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Circuit Events in the Hippocampus during Goal-Oriented Spatial Learning

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European Research Council
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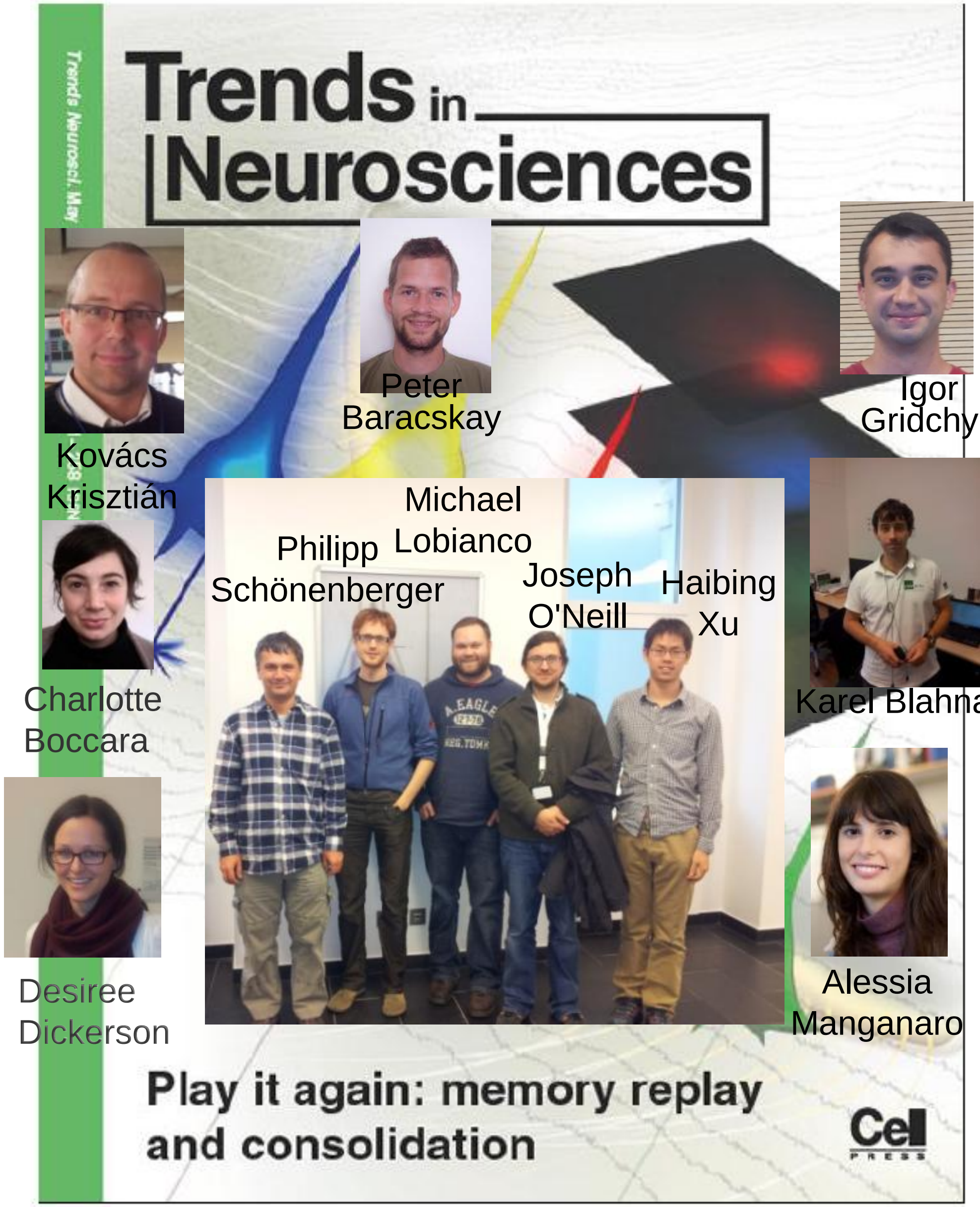
Lab members



FENS Meeting, Amsterdam, 2010

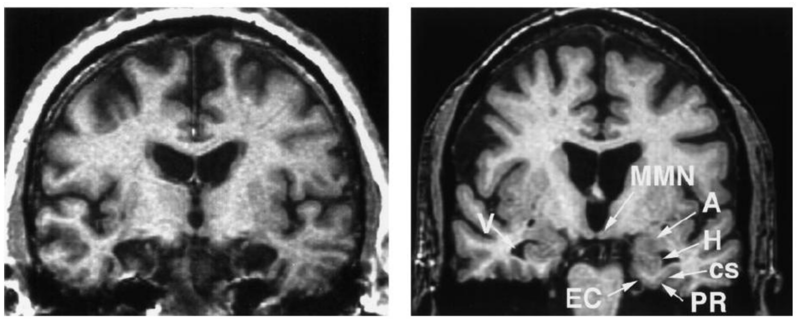
The hippocampus is a key brain circuit for certain forms of memory

LOSS OF RECENT MEMORY AFTER BILATERAL HIPPOCAMPAL LESIONS

BY

WILLIAM BEECHER SCOVILLE and BRENDA MILNER

J. Neurol. Neurosurg. Psychiat., 1957, **20**, 11.



H.M. *normal brain*

H.M. (Henry Gustav Molaison, 1926–2008)

Anterograde amnesia
Retrograde amnesia
Events
Places

"(…) After operation this young man could no longer recognize the hospital staff nor find his way to the bathroom, and he seemed to recall nothing of the day-to-day events of his hospital life. (…) he did not remember the death of a favourite uncle three years previously (…). The family moved from their old house to a new one a few blocks away on the same street; he still has not learned the new address, though remembering the old one perfectly, nor can he be trusted to find his way home alone. (…) This patient has even eaten luncheon in front of one of us (…), a mere half-hour later (…) he could not remember having eaten luncheon at all. Yet to a casual observer this man seems like a relatively normal individual, since his understanding and reasoning are undiminished."

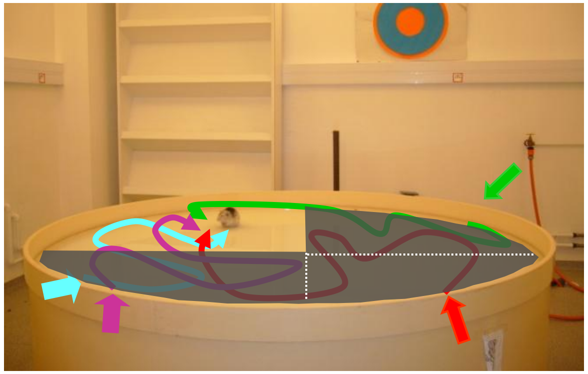
in Scoville and Milner, 1957

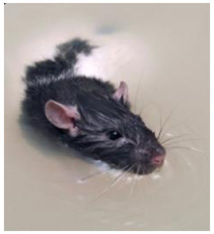
The hippocampus is a key brain circuit for certain forms of memory

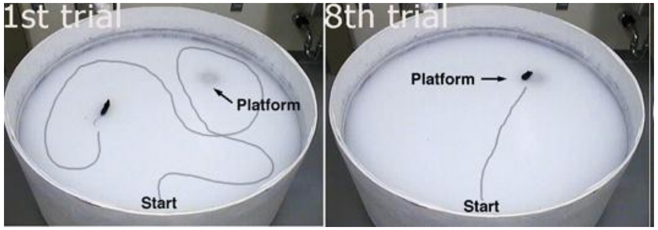
Place navigation impaired in rats with hippocampal lesions

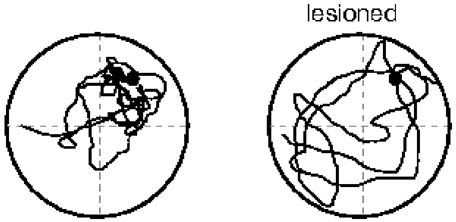
Nature Vol. 297 24 June 1982

R. G. M. Morris*, P. Garrud*, J. N. P. Rawlins† & J. O'Keefe‡









Learning trials

Post-learning probe test (no platform)

Fig. 1 Mean latency of escape (s) for the 50 trials of the experiment. ■, Hippocampal lesion; ●, cortical lesion; ○, control;. The trial number of the first of each daily set of trials is shown on the abscissa.

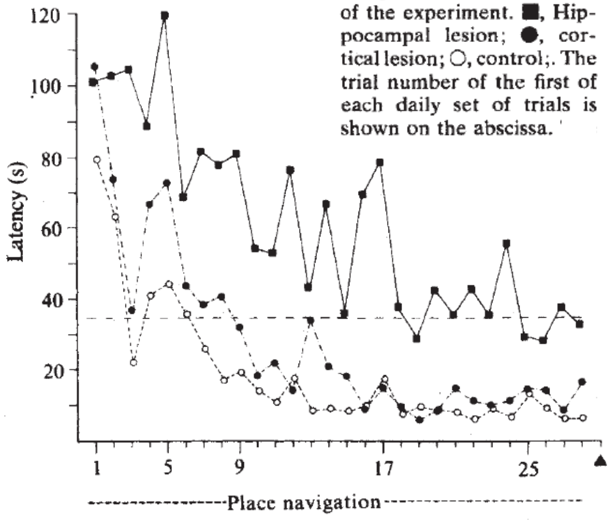
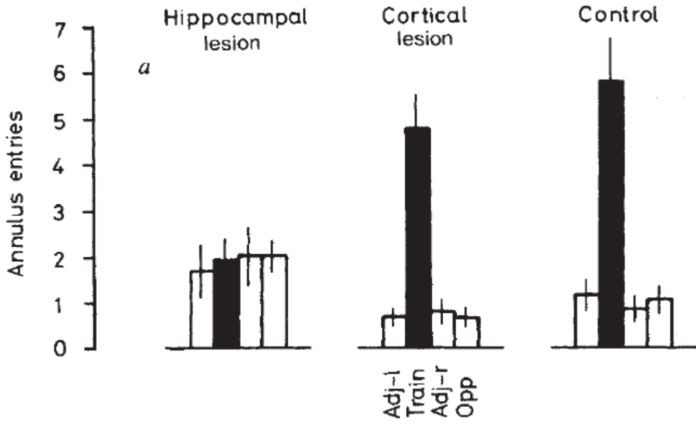
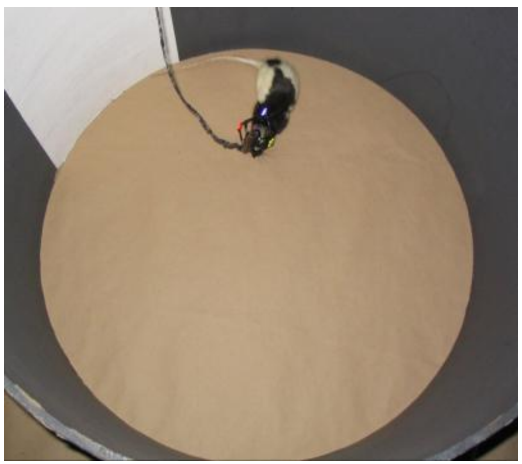


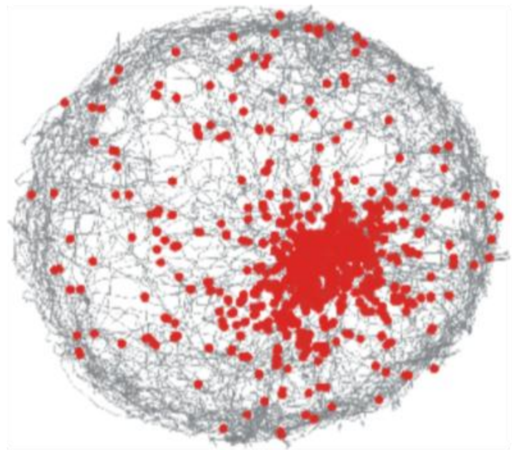
Fig. 3 Mean crossings of each of the annuli (± 1 s.e.) marking the former platform positions during *a*, transfer test A (after place-navigation training)

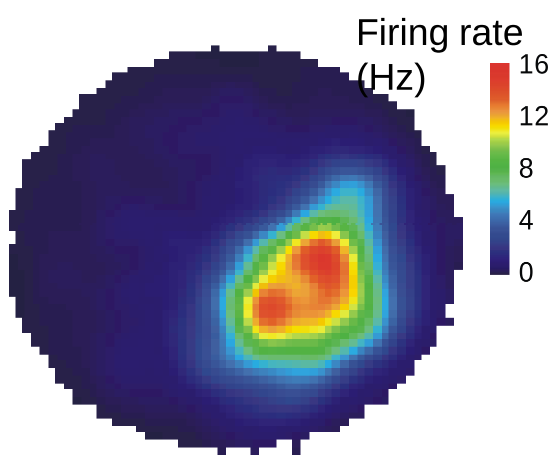


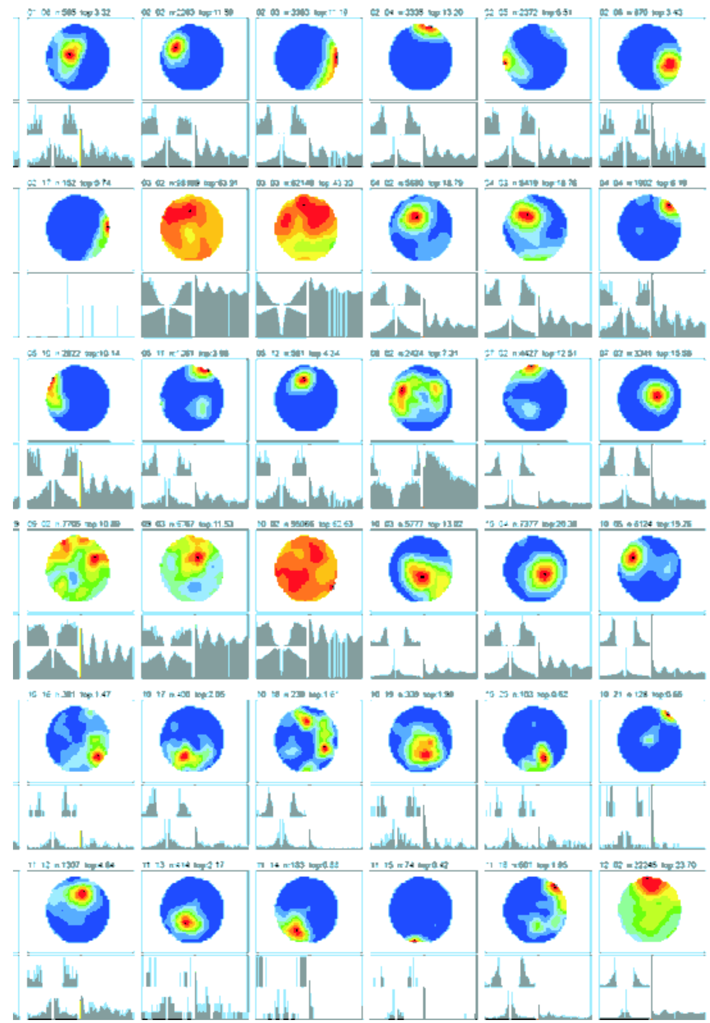
Place cells a substrate to code for memory traces?

Hippocampal principal cells fire in relation to space (O'Keefe & Dostrovsky, 1971)

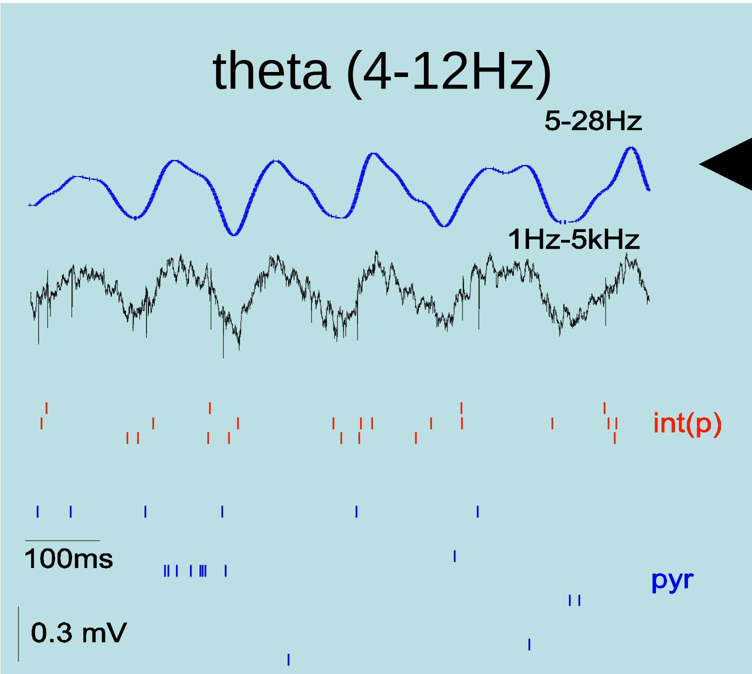






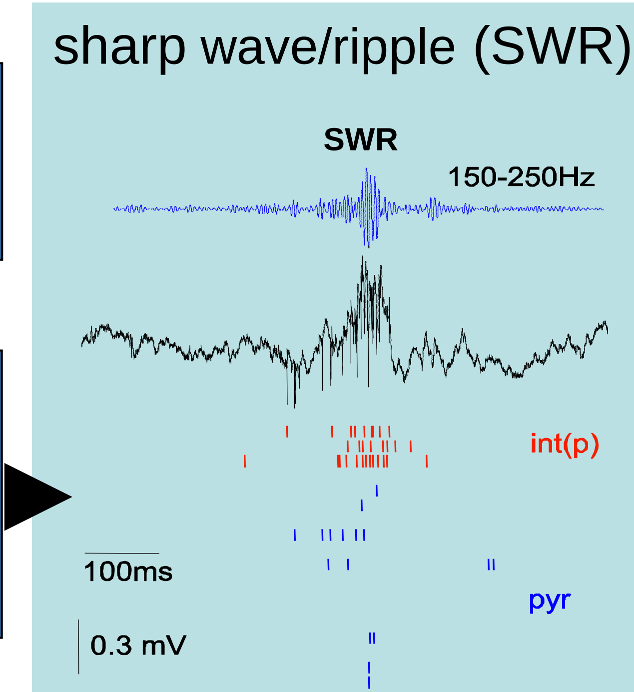


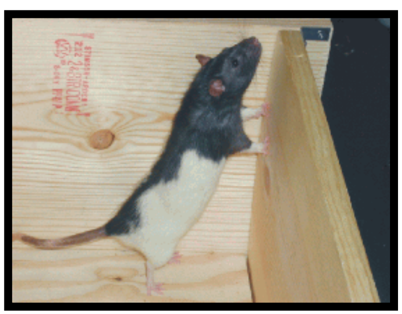
Different network patterns during waking exploration and sleep are involved at different stages of memory processing



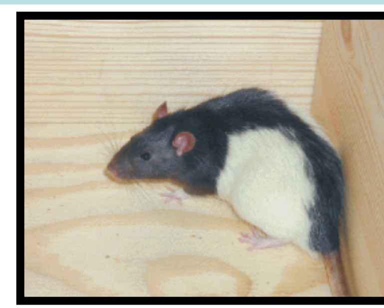
Exploration
and REM sleep

slow-wave sleep
and immobility,
consummatory
behaviours



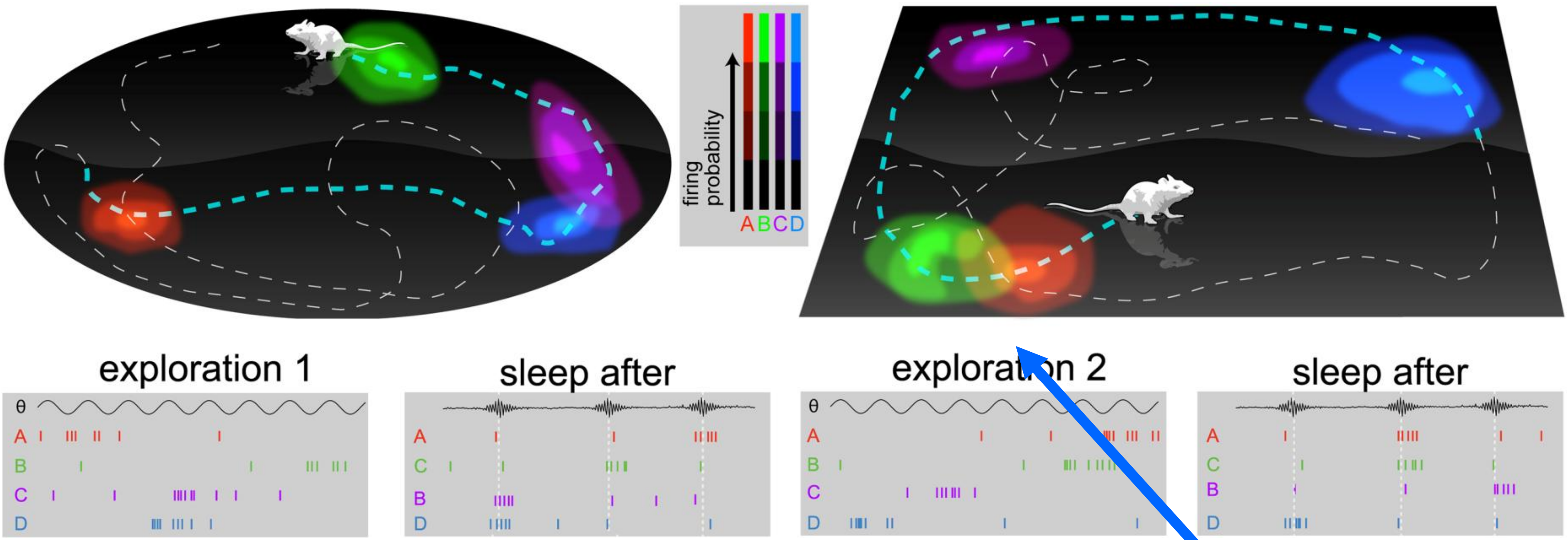


Encoding, recall

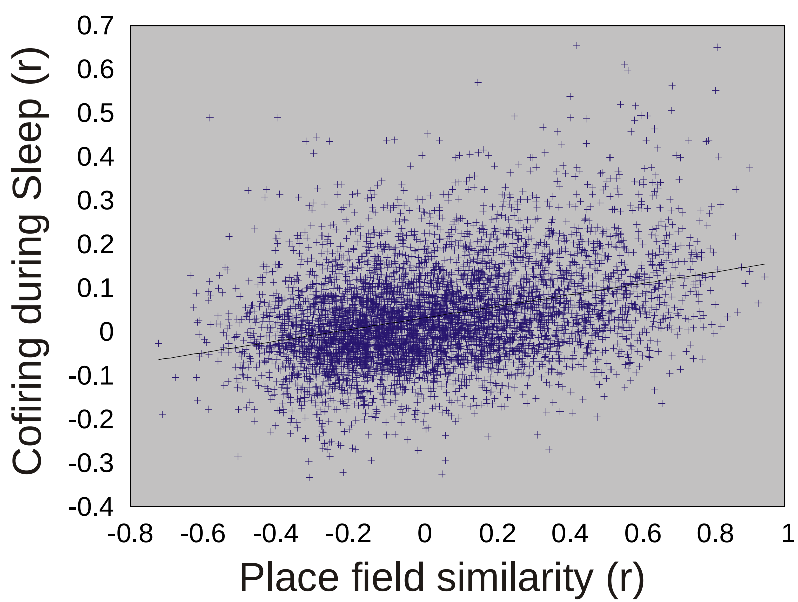


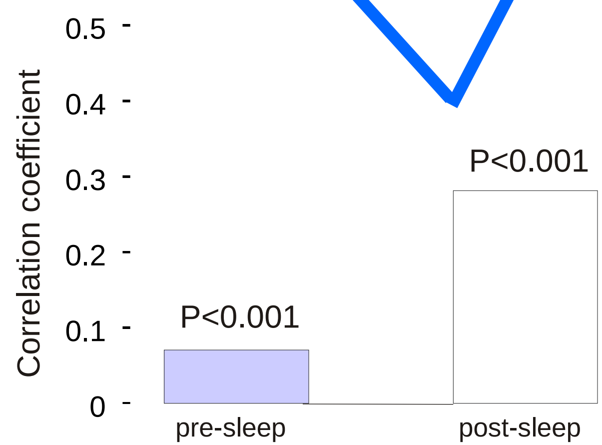
consolidation

Cells with similar place fields also fire together in post-sleep



O'Neill, Pleydell-Bouverie, Dupret & Csicsvari, TINS, 2010

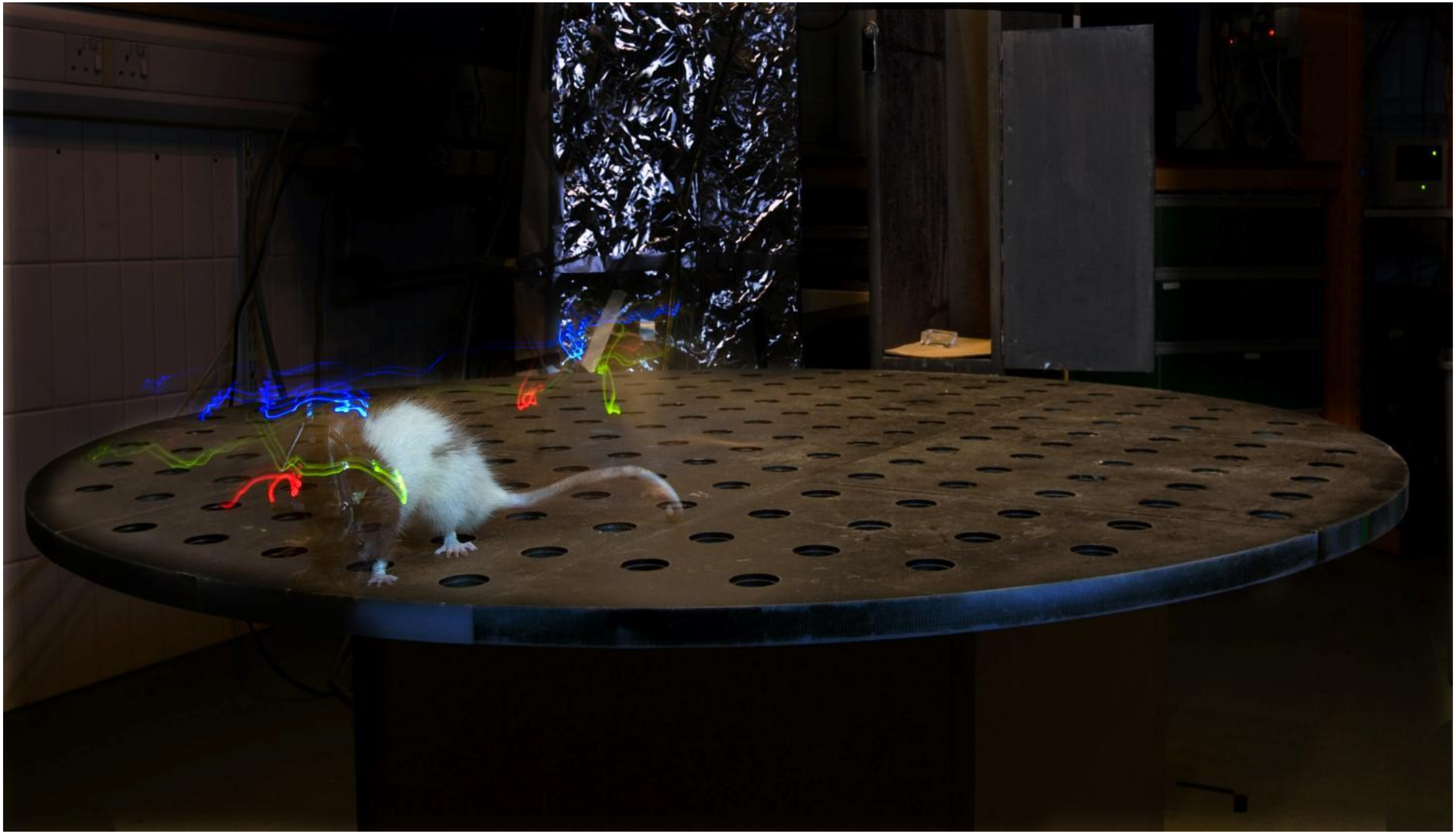




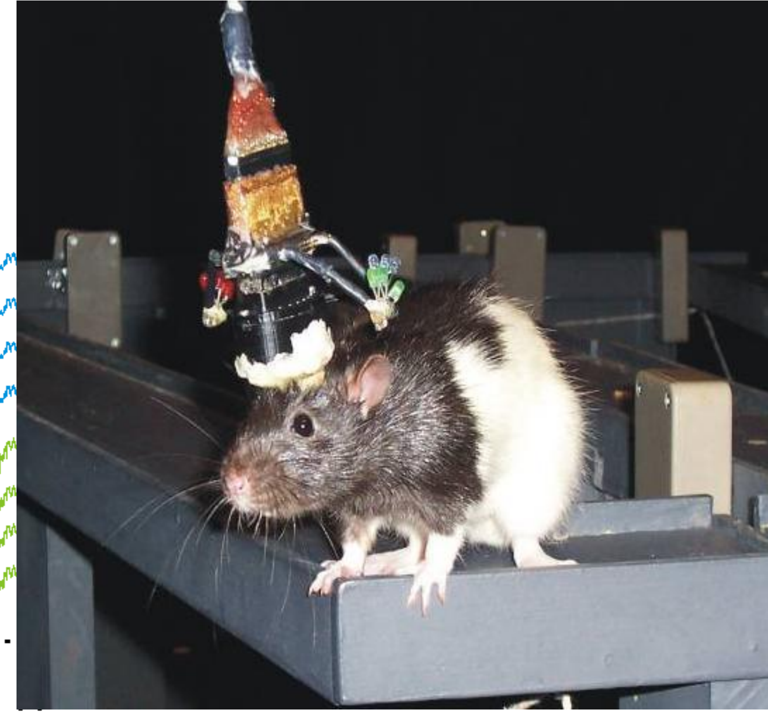
O'Neill, Senior, Csicsvari, Neuron, 2006

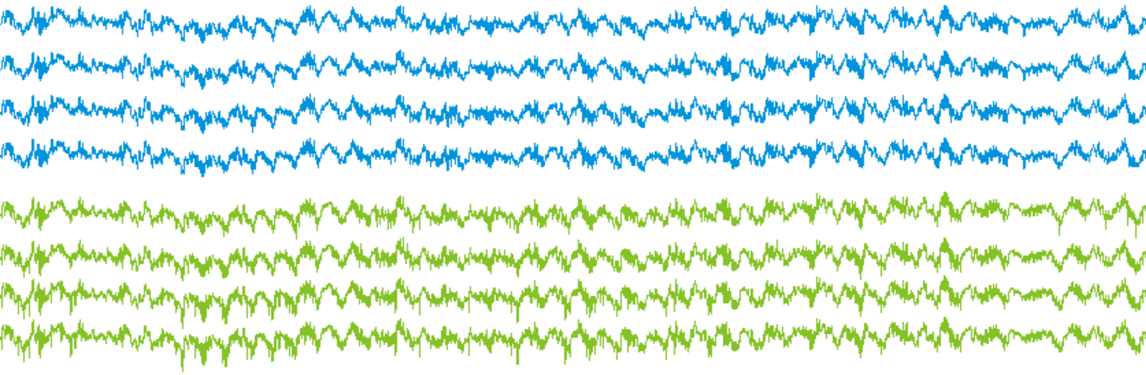
Wilson and McNaughton, 1995

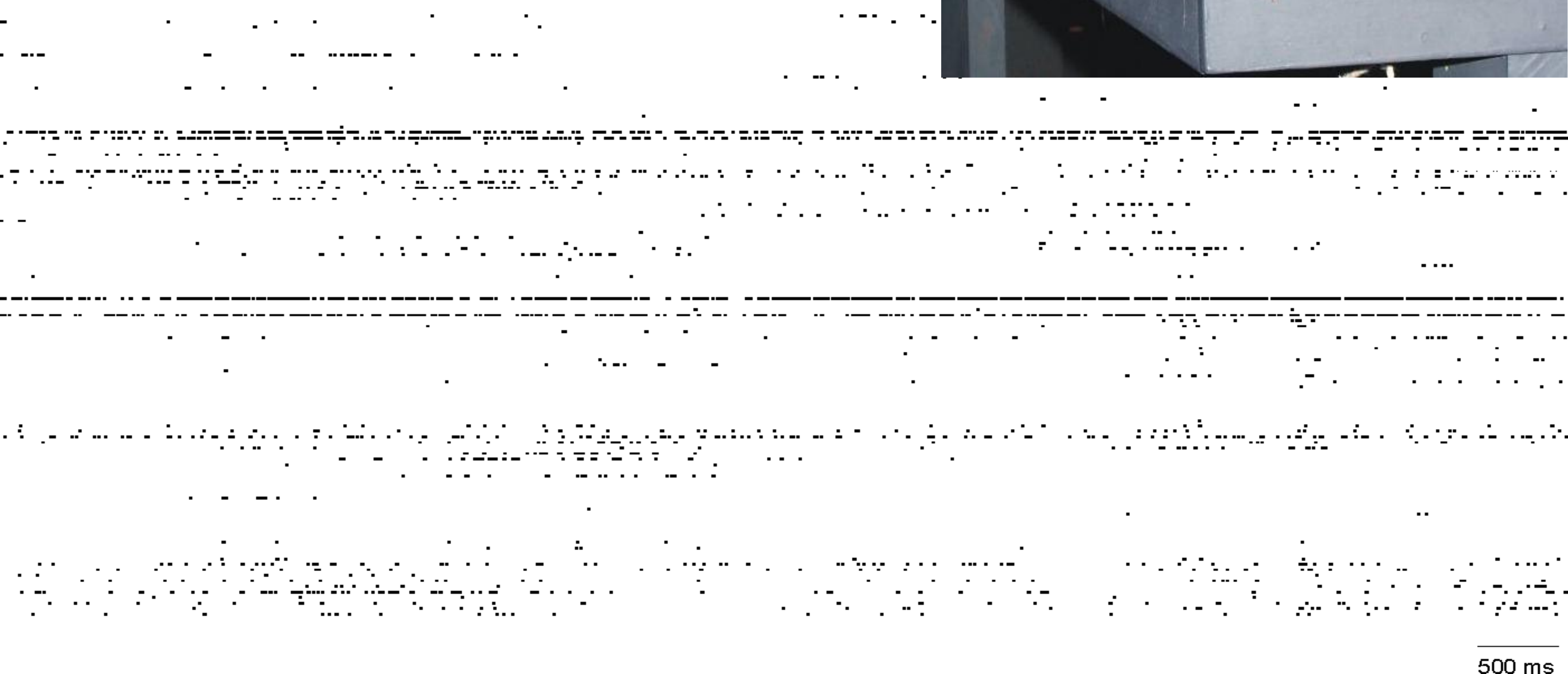
Spatial learning on the cheeseboard maze



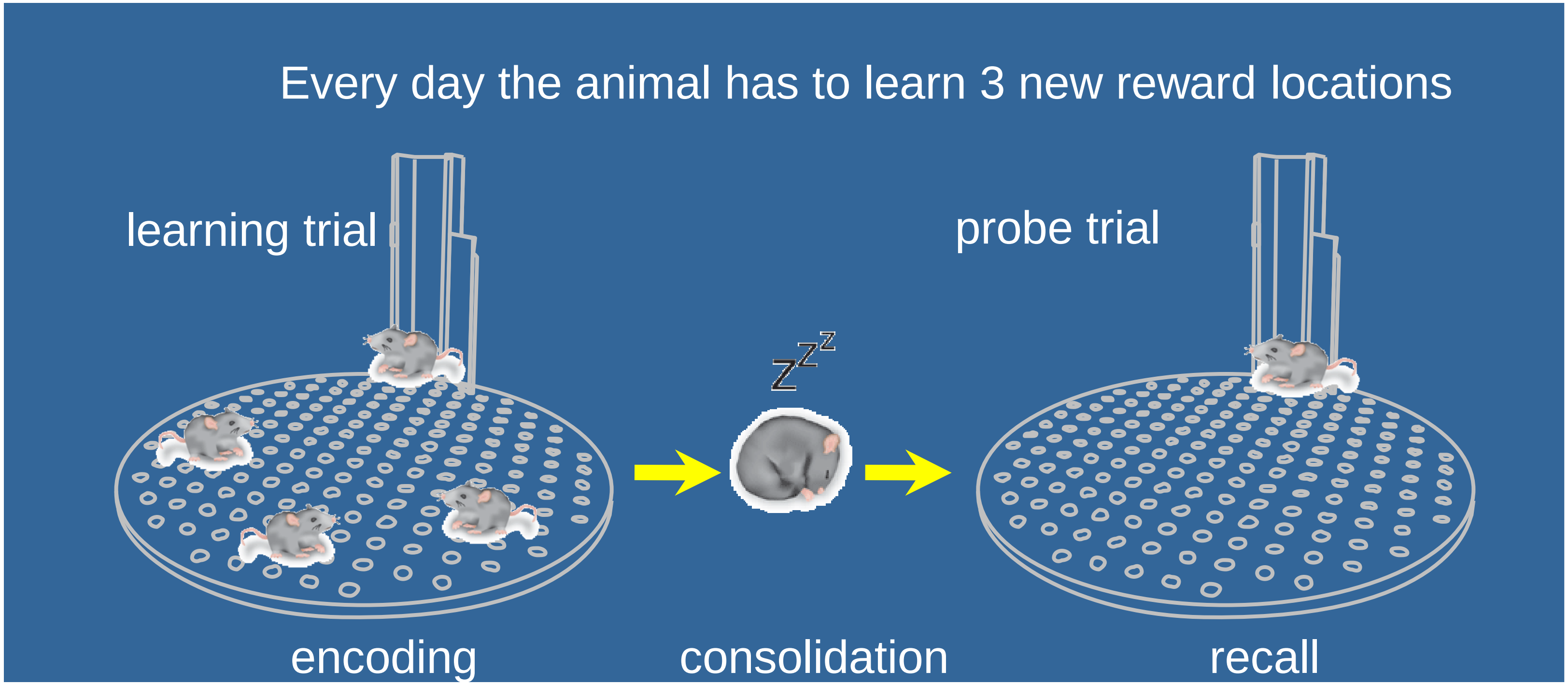
Simultaneous recordings of network activity in the CA1 region

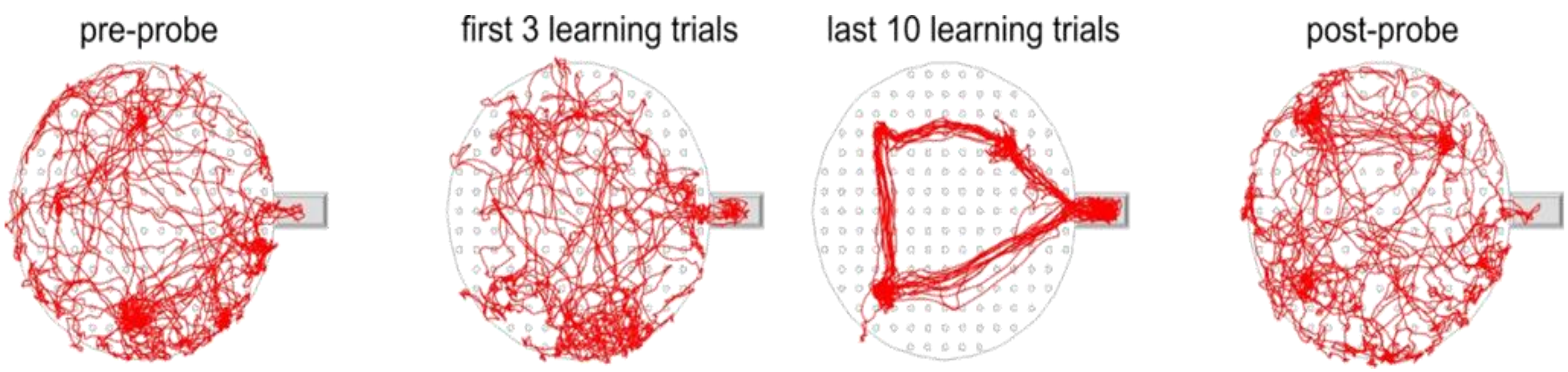






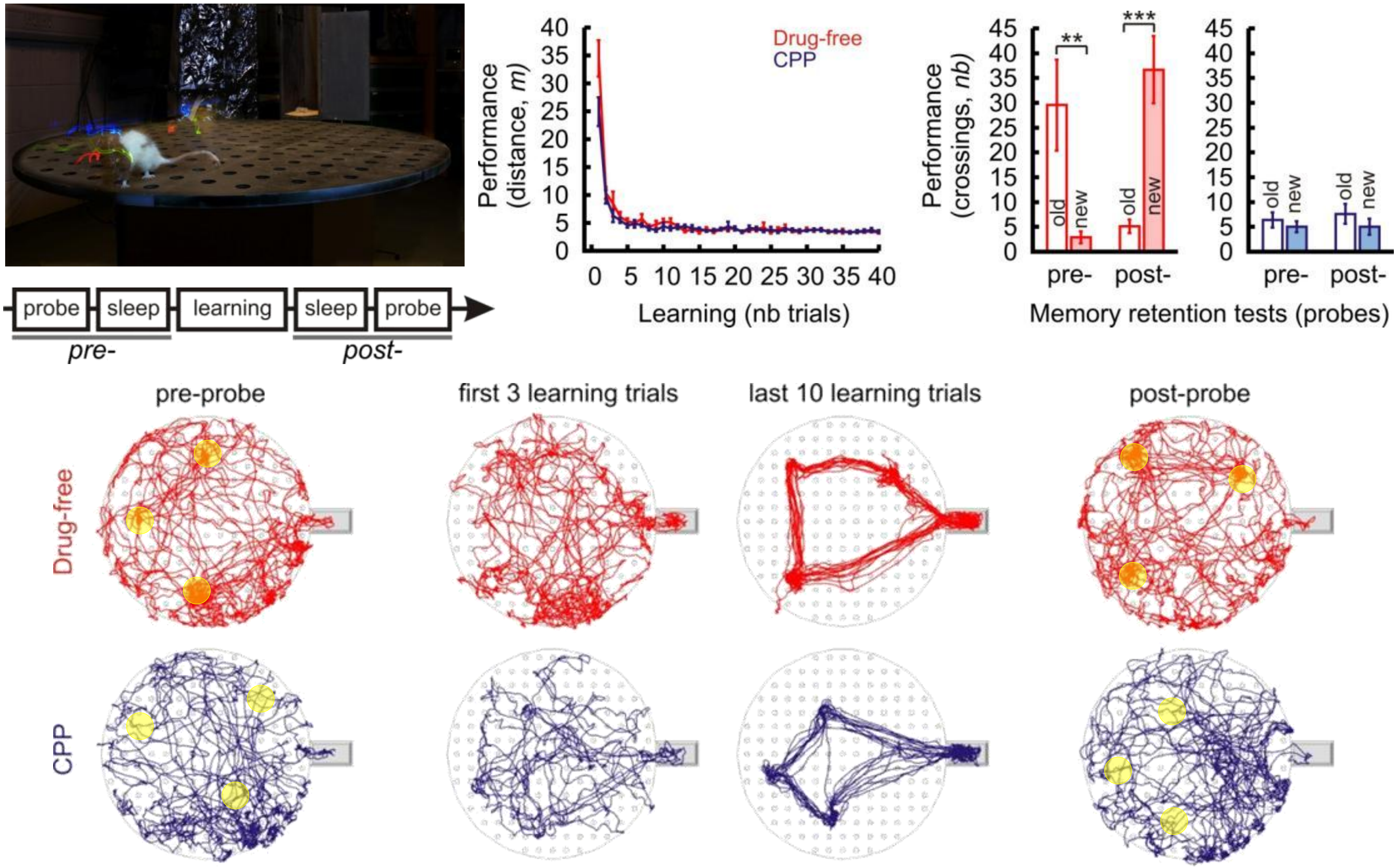
Place learning task on the cheese board maze





Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

Learning and remembering the positions of new goal locations

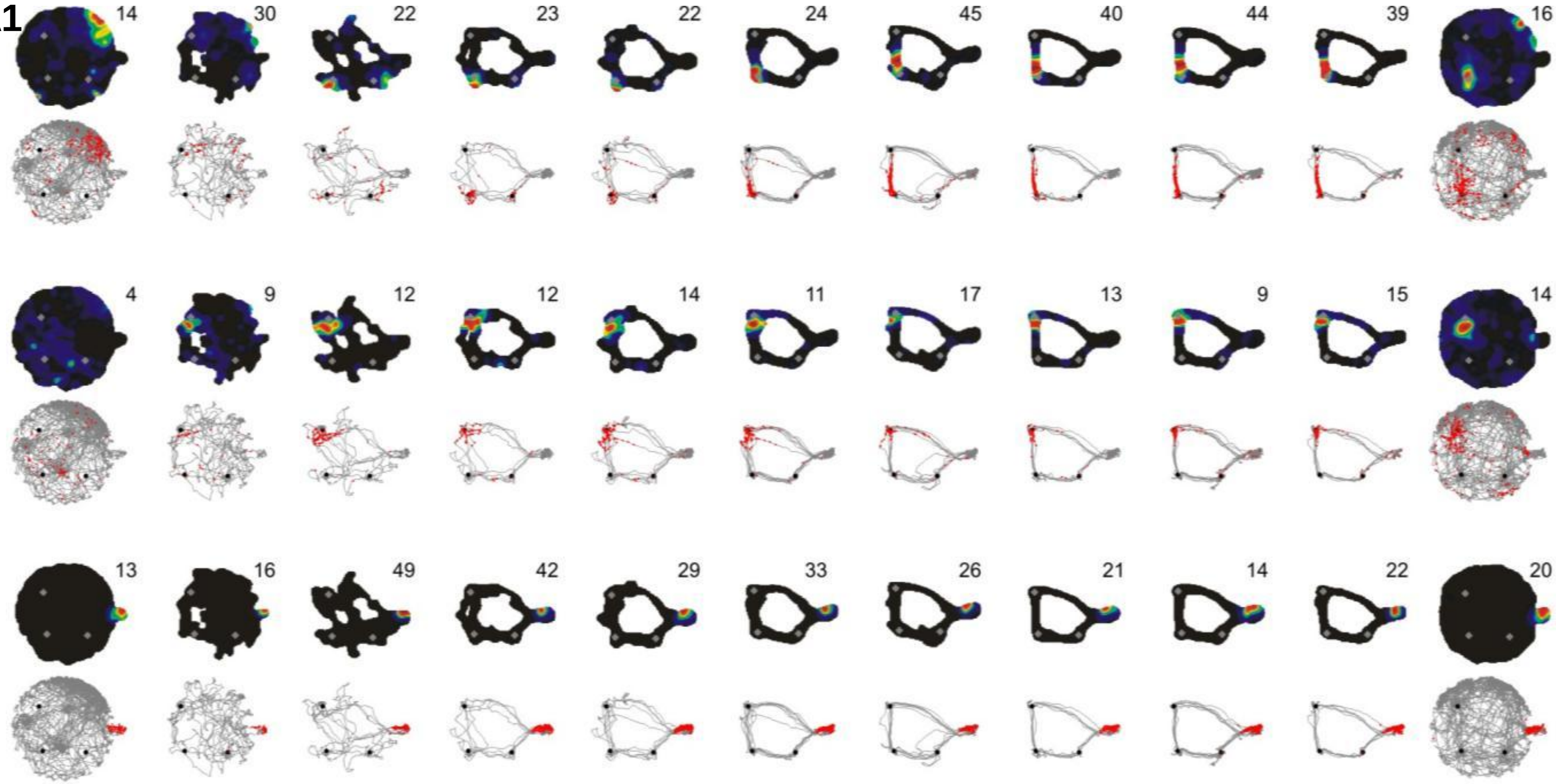


Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

Learning

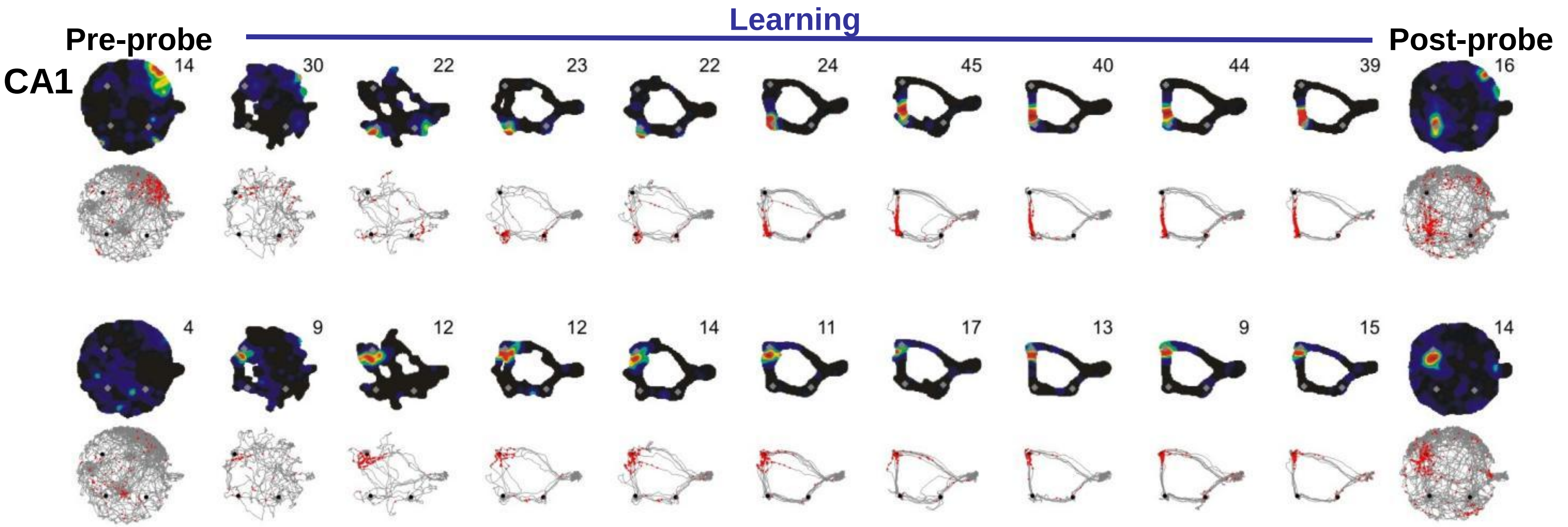
Probe **Probe**

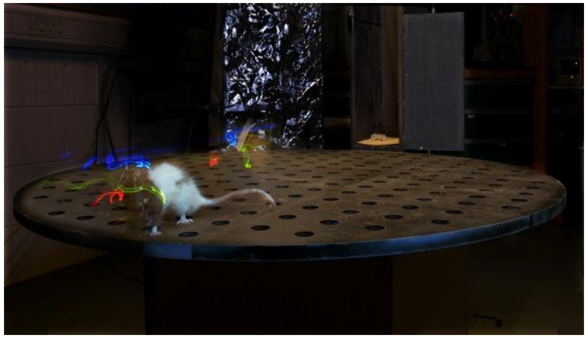
CA1

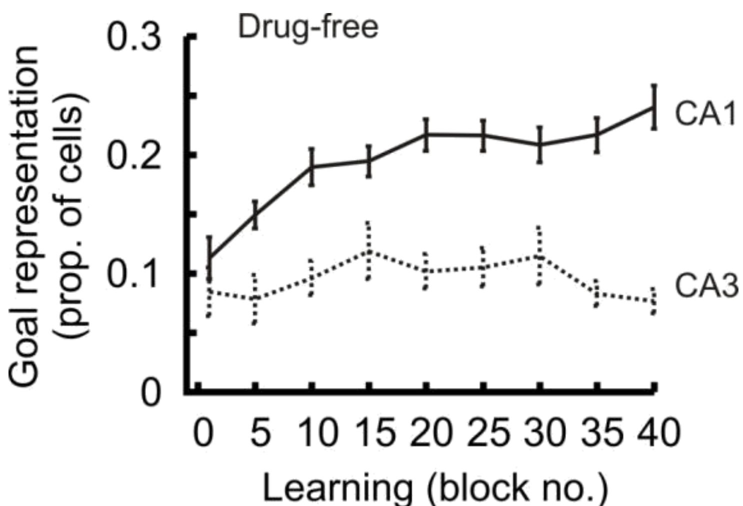


Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

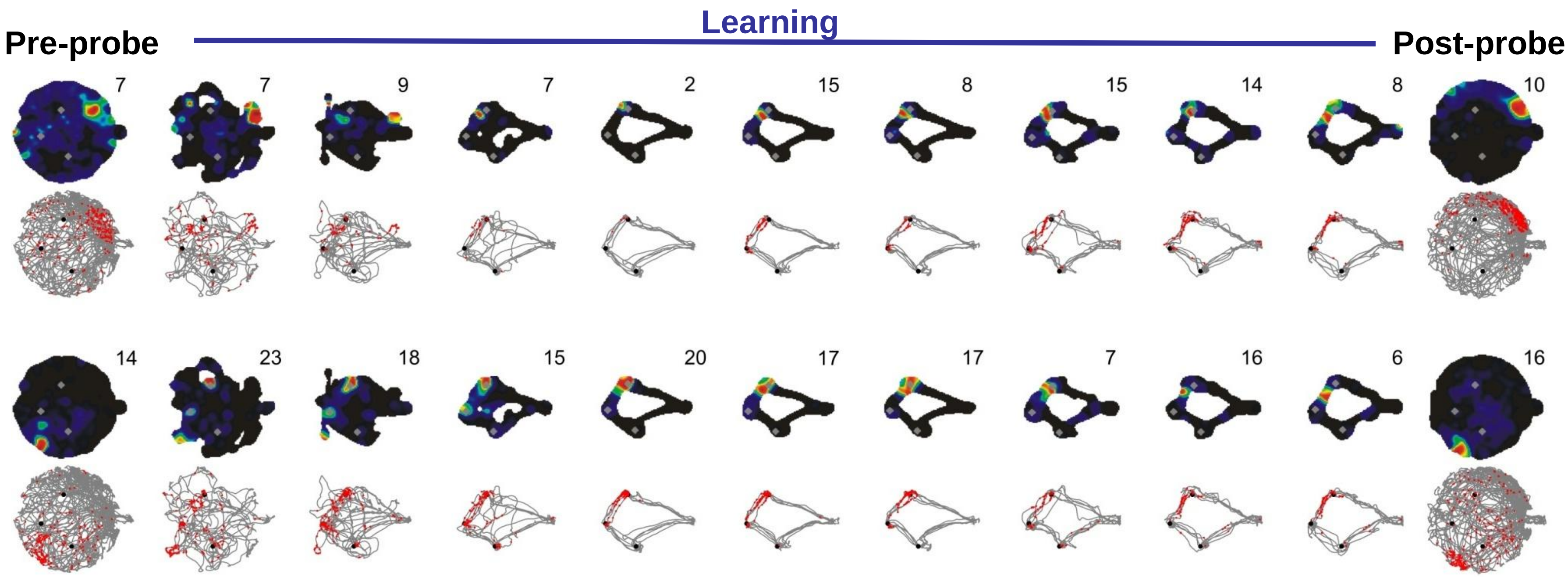
Goal-oriented reorganisation of CA1 representation

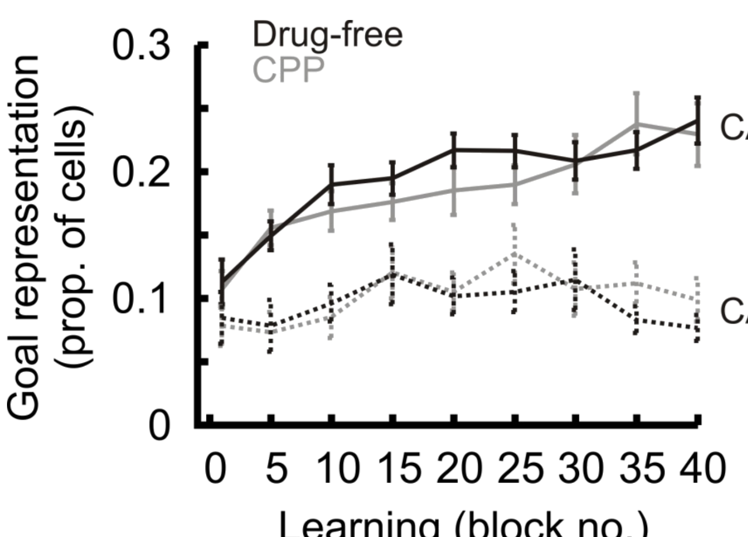


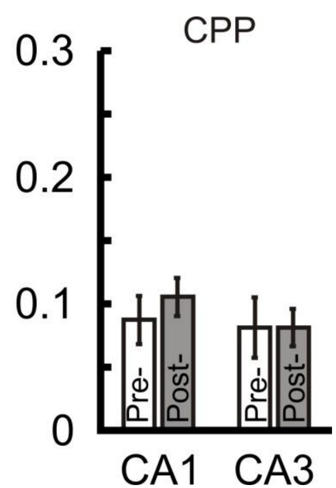




NMDAR blockade prevent the stabilisation of CA1 goal-oriented representation

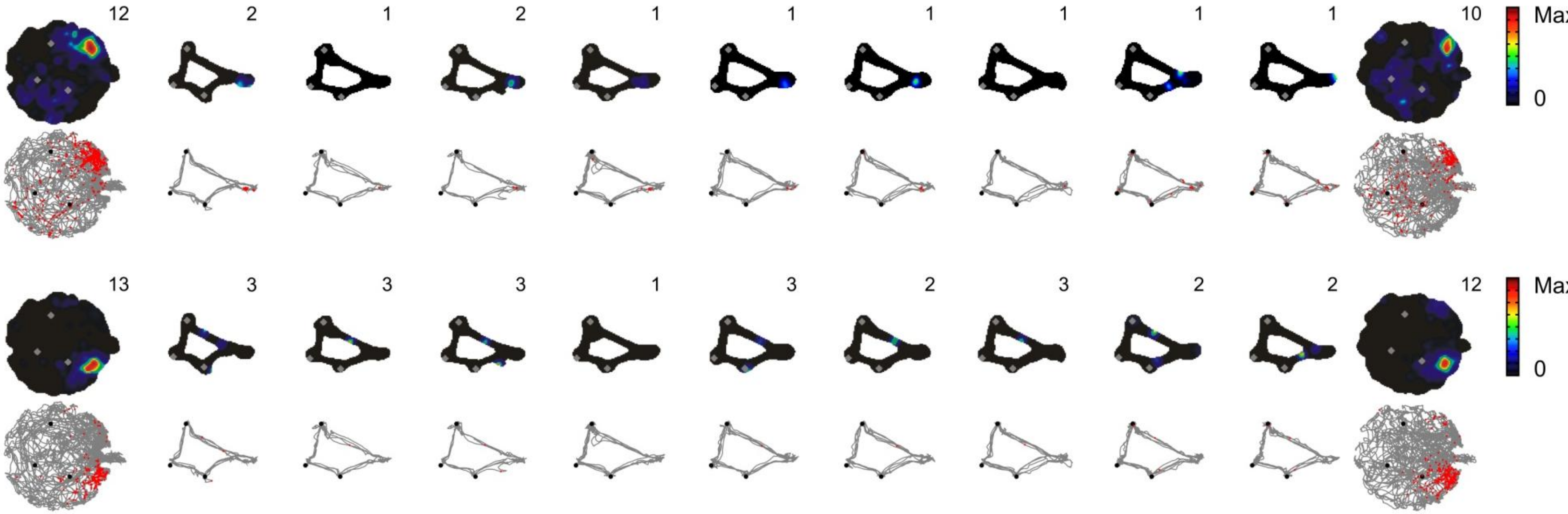


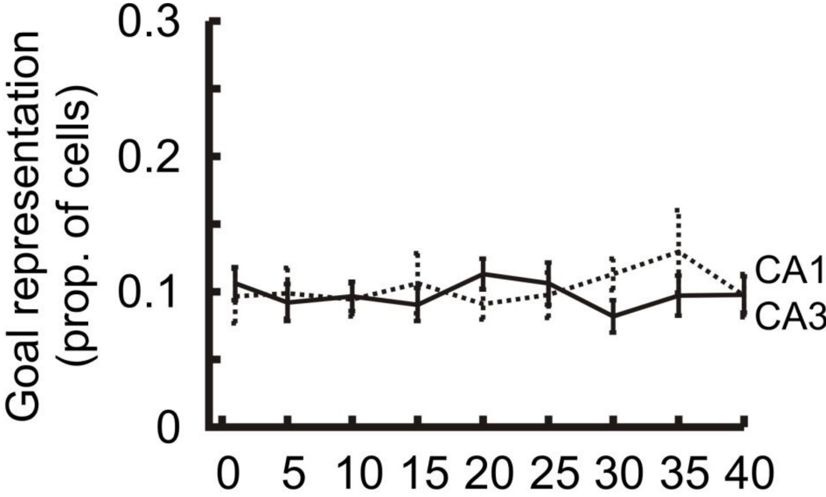




Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

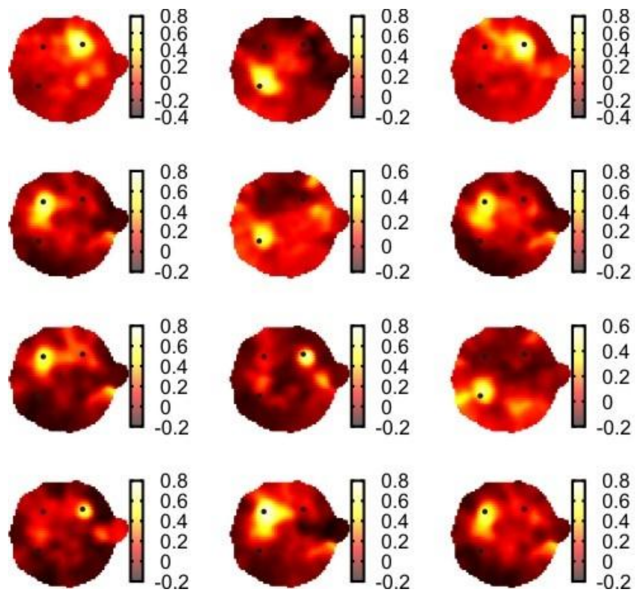
CA1 place cells do not reorganise when allocentric learning was not needed

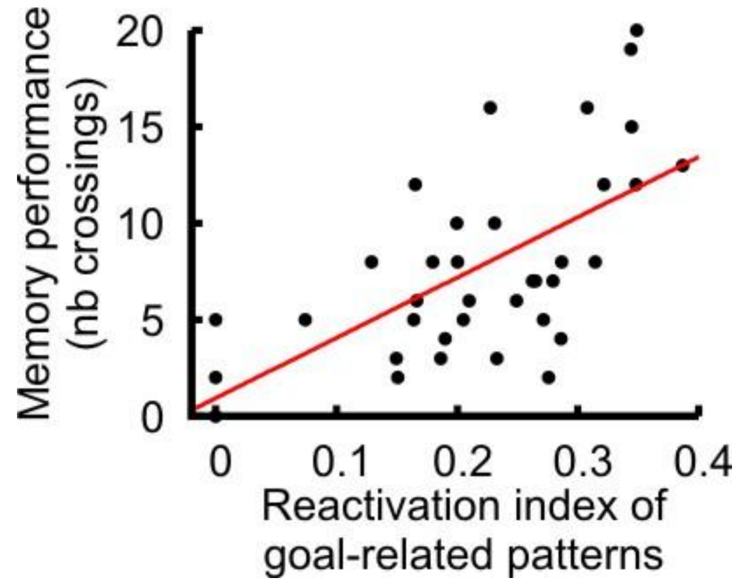


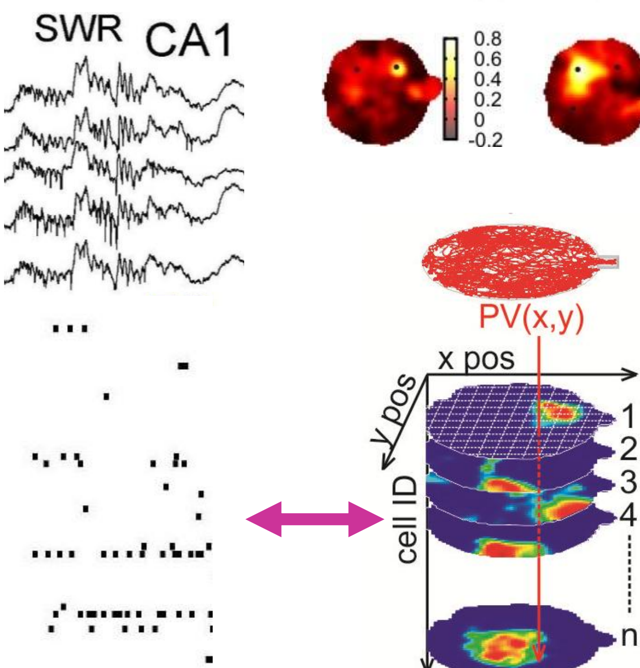


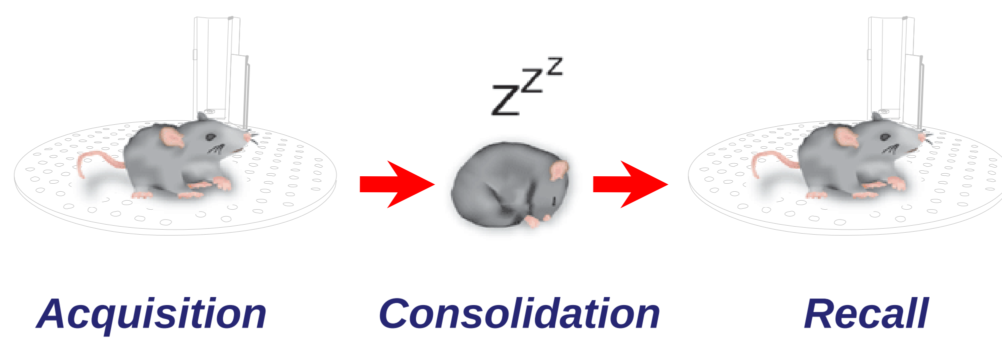
Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

Reactivation map analysis predict predict subsequent memory performances during goal learning



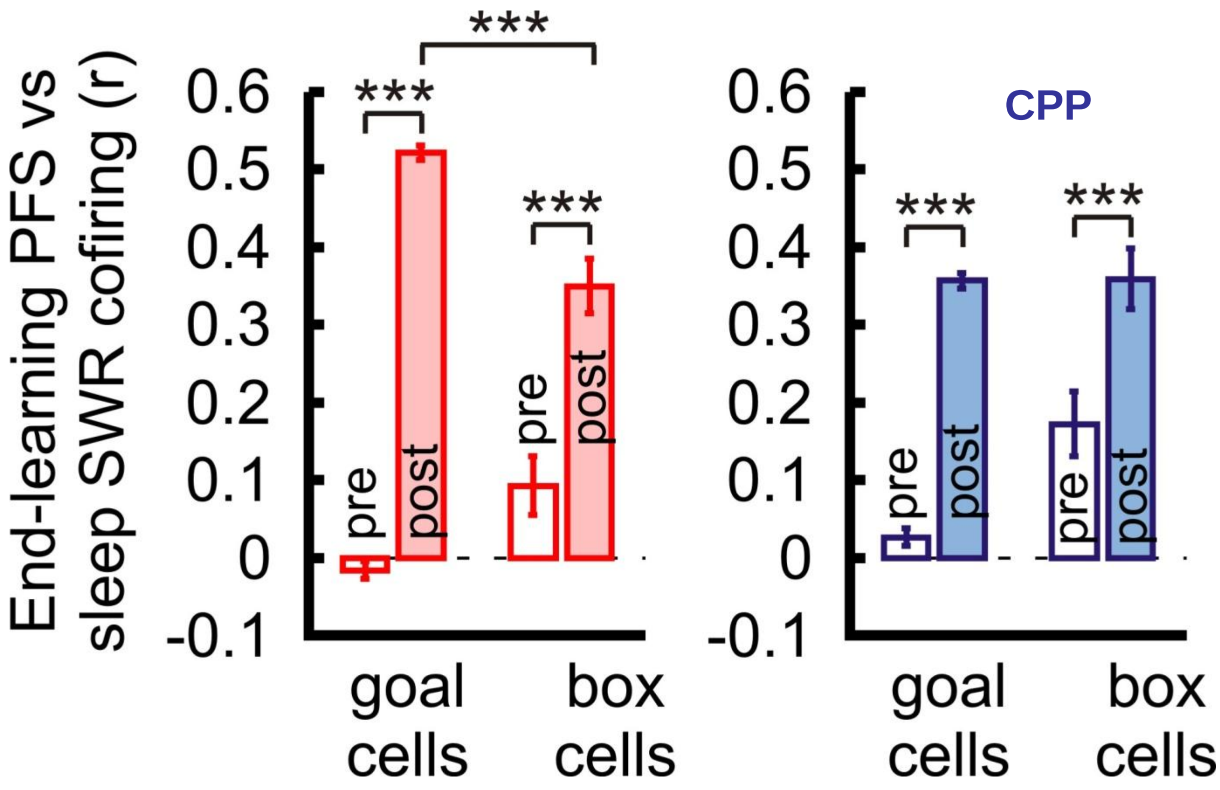






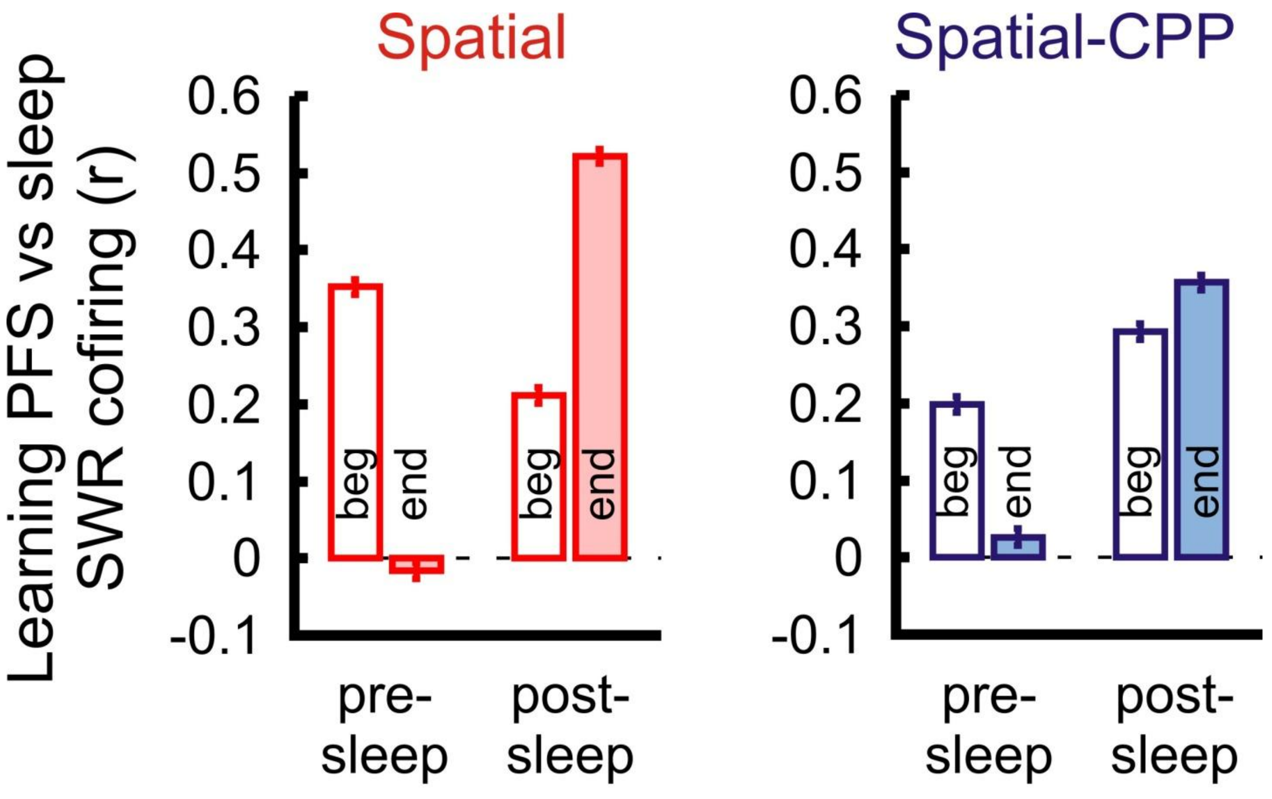
Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

Facilitated *off-line* reactivation of new goal-related firing patterns



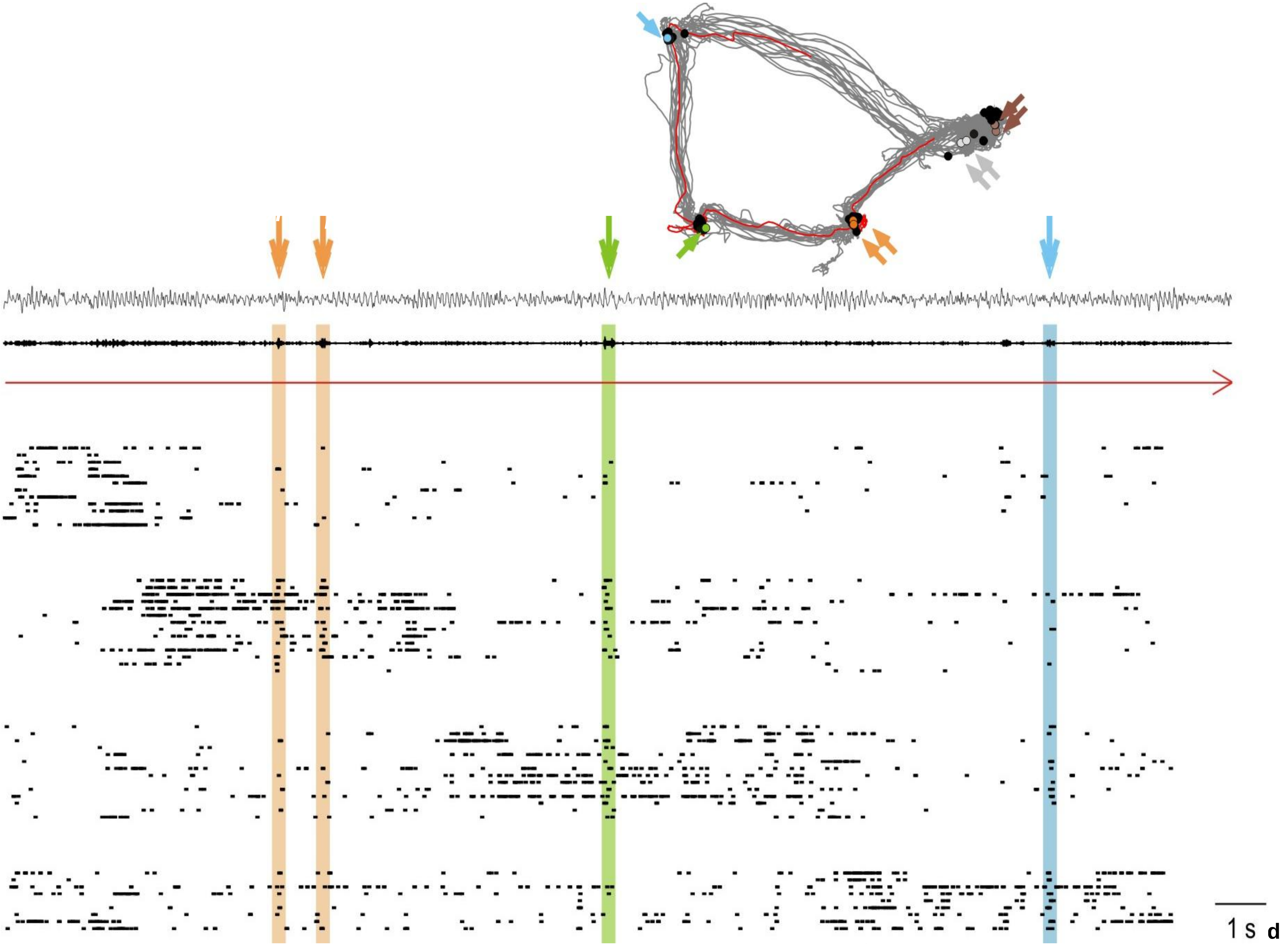
Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010

Reactivation of conflicting representations under NMDA-blockade



Goal-centric cells

Dupret, O'Neill, Pleydell-Bouverie and Csicsvari, Nat. Neurosci, 2010



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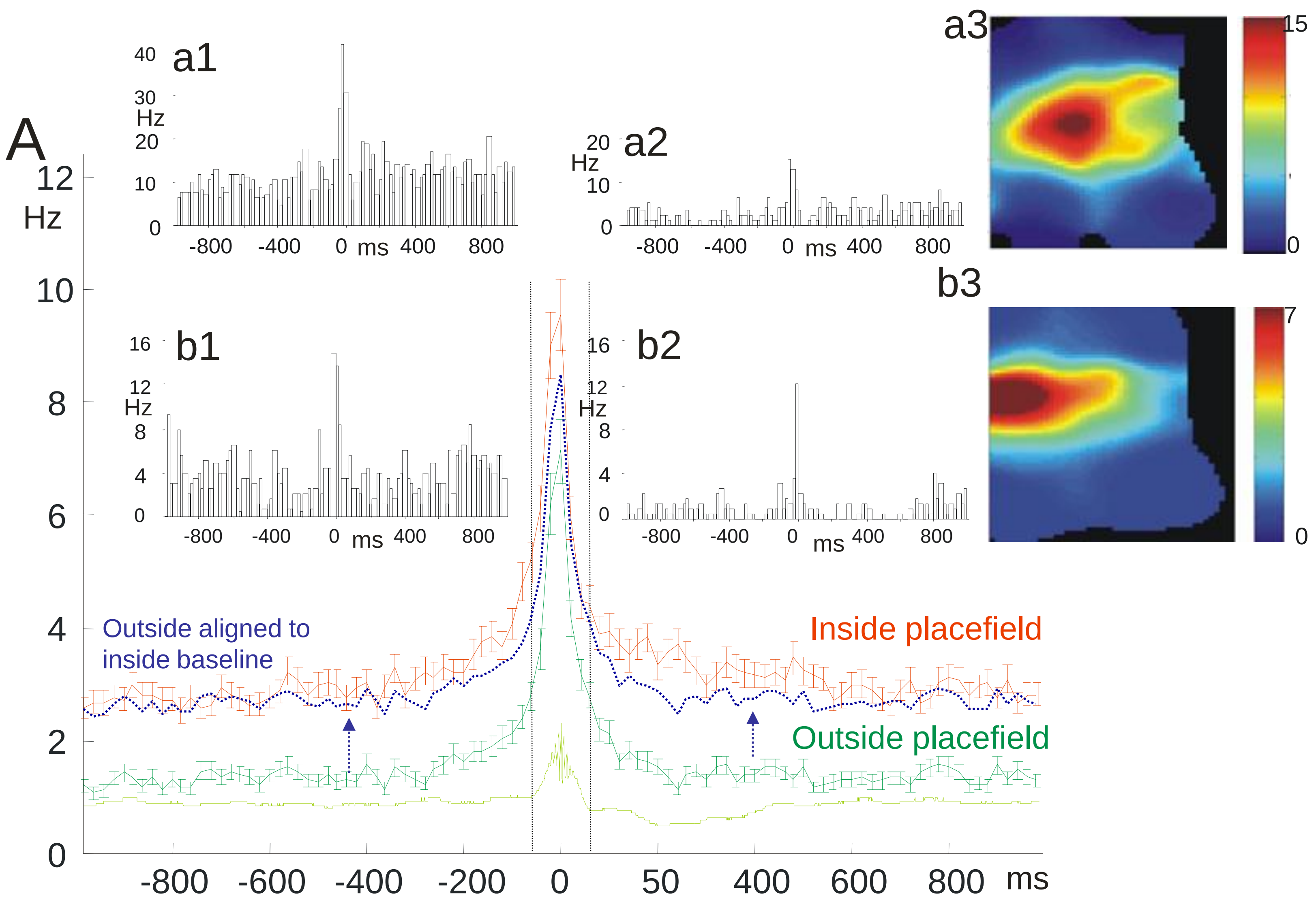
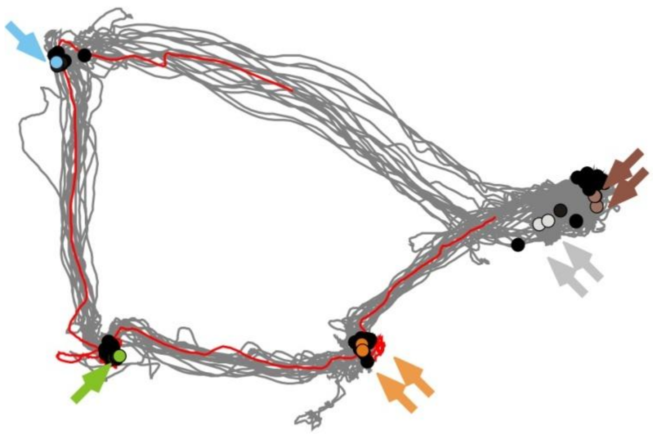
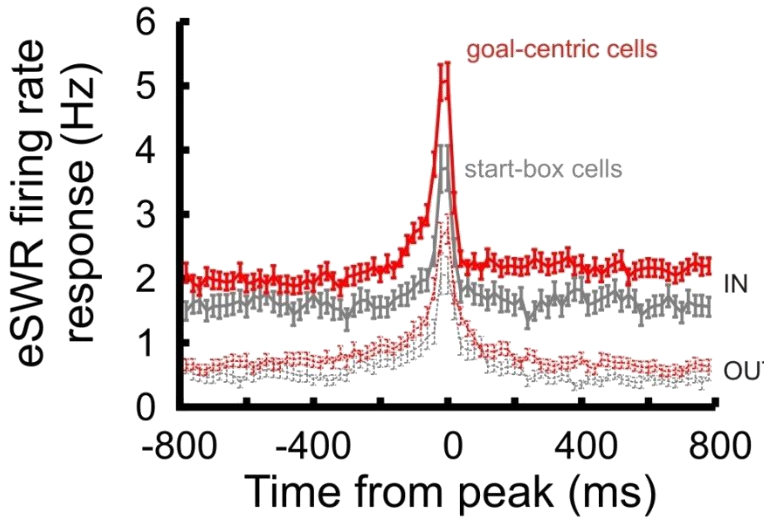
Place-related firing remains during eSWRs. There is a nonlinear summation of place-related and SWR inputs suggesting the occurrence of local dendritic spikes during eSWRs

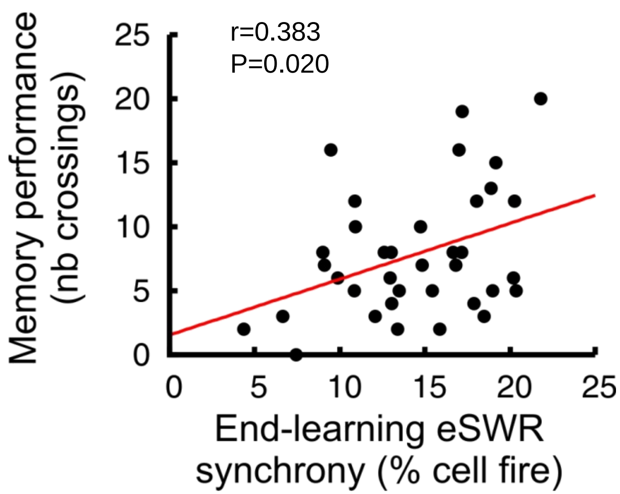


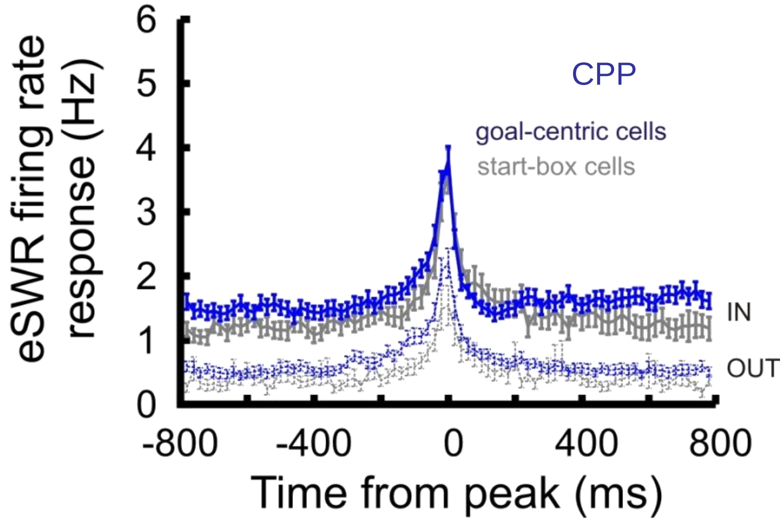
O'Neill, Senior, Csicsvari, Neuron, 2006

NMDA-dependent *on-line* strengthening of new, goal-related patterns









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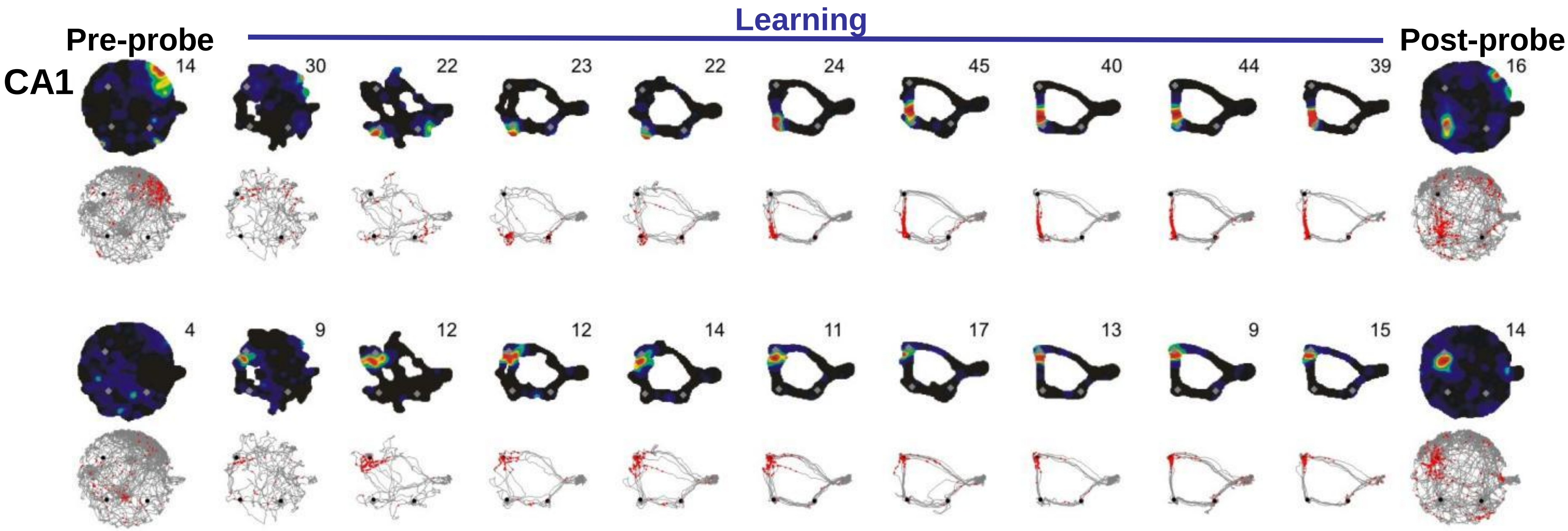
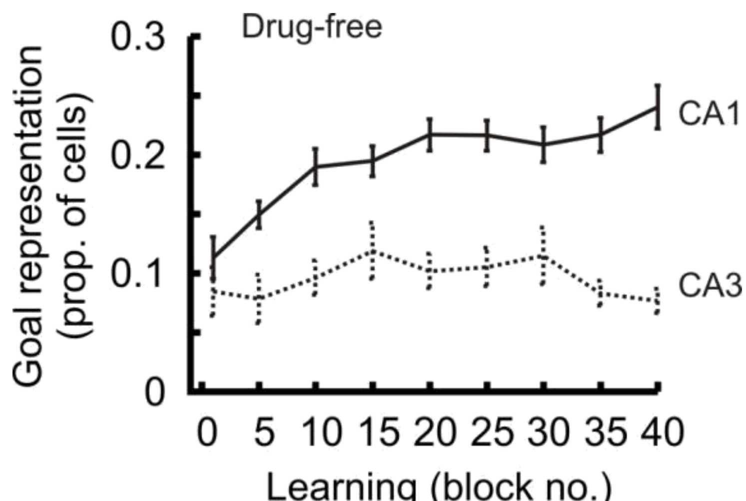
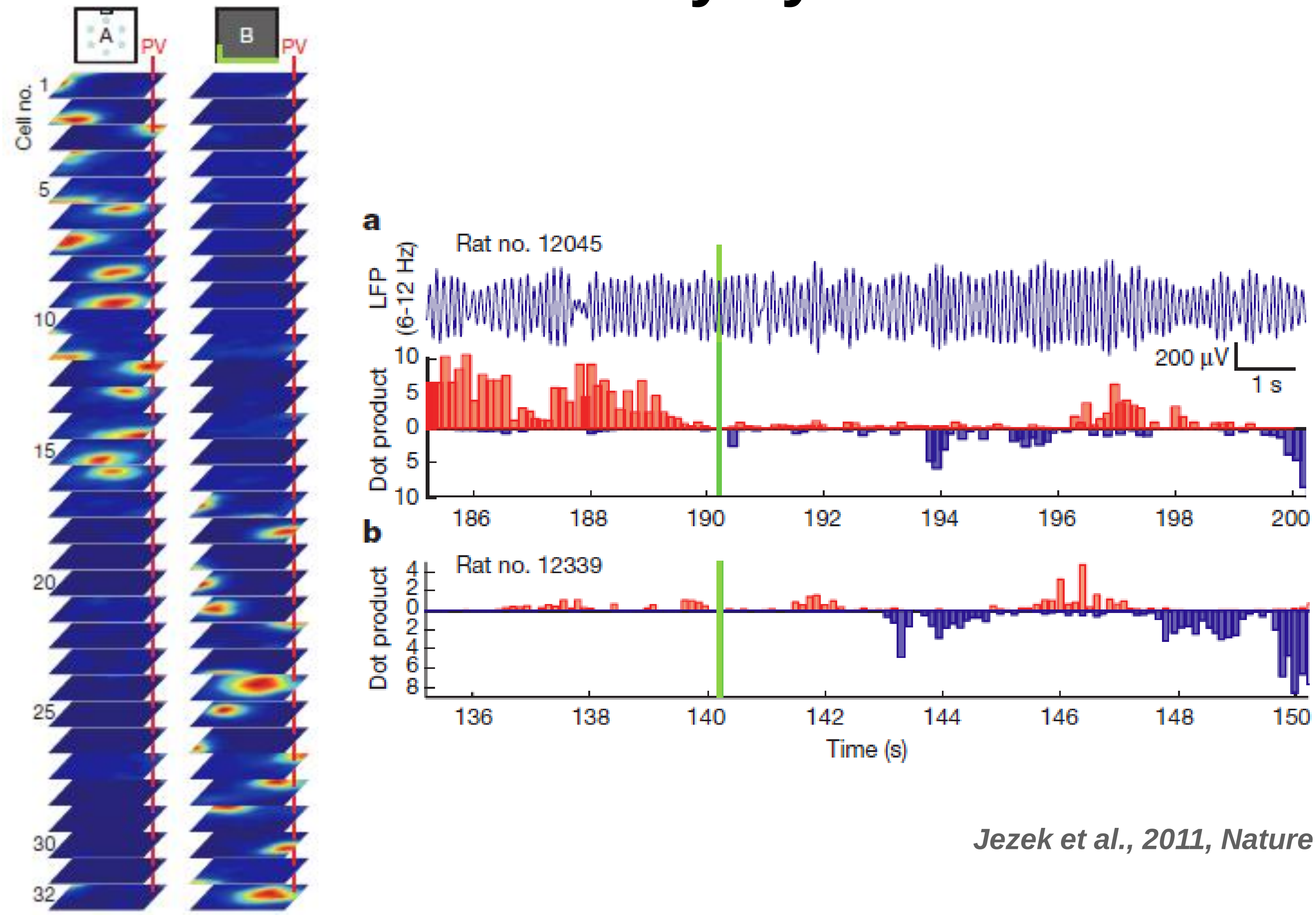
Goal-oriented reorganisation of CA1 representation



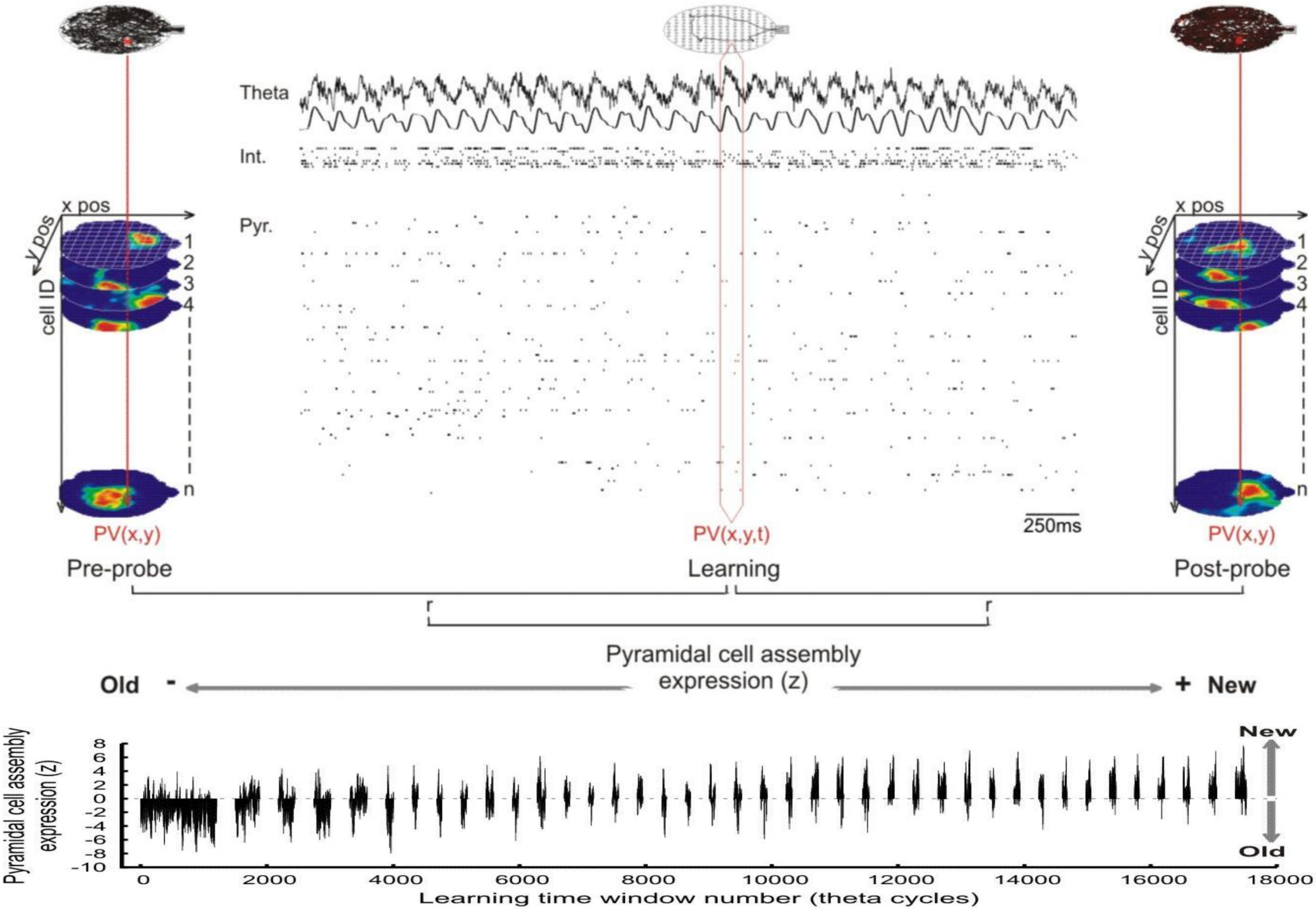


Cell assembly flickering across theta oscillatory cycles



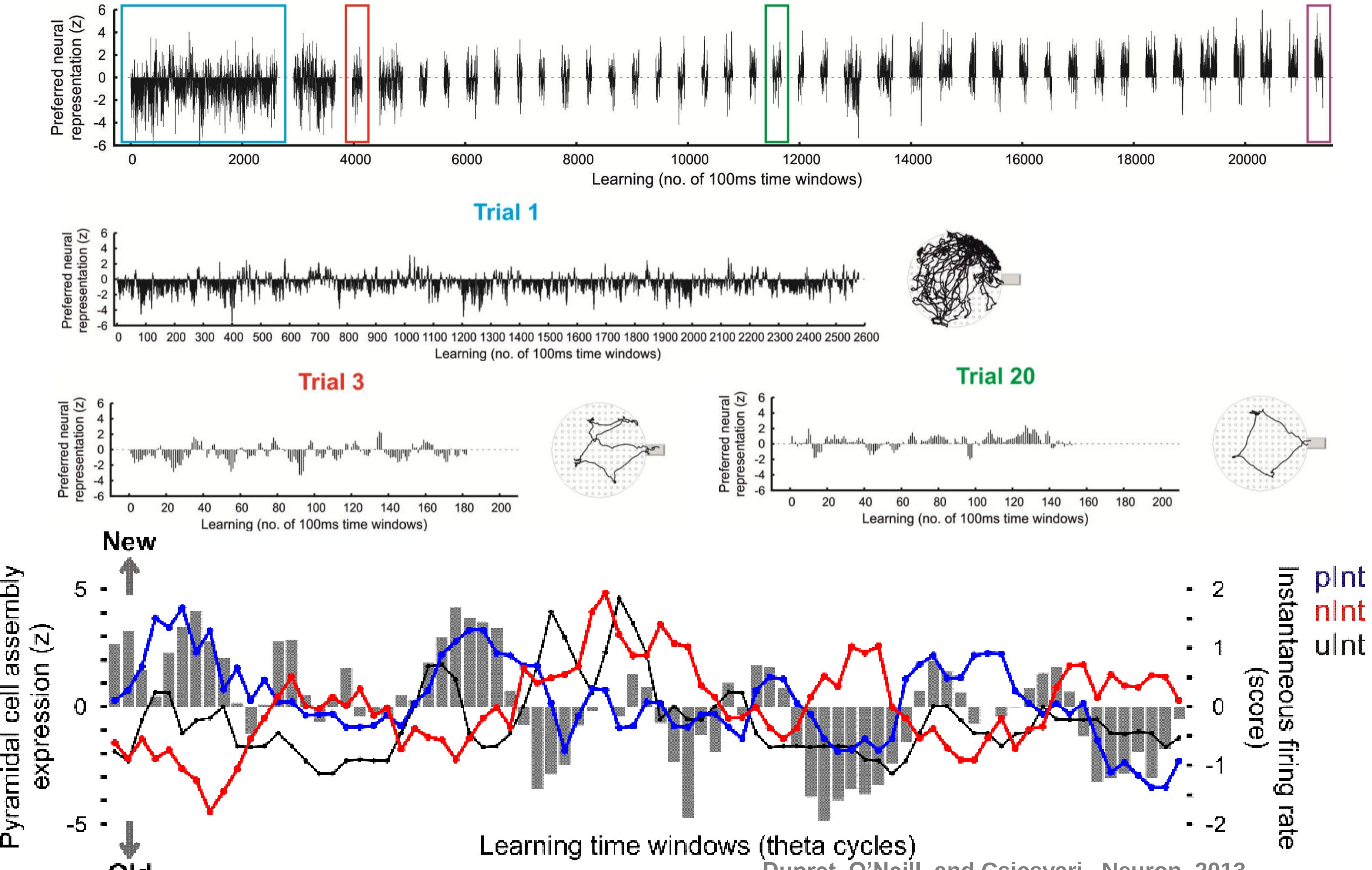
Jezek et al., 2011, Nature

Old and new assemblies flicker across consecutive theta cycles



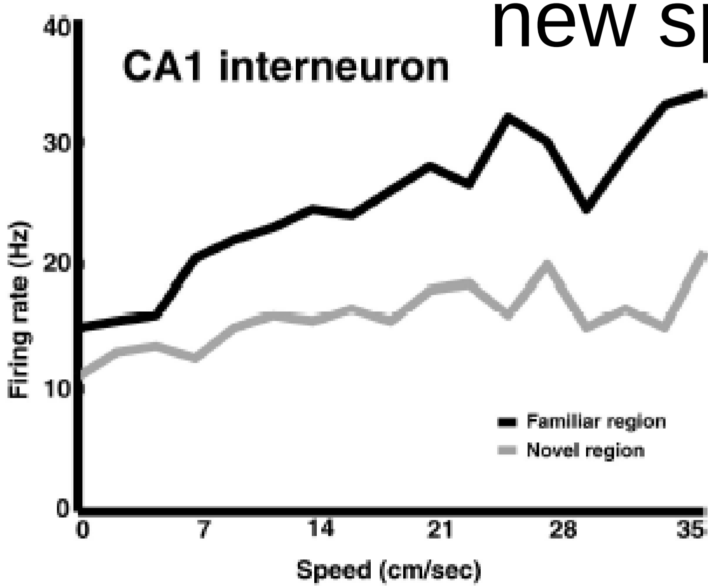
Dupret, O'Neill, and Csicsvari, Neuron, 2013

Old and new cell assemblies alternate initially, while the new ones dominate in later trials

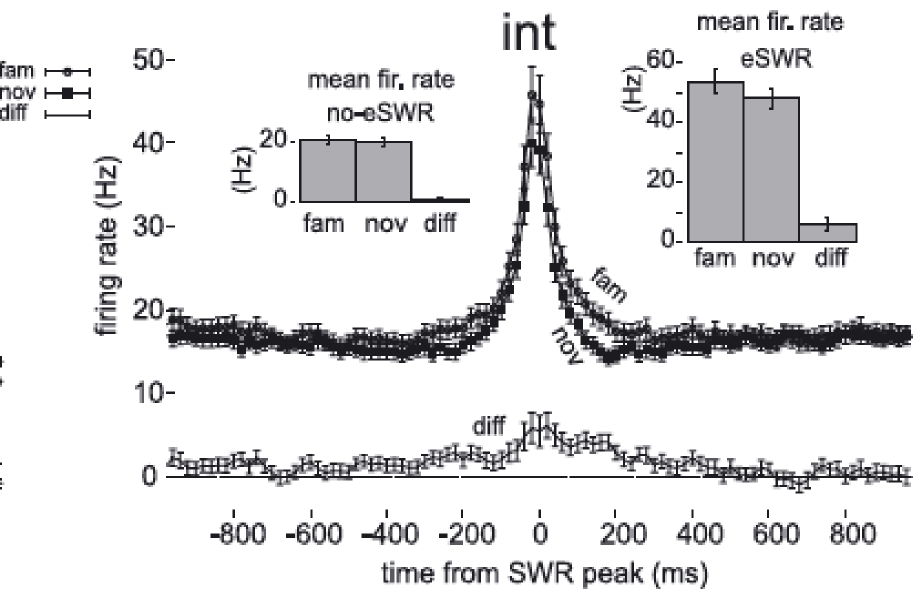


Dupret, O'Neill, and Csicsvari, Neuron, 2013

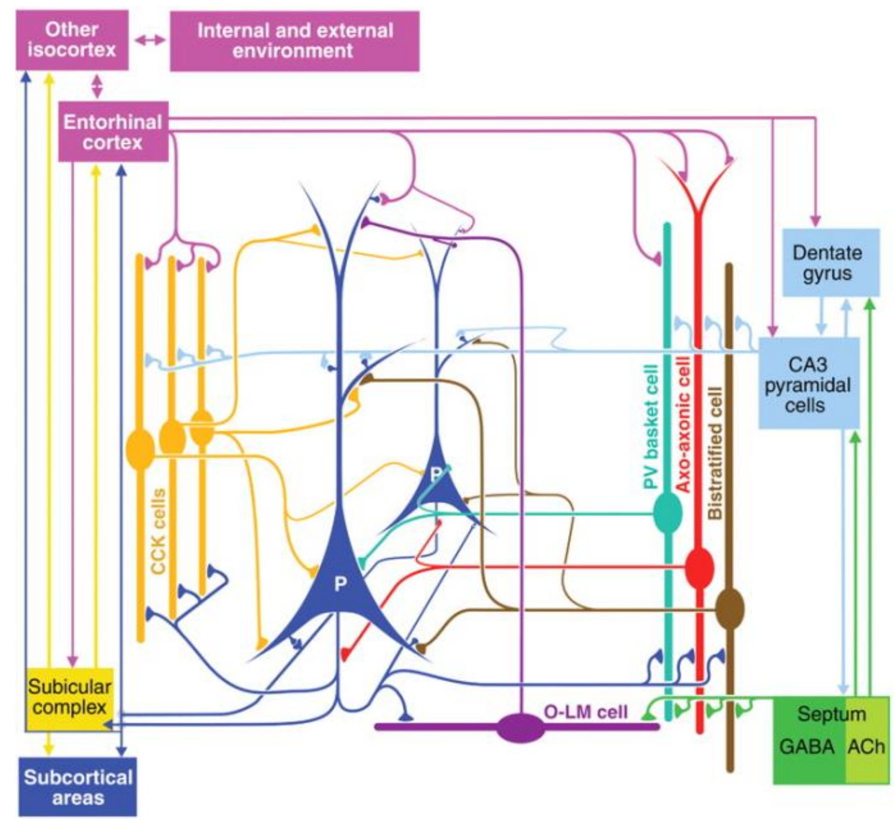
Some interneurons change their firing rate during new spatial map formation



Nitz & McNaughton, J Neurophys., 2003

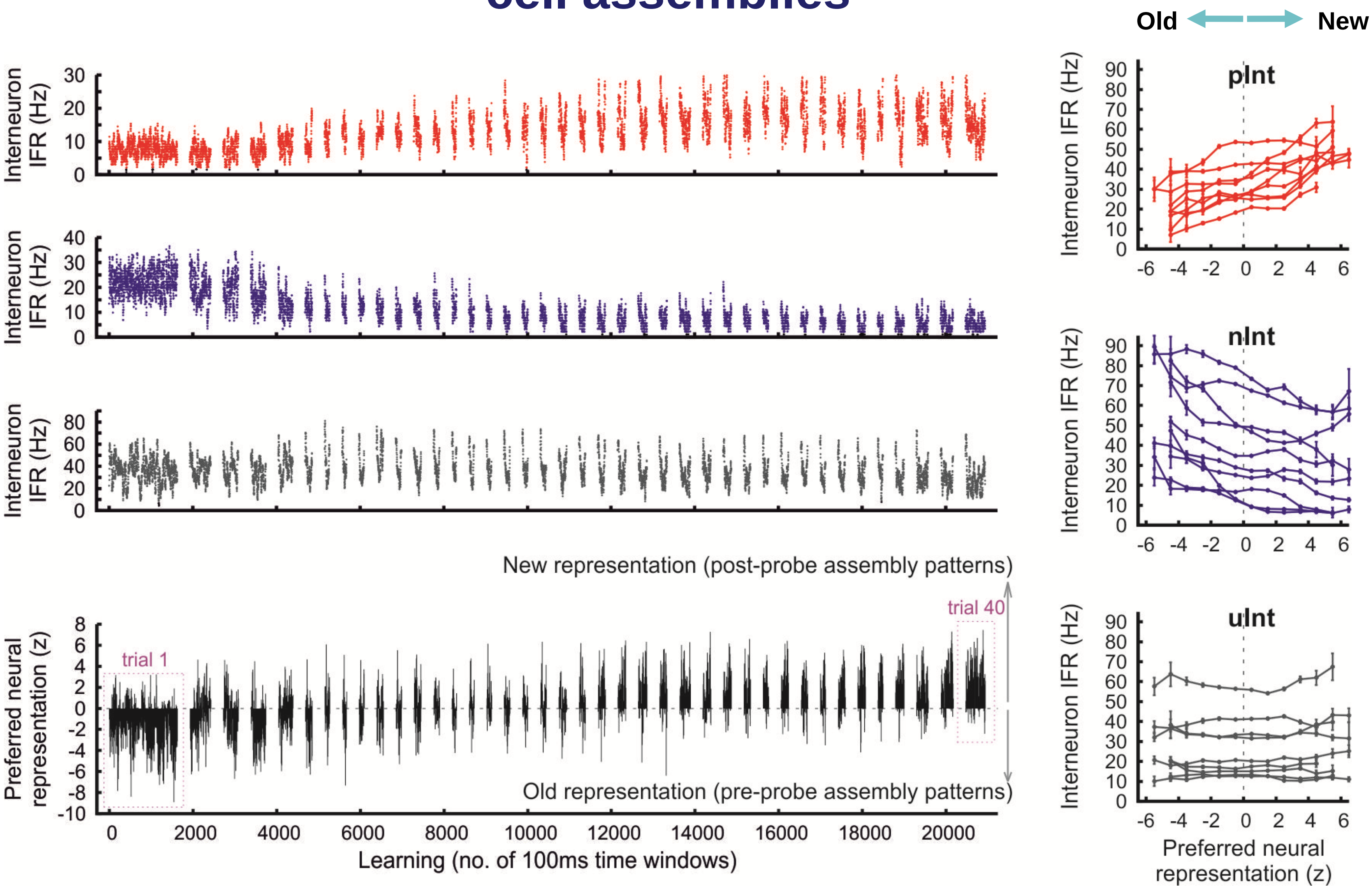


Csicsvari et al., EJN, 2007



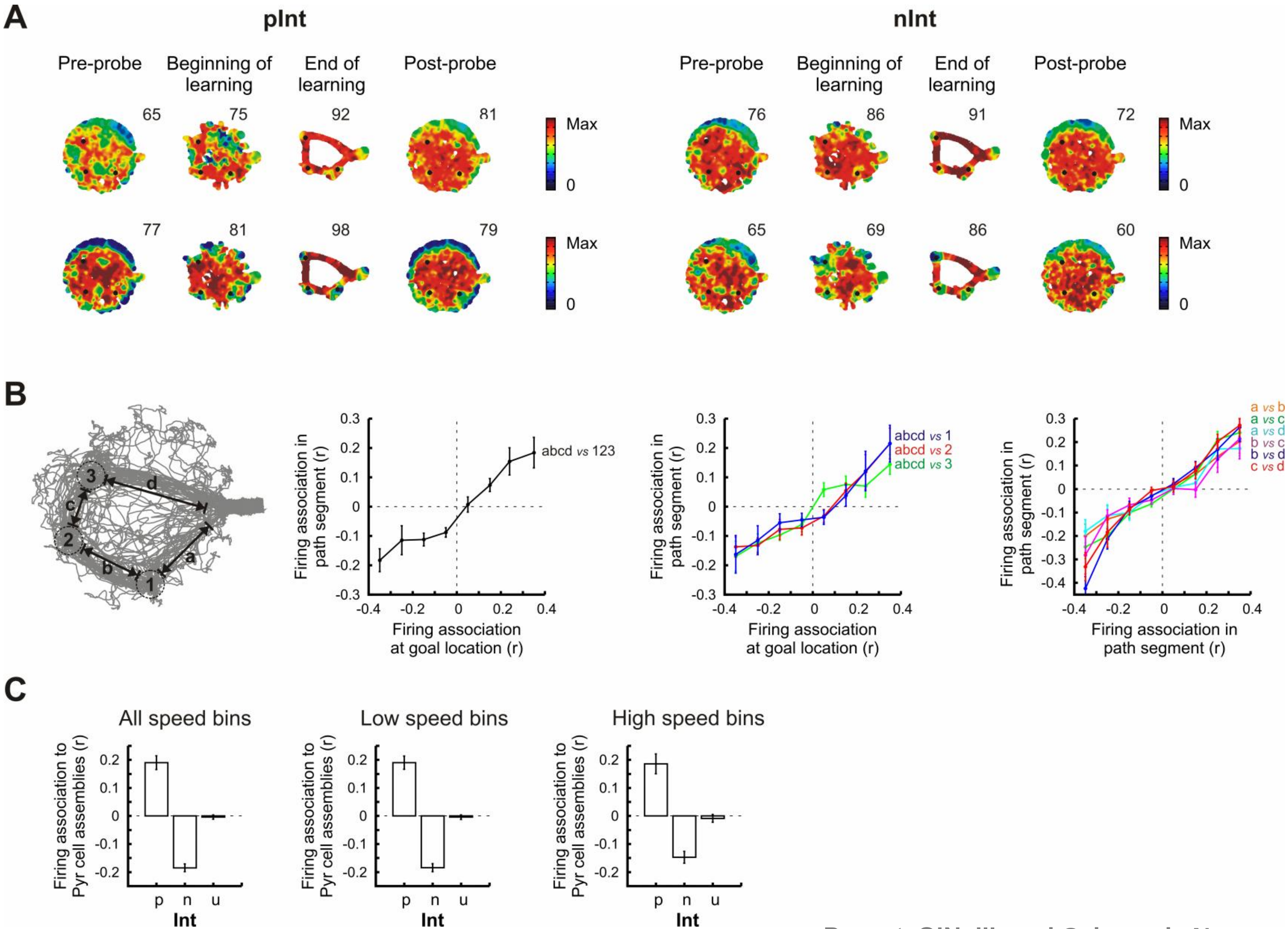
Klausberger and Somogyi 2008, Science

Interneuron firing rate correlates with the expression of cell assemblies



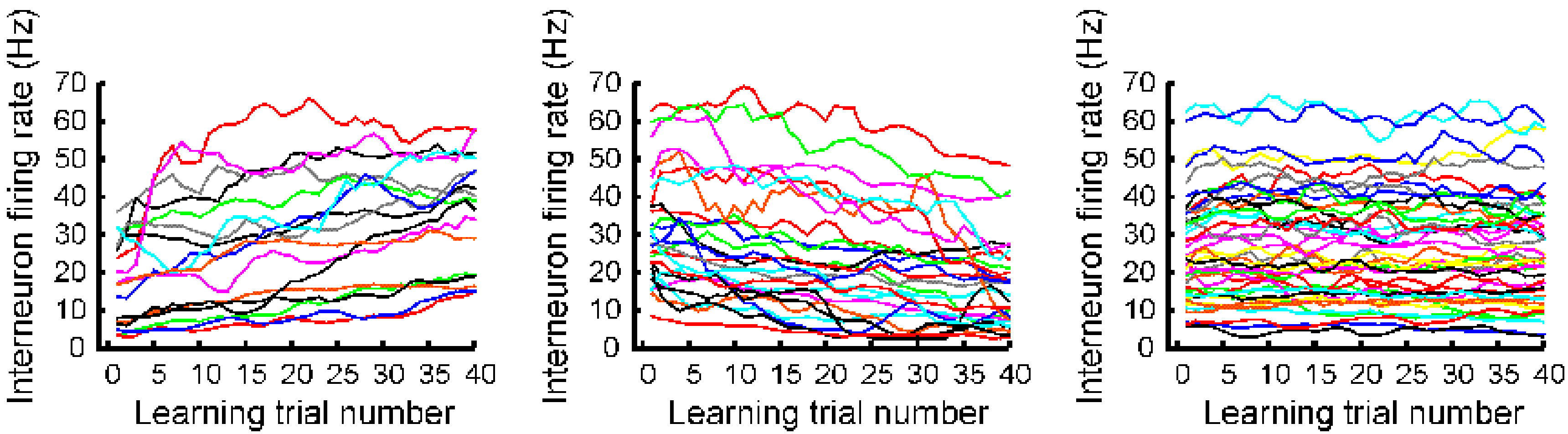
Dupret, O'Neill, and Csicsvari, Neuron, 2013

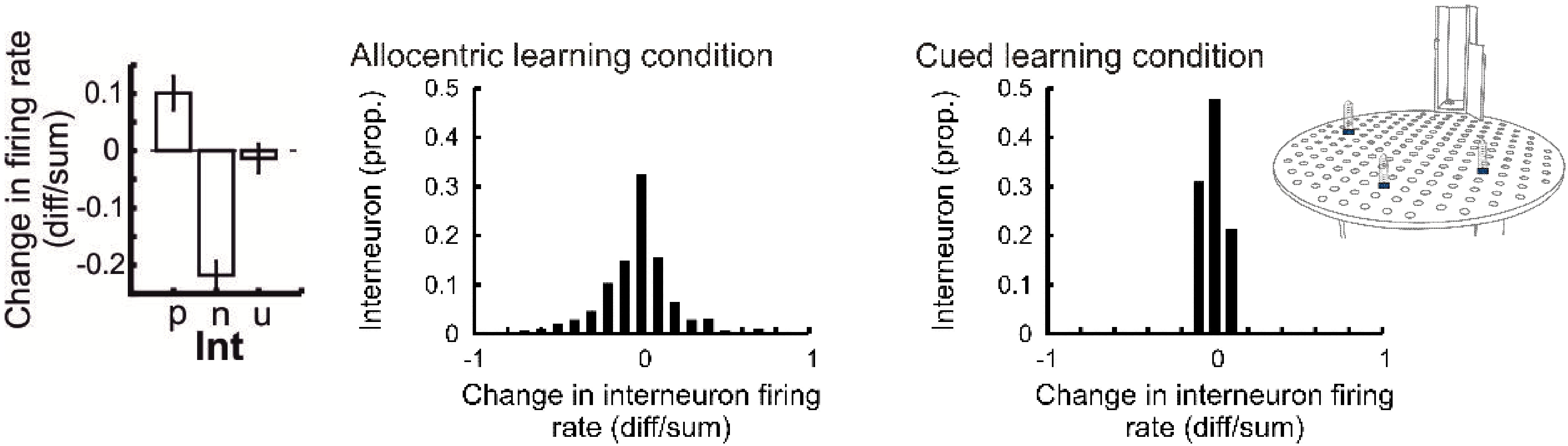
Firing associations of interneurons is related to associations to entire maps



Dupret, O'Neill, and Csicsvari, Neuron, 2013

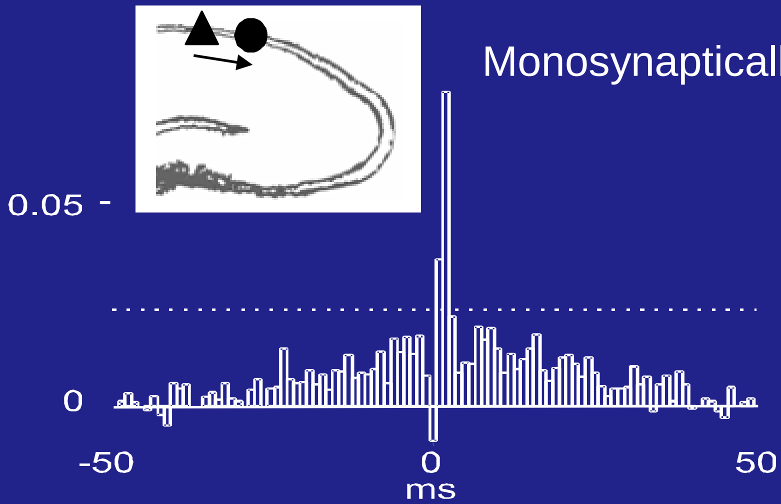
Interneuron rate changes during spatial learning

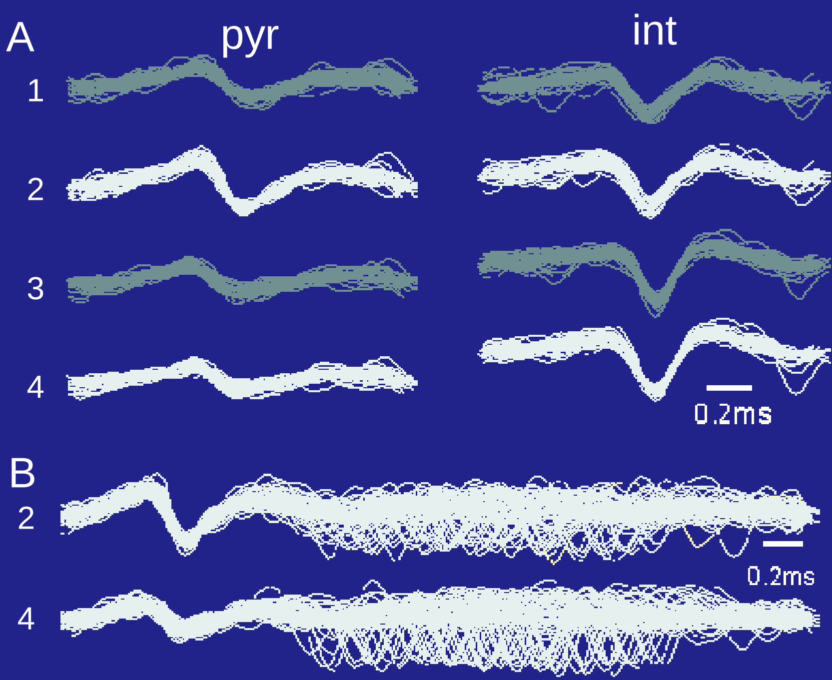




Dupret, O'Neill, and Csicsvari, Neuron, 2013

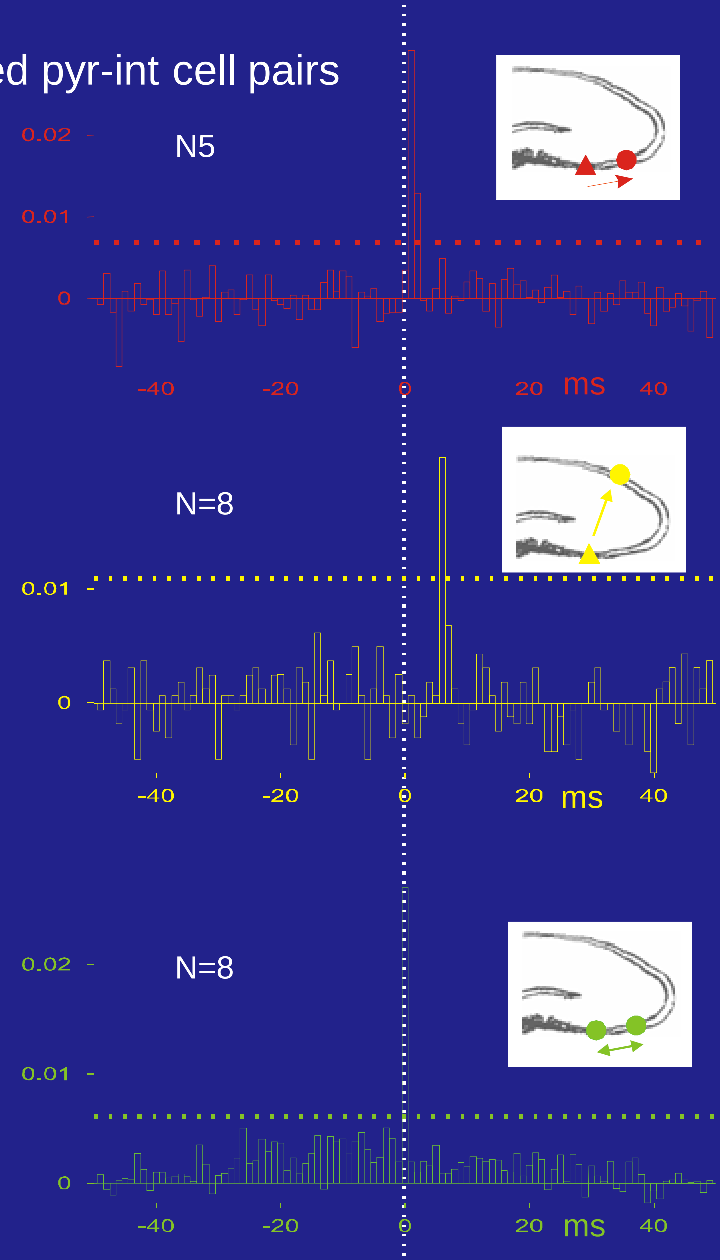
Cell interactions





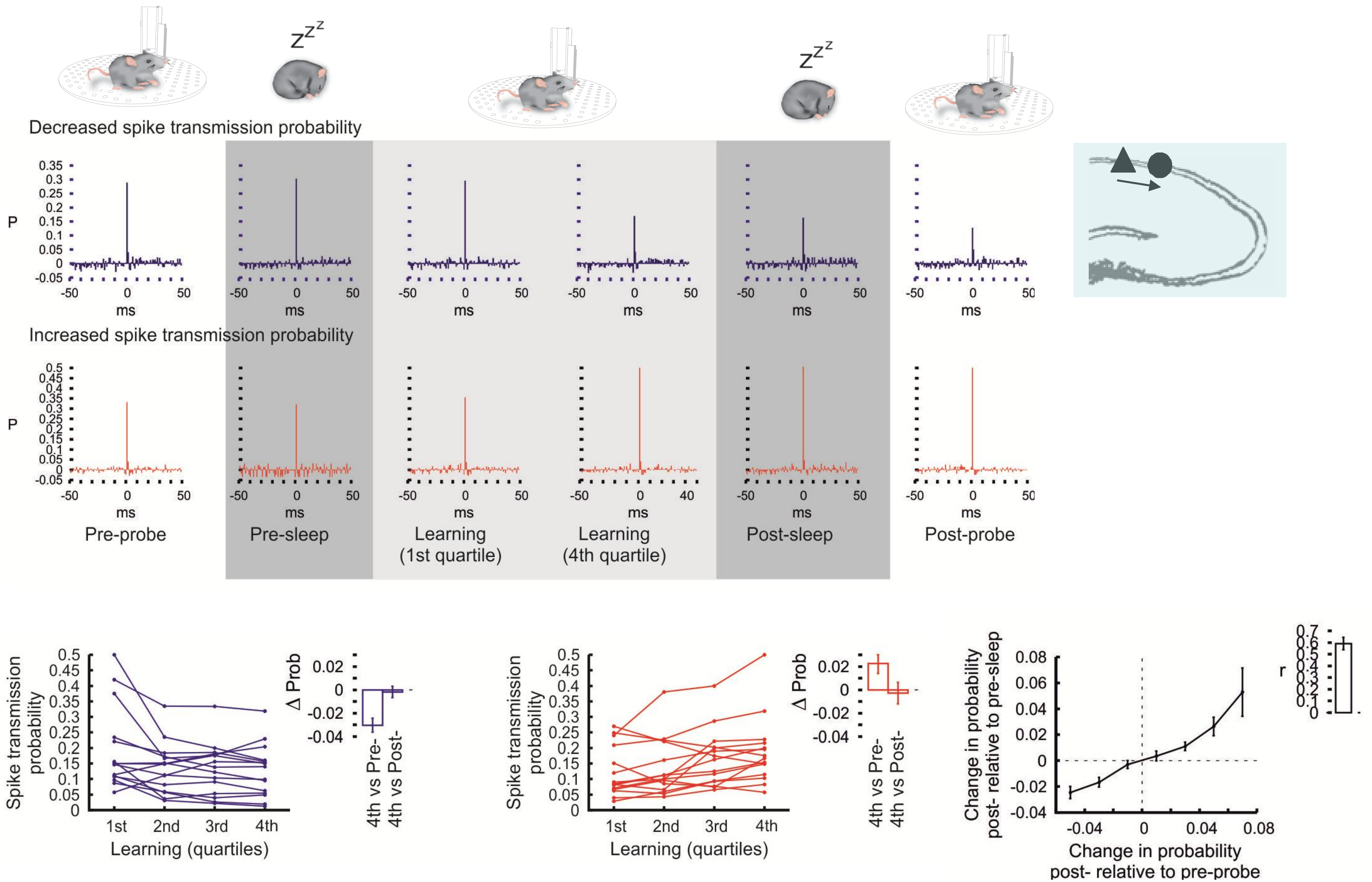
Csicsvari, Hirase, Czurko & Buzsaki Neuron 1998

Monosynaptically connected pyr-int cell pairs

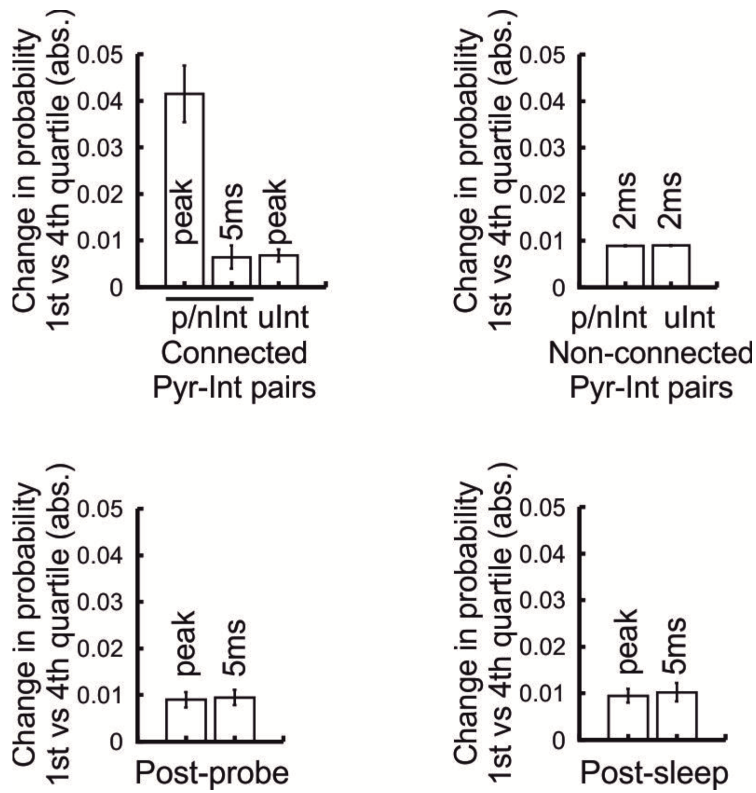


Csicsvari, Jamieson, Wise & Buzsaki Neuron 2003

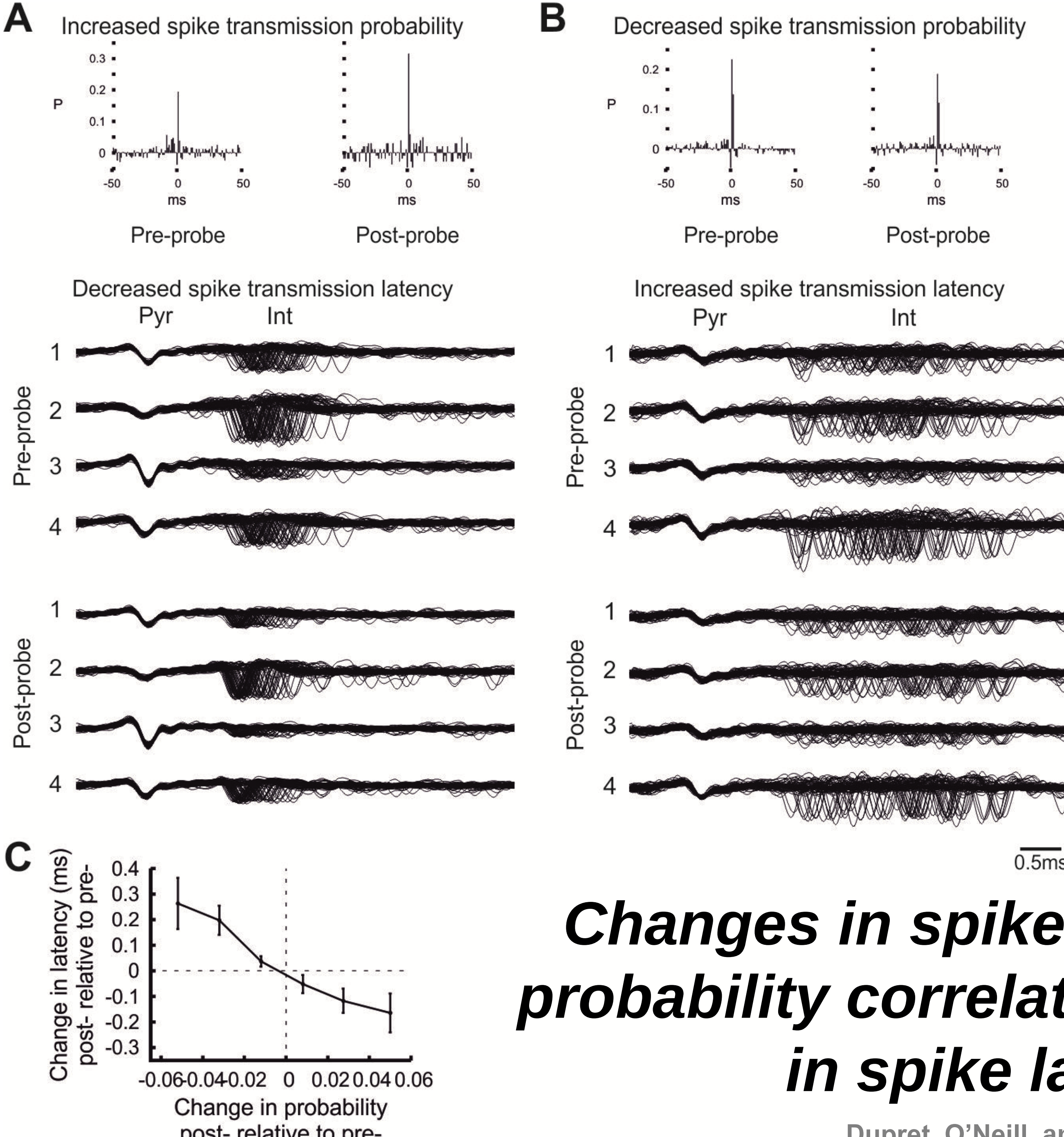
Pyramidal-interneuron connections change during learning but stable before and after



Dupret, O'Neill, and Csicsvari, Neuron, 2013



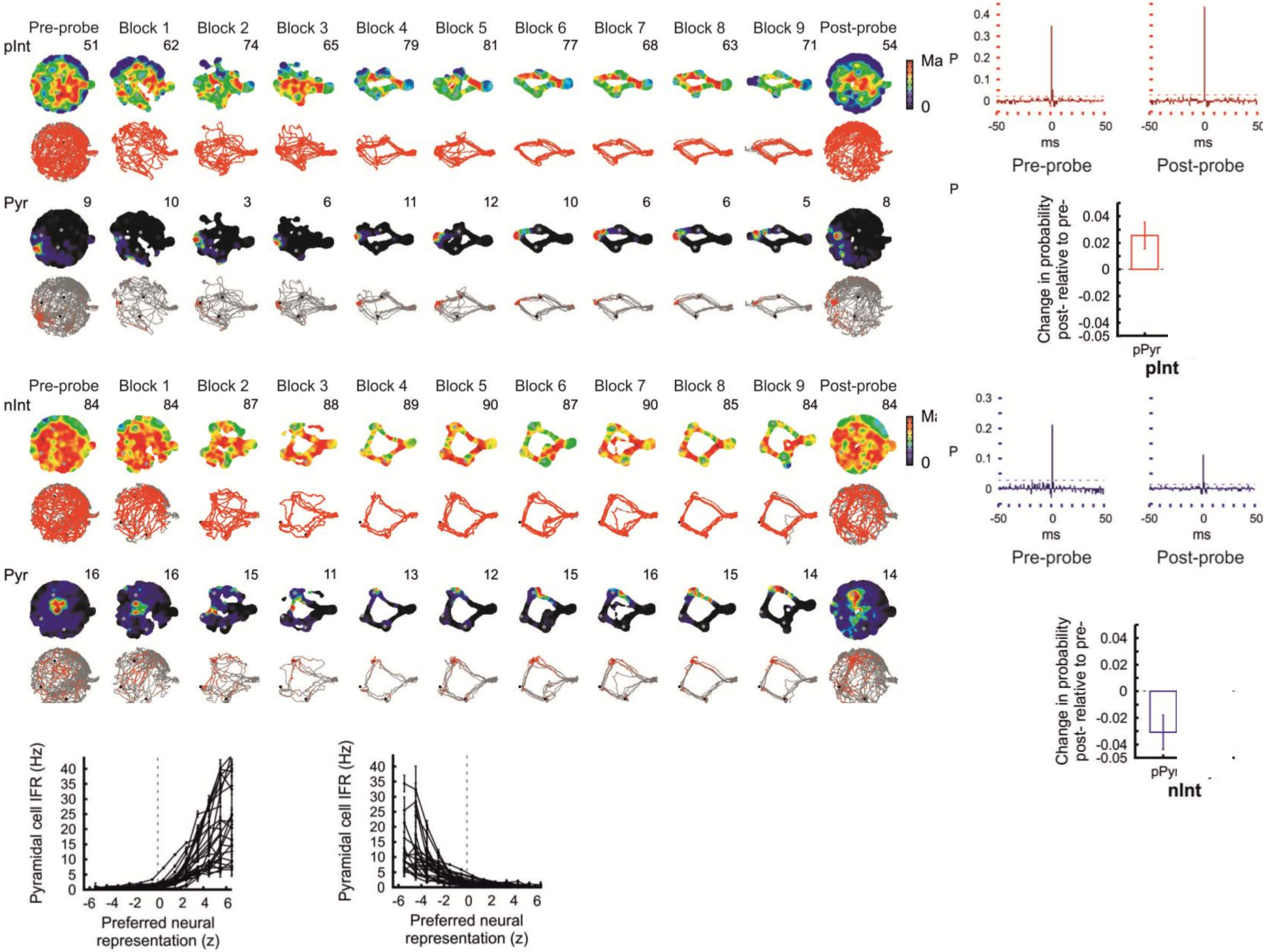
Dupret, O'Neill, and Csicsvari, Neuron, 2013



Changes in spike transmission probability correlate with changes in spike latency

Dupret, O'Neill, and Csicsvari, Neuron, 2013

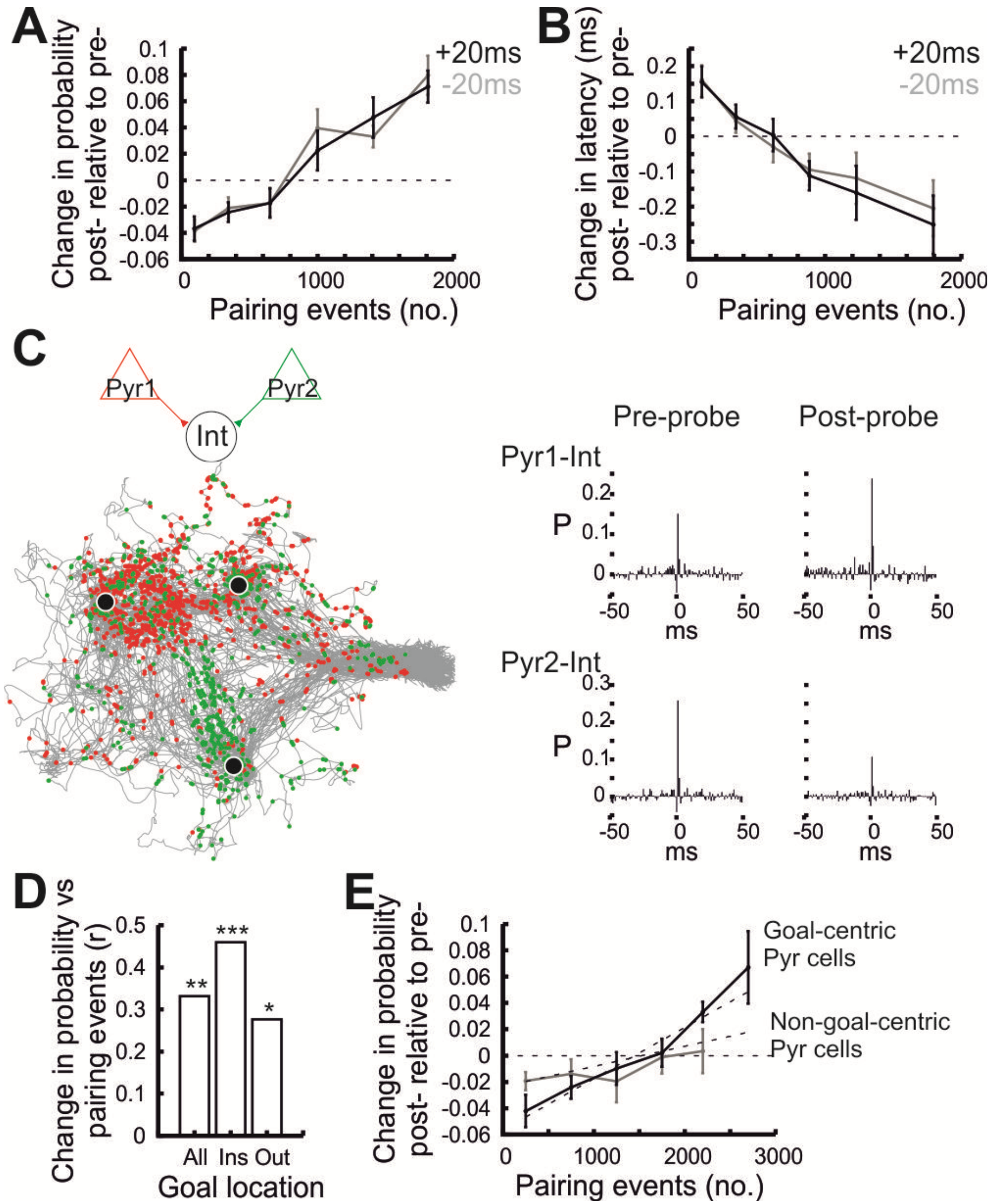
Pyramidal-interneuron connection changes support interneuron association to new assemblies



pPyr

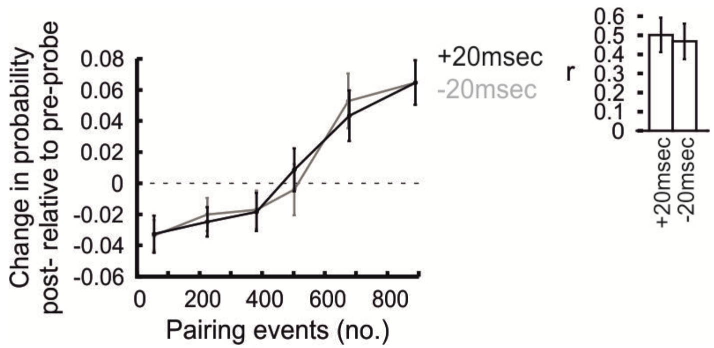
nPyr

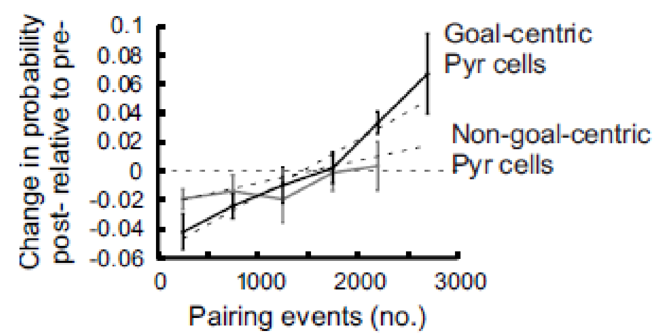
Dupret, O'Neill, and Csicsvari, Neuron, 2013

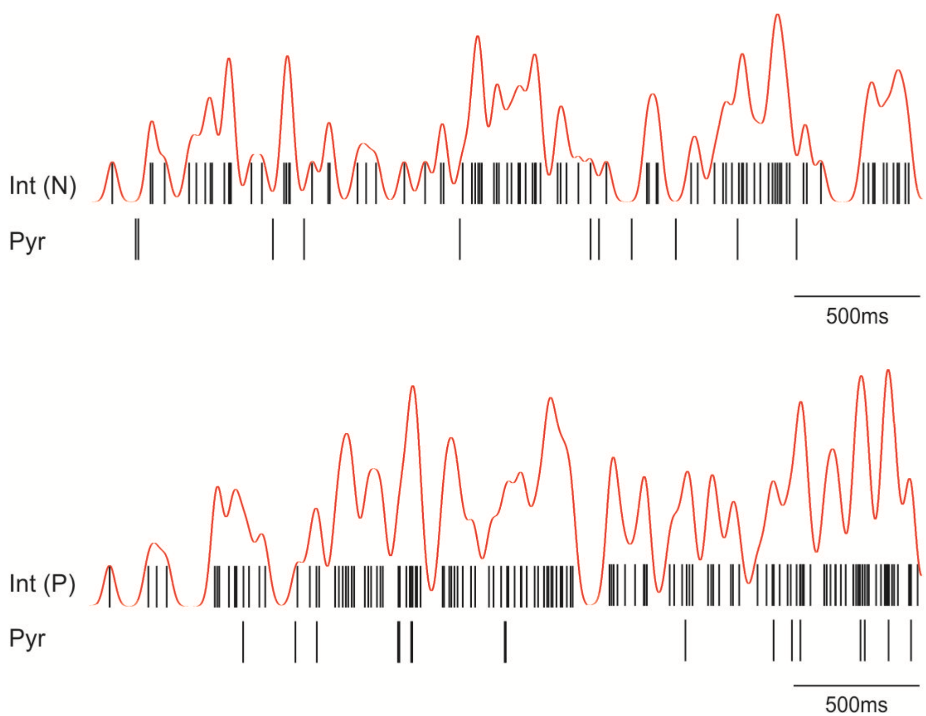


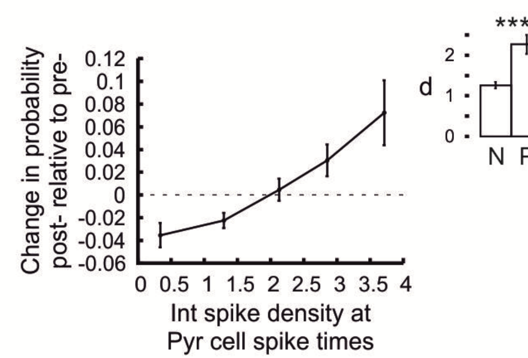
Dupret, O'Neill, and Csicsvari, Neuron, 2013

Hebbian learning rule govern the change of pyramidal-interneuron connections









Dupret, O'Neill, and Csicsvari, Neuron, 2013

Plastic changes in interneuron circuits during spatial learning

- Newly learned goal locations are encoded by the goal-oriented remapping of CA1 place cells
- Goal oriented maps flicker with old maps in the early stages of learning
- CA1 interneurons develop firing associations (either positive or negative) to new goal-oriented maps
- Firing associations can be explained by changes of pyramidal-cell interneuron connections during learning
- Interneurons may have a role in map selection