A TWO LAYER MODEL OF THE SPINAL LOCOMOTOR CPG: INSIGHTS FROM DELETIONS OF ACTIVITY DURING FICTIVE LOCOMOTION.

I.A. Rybak[1], M. Lafreniere-Roula[2], N.A. Shevtsova[1] & D.A. McCrea[2]*

1. School of Biomedical Engineering, Drexel University, Philadelphia, PA, USA
2. Spinal Cord Research Centre, University of Manitoba, Winnipeg, MB, Canada

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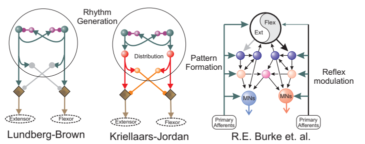
Half-centre CPG models



- simple organization
- inhibitory interactions between half centres - flexor - extensor alternation
- reciprocal inhibition of antagonists
- distribution (pattern formation) and rhythm networks accessed by afferent feedback
- CPG period and flexor/extensor phase proportions intertwined

Analysis of spontaneous deletions during fictive locomotion* motivated development of a new half-centre CPG model

The model must:

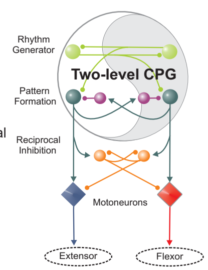
1. produce realistic step cycle periods
2. control flexor-extensor phase durations within the step cycle period.
3. reproduce deletions in which the pre-existing rhythm is maintained - a "clock" function
4. reproduce deletions with reciprocity maintained and deletions resembling "independent" flexor and extensor cycling

* Lafreniere-Roula and McCrea. Deletions of ENG activity during fictive locomotion and scratch show maintained cycle period timing despite failures of rhythmic motoneuron excitation and inhibition. SFN #883.1

Why such a simple model?

Similar variations in extensor and flexor phase durations during fictive locomotion (Yakovenko et al.) suggest symmetrical flexor & extensor sides of the CPG.

The tightly coupled (common) excitatory drive to proximal and distal motoneuron pools during deletions justifies starting with 2 antagonist motoneuron pools.

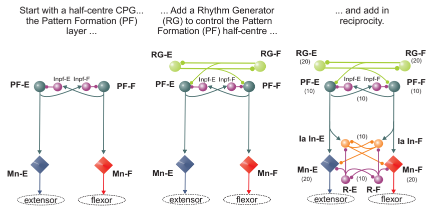


Description of modeled neurons

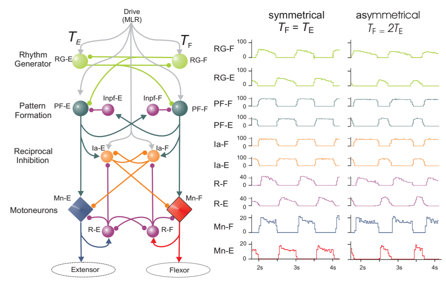
- Hodgkin-Huxley style neurons
- Interneurons are one-compartment models
  Ionic channels:
  RG, PF and R neurons: Na^+; K^+_{DR}; Ca^{2+}_L; $K^+(Ca^{2+})$; Leakage
  Others: Na^+; K^+_{DR}; Leakage
- Motoneurons have a soma and one dendritic compartment.
  model of Booth, Rinzel and Kiehn (J. Neurophysiol. 1997).
  Ionic channels:
  Soma: Na^+; K^+_{DR}; Ca^{2+}_N; $K^+(Ca^{2+})$; Leakage
  Dendrite: Ca^{2+}_N; Ca^{2+}_L; $K^+(Ca^{2+})$; Leakage
- Motoneuron pools and rhythm generator neurons have 20 neurons per pool. All other pools contain 10 neurons each.
- Synaptic weights and maximal leakage channel conductances were randomized (mean ± 3% variance)

Structure of the two layer CPG model

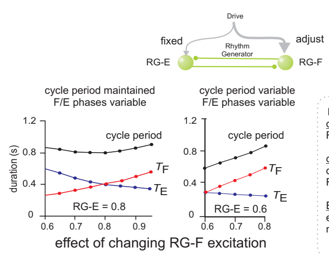
Known interneuron populations and their interconnections combined with postulated two-level architecture (rhythm generator and pattern formation layers)



Modeling fictive locomotion: Interneuron activities

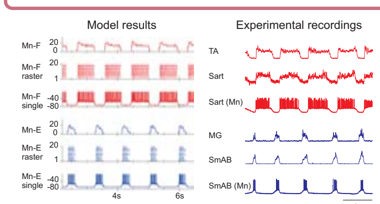


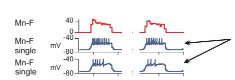
Rhythm & Phase control in the 2 level CPG model



model control of:
cycle period: drive to RG-E and RG-F
cycle phase: ratio of drives to RG-E and RG-F
ENG burst amplitude: excitability of PF network

Modeling fictive locomotion - Motoneuron activities

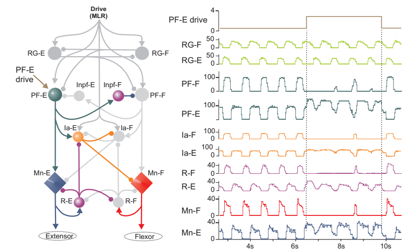




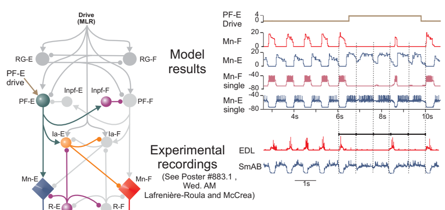
Individual neurons within the populations have varying membrane potential profiles

Modeling reciprocal deletions

An increased excitation to the extensor side of the pattern formation layer leads to a deletion of flexor activity

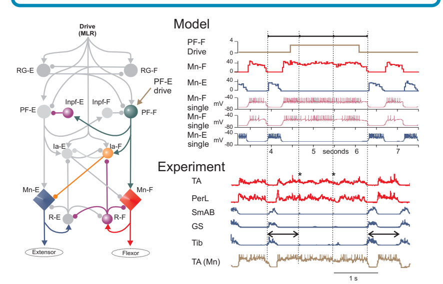


Reciprocal deletions with maintained timing: flexor



Individual motoneurons display membrane fluctuations similar to those observed during deletions in the cat

Reciprocal deletions with maintained timing: extensor



ABBREVIATIONS

Ca^{2+}_L	- high-threshold Ca^{2+} channels	PBSt	- posterior biceps + semitendinosus
Ca^{2+}_N	- Ca^{2+} -N channels	PerL	- peroneus longus
CPG	- central pattern generator	PF	- pattern formation
EDL	- extensor digitorum longus	PF-E/F	- pattern formation- extensor / flexor
GS	- gastrocnemius	Plant	- plantaris
Ia In-E/F	- Ia interneuron-extensor/flexor	RG-E/F	- rhythm generation-extensor / flexor
Inpf-E/F	- pattern formation extensor/ flexor interneurons	R-E/F	- renshaw-extensor / flexor
$K^+(Ca^{2+})$	- Ca^{2+}-dependent potassium channels	RG	- rhythm generation
K^+_{DR}	- delayed-rectifier potassium channels	Sart	- sartorius
		SmAB	- semimembranosus + anterior biceps
		T_E/T_F	- duration of extension/flexion
		TA	- tibialis anterior

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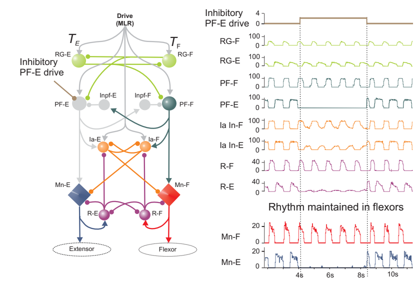
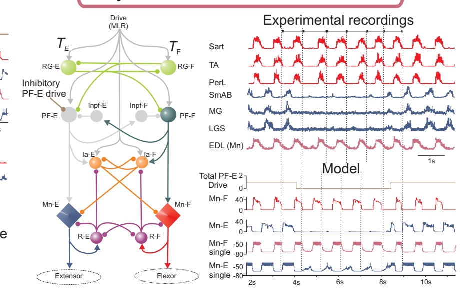
Modeling non-reciprocal deletions: rhythm maintained on one side



Pattern formation inhibition: rhythm maintained on one side



CONCLUSIONS

The 2 layer CPG architecture in which oscillation can occur at both the RG and PF levels offers a computational model that:

- produces realistic step cycle periods with independent control of flexor-extensor phase durations
- separates motoneuron recruitment from rhythm and phase generation
- reproduces deletions in which the pre-existing rhythm is maintained - a "clock" function
- reproduces deletions with maintained reciprocity and deletions resembling "independent" flexor and extensor cycling

Simple additions to this model can:

- reproduce afferent-evoked perturbations of the step cycle

McCrea, Shevtsova, Stecina & Rybak. Modelling proprioceptive sensory control of the mammalian locomotor CPG. SFN #883.4

- reproduce bifunctional motoneuron activity

Chakrabarty, Rybak & McCrea. Modelling the variety of activation patterns of bifunctional hindlimb motoneurons during fictive locomotion. SFN #883.2)