Unravelling the role of collective bursting neurons, quiet waking and structural plasticity in memory consolidation

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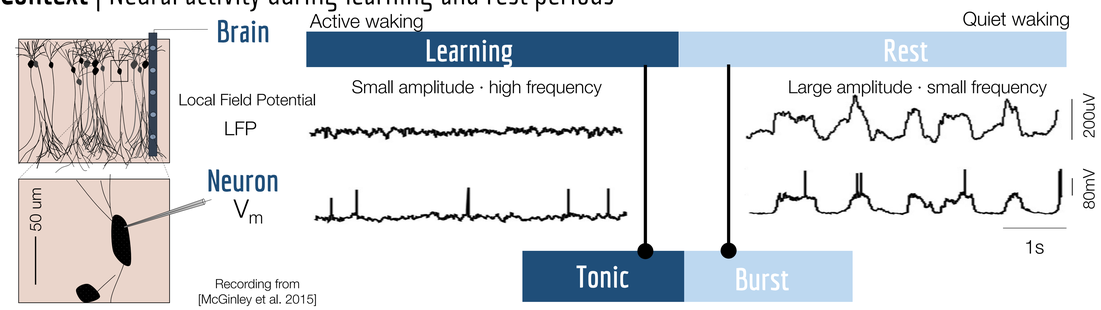
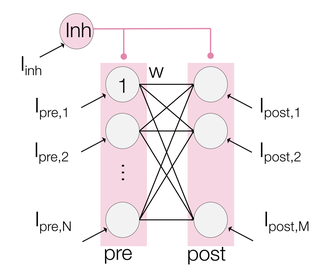
Context | Neural activity during learning and rest periods

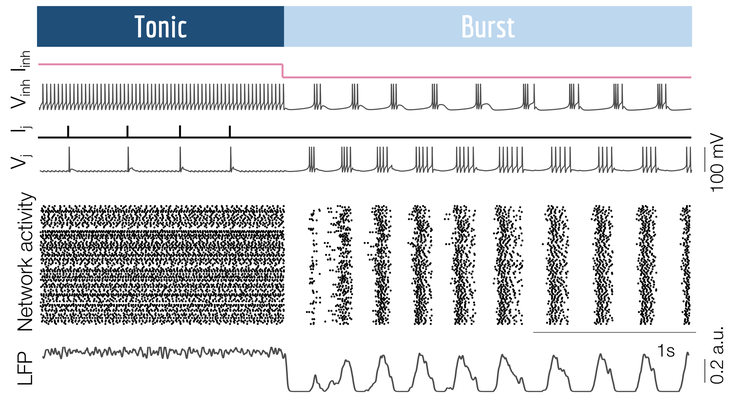


Computational model | Biophysical neurons model are able to switch from tonic (learning) to burst (rest)



Conductance-based model robust to neuromodulation, variability and plasticity

[Jacquerie and Drion, 2021]



Synaptic plasticity

Synaptic weight = **early weight (w)** x **late weight (l)**

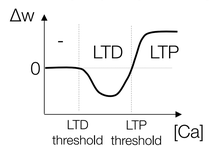
NEW

Traditional synaptic plasticity

[Graupner and Brunel, 2012]

w = f([Ca])

✓ Fitted on experimental data
✓ Validated on learning tasks



Structural Plasticity

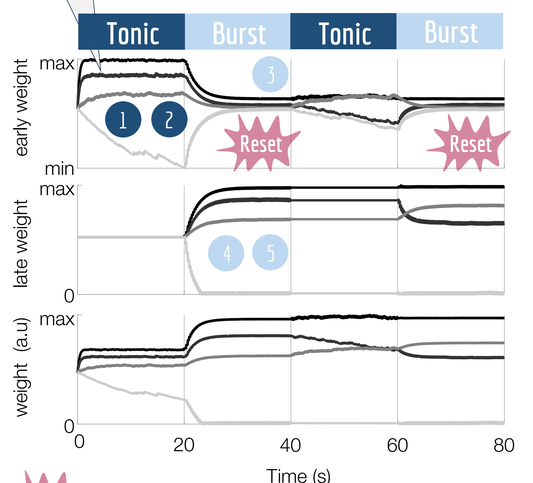
We developed an innovative burst-induced structural plasticity: **l=f(w)**.

It aims to better understand the role of collective bursting activity associated with rest periods on memory consolidation. The late weight models the insertion of newly generated proteins and the change in the synapse morphology.

Computational experiment

· 4 circuits of 1pre-1post with traditional and structural plasticity
· we compare the evolution of the synaptic weights during the transition between tonic and burst for different levels of tonic correlation

strong correlated tonic (strong corr.)
weak correlated tonic (weak corr.)

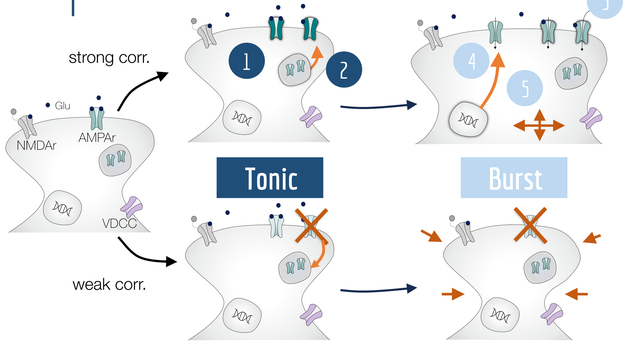


Reset — Collective bursting induces a reset in early weights.

Plasticity mechanisms during learning and rest

Early-phase of Long-Term Potentiation (E-LTP)

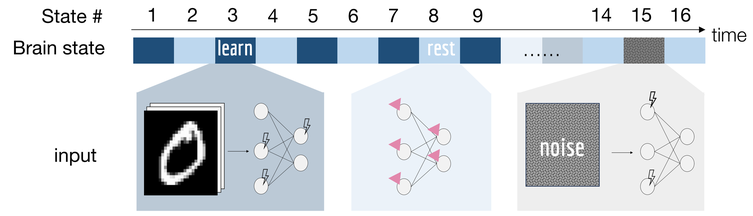
1. Increase of postsynaptic receptor efficacy
2. Insertion of new postsynaptic receptors using exocytosis with fast insertion of proteins available in a pool



Late-Phase of Long-Term Potentiation (L-LTP)

3. Restoration of the postsynaptic receptor efficacy – called reset
4. Insertion of newly generated proteins
5. Change in the morphology of the synapse

Protocol | Alternate periods of learning and rest to test the role of rest periods in memory consolidation



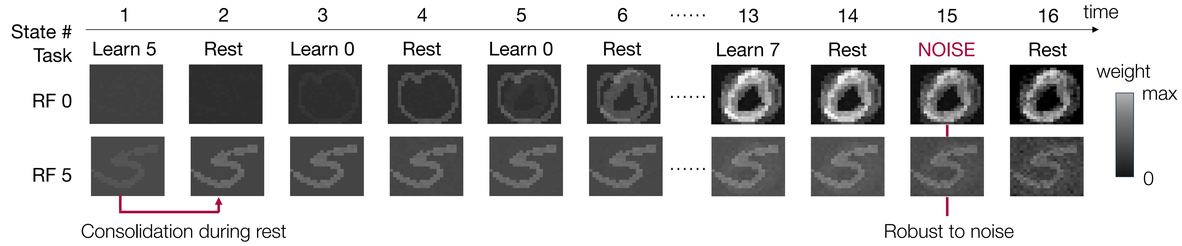
Tonic
- Pixel ON: neurons fire at ~45Hz
- Pixel OFF: neurons fire at ~0.01Hz

Burst
Neurons are collectively bursting. It is reflected in the large-amplitude, low-frequency LFP recordings. No input is presented.

Noise
Neurons randomly fire between [5;25] Hz.

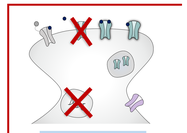
Result | Evolution of the Receptive Fields (RF)

To check the learning progress in our network, we can track the receptive fields (RF). It corresponds to the weight matrix of each output neuron corresponding to each digit.

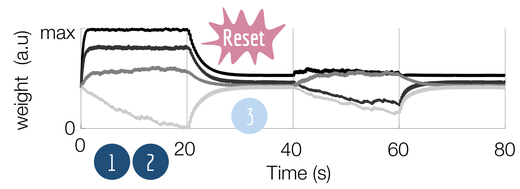


Mechanisms | Memory consolidation *simultaneously* requires brain-state switches and structural plasticity

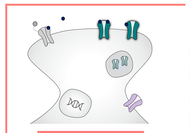
Blocking structural plasticity



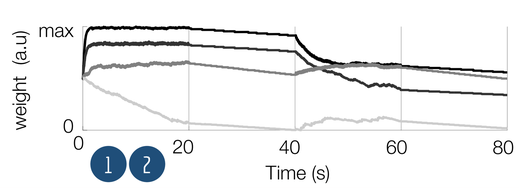
- The early weight (w) is **reset** during each burst state. It allows the network to learn new information but it forgets previous learning.
- The late weight is constant because structural plasticity is blocked.

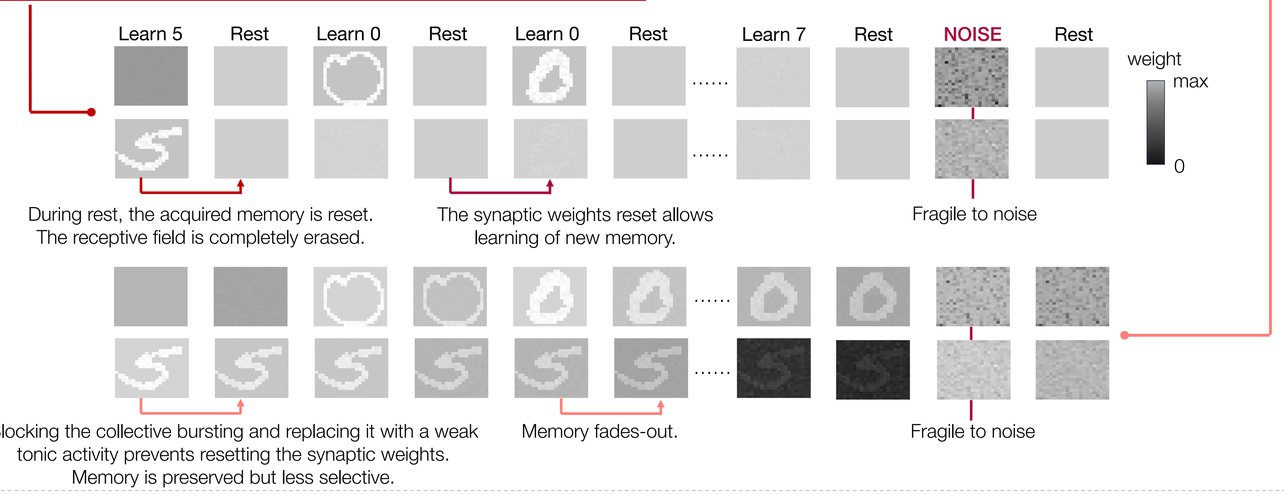


Blocking collective bursting



Rest is associated with a collective bursting activity. Modeling rest with a weak tonic activity or blocking bursting prevents reset in the synaptic weights. New memory will erase the previous one and no memory consolidation occurs.





Take home messages

- We have developed a biophysical neuron network able to reproduce different brain states: learning (tonic) and rest (burst).
- This work offers a better understanding of the role of rest in memory consolidation by demonstrating the importance of new-protein synthesis and morphological change in the synapse.
- We created a burst-induced structural plasticity that supports memory consolidation.
- This new rule is independent of the traditional synaptic plasticity used and robust to neuromodulation. It can provide synaptic homeostasis during rest or consolidation by tuning the structural plasticity parameters.