nano-tera.ch
swiss scientific initiative in health / security / environment systems

SpineRepair RTD 2013

FNSNF

A Computational Model of the Rat Spinal Cord: Multipolar Electrical Epidural Stimulation with Multi-Electrode Arrays

M. Capogrosso* [1,2], N. Wenger* [3], J. Gandar [3], G. Courtine [3], S. Micera [1,2].

[1] Translational Neural Engin. Lab., Center for Neuroprosthetics, École Polytechnique Fédérale de Lausanne, Switzerland;
[2] Biorobotics Institute, Scuola Superiore Sant'Anna, Pontedera, Italy;
[3] International Paraplegic Foundation Chair in Spinal Cord Repair, Center for Neuroprosthetics and Brain-Mind Institute, École Polytechnique Fédérale de Lausanne, Switzerland.
* equal contribution.

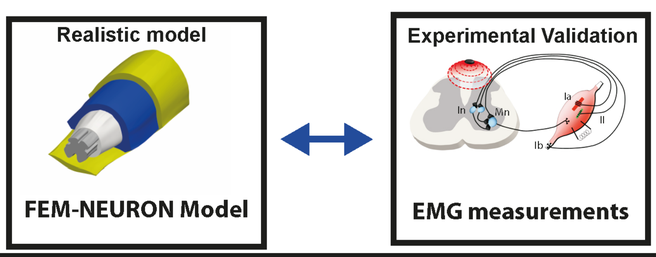
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE TNE IFP

A theoretical framework for spinal neuroprostheses

Spinal Cord Stimulation: a promising intervention to improve motor function after spinal cord injury (SCI) [1].

Open questions: mechanisms underlying site-specific facilitation of movement are poorly understood. Consequently, there is limited information available on the optimal strategy for the design and use of modern interfaces like Multi-Electrode Arrays.

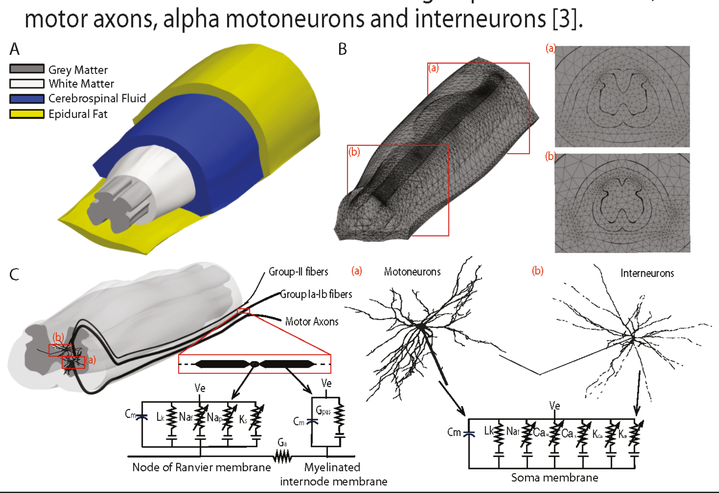
Apporach: we developed a realistic computational model of the rat lumbosacral spinal cord, which we comprehensively validated with electrophysiological and pharmacological experiments [2] to tackle the problem.



The Computer Model

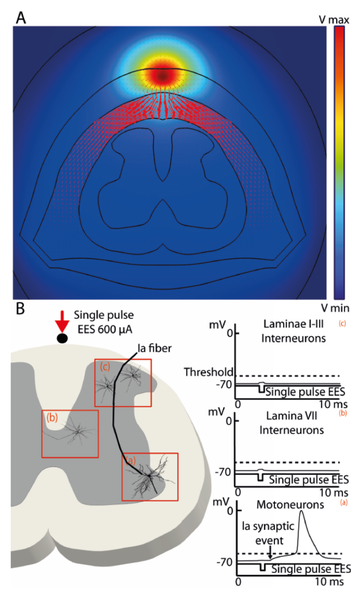
A Finite Element model coupled to a realistic model of cells, sensory and motor fibers.

Spinal cord. Lumbosacral tract of the Rat Spinal cord L2-S1 from realistic histology.
Cell/fiber models. Realistic models of group I and II afferents, motor axons, alpha motoneurons and interneurons [3].



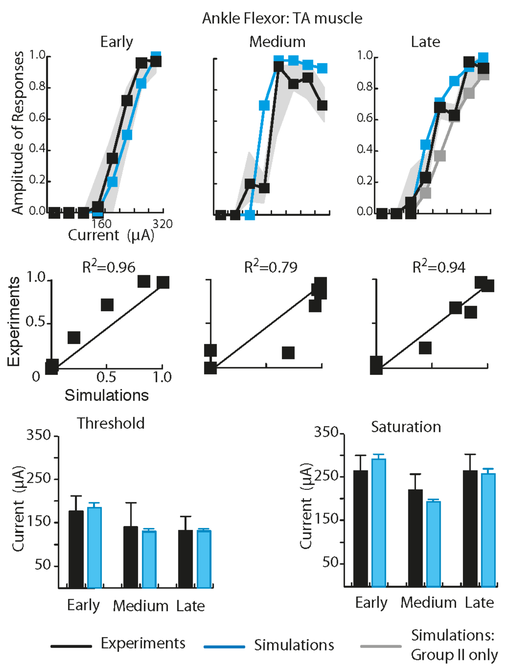
Voltage Solutions.
The current density spreads in the high conductive CSF surrounding the cord.

Cells are not recruited.
Cells are not directly stimulated. Indirect cell recruitment occurs by means of afferents stimulation.
In fact the excitability of cells is lower than fibers due to the lower variation of the voltage potential along the membrane [4]

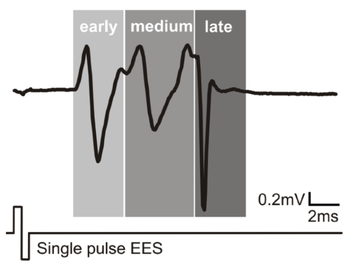


Results and Validation

Quantitative Validation and hypotheses confutation

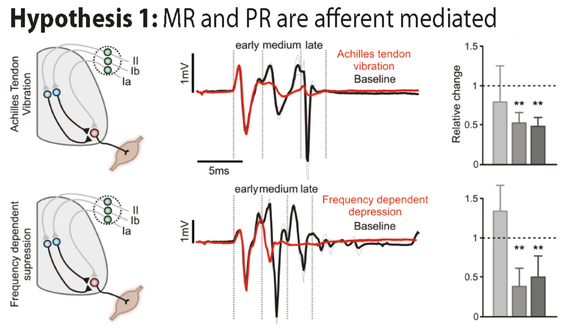


Quantitative Validation.
Is performed by comparing EMG reflex response recruitments with model recruitment predictions

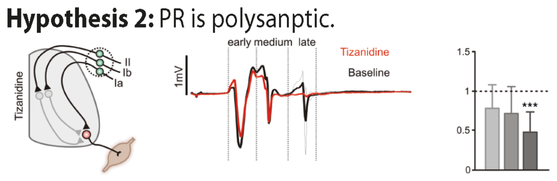


Hypotheses confutaion.
Tests are carried out to confute Model driven hypotheses

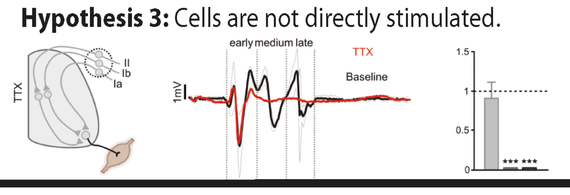
Hypothesis 1: MR and PR are afferent mediated



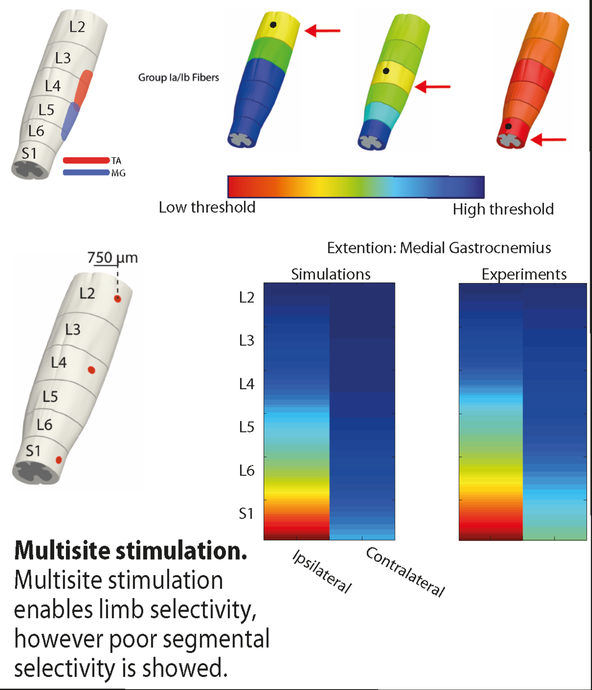
Hypothesis 2: PR is polysanptic.



Hypothesis 3: Cells are not directly stimulated.



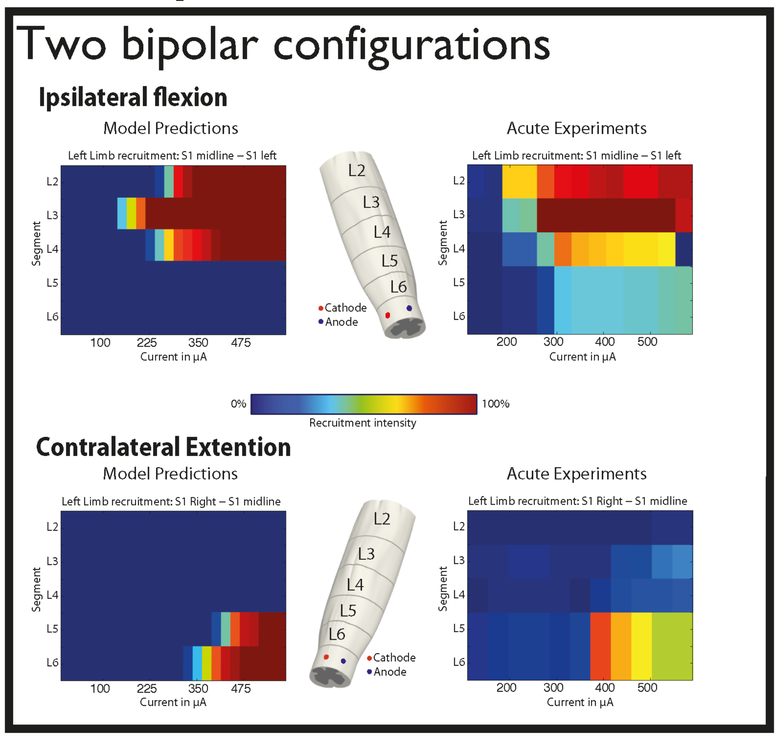
Multisite Stimulation



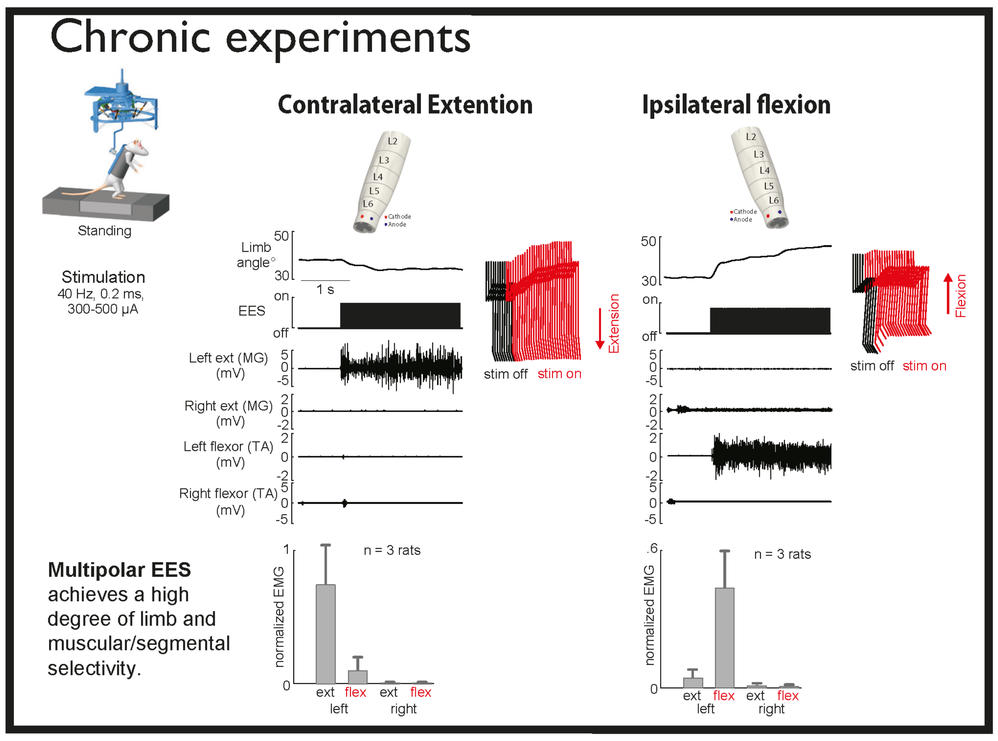
Multisite stimulation.
Multisite stimulation enables limb selectivity, however poor segmental selectivity is showed.

Multipolar Stimulation

Two bipolar configurations



Chronic experiments



Conclusions

In terms of **spatial selectivity** a precise selection of lower and upper lumbar segments is possible, overcoming the difficulties found with classic monopolar EES.

These results demonstrate the **ability of multipolar EES to boost the controllability** of spinal sensorimotor circuits during movement execution.

For the first time, we applied a **validated computational model** to predict near-optimal configuration of the stimulation to facilitate specific types of movements with multipolar EES.

These results establish a practical and mechanistic framework to steer the design of Multi Electrode Arrays configuration, and the **development of multisite EES patterns**, to facilitate recovery of motor functions after a range of neurological disorders.

References

[1] Courtine G, Gerasimenko Y, van den Brand R, Yew A, Musienko P, Zhong H, Song B, Ao Y, Ichiyama RM, Lavrov I, Roy RR, Sofroniew MV, Edgerton VR (2009) Transformation of nonfunctional spinal circuits into functional states after the loss of brain input. Nature neuroscience 12:1333-1342.
[2] Capogrosso M., Wenger N., Raspopovic S., Musienko P., Beauparlant J., Bassi Luciani L., Courtrine G., Micera S. (2013) A computational model for epidural electrical stimulation of spinal sensorimotor circuits, The Journal of Neuroscience, *in press.*
[3] McIntyre CC, Richardson AG, Grill WM (2002) Modeling the Excitability of Mammalian Nerve Fibers: Influence of Afterpotentials on the Recovery Cycle. Journal of neurophysiology 87:995-1006.
[4] Rattay F (1986) Analysis of Models for External Stimulation of Axons. Biomedical Engineering, IEEE Transactions on BME-33:974-977.