Learning and Adaptation for Sensorimotor Control

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Action-based learning in sensorimotor systems

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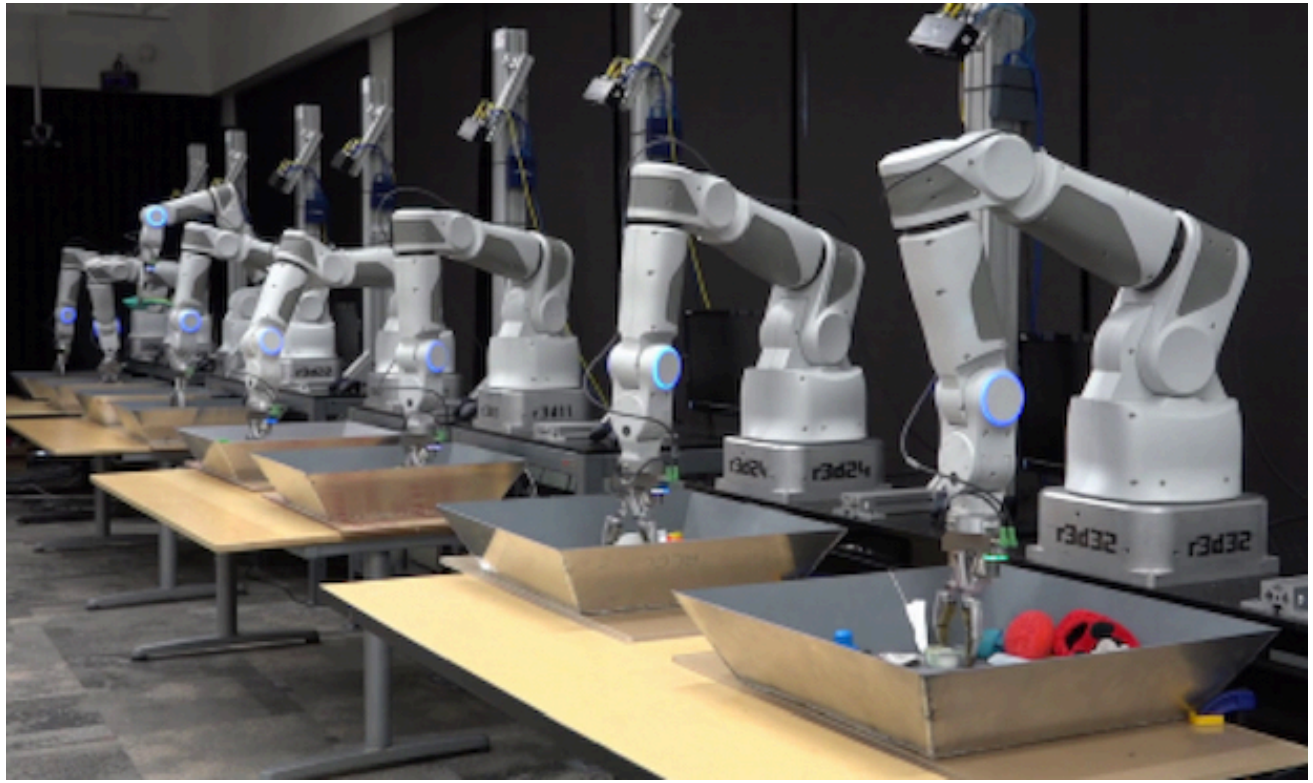
What can we learn from action-based learning in biological systems?

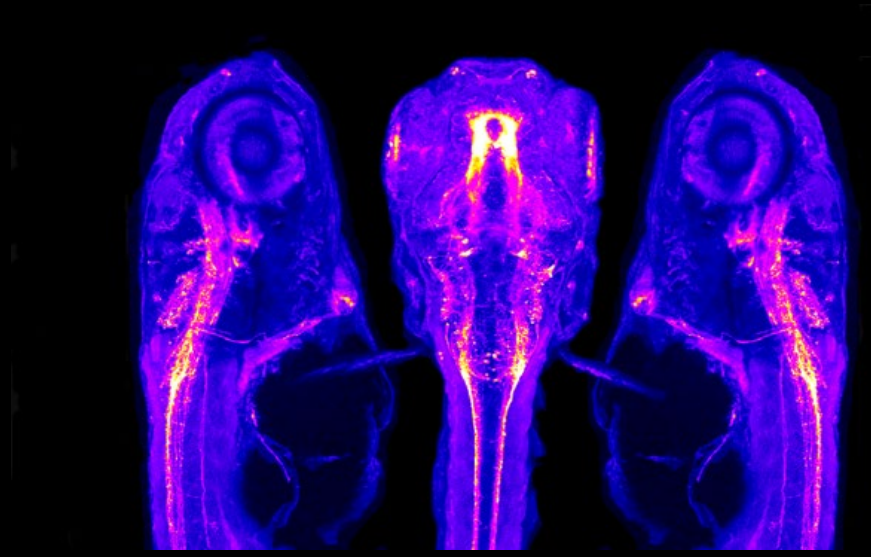


n= 800 000

Levine et al., Google Inc.

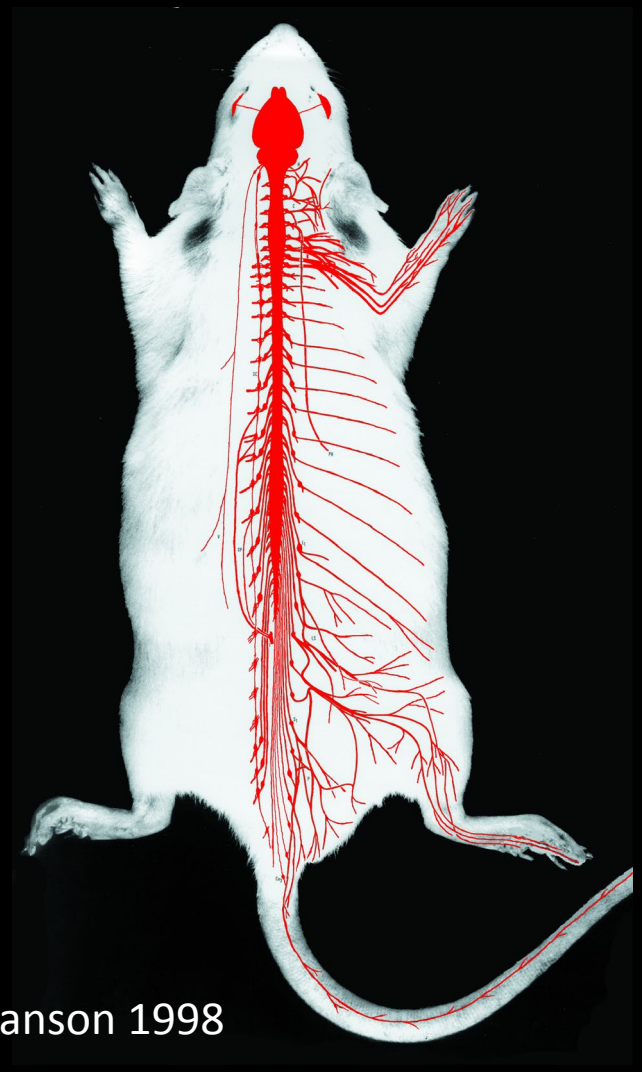
The nervous system guides our actions in a complex world

But first, the nervous system needs to learn about the own body

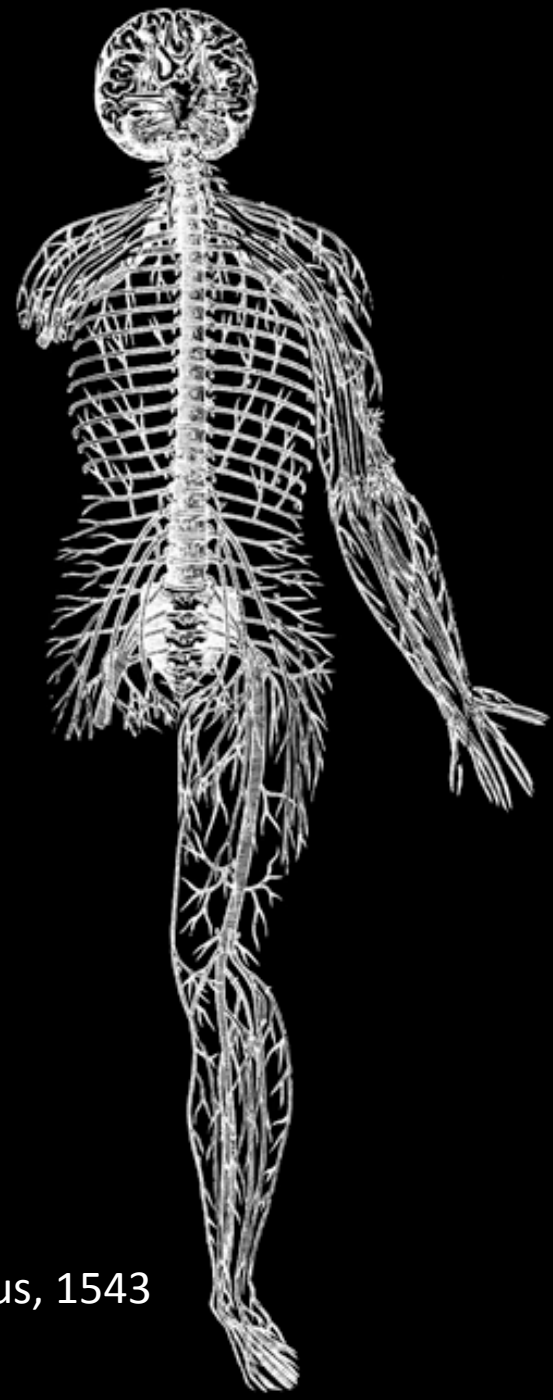


Lambert et. al 2012

-How do different motor commands map onto patterns of sensory feedback?



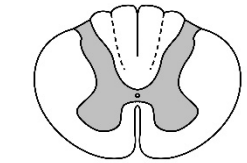
Swanson 1998

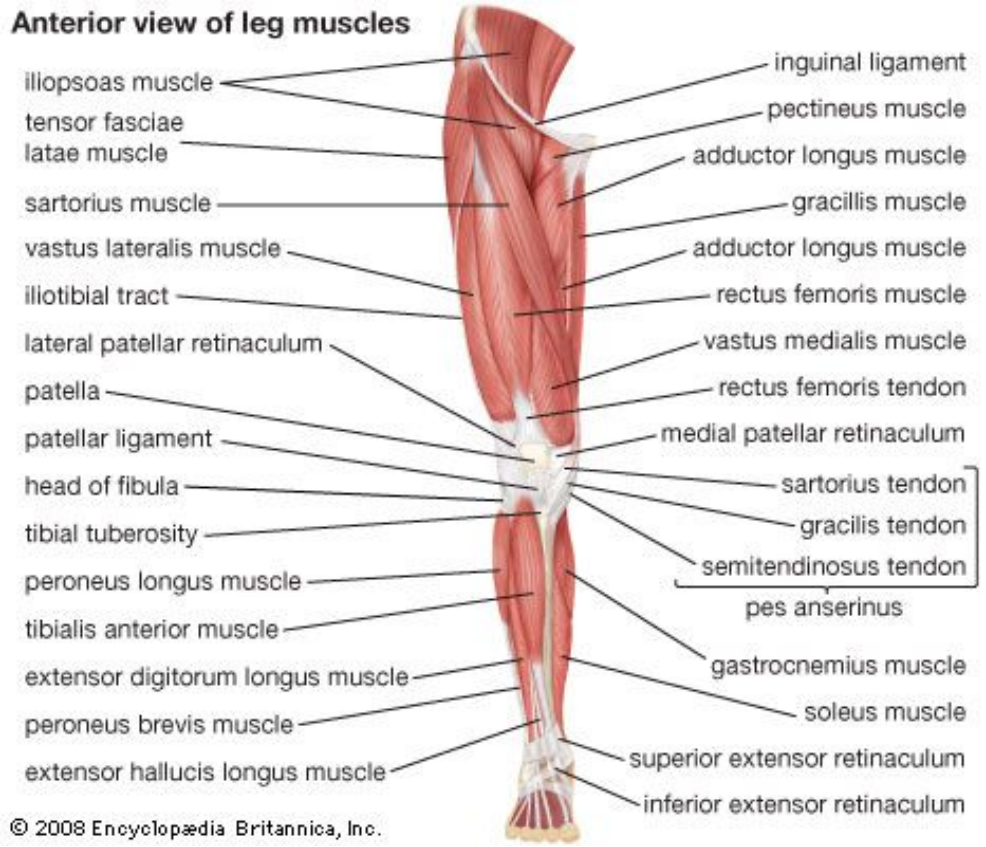


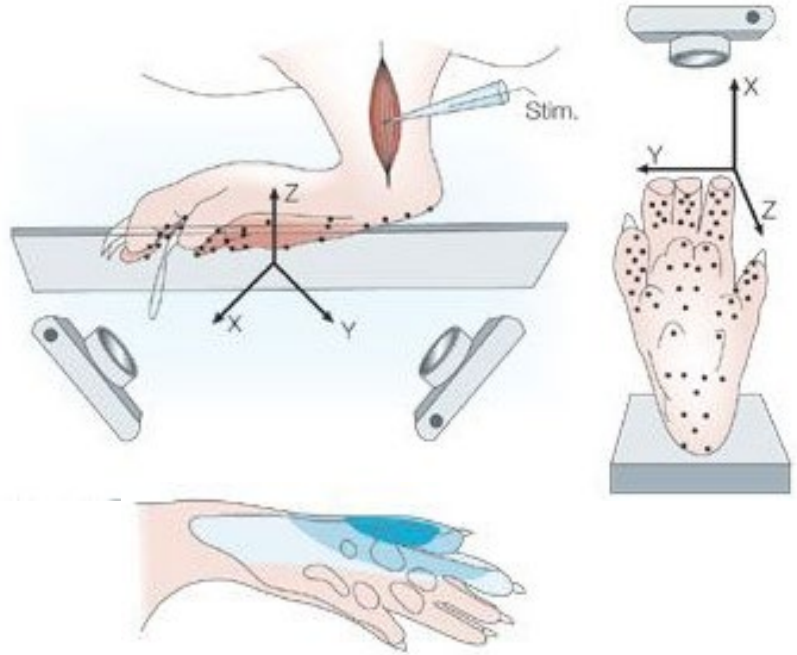
Vesalius, 1543

Spinal reflexes as a model system for the learning of sensorimotor transformations

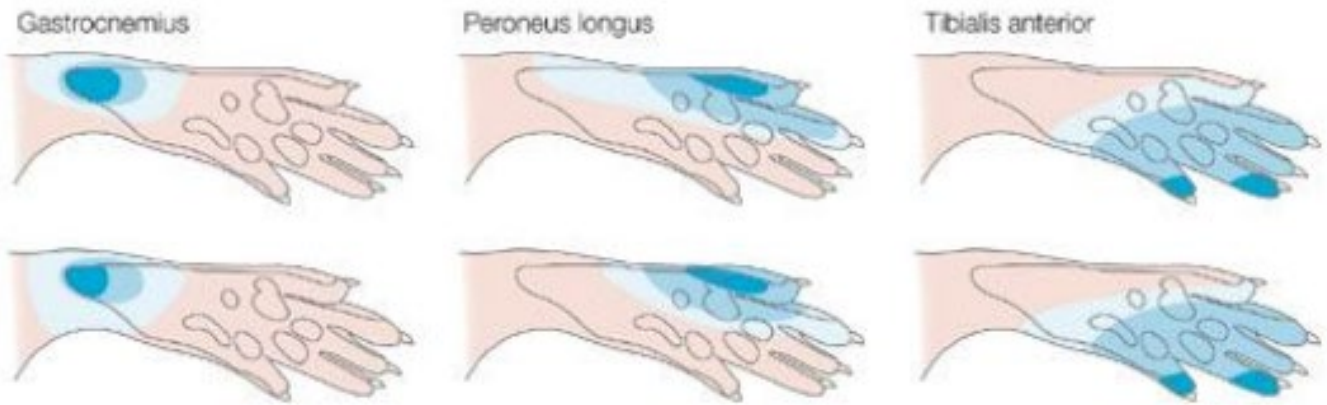
Descartes, 1664





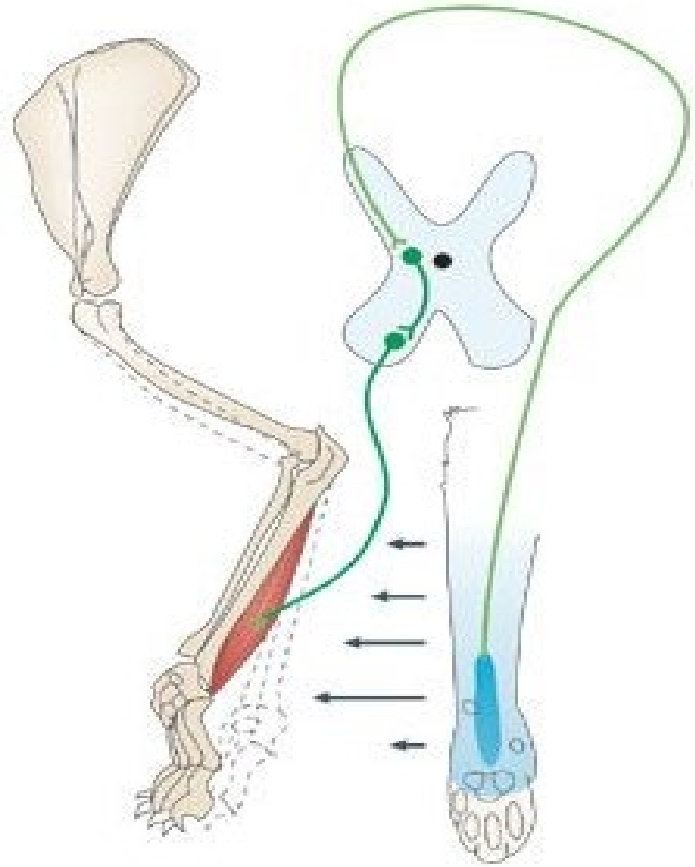


In the 90s, Jens Schouenborg and co-workers demonstrated that withdrawal reflexes have a modular organization – defined by the mechanical action of single muscles

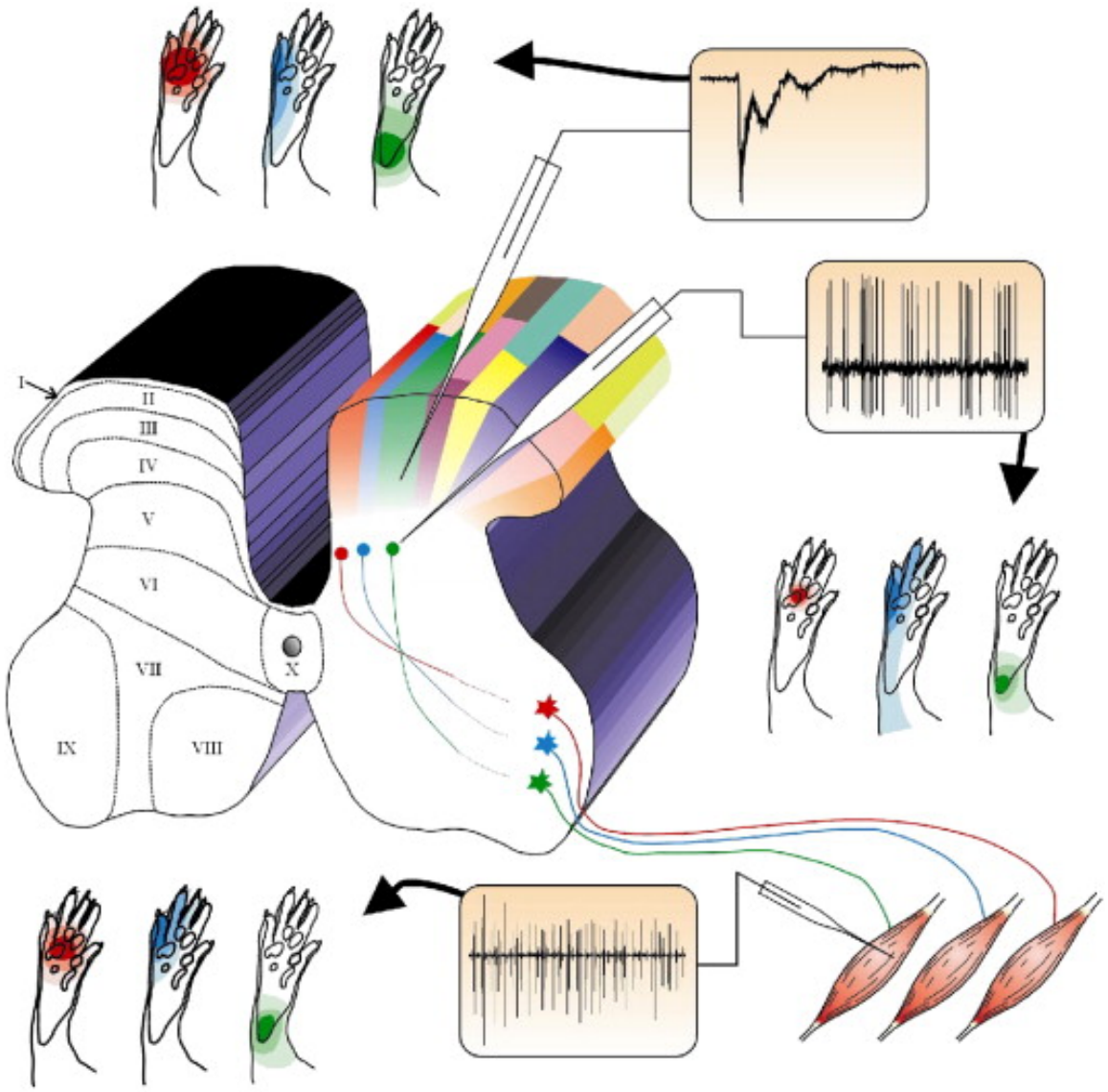


Withdrawal fields

Receptive fields (EMG)



Apps&Garwicz, 2005



Schouenborg 2008

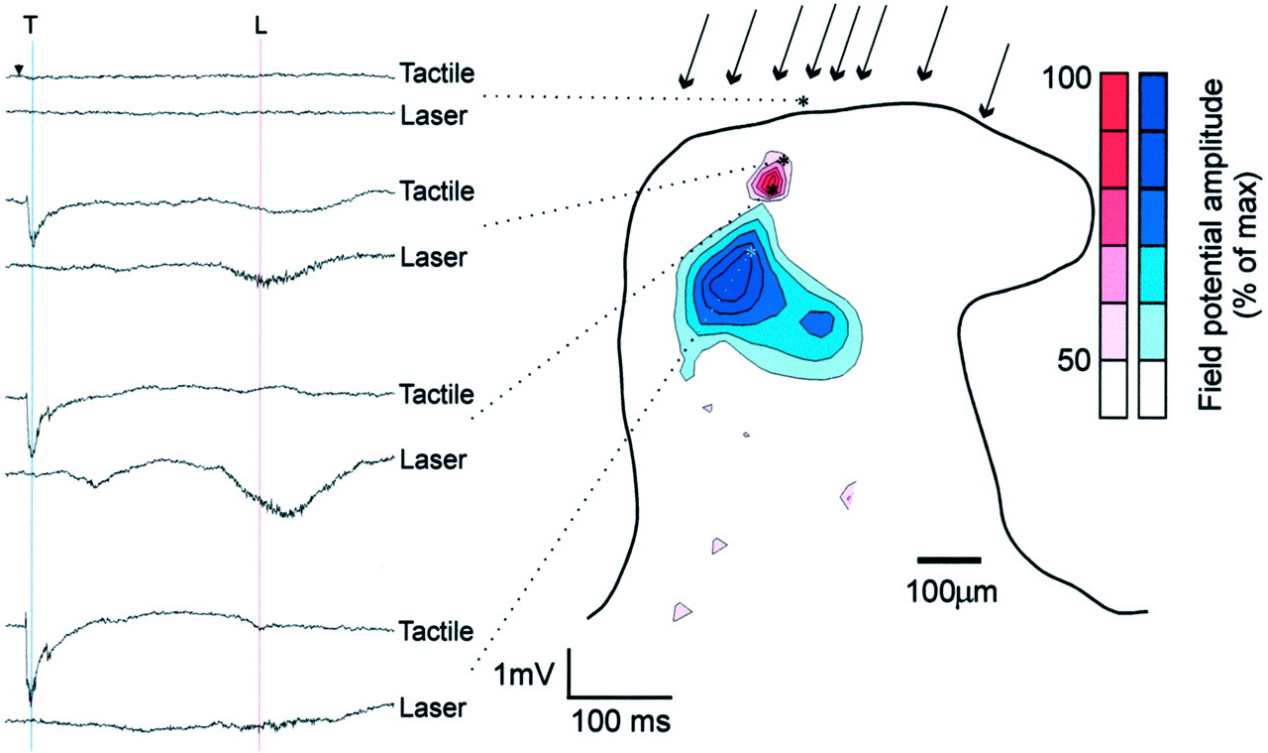
Neurons in the deep dorsal horn of the spinal cord have receptive fields that perfectly match the withdrawal fields/muscle receptive fields

If these neurons are encoding the reflex patterns – how have they learned the very precise input-output relations?

Is experience-dependent learning an efficient strategy for nociceptive processing?

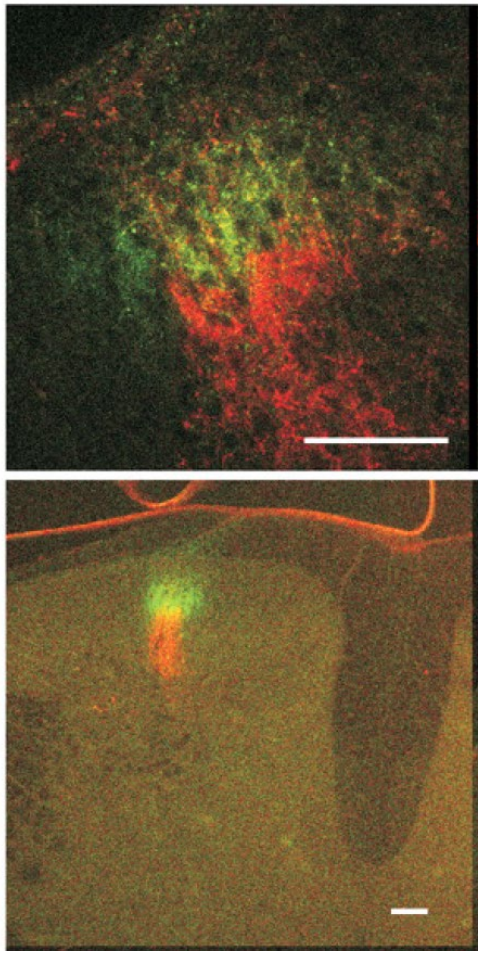
Can tactile input be used –> multimodal integration

Tactile and nociceptive afference is mediated by different nerve fibers – but the input to the dorsal horn is aligned somatotopically



Levinsson et al. 2002

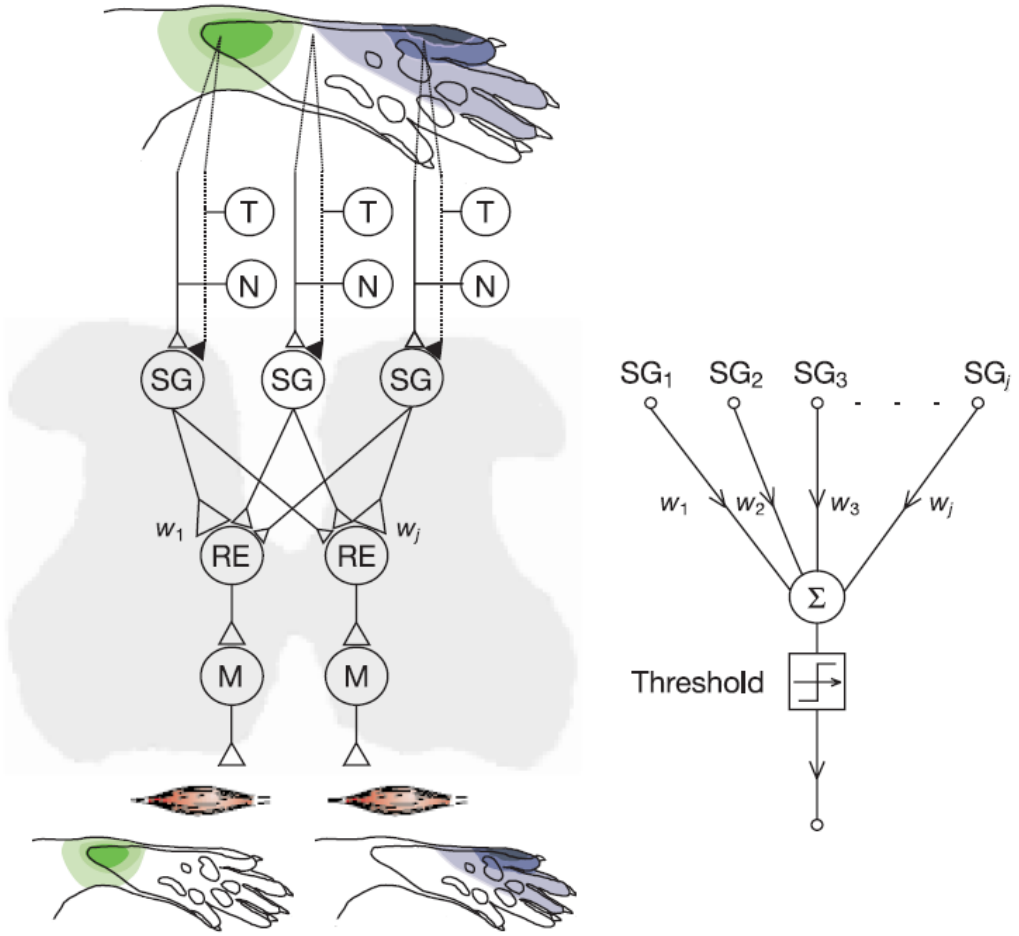
Cells deeper in the dorsal horn may be multi-modal



Granmo et al. 2007

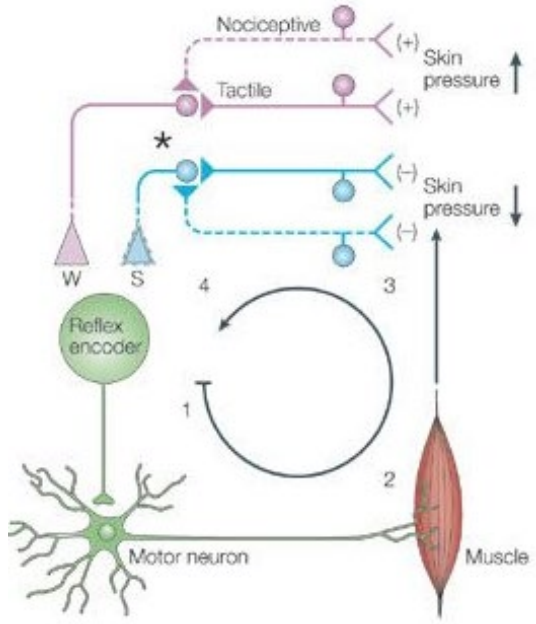
Early in life tactile input appears to reach also superficial laminae

Suggested simple network architecture



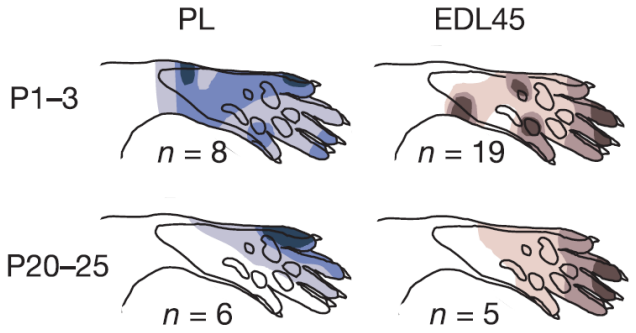
Petersson et al. 2003

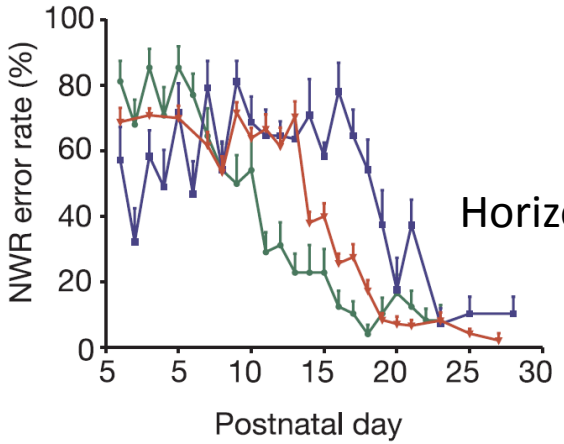
Could self-organize via local Hebbian-like synaptic learning rules



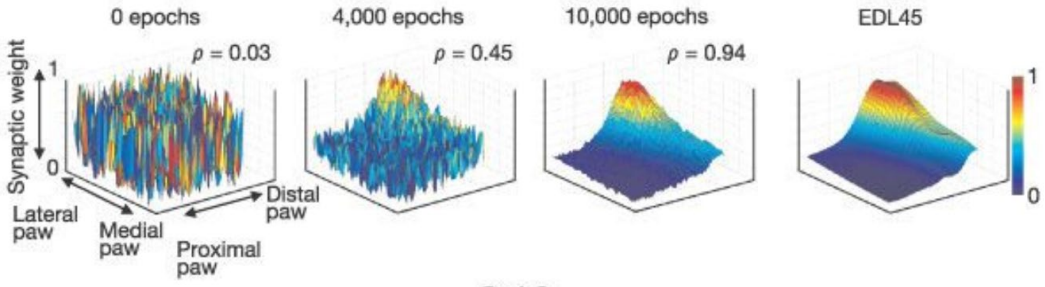
Positive feedback

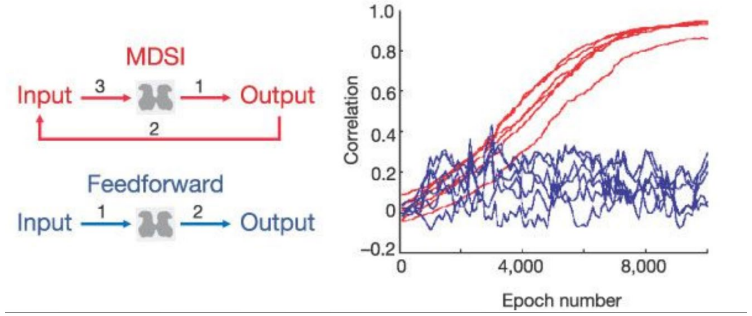
Simulations replicate the gradual functional adaptations that occur during development





Horizontal tail withdrawals





But what kind of spontaneous motor activity is mediating these reflex adaptations?

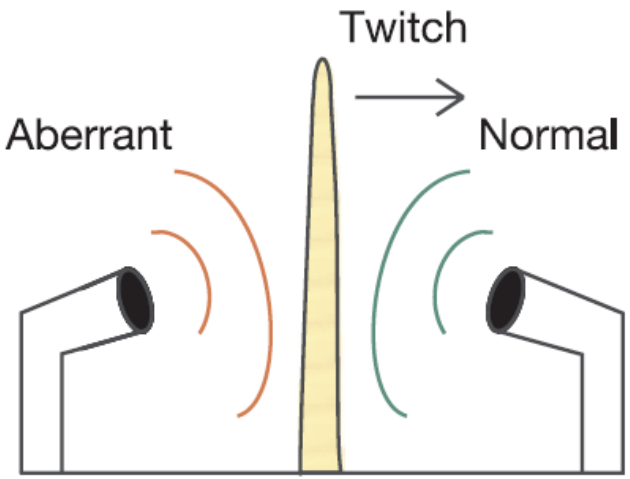
Petersson et al. 2003

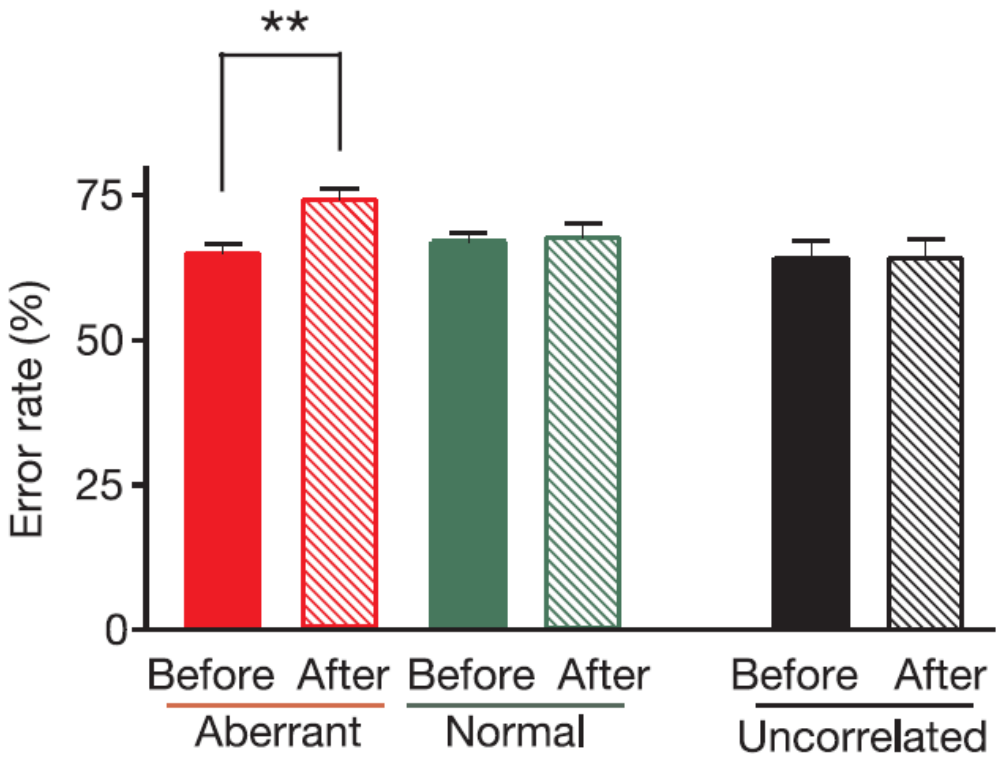
Spontaneous movements during sleep

Blumberg et al

Can the tactile feedback associated with sleep twitches be manipulated?

Withdrawal reflexes tested before and after a few hours of air-puff conditioning

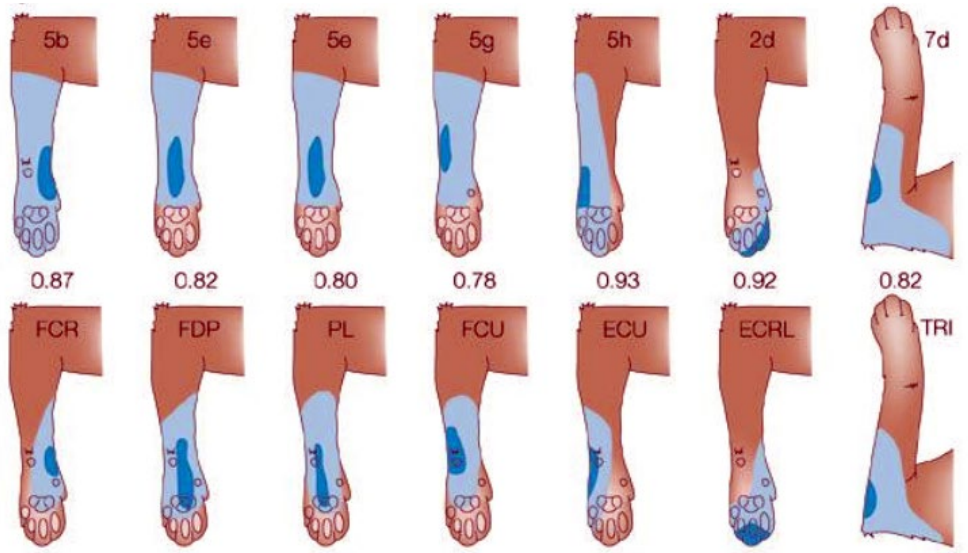




What about supraspinal structures?

Cerebellum

Purkinje cell climbing fiber receptive fields closely match muscle receptive fields

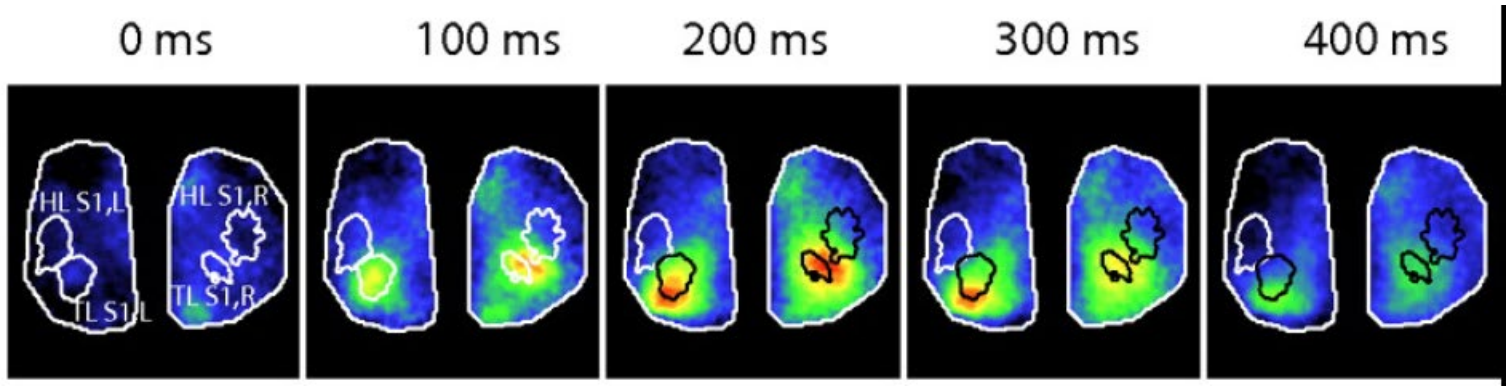


'Cerebellar modular organization'

Apps&Garwicz 2005

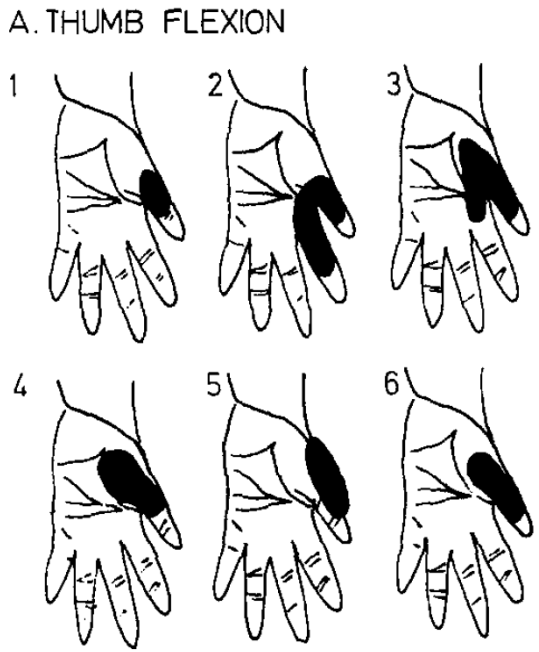
Sensorimotor cortex

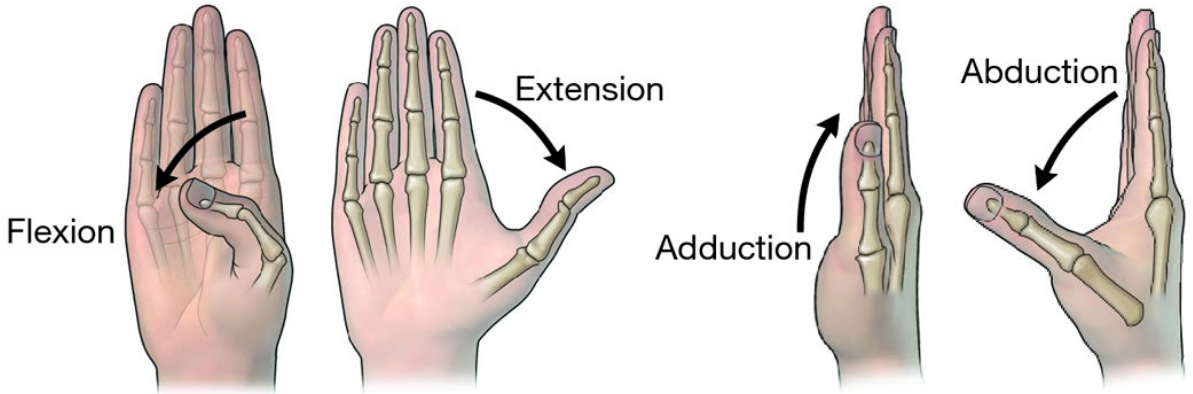
Bursts of cortical activity occur following spontaneous muscle twitches

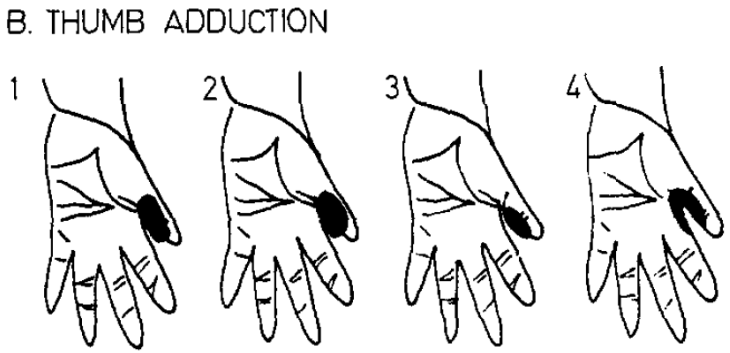


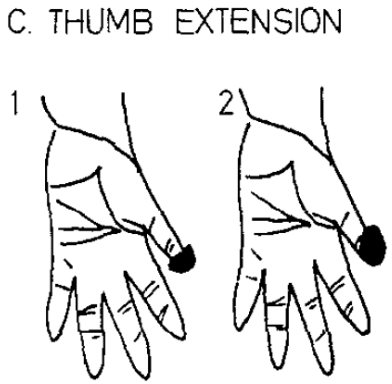
McVea et al. 2012

Receptive fields of cells in monkey motor cortex reflects the biomechanical action of that cell induced by microsimulation

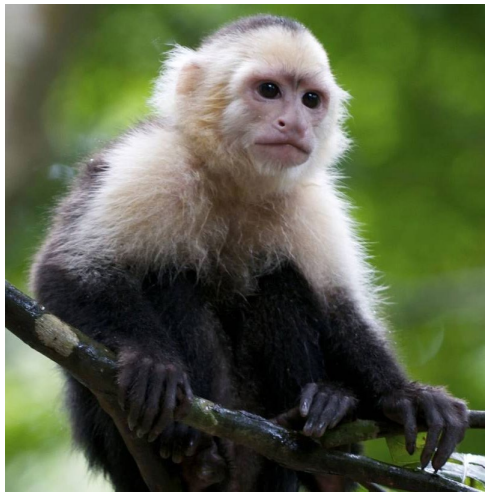








Rosén&Asanuma 1972



Developmental adaptations = learning?

Is it possible to induce similar experience-dependent adaptations in the adult nervous system by excessive training?

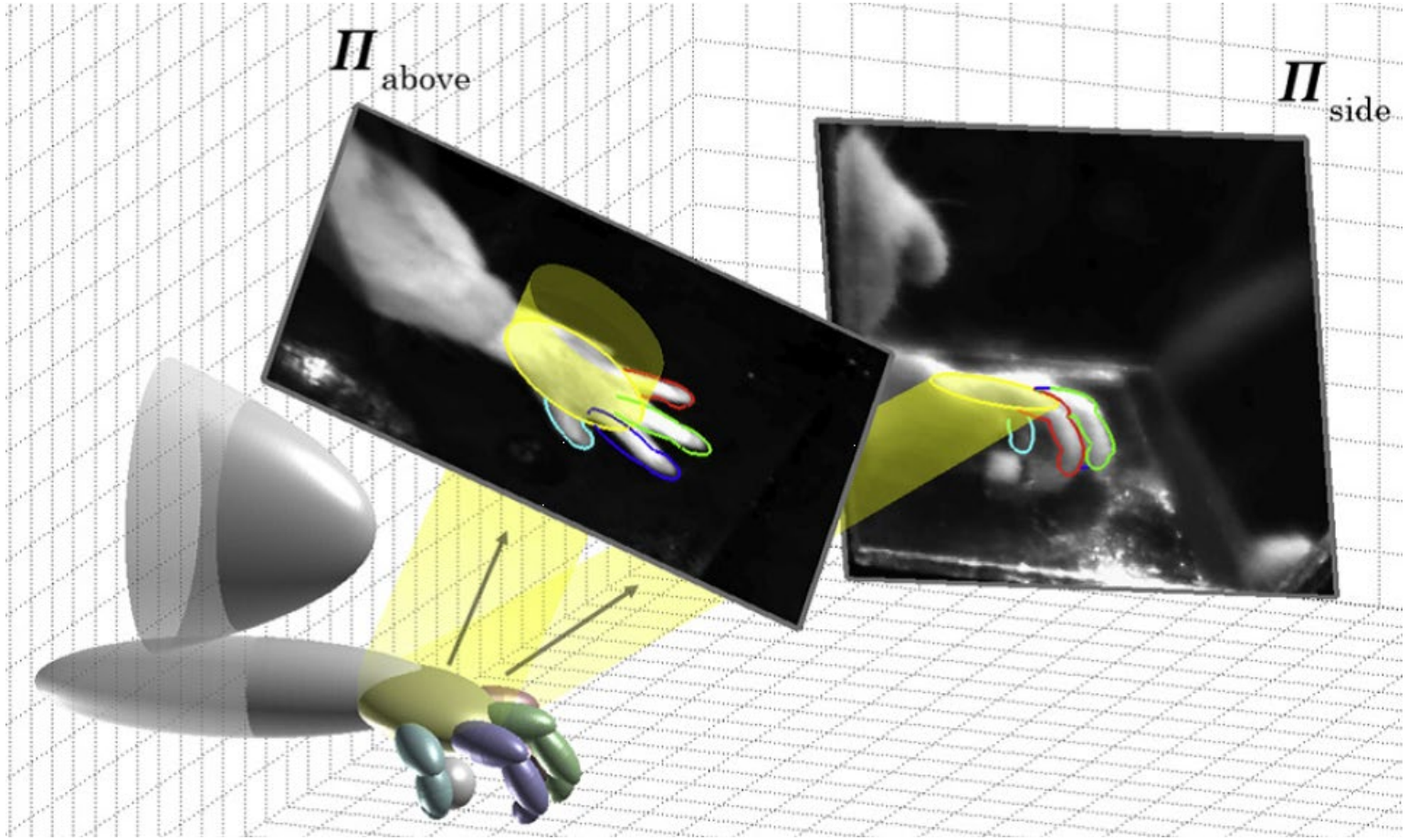
Experimental challenges:

+ Behavioral training – task suitable for a rodent, motivation etc.

+ Detail descriptions of kinematics in freely moving animals

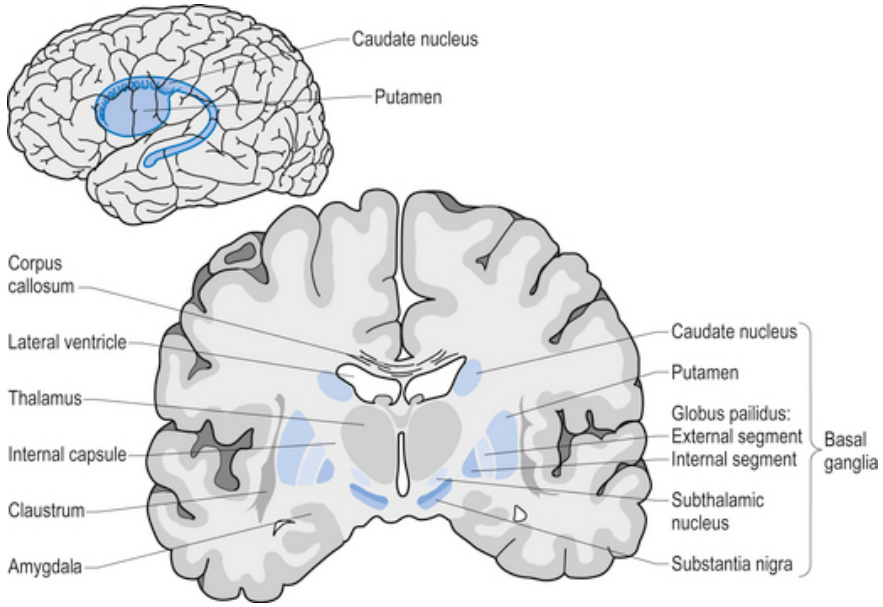
+ Recording of brain activity in distributes brain circuits

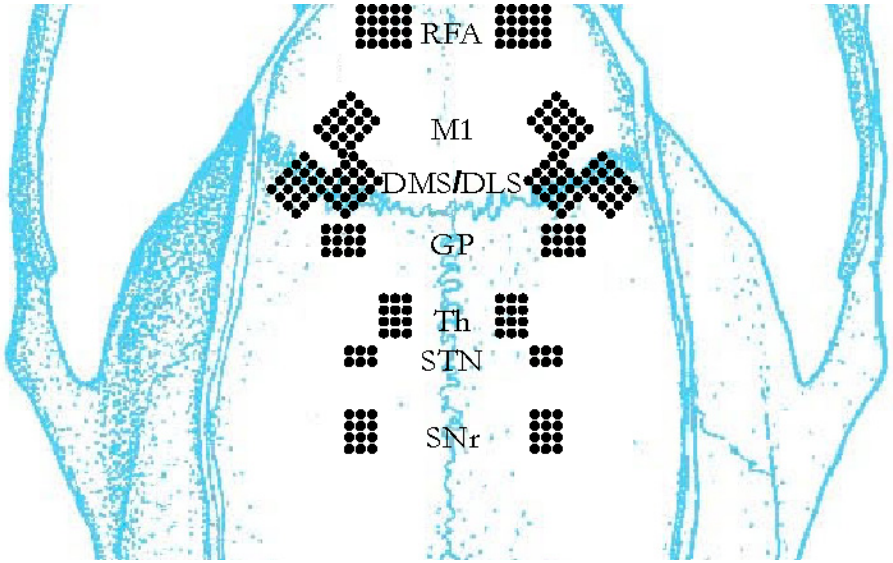
Detailed kinematics from mathematical image analyses

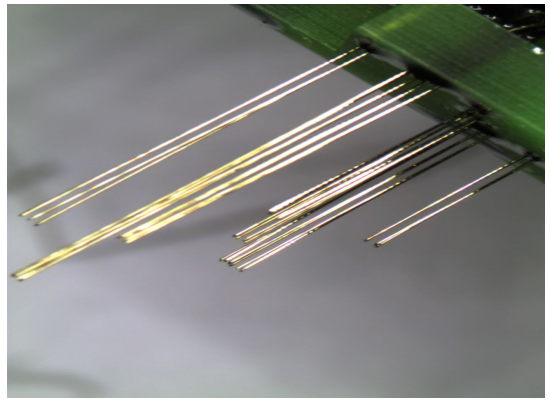


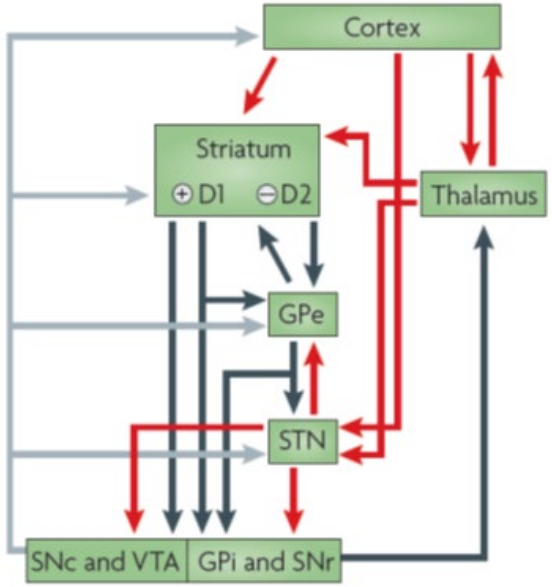
Palmer et al. 2012

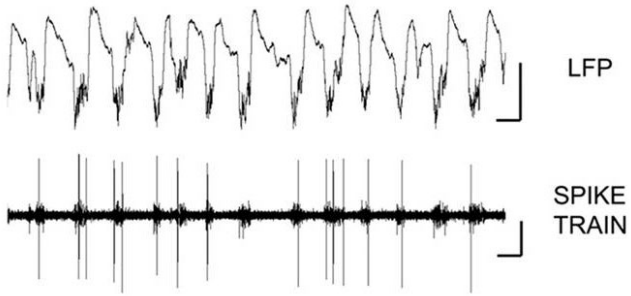
Large-scale parallel neuronal recordings in cortico-basal ganglia circuits

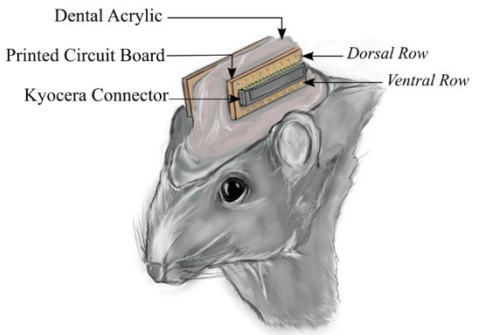












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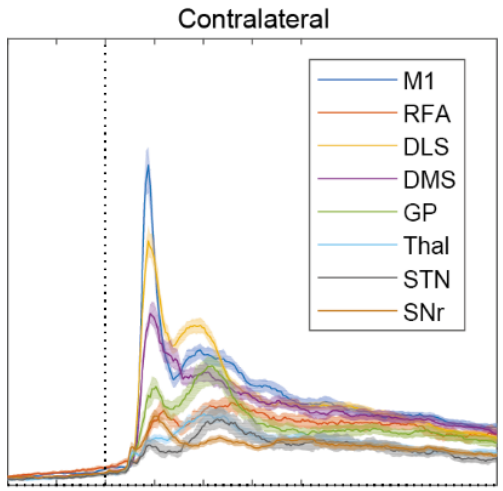
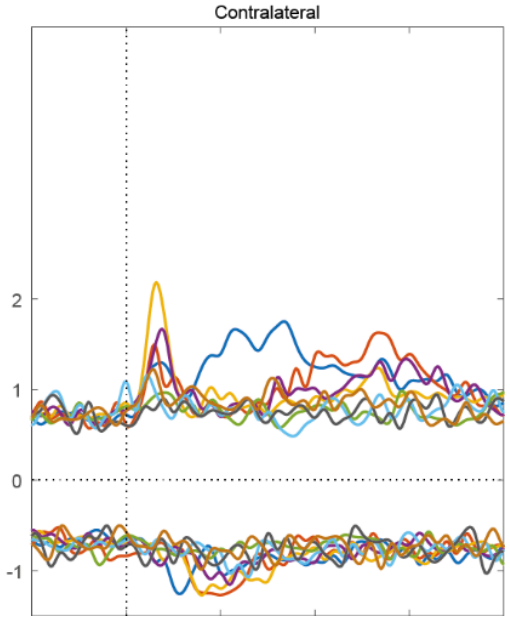
‘Action-selection’
‘Reinforcement learning’
- Encodes both policies and values

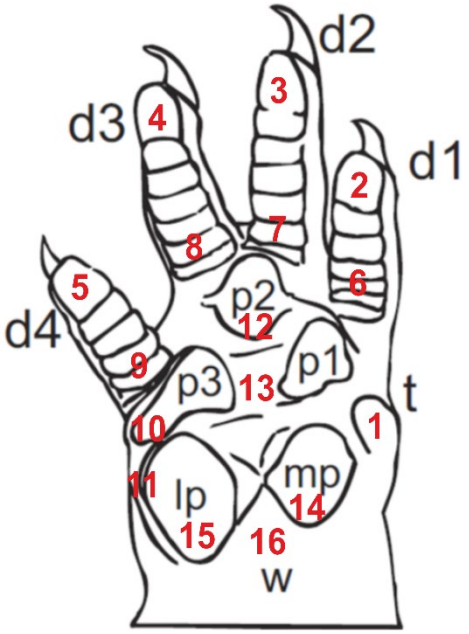
Mapping of tactile receptive fields in different motor structures after excessive training for 3 weeks

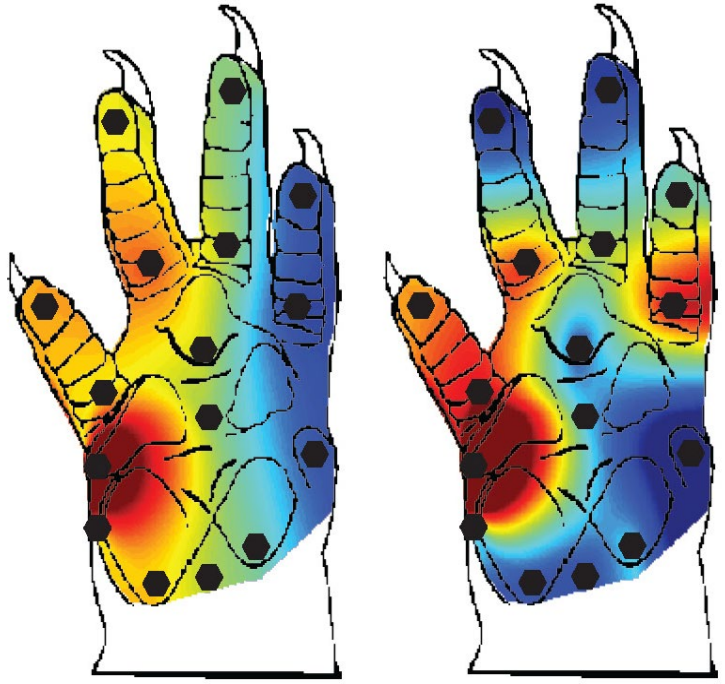
Evoked potentials



Evoked unit activity







Example of RF change resembling Rosén&Asanuma 1972

… work in progress – but so far only MI display clear RF changes

+ This type of sensorimotor adaptations are most useful in systems that allow for single-muscle control

+ May not be so common in higher motor systems
- Perhaps the basal ganglia are not encoding actions at his level

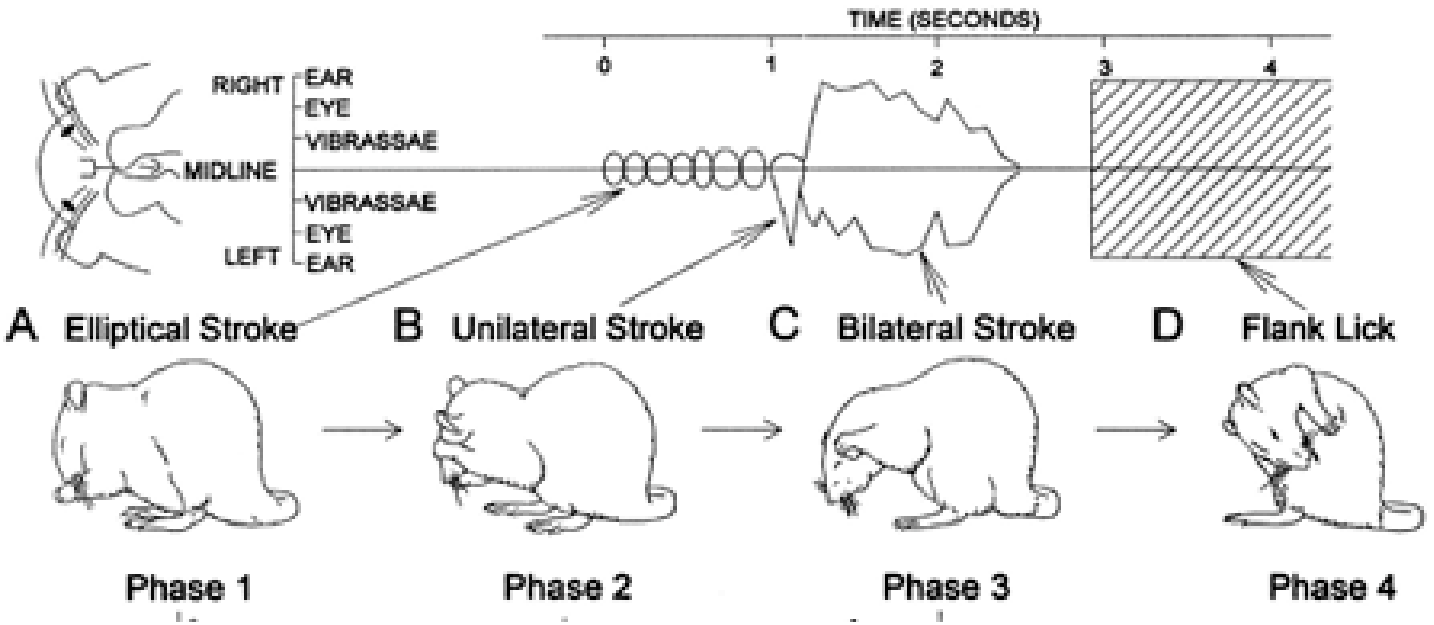
+ In many situations detailed somatosensory feedback is less important since we can rely on learned actions/habits

-Sufficient to get information about the current motor state

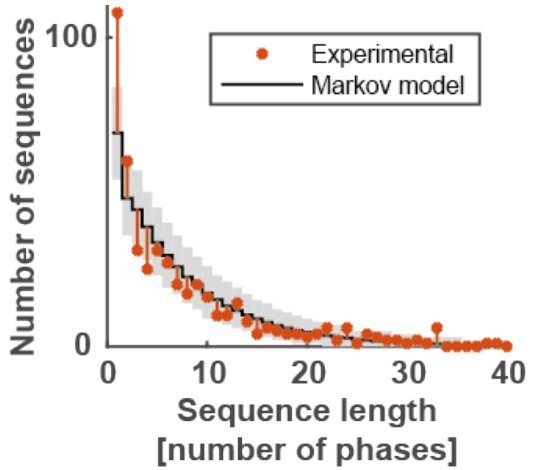
‘Open- or closed-loop’ motor control

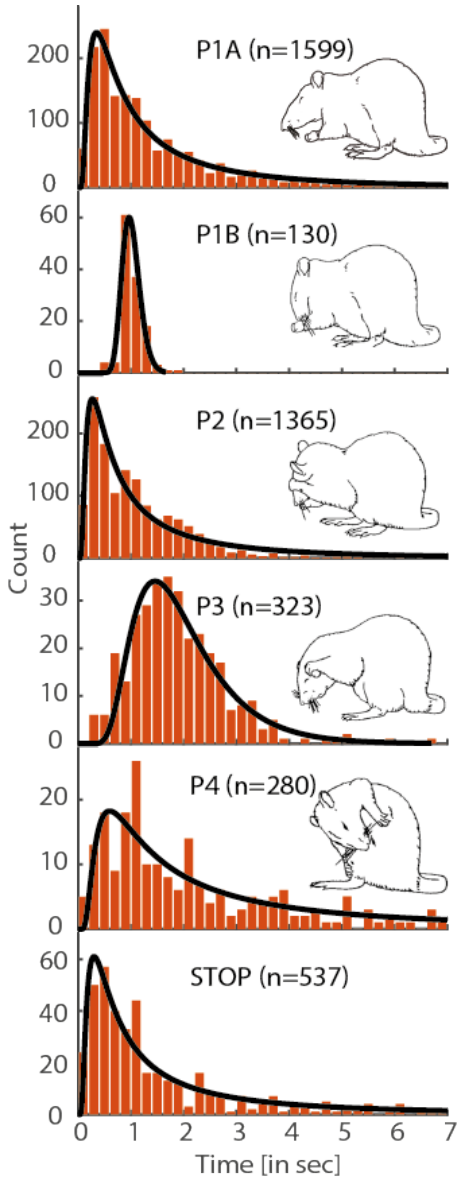
Let’s study a natural rodent behavior that appears to be more habitual and ‘open-loop’

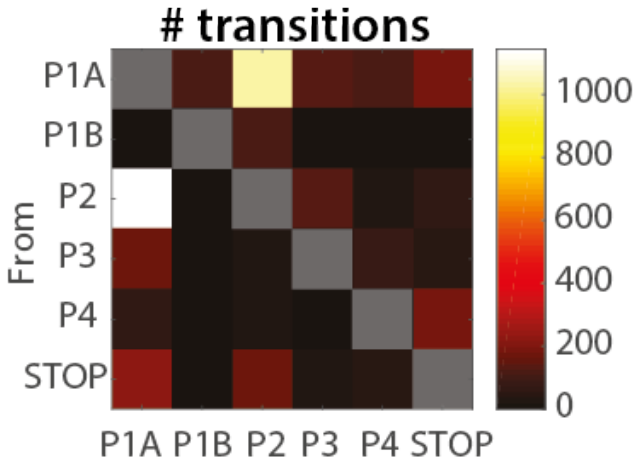
How do we build actions sequences consisting of several discrete motor programs?

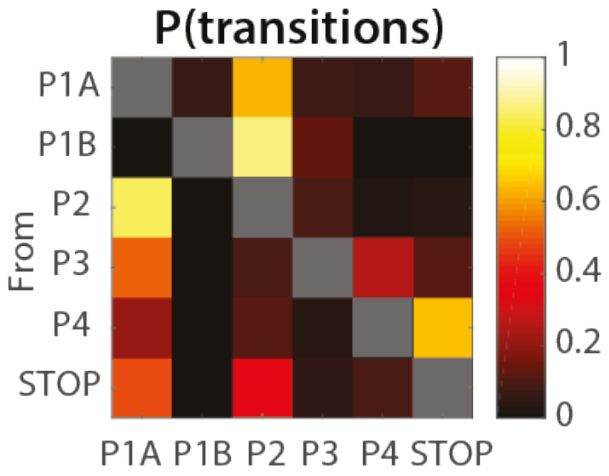


Action sequences are in fact quite variable



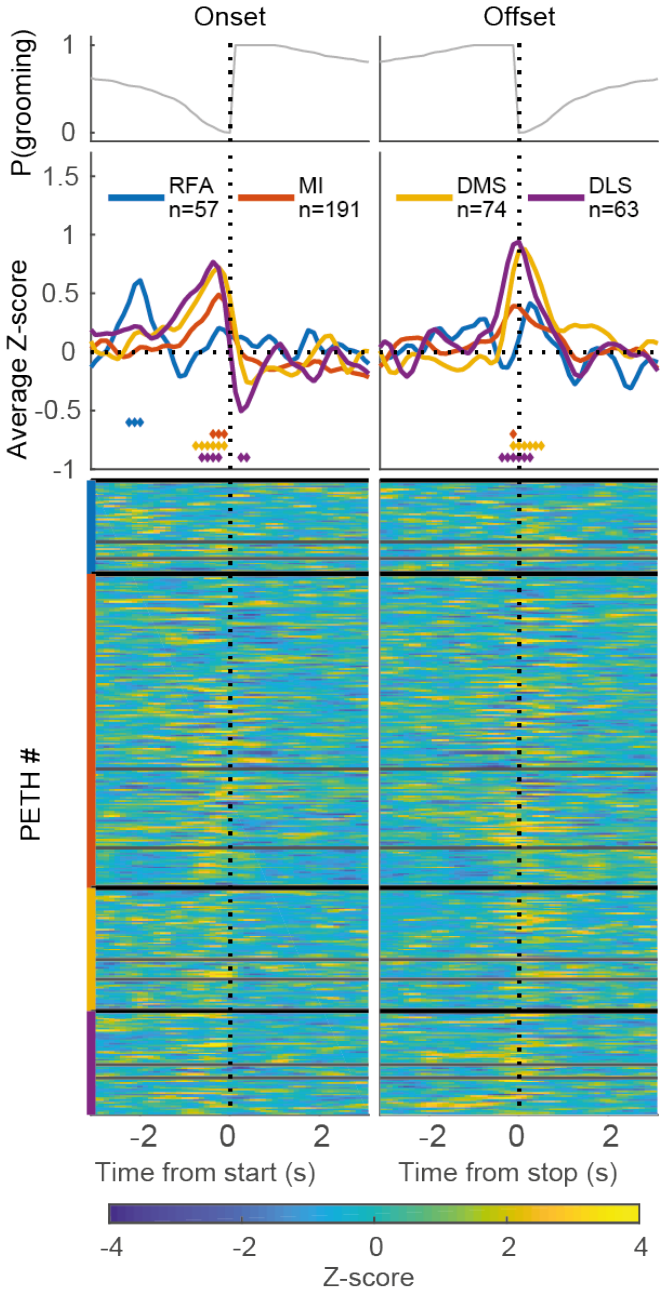


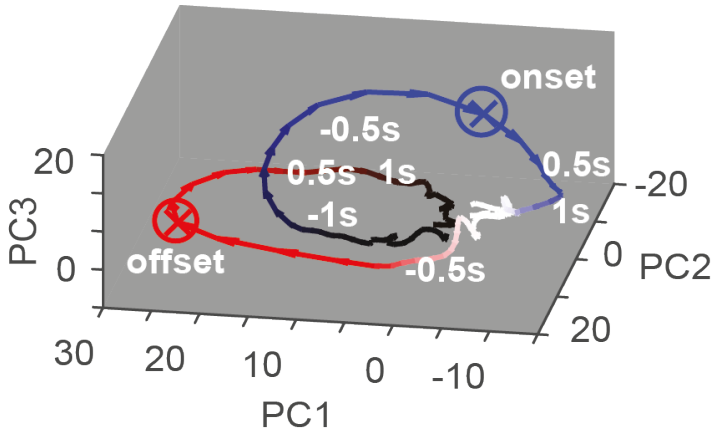




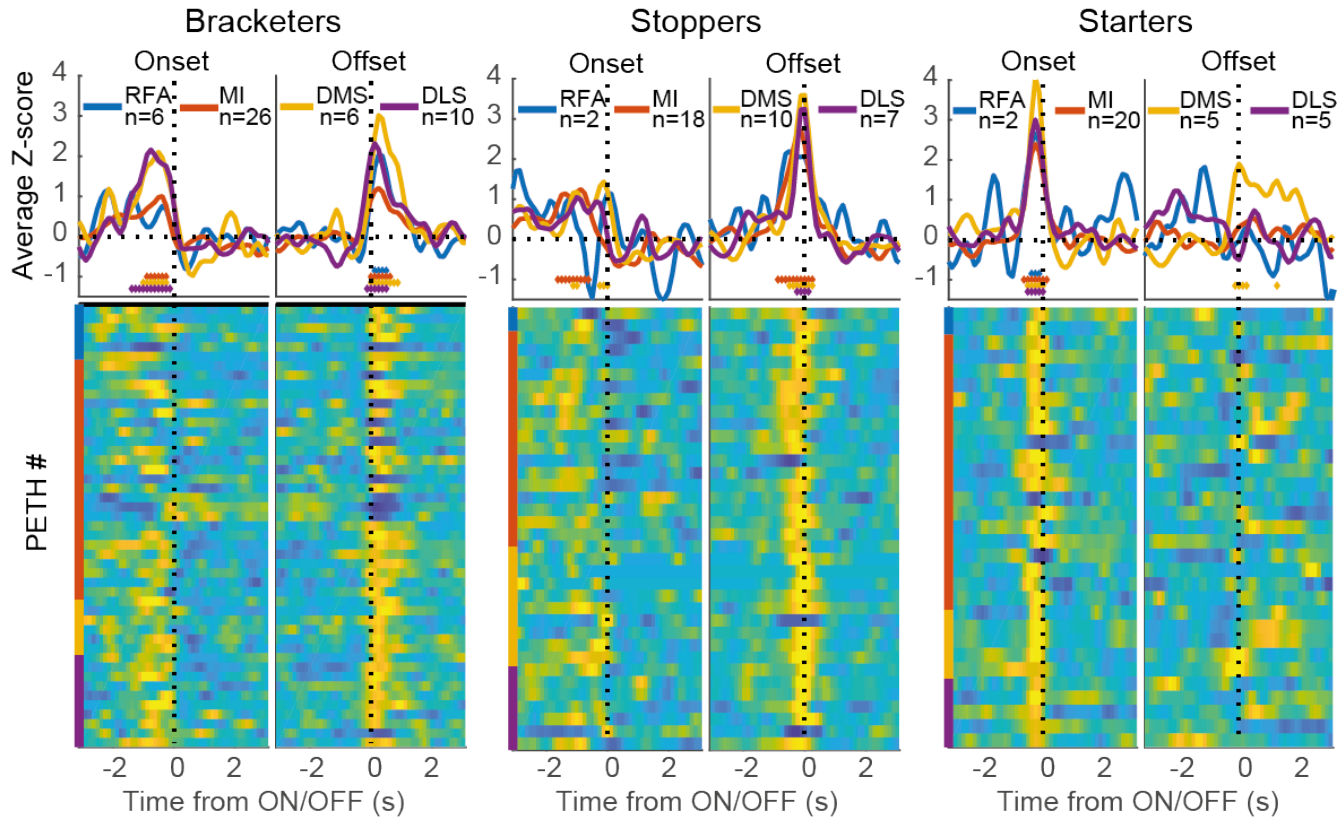
Are cortico-basal ganglia circuits controlling actions sequencing in this spontaneous behavior?

Action selection filter…

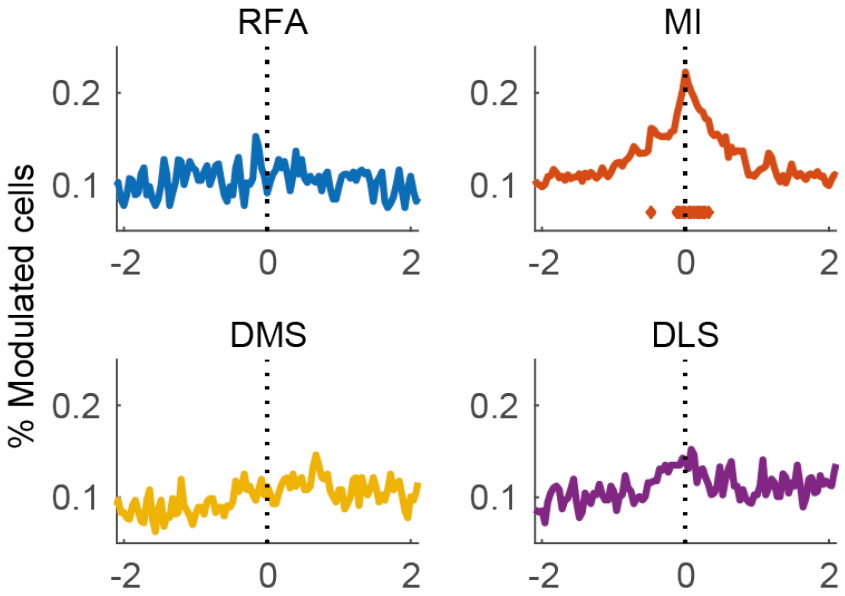




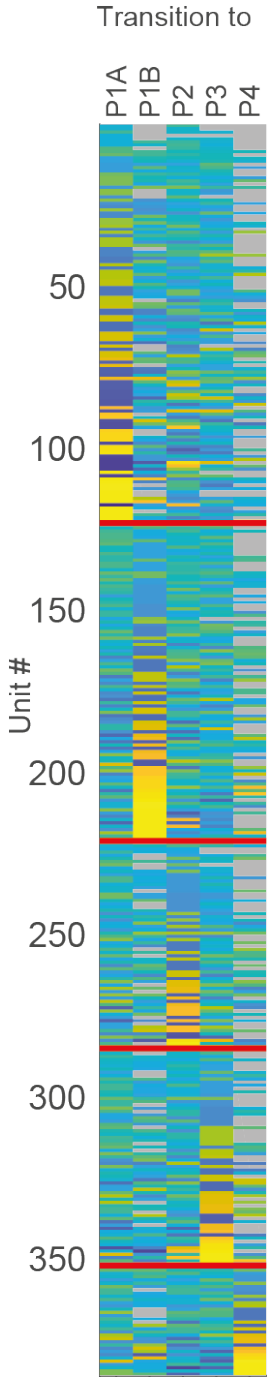
Strong encoding of start and end of a full sequence

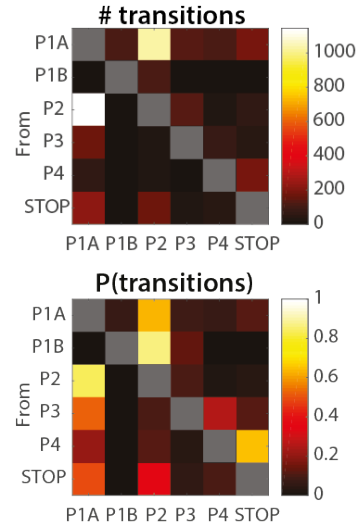


Phase transitions within a sequence

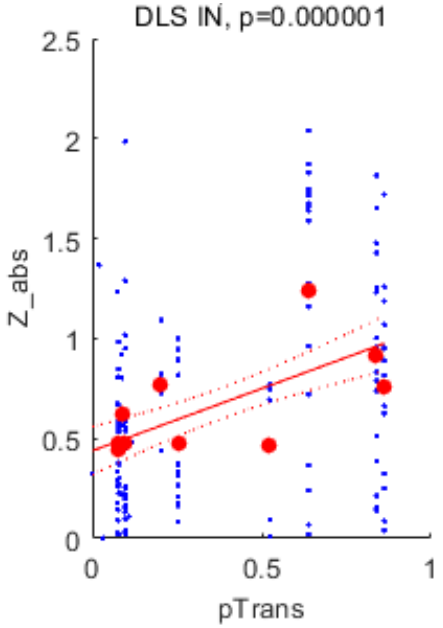


Phase transition events are primarily encoded in MI





DLS dynamics scales with P(transition)



Different systems ('levels') for sensorimotor integration and action selection

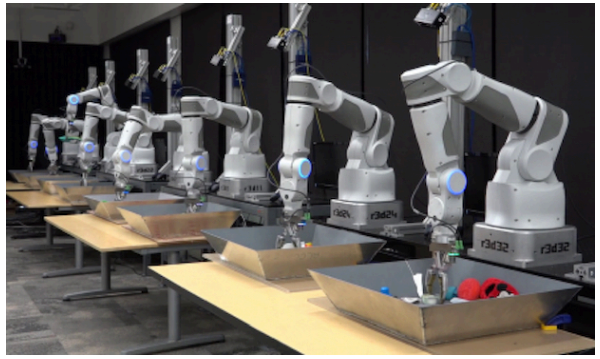
+ Spinal cord - reflex modules - functionally adapted by experience

+ Cerebral cortex - grasping modules - functionally adapted by experience*

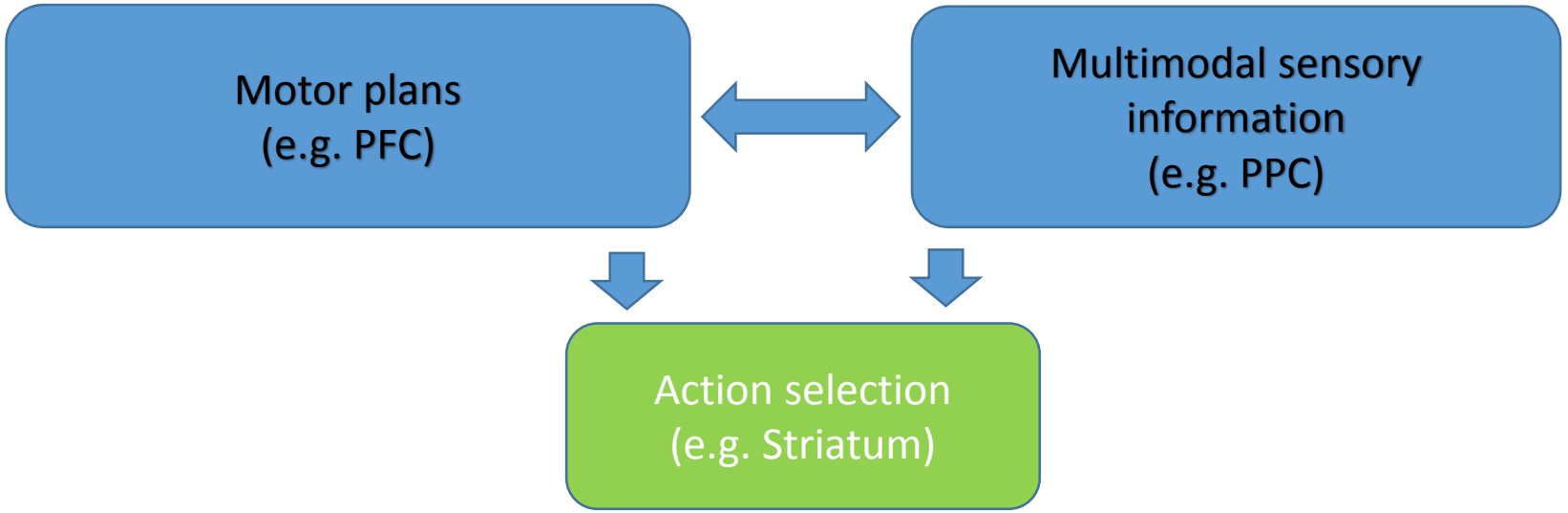
*) preliminary data

+ Basal ganglia (dorsolateral striatum) – state-dependent motor commands in actions sequences - building-blocks of habits

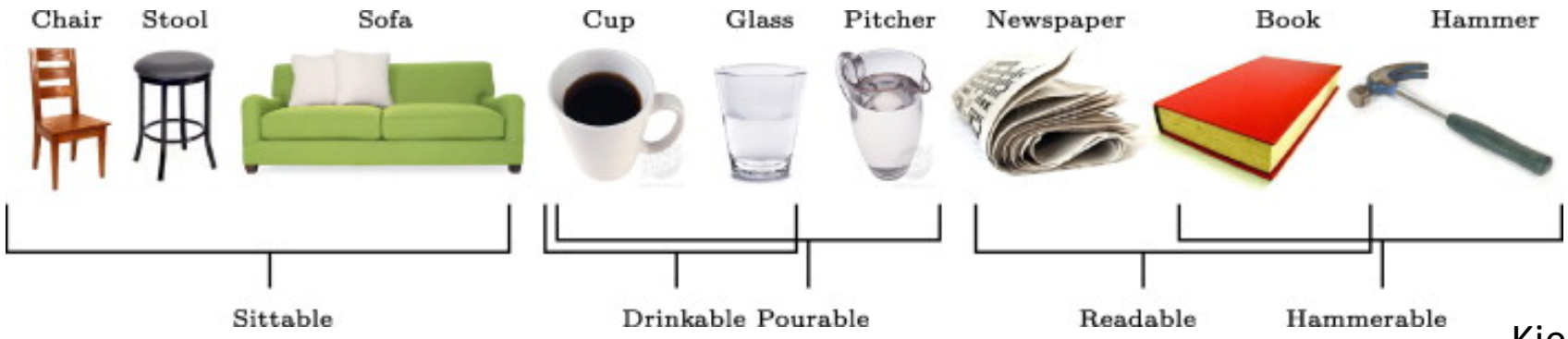
- What about the more general case? Interaction with novel/familiar objects in the external world



Action-selection based on on-line sensory cues



<u>Prediction</u>: In an action-based frame-work the sensory representation of objects in the external world should be heavily influenced by our prior knowledge of how to interact with them



affordances

Kjellström et al 2011


Pär Halje
Ulrike Richter
Ivani Brys
Martin Tamtè
Nela Ivica
Joel Sjöbom
Tobias Palmér
Jens Schouenborg
Marcus Granmo
Alexandra Waldenström
Christer Fåhraeus