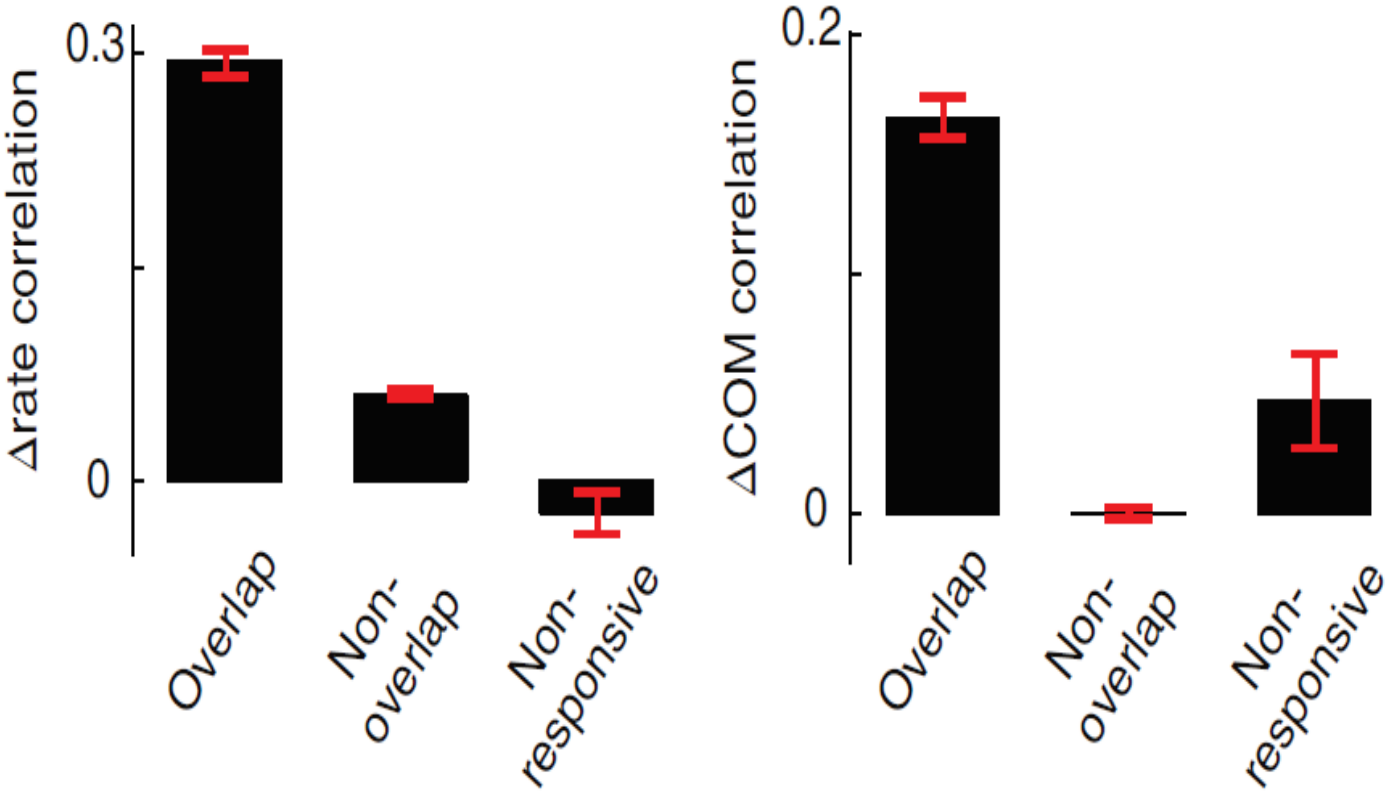




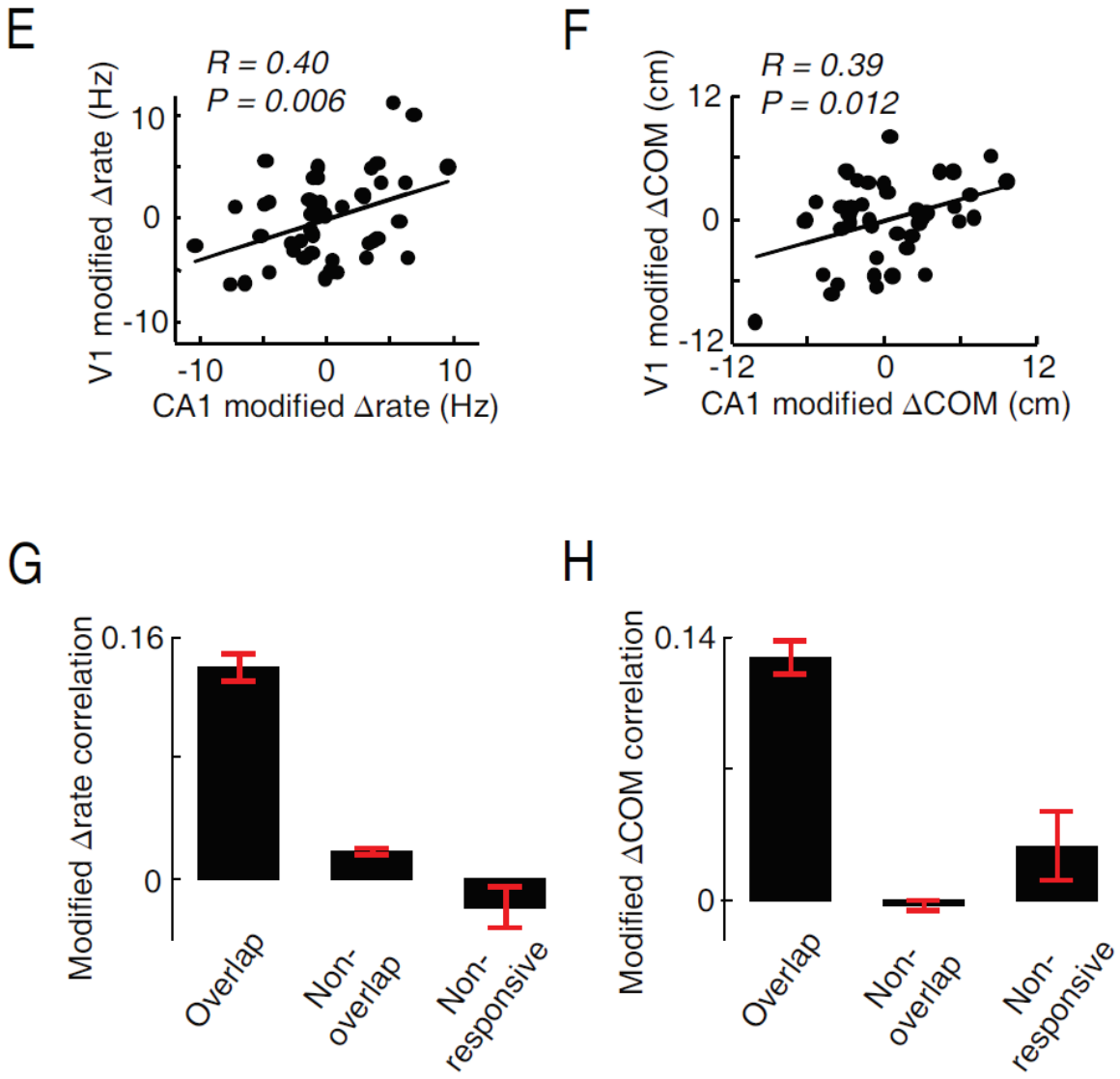
Different types of V1-CA1 cell pairs



“Noise” correlation of pairs of overlapping V1-CA1 cells



Modified "noise" correlation of pairs of overlapping V1-CA1 cells after removing speed/head direction modulation



Outline

- Recording techniques

- **Memory encoding: V1 and hippocampal neurons during active behavior**
  - **Stable responses of V1 (landmarks) / CA1 (places) cells to specific locations**
  - **Cross-correlation analysis: V1 activity leading CA1 activity**
  - **Field distribution: V1 fields leading CA1 fields**
  - **"Noise" correlation: precise co-fluctuation of V1 and CA1 cells with overlapping fields**
  - **These V1 cells may encode/store visual components of spatial/episodic memories**

- Memory consolidation: V1 and hippocampal neurons during sleep

- Summary

Outline

- Recording techniques
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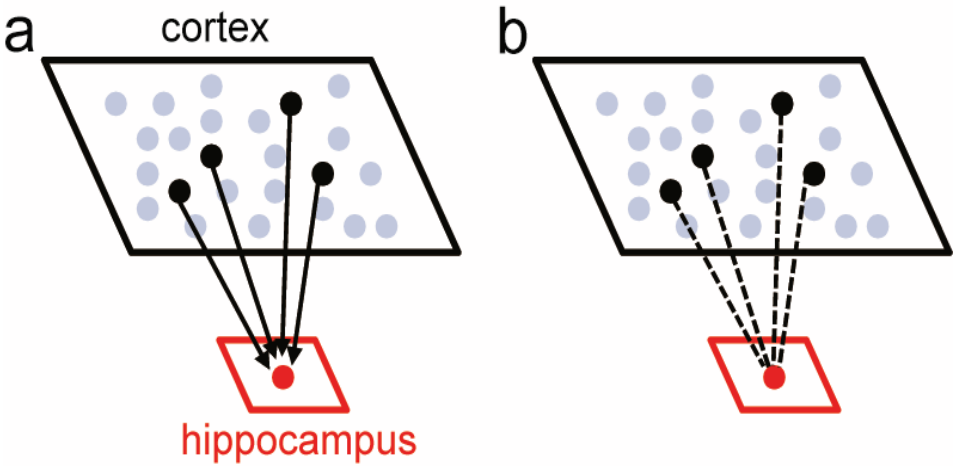
- Summary

Index theory of spatial memory

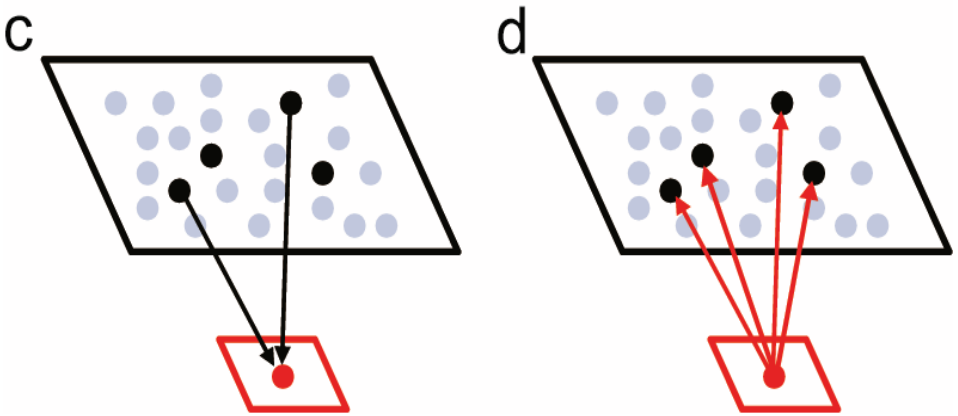
Memory encoding /formation



Cortical memory code

Hippocampal memory code

Memory retrieval /consolidation

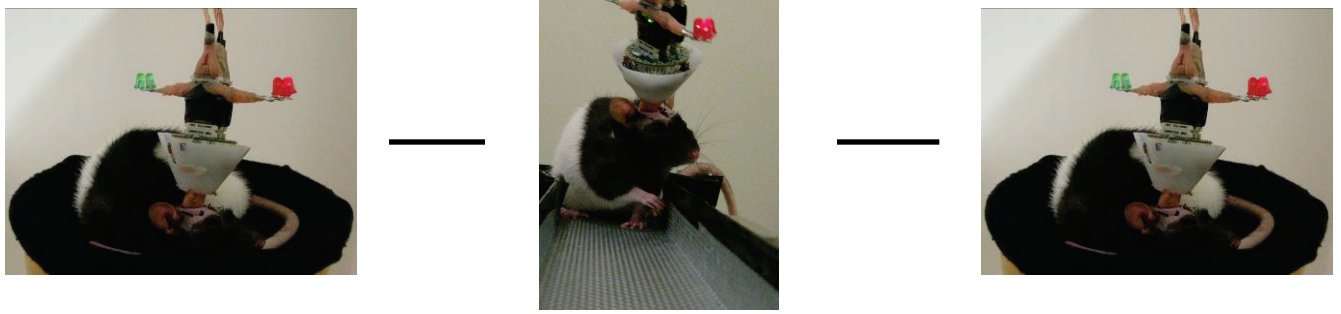


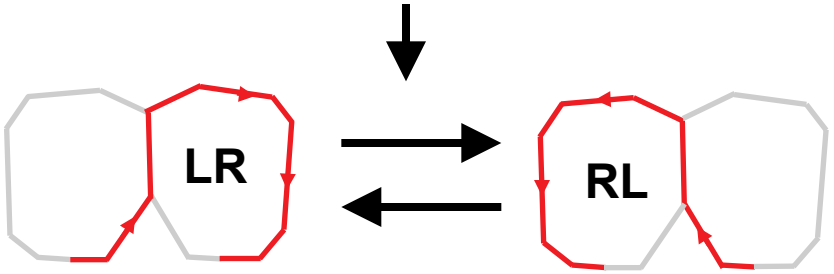
Cortical memory code

Hippocampal memory code

Experimental design

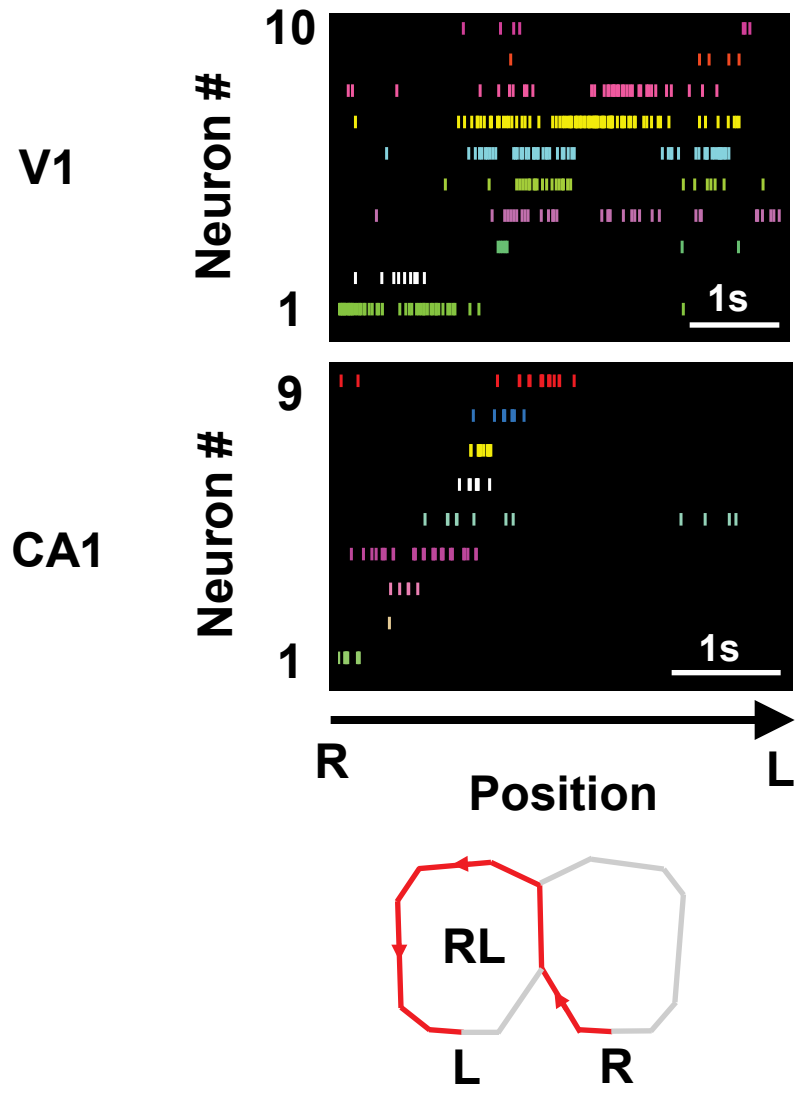
PRE (1-2hrs) — **RUN (~30mins)** — **POST (1-2hrs)**



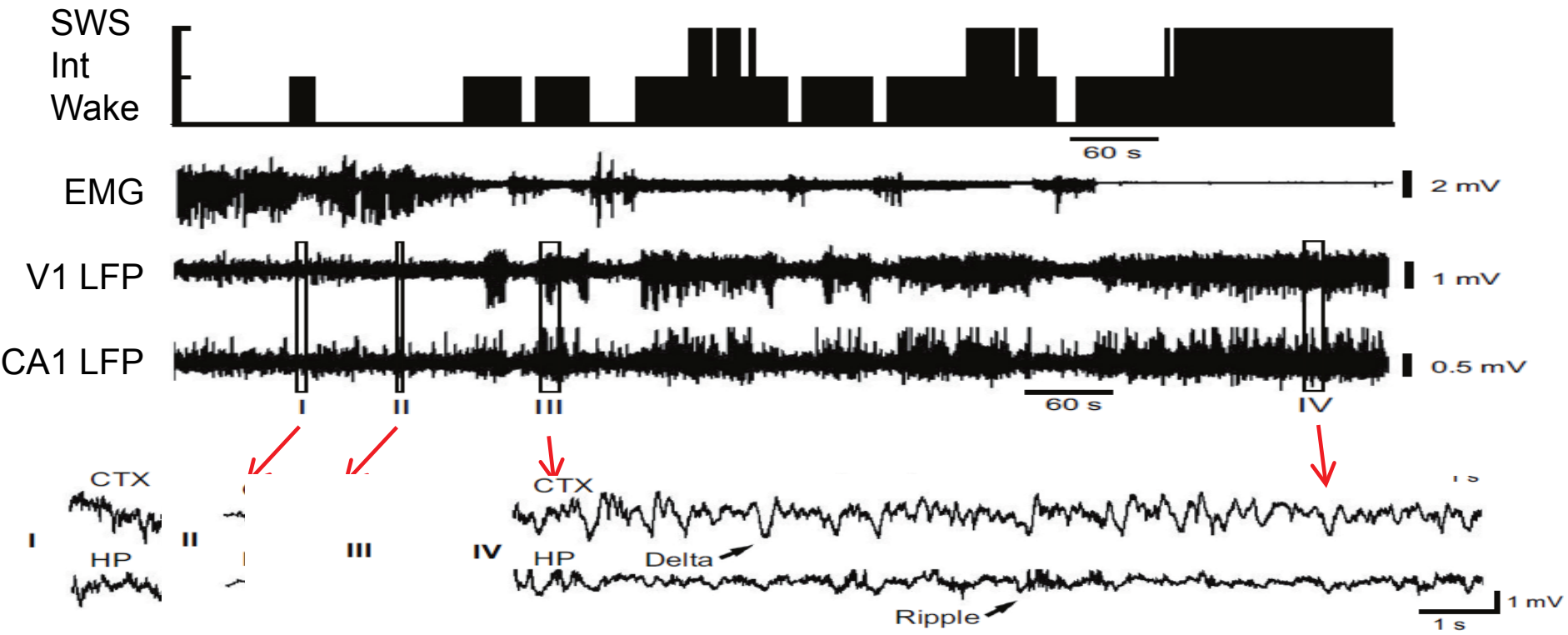


Trajectory alternation task

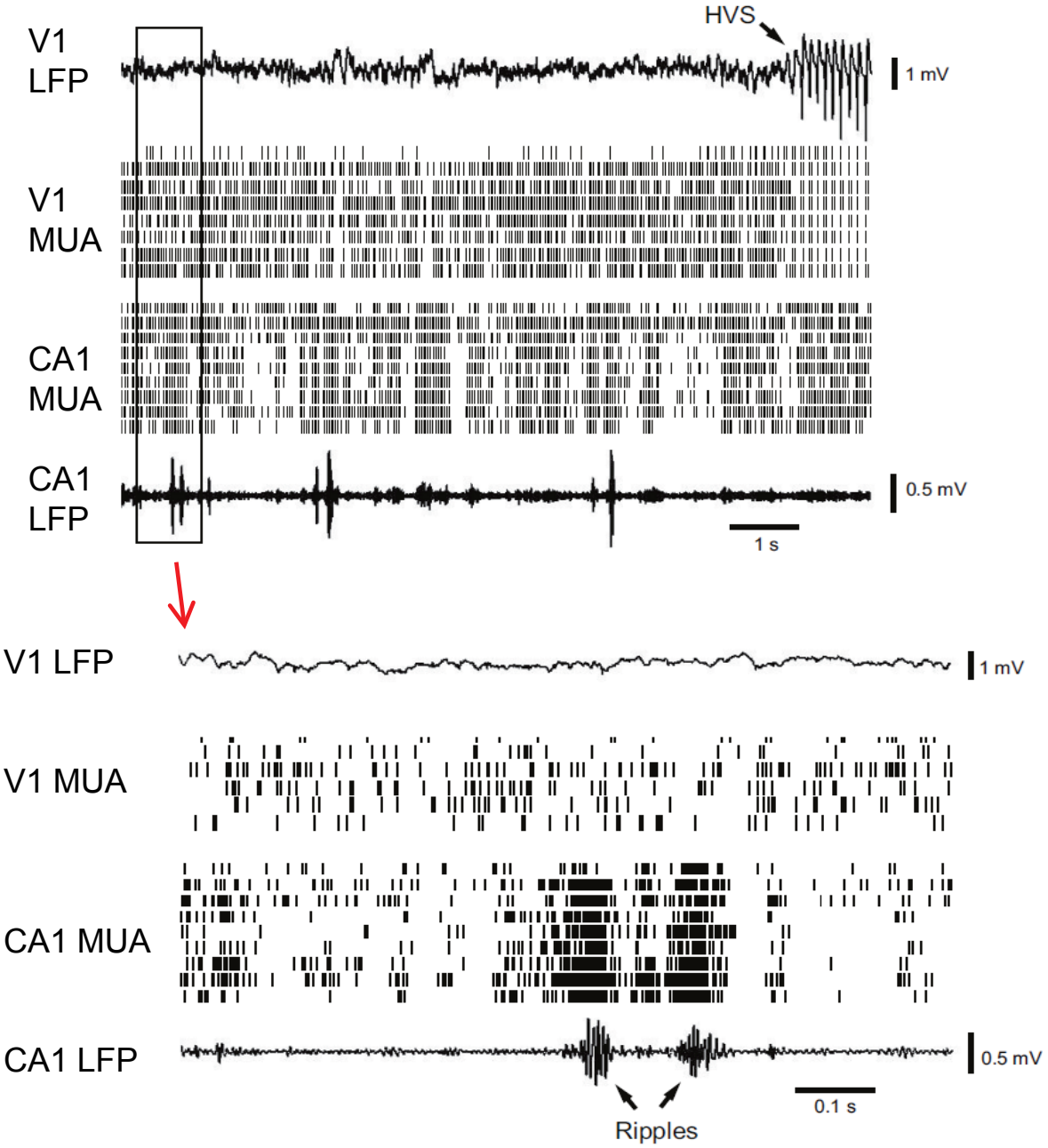
Trajectory encoding in both the hippocampus and visual cortex

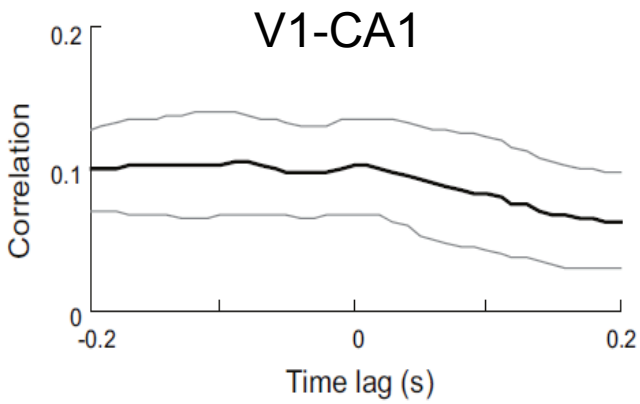


LFP events at sleep onset

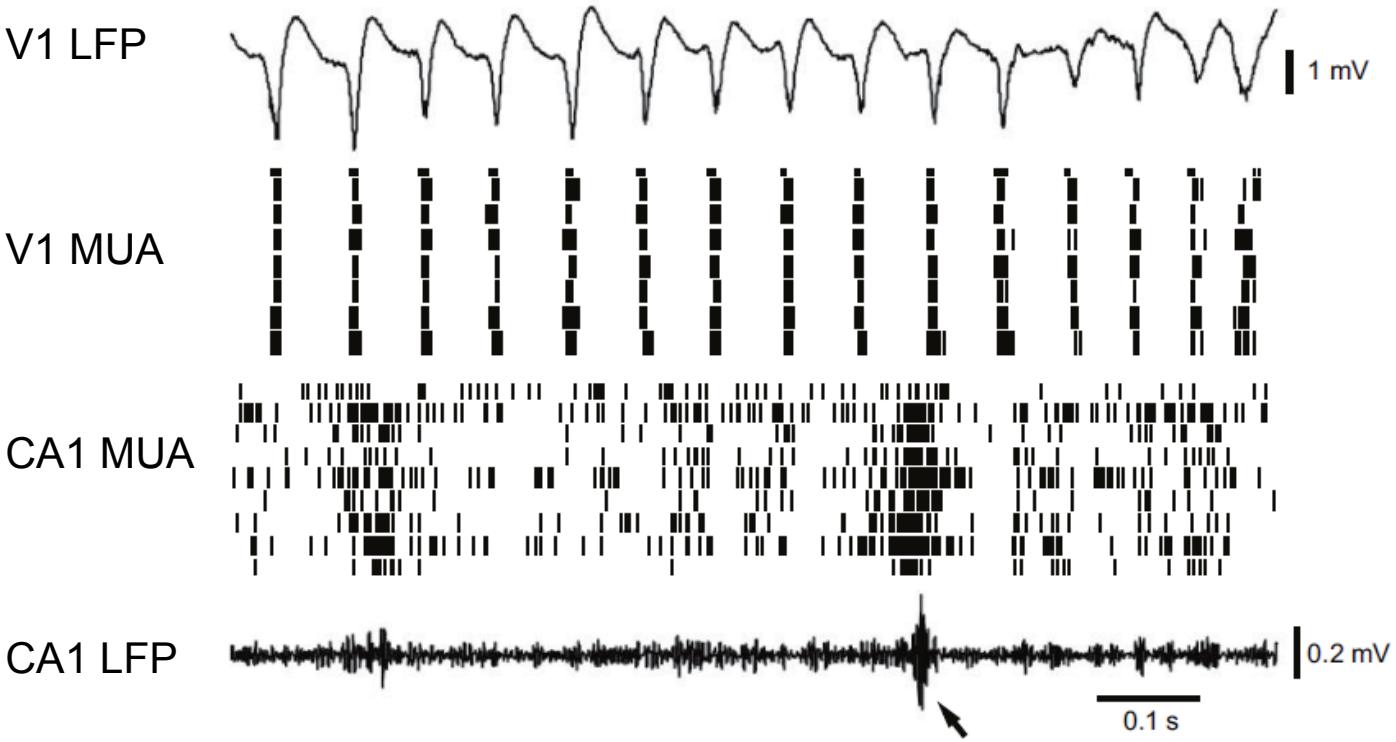


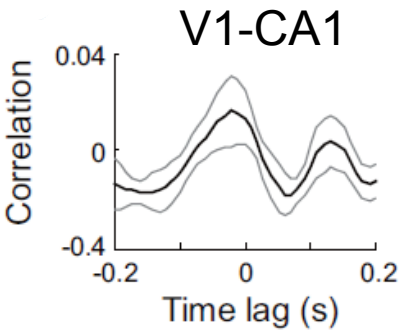
Hipocampal neuronal synchrony occur first, without cortical-hippocampal correlation



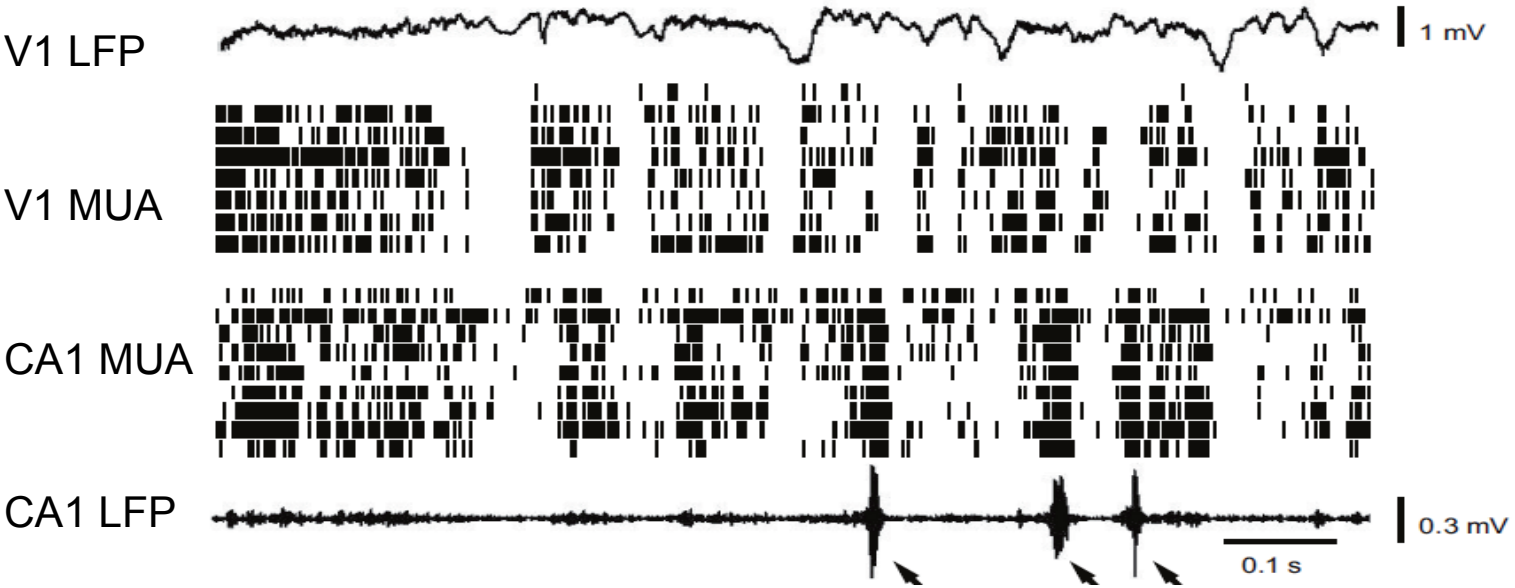


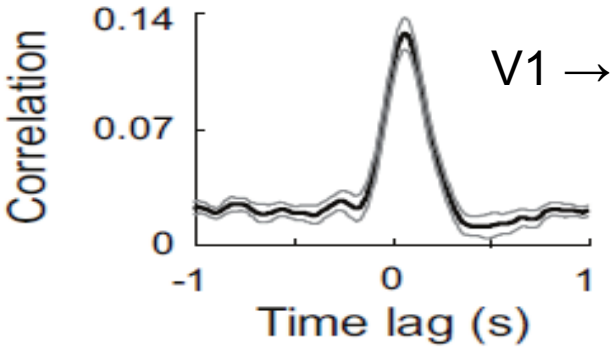
Strong cortical neuronal synchrony occur next, with weak cortical-hippocampal correlation





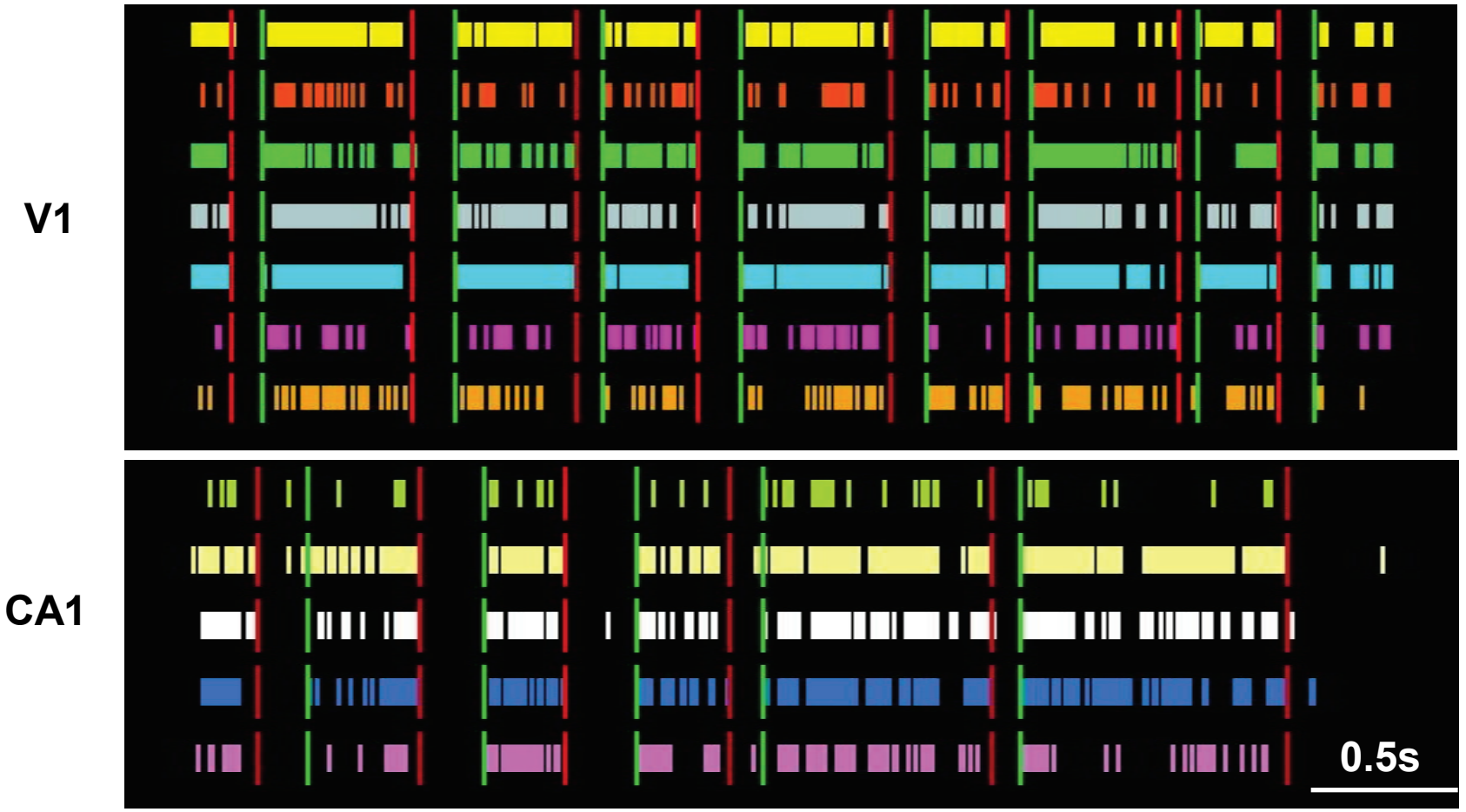
Then both cortical and hippocampal neuronal synchrony occur during slow-wave sleep, with strong cortical-hippocampal correlation



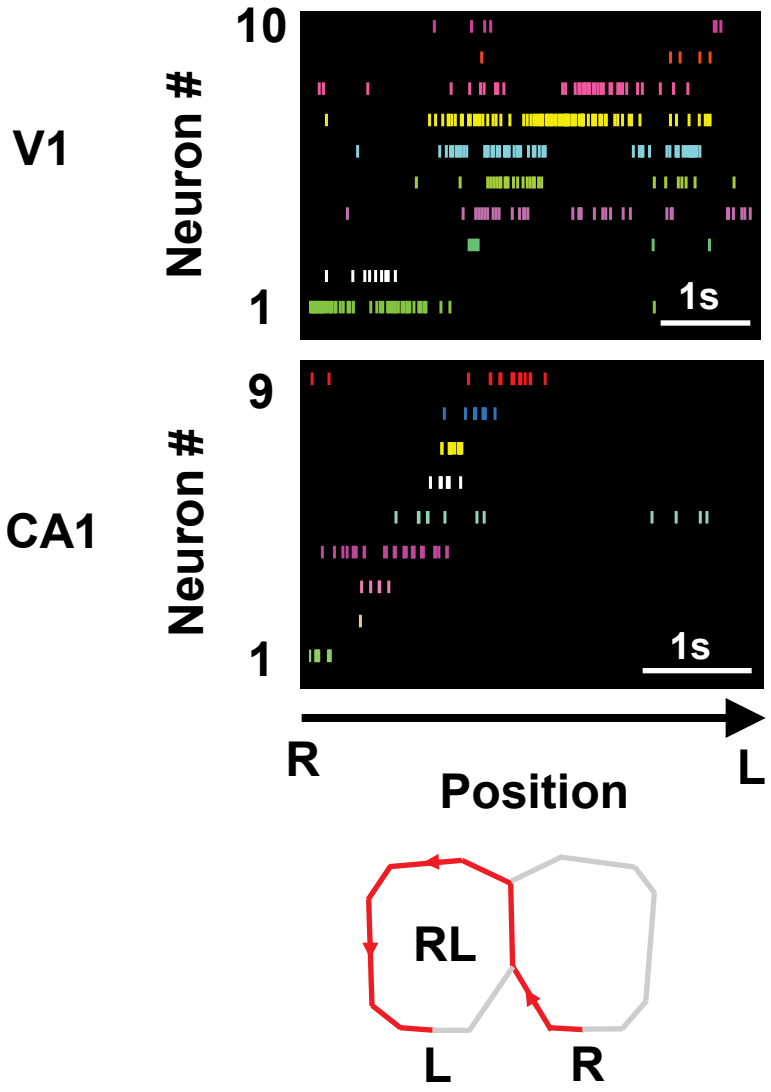


V1 → CA1 (by ~60 ms)

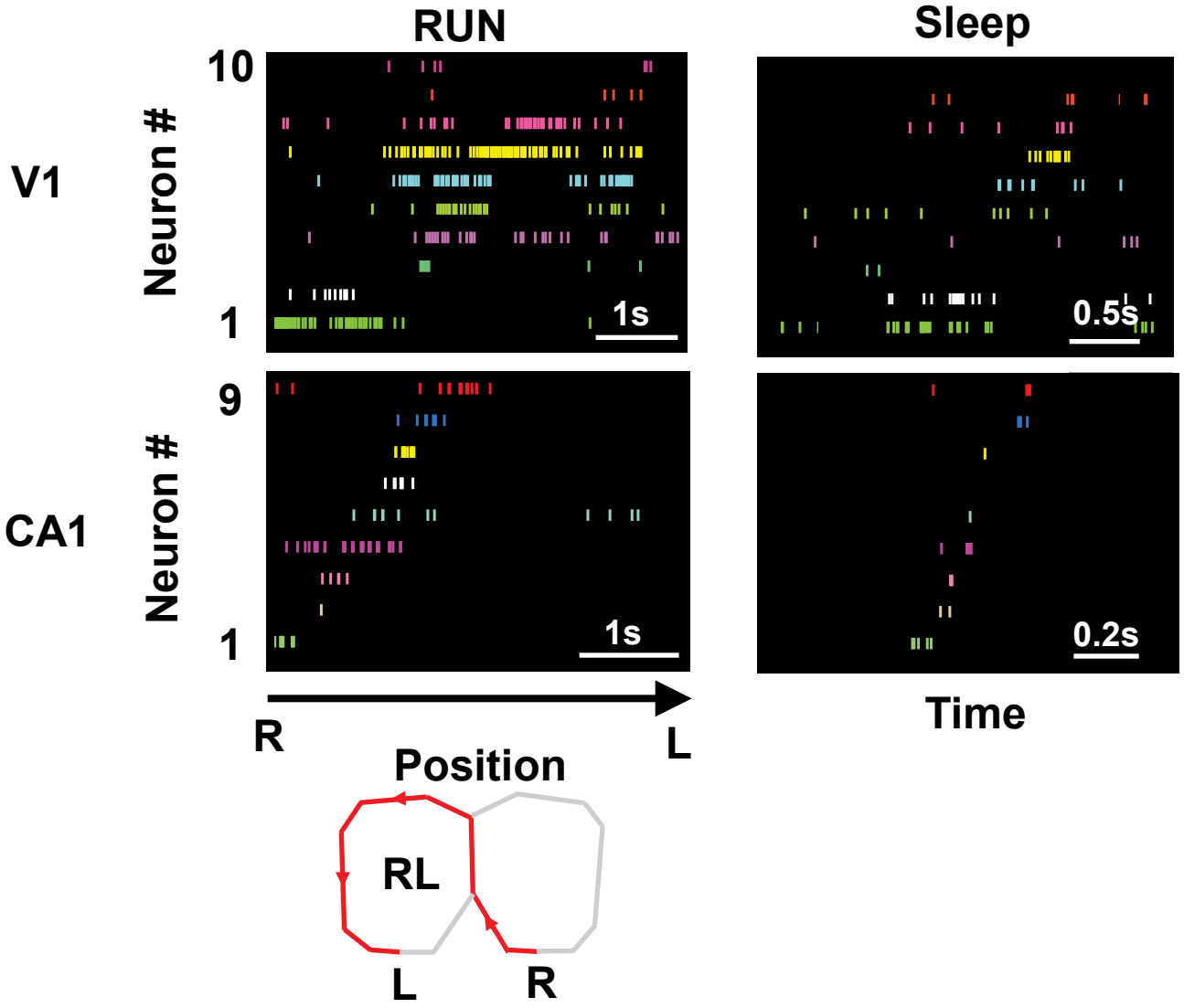
Discrete events during slow-wave sleep



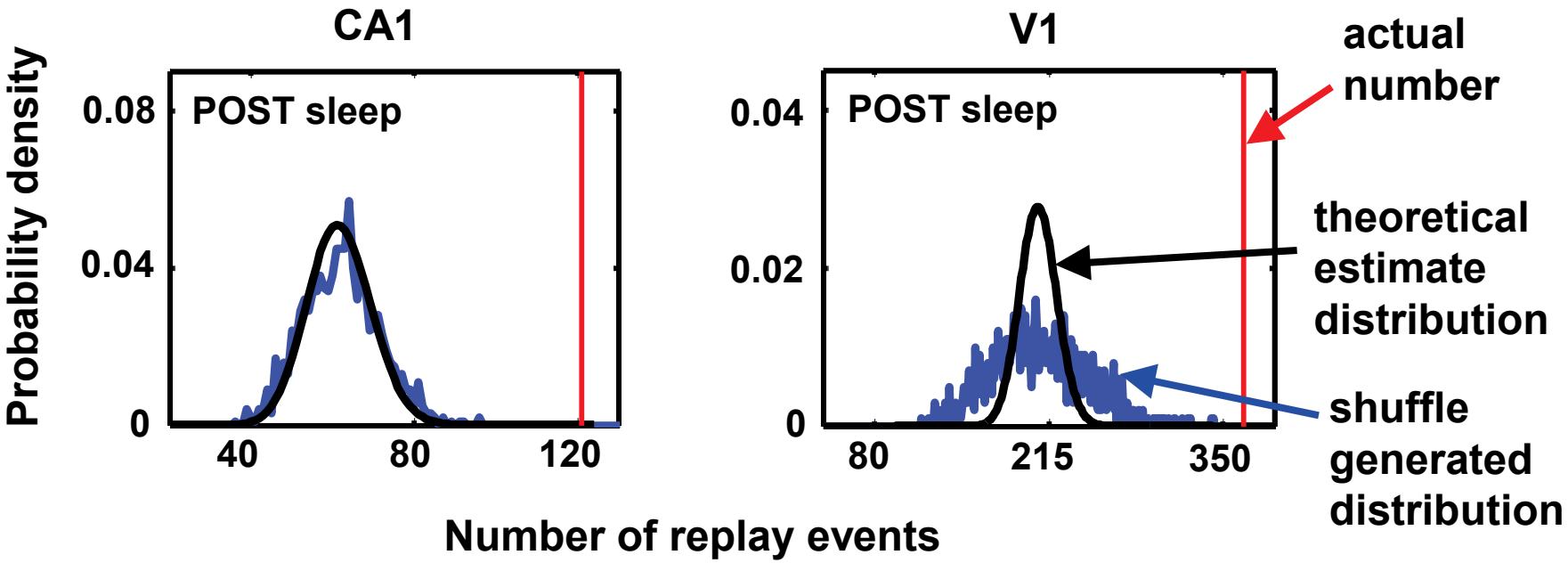
Trajectory encoding in both the hippocampus and visual cortex



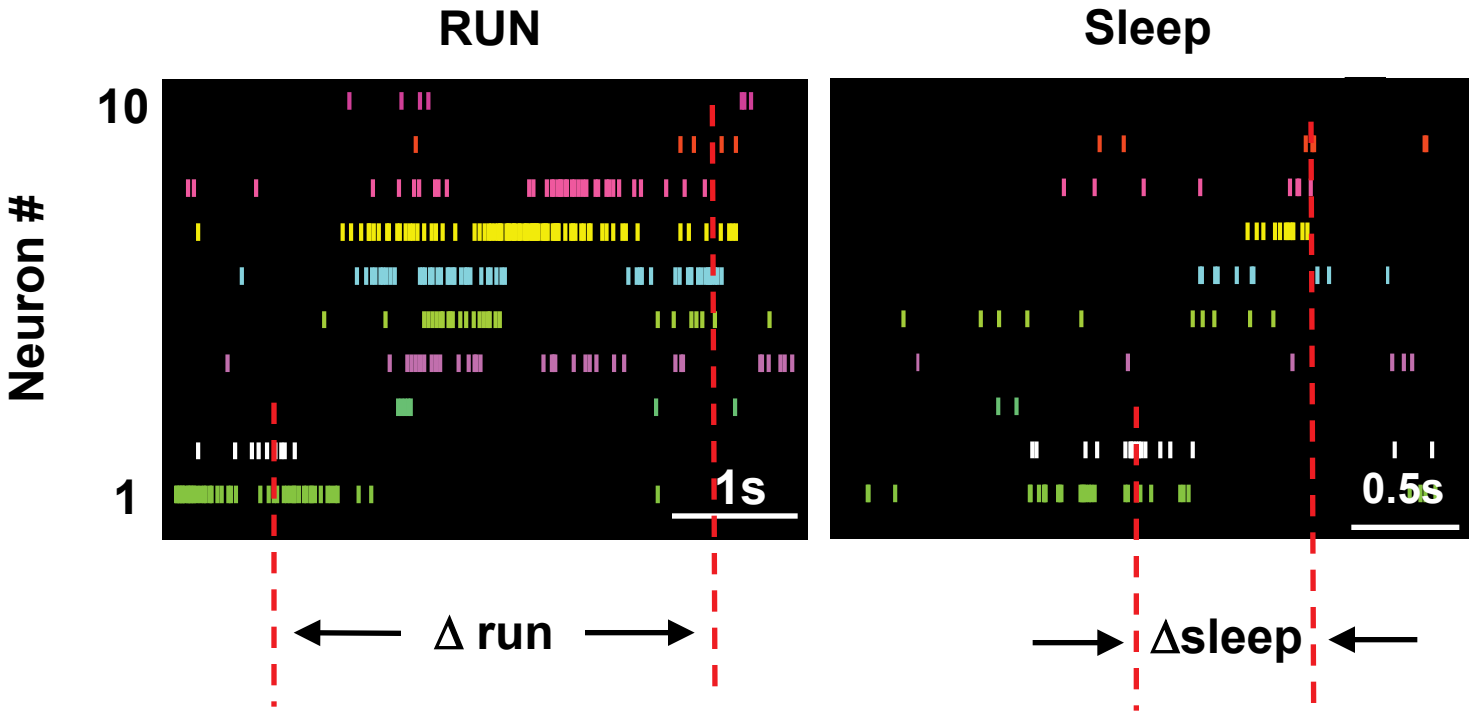
Replay of firing sequences during slow-wave sleep



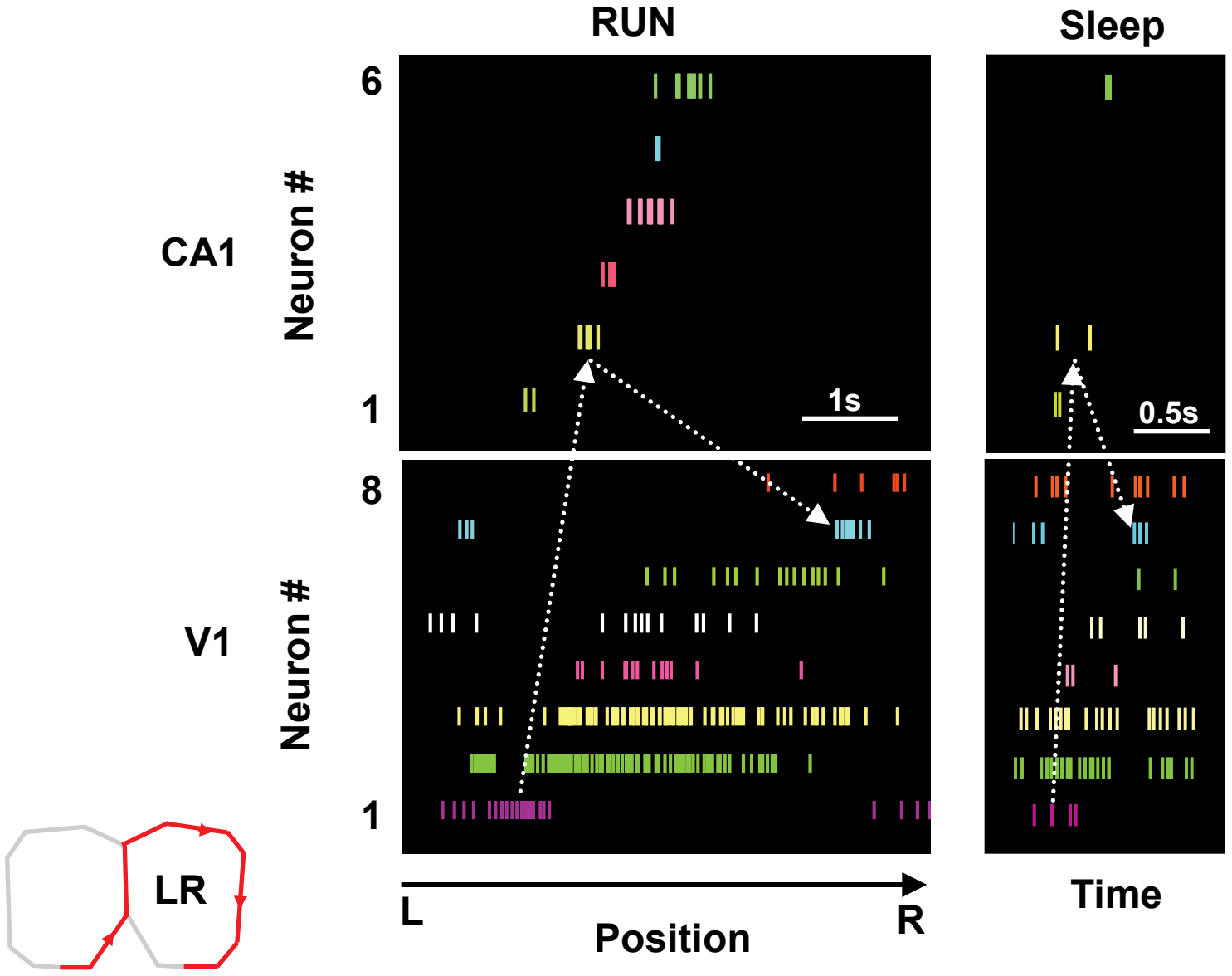
More replay events than what expected from chance



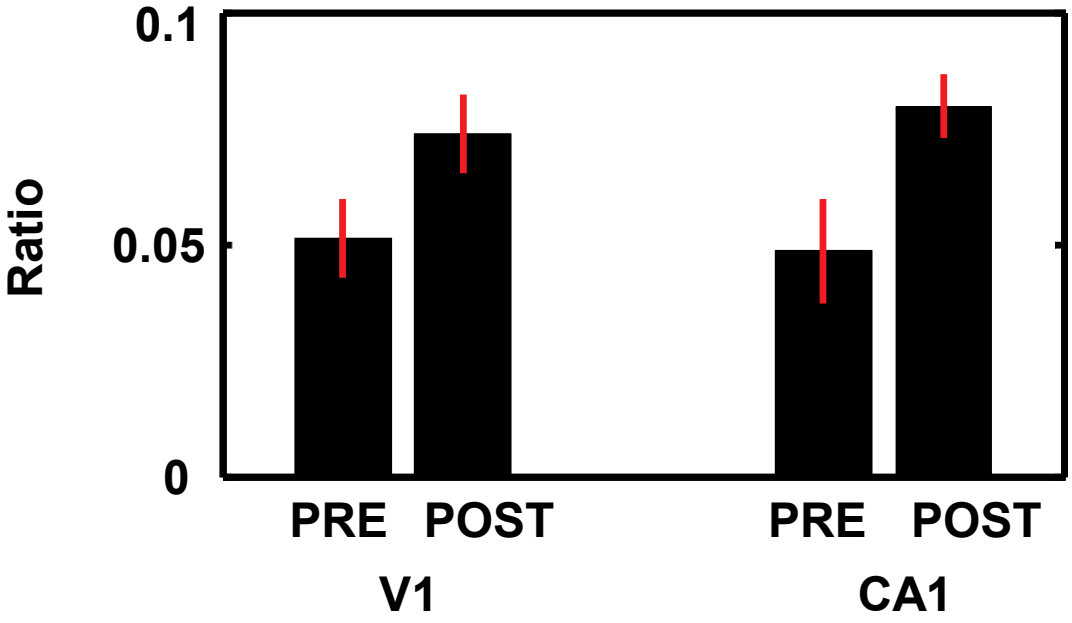
Replays are 5-10 times faster.



Coordination between V1 and CA1 replaying events



More replay events during POST sleep than PRE sleep



$$\text{Ratio} = \frac{\text{\# of replay events}}{\text{\# of candidate events}}$$

Outline

- Recording techniques
- Memory encoding: V1 and hippocampal neurons during active behavior
- **Memory consolidation: V1 and hippocampal neurons during sleep**
  - **Sleep onset: cortex (V1) and hippocampus (CA1) synchronize within each area and then correlate cross the two areas**
  - **Slow-wave sleep: activity patterns are coordinately replayed**
  - **Communication between V1 and CA1 neurons during sleep for memory consolidation**
- Summary

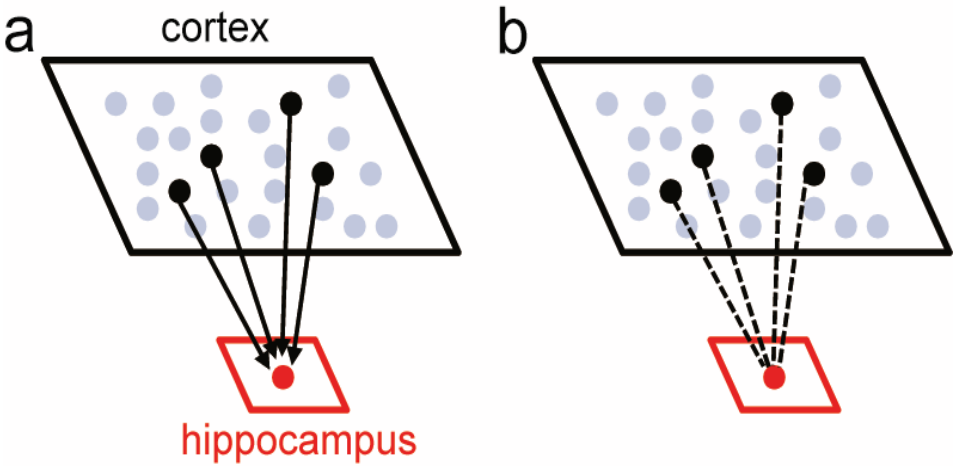
Objectives

Experimental evidence for neocortical-hippocampal interactions

Breakdown of the interaction in diseases

Index theory of spatial memory

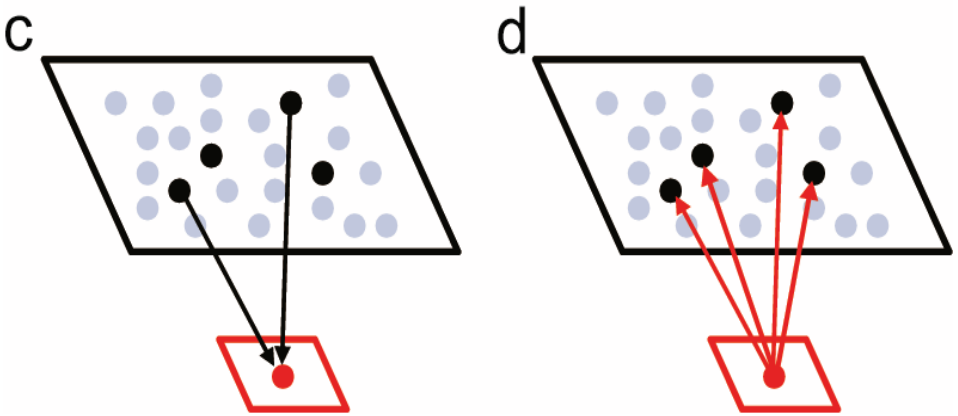
Memory encoding /formation



Cortical memory code

Hippocampal memory code

Memory retrieval /consolidation



Cortical memory code

Hippocampal memory code