

Theory/modelling club!

Structural plasticity and associative memory in balanced neural networks with spike-time dependent inhibitory plasticity

Ankur Sinha

02/06/2020

Context: what and why?

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└ Context: what and why?

2020-07-15

Context: what and why?

Peripheral lesions: large scale reorganisation in the brain

- Rasmusson, D. D. Reorganization of raccoon somatosensory cortex following removal of the fifth digit.
Journal of Comparative Neurology **205**, 313–326 (1982)

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└ Peripheral lesions: large scale reorganisation in the brain

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- Merzenich, M. M. et al. Somatosensory cortical map changes following digit amputation in adult monkeys. *Journal of Comparative Neurology* **224**, 591–605 (1984)
- Calford, M. B. & Tweedale, R. Immediate and chronic changes in responses of somatosensory cortex in adult flying-fox after digit amputation. *Nature* **332**, 446–448 (1988)
- Heinen, S. J. & Skavenski, A. A. Recovery of visual responses in foveal V1 neurons following bilateral foveal lesions in adult monkey. *Experimental Brain Research* **83**, 670–674 (1991)
- Rajan, R. et al. Effect of unilateral partial cochlear lesions in adult cats on the representation of lesioned and unlesioned cochleas in primary auditory cortex. *Journal of Comparative Neurology* **338**, 17–49 (1993)

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Also confirms structural plasticity in the unlesioned adult brain

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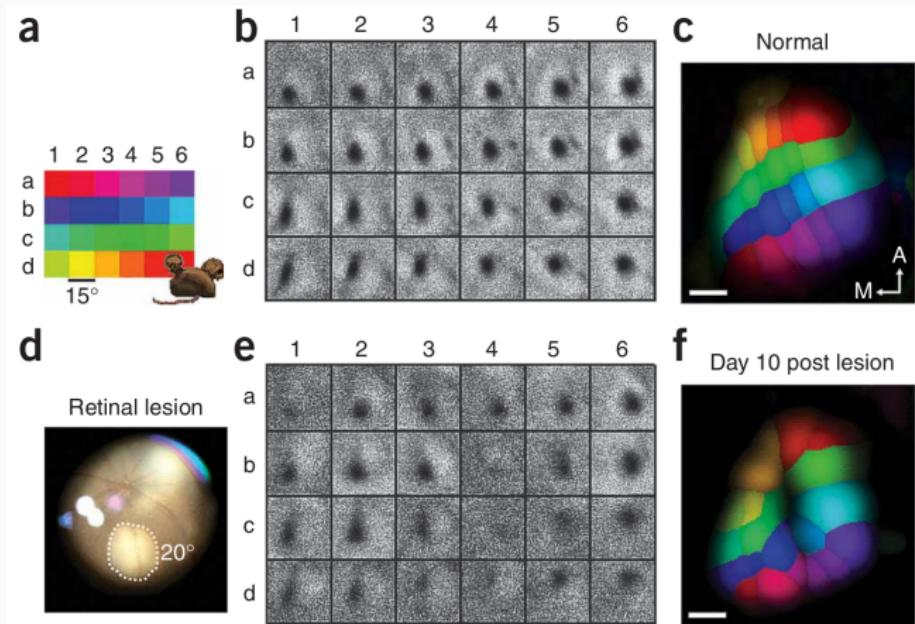
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Example: Keck et al. 2008

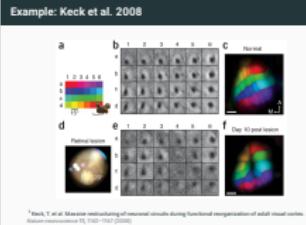


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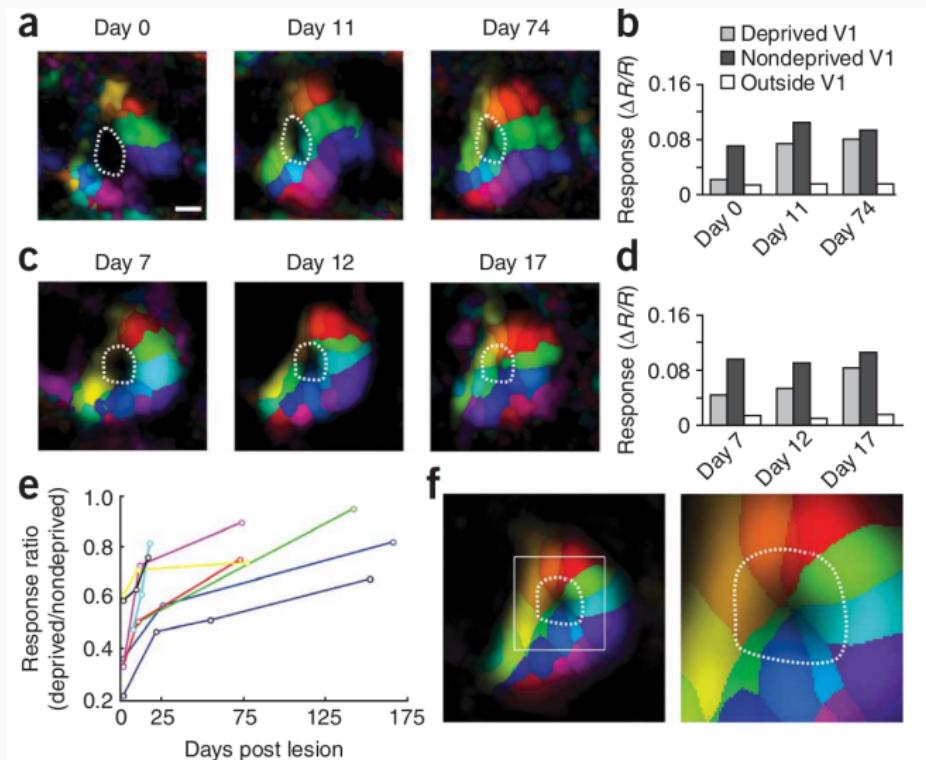
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└ Example: Keck et al. 2008



Example: Keck et al. 2008: II

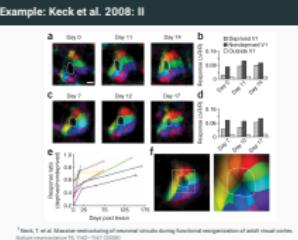


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└ Example: Keck et al. 2008: II



Features of repair

Table 1: Summary of review of literature on peripheral lesion experiments.

Observation	References
Recovery of neural response in deafferented regions. Inward restoration of activity in LPZ.	Rasmusson [1], Merzenich et al. [3], Calford & Tweedale [4], Heinen & Skavenski [5], Rajan et al. [6], Florence et al. [8], Gilbert & Wiesel [17], and Pons et al. [18].
Sprouting of axons into the LPZ.	Darian-Smith & Gilbert [7, 19].
Increase in density of dendritic spines on pyramidal cells in the LPZ.	Keck et al. [9].
Ingrowth of excitatory axonal terminals to the LPZ, resulting in increase in density of axonal terminals in the region.	Yamahachi et al. [20].
Loss in dendritic spines on inhibitory neurons receiving glutamatergic inputs in LPZ.	Keck et al. [10].
Reduction in inhibitory boutons in LPZ.	Keck et al. [10].
Disinhibition in LPZ after deafferentation.	Keck et al. [10] and Chen et al. [21].
Outgrowth of inhibitory axons from the LPZ.	Marik et al. [11, 14].

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Research question

How does repair by structural plasticity affect the function of the brain network?

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└ Research question

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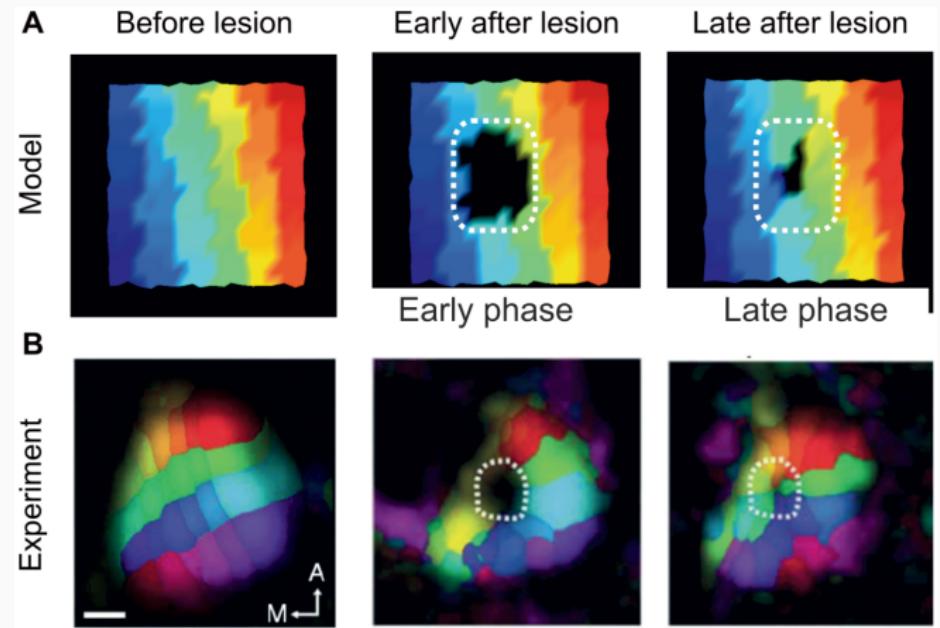
How?

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How?

Network dynamics during repair: Butz et al.

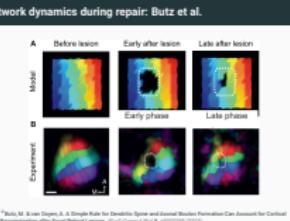


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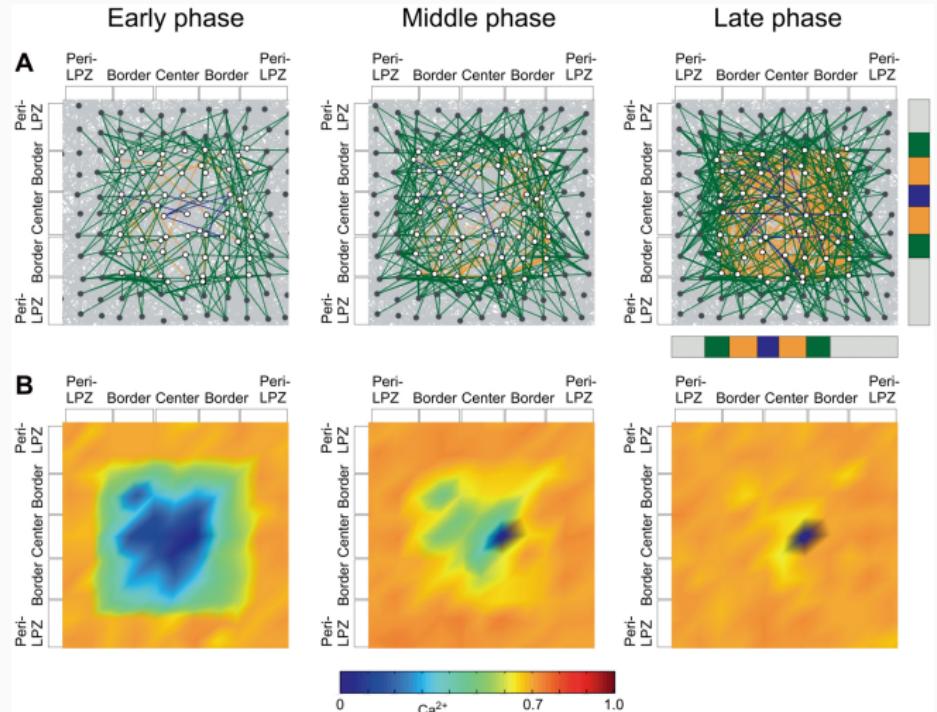
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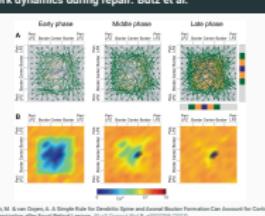


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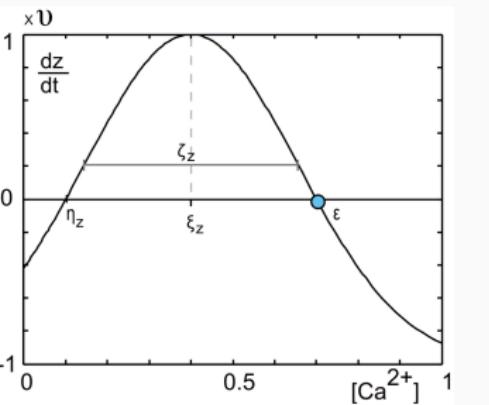
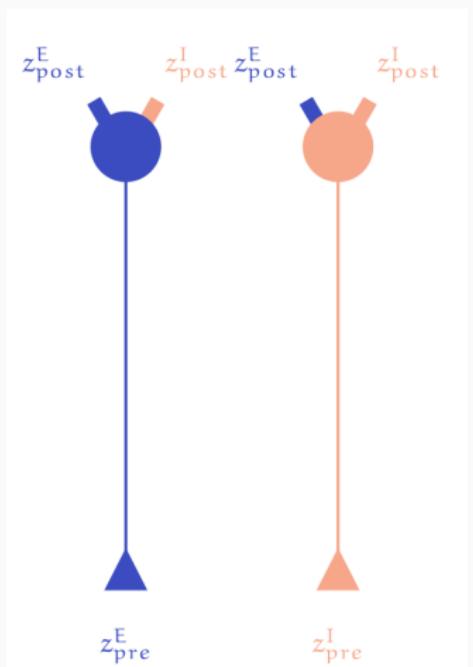
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Network dynamics during repair: Butz et al.



Butz2013: activity dependent homeostatic structural plasticity

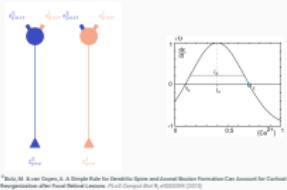


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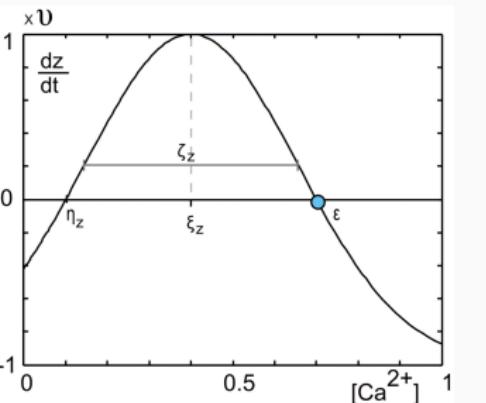
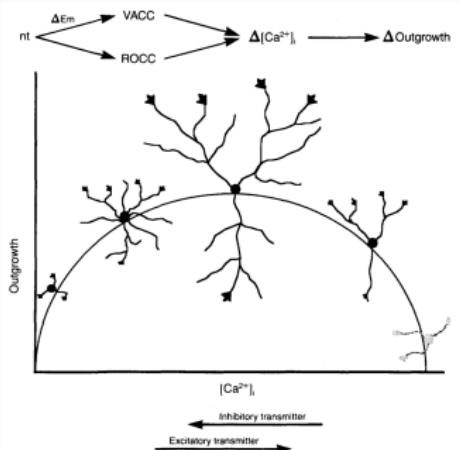
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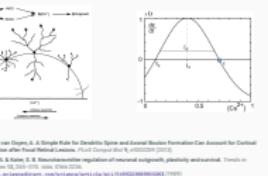
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Re-implementation/investigation of Butz et al.'s model

Table 2: Summary of experimental observations reproduced in the model proposed by Butz & van Ooyen [22].

Experimental observation	Reproduced
Gradual inward restoration of activity in LPZ.	Yes.
Sprouting of axons into the LPZ.	Yes.
Increase in density of dendritic spines on pyramidal cells in the LPZ.	Yes.
Ingrowth of excitatory axonal terminals to the LPZ, resulting in increase in density of axonal terminals in the region.	Yes.
Loss in dendritic spines on inhibitory neurons receiving glutamatergic inputs in LPZ.	No—increase of all synaptic elements in neurons of LPZ.
Reduction in inhibitory boutons in LPZ.	No—increase in inhibitory axonal contacts also.
Disinhibition in LPZ after deafferentation.	No.
Outgrowth of inhibitory axons from the LPZ.	No—ingrowth of inhibitory axons also.

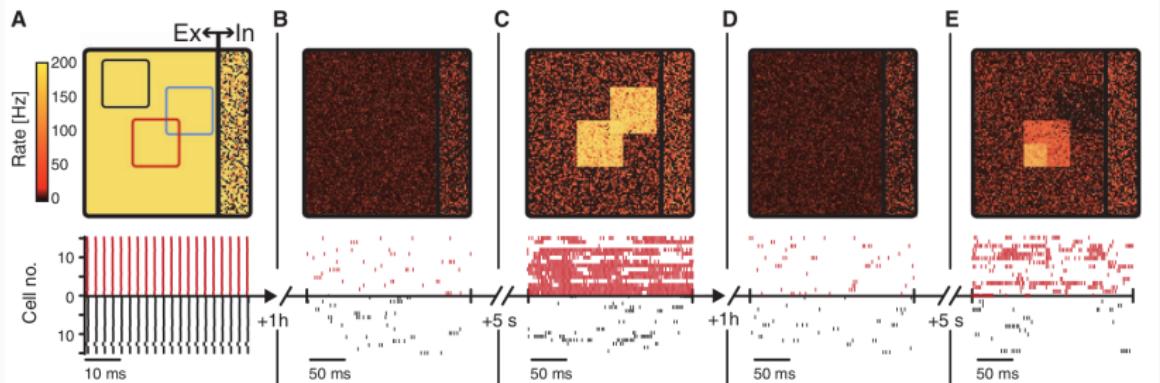
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Proxy for network function: associative memory storage

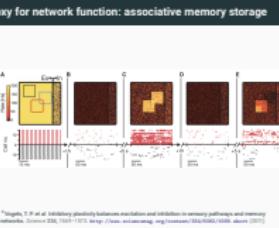


⁴Vogels, T. P. et al. Inhibitory plasticity balances excitation and inhibition in sensory pathways and memory networks. *Science* 334, 1569–1573. <http://www.sciencemag.org/content/334/6062/1569.short> (2011)

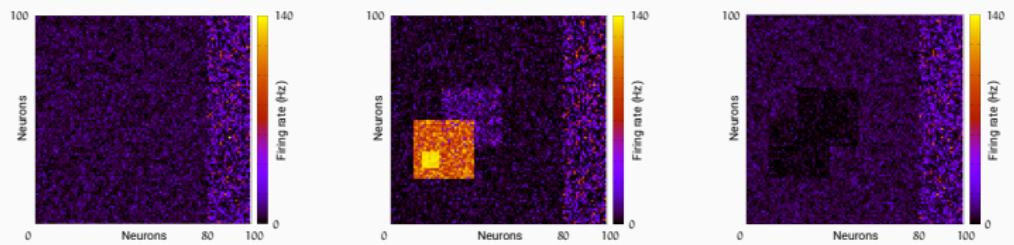
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└ How?

└ Proxy for network function: associative memory storage

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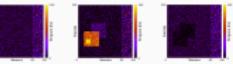
Re-implementation/verification of associative memory model



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└ Re-implementation/verification of associative memory model



Expected research path

Apply Butz et al.'s model of structural plasticity to the Vogels-Sprekeler's cortical model, store associative memories, measure performance before, during, after repair.

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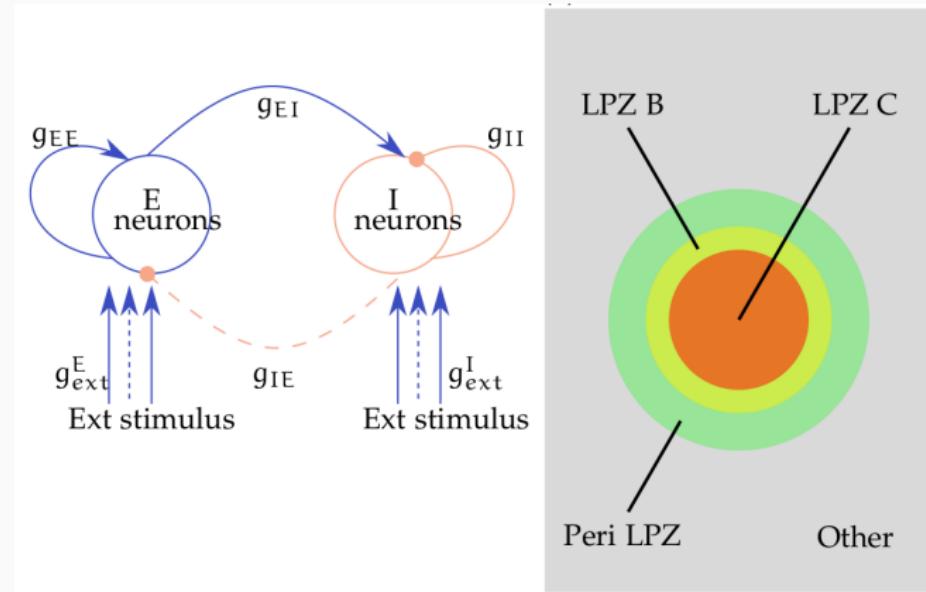
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Model schematic

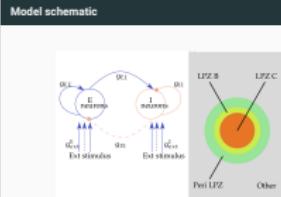


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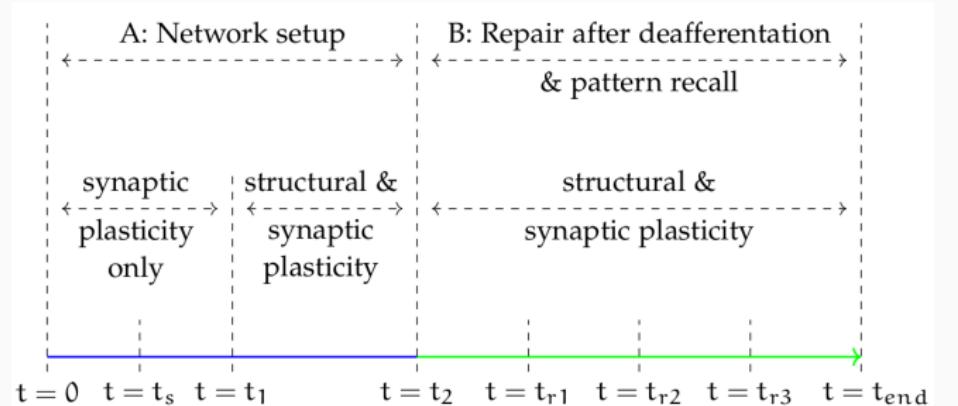
└ How?

└ Model schematic

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Simulation protocol

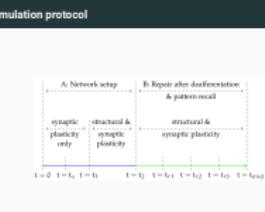


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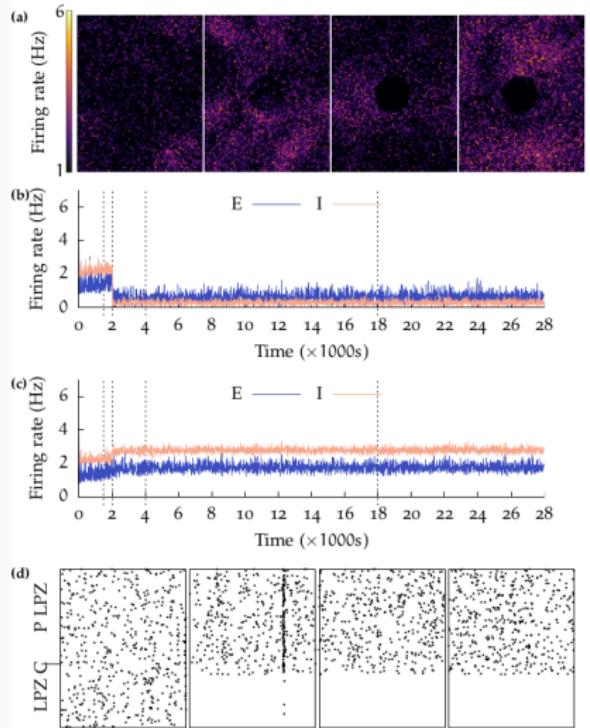
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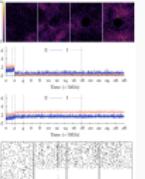
Effect of deafferentation on cortical model



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└ Effect of deafferentation on cortical model

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Rejection of Butz et al.'s growth curve hypothesis

If Butz et al.'s single growth curve for all neurites is correct, the increase in activity outside the LPZ as a result of deafferentation will cause:

- retraction of excitatory pre-synaptic elements outside the LPZ,
- retraction of inhibitory post-synaptic elements outside the LPZ.

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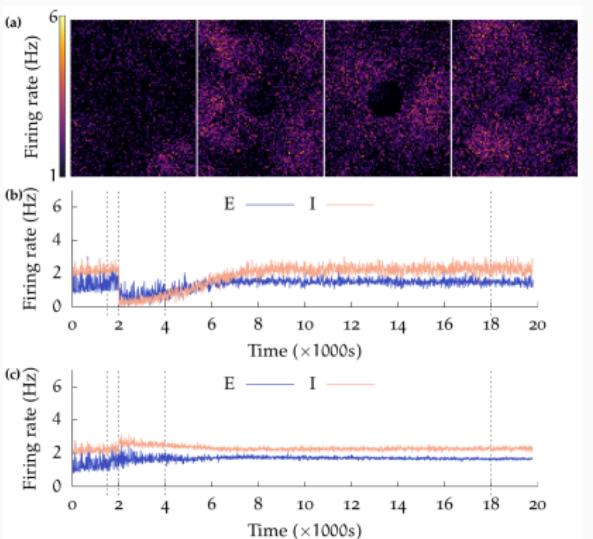
Results

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└ Results

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Results

New model of peripheral lesioning and repair in cortical network

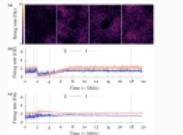


⁵ Sinha, A. et al. Growth Rules for the Repair of Asynchronous Irregular Neuronal Networks after Peripheral Lesions. bioRxiv. eprint: <https://www.biorxiv.org/content/early/2019/10/21/810846.full.pdf>.
<https://www.biorxiv.org/content/early/2019/10/21/810846> (2019)

Theory/modelling club! └ Results

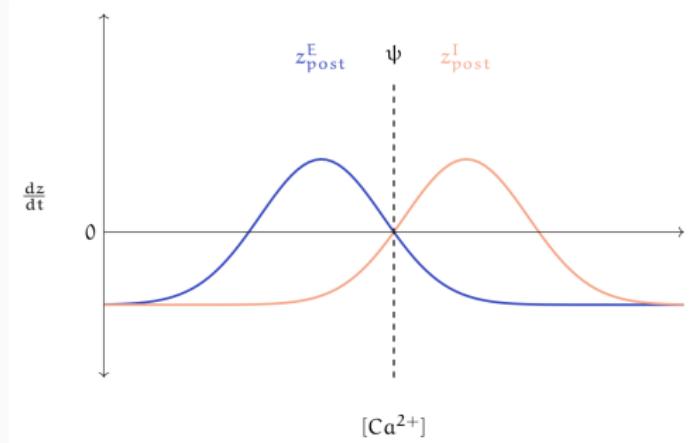
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- └ New model of peripheral lesioning and repair in cortical network



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New growth curves for post-synaptic neurites



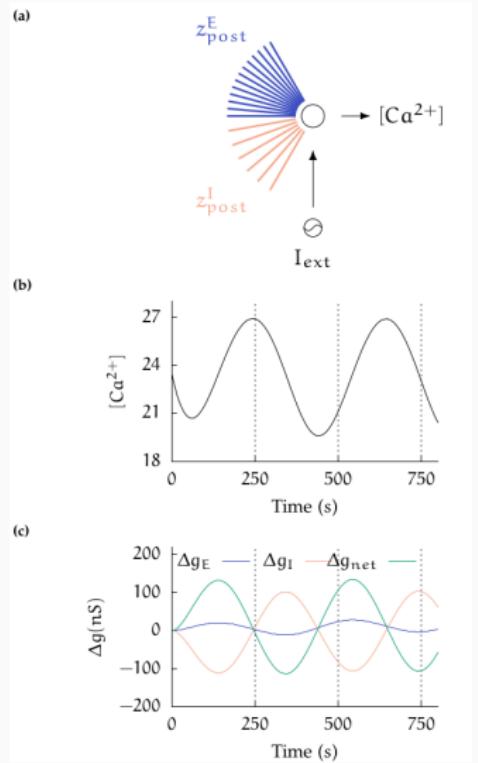
Theory/modelling club!
└ Results

└ New growth curves for post-synaptic neurites

New growth curves for post-synaptic neurites



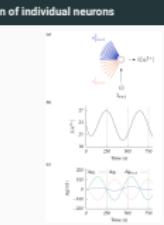
Stabilisation of individual neurons



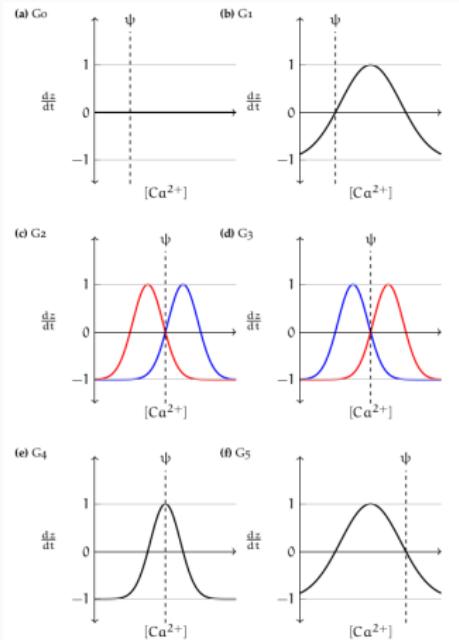
Theory/modelling club!
└ Results

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└ Stabilisation of individual neurons



New growth curves for pre-synaptic neurites



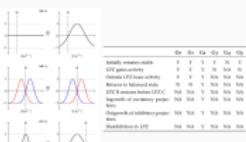
	G0	G1	G2	G3	G4	G5
Initially remains stable	Y	Y	Y	Y	N	Y
LPZ gains activity	Y	Y	Y	N	NA	N
Outside LPZ loses activity	Y	Y	Y	NA	NA	NA
Returns to balanced state	N	N	Y	NA	NA	NA
LPZ B restores before LPZ C	NA	NA	Y	NA	NA	NA
Ingrowth of excitatory projections	NA	NA	Y	NA	NA	NA
Outgrowth of inhibitory projections	NA	NA	Y	NA	NA	NA
Disinhibition in LPZ	NA	NA	Y	NA	NA	NA

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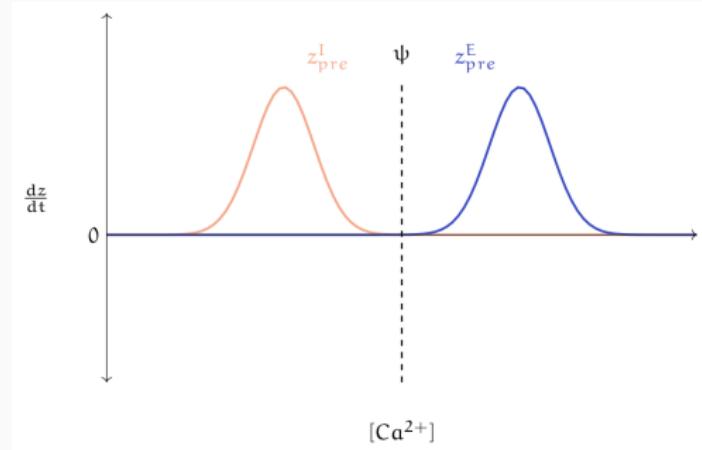
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└ New growth curves for pre-synaptic neurites

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New growth curves for pre-synaptic neurites



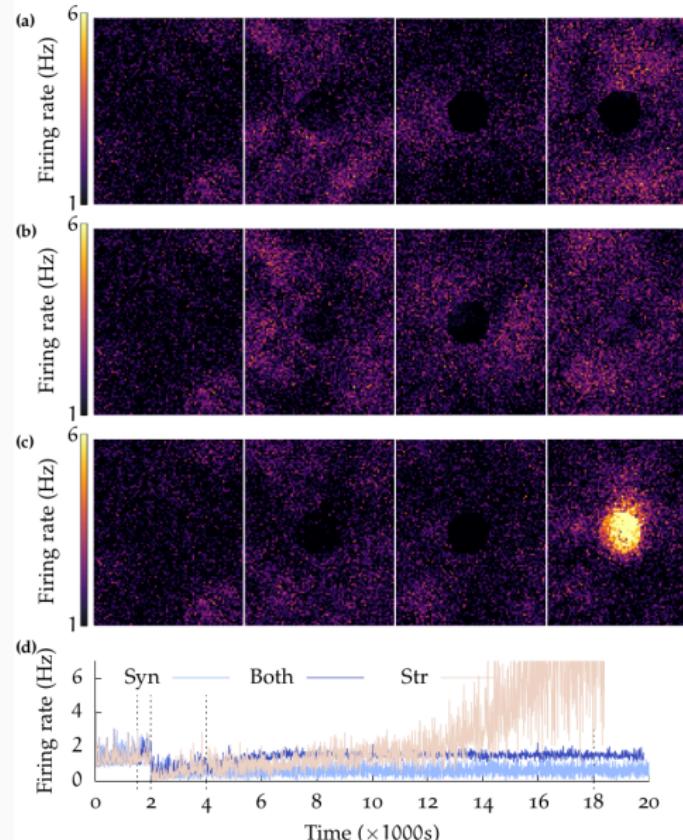
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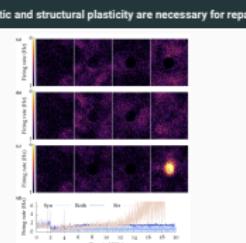
Both synaptic and structural plasticity are necessary for repair



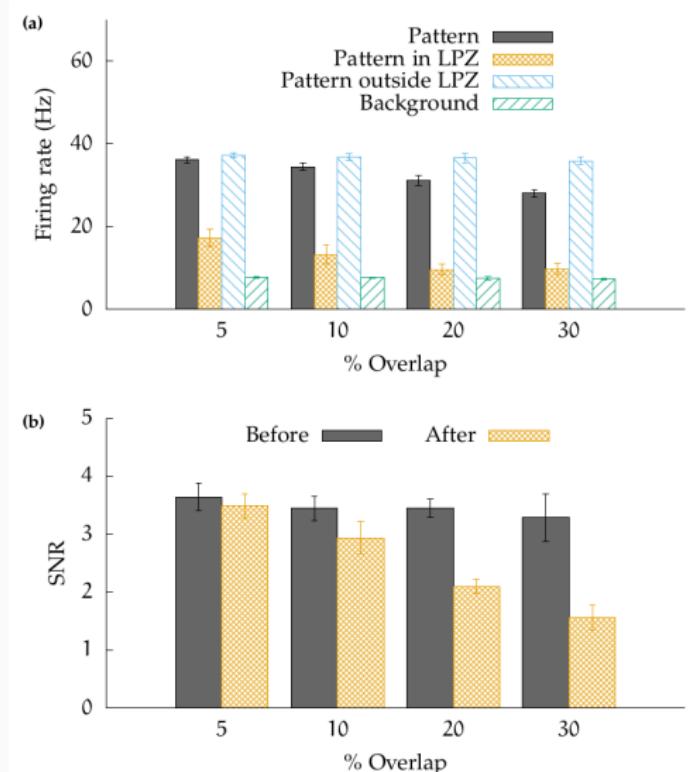
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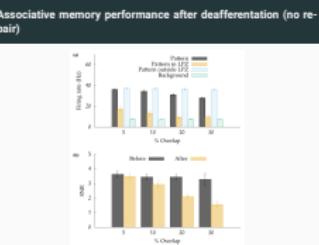
Associative memory performance after deafferentation (no repair)



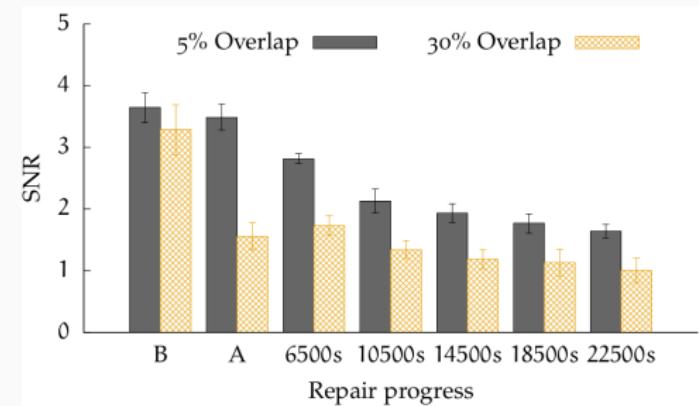
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└ Associative memory performance after deafferentation (no repair)

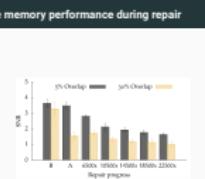


Associative memory performance during repair



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└ Associative memory performance during repair



Conclusions

- New model of peripheral lesioning and repair in a balanced cortical network model.
- New activity dependent growth curves for all types of neurites.
- Lack of AI firing characteristics in the LPZ post-repair.
- Deterioration in associative memory recall performance after deafferentation even with repair.

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