Applying a biological model of the vestibulo-ocular reflex to control gaze stabilitzation in a humanoid robot

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Motor learning

Vestibulo-ocular reflex (VOR) adaptation is one of the most studied cerebellar dependent motor learning tasks. It is used to provide insight about the connections and the coding of the circuitry of the cerebellum.

Vestibulo-ocular reflex (VOR)

This reflex functions to **stabilize images** on the retinas during **head movement** by producing **eye movements** in the direction opposite to head movement, thus preserving the image on the center of the visual field.

Cerebellar cortex

- Uniform structure throughout the cerebellum
- Composed of repeated modules or microzones
- Same cell types and connectivity
- Functional units
- Different inputs, different targets
- Cerebellar algorithm

# Flocculus

- Main cerebellar region that is responsible of the control of eye movements
- Small lobe situated on the vestibulocerebellum
- Optimize ocular motor performance
- Image still enough on the fovea to interpret the scene in real time

Problem statement

Computational models of the vestibulo-ocular reflex don't take into account the role of the nucleo-olivar inhibition

Cerebellar microcircuit

Nature Reviews | Neuroscience [2]
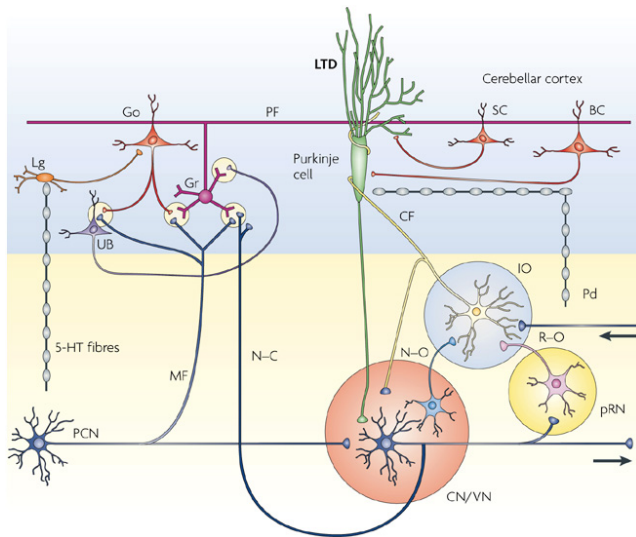
Nucleo-olivary inhibition (NOI)

On the neuroanatomical circuitries and sites of cellular plasticity underlying adaptation of the vestibulo-ocular reflex there's a pathway that provides feedback for adjustment of the learning instruction.

It is formed by GABAergic neurons that innervate the neurons in the inferior olive from which the climbing fibres originate (De Zeeuw and Yeo 2005)

- ▶ NOI **is not** present on computational models of the VOR
- ▶ NOI **is** present on **eye-blink** reflex computational models

Trade-offs in avoidance actions
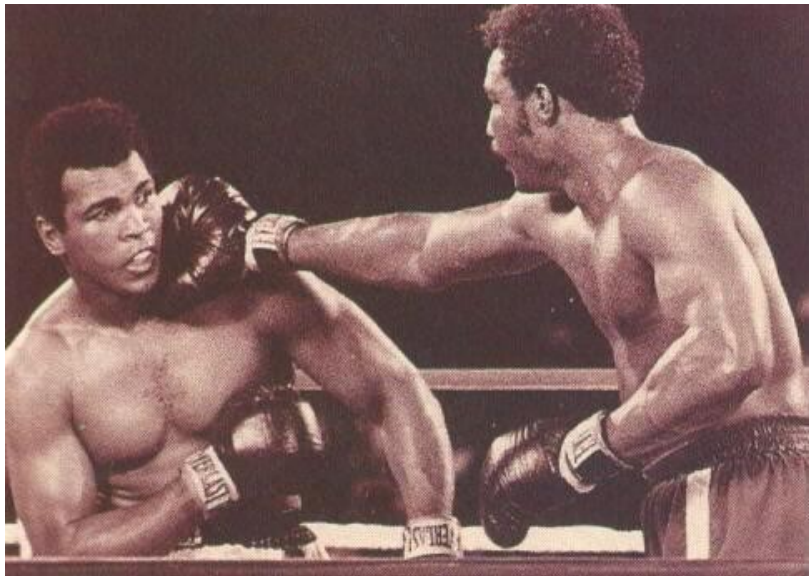
Extinction and NOI

- Cost-optimization
- Error-based learning
- Control the gain of the cerebellar output
- Acquired conditioned responses are extinguished once they become no longer necessary

(Herreros and Verschure 2013)

Research question

What's the role of the nucleo-olivary inhibition in the vestibulo-ocular reflex?

Fingerprints

- NOI has a role in the eye-blink reflex
- There is extinction of the adaptive response in the absence of peripheral error
- VOR has a non-perfect performance, with a residual error proportional to the amount of cerebellar action required

(Herreros and Verschure 2013)

Hypothesis

Adding nucleo-olivary inhibition in the vestibulo-cerebellum explains extinction in the state of the art vestibulo-ocular reflex computational models.

Computational models of the VOR

Marr-Albus classical models

Computational models of the VOR

The cerebellum as an adaptive filter

Computational models of the VOR

Plasticity in the brainstem

Computational models of the VOR

A detailed model

Methods

- Implementation of the detailed model (Clopath et al. 2014) of the VOR
- Reproduction of the results of the paper
- Add the NOI to the detailed model
- Simulation of adaptation, extinction and readaptation of the VOR

Implementation of the detailed model

- Simple model without delay
- Simple model with delay
- Detailed model

Experimental setup
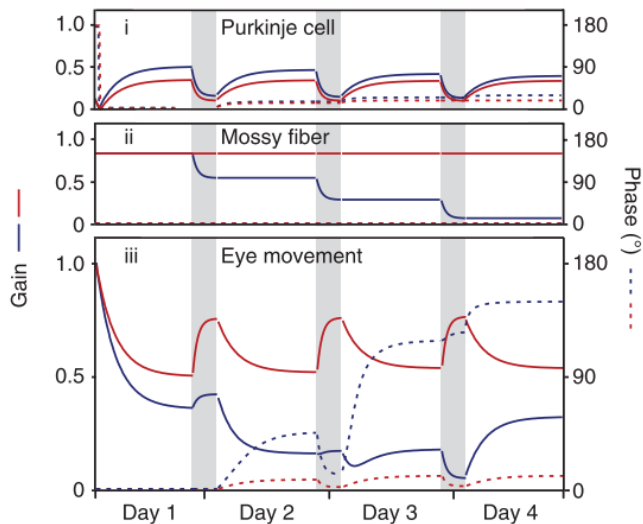

Day 1
Table 5°, drum 5°

Day 2
Table 5°, drum 7.5°

Day 3
Table 5°, drum 10°

Day 4
Table 5°, drum 10°

(Wulff et al. 2009)

- ▶ Day 0: Normal VOR
- ▶ Day 1: VOR cancelation (gain decrease)
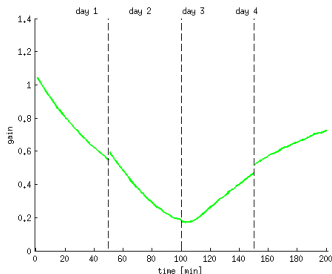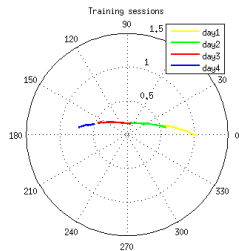- ▶ Day 2 to 4: Phase-reversal learning

Reproduction of the results

(Wulff et al. 2009)

Reproduction of the results

Evolution of the gain of the VOR on the different training sessions

Adding the NOI to the detailed mode

Modulation in the dark of the teaching signal
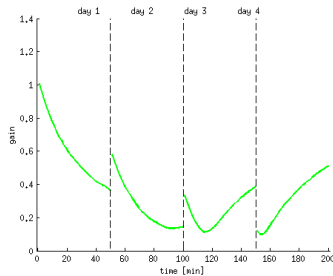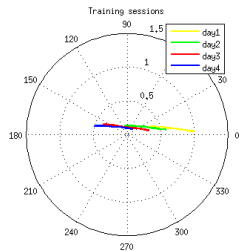
- Modulated by vestibular information

$$C(t) = \nu_{CF} - L(V(t - \delta) - V_t(t - \delta)) - H(M(t) - M_0)$$

- Modulated by cortical information

$$C(t) = \nu_{CF} - L(V(t - \delta) - V_t(t - \delta)) - H(kP(t))$$

Preliminary results

Evolution of the gain of the VOR on the different training sessions (arbitrary k)

Project planning

Where we are now

- ▶ Detailed model (Clopath et al. 2014) implemented in Matlab
- ▶ Results reproduced as on the article
- ▶ NOI added to the model

Future work

- Analyze detailed model assumptions
  - What are the effects of clipping weights on the PF-PC synapses?
  - Identify other assumptions of the detailed model
- Comparing detailed and NOI models
  - Do they show linear or exponential decay after one week light deprivation?
  - What does maintaining the training to the cortex-nuclei memory balance?

References

Clopath, Claudia, Aleksandra Badura, Chris I De Zeeuw, and Nicolas Brunel. 2014. "A Cerebellar Learning Model of Vestibulo-Ocular Reflex Adaptation in Wild-Type and Mutant Mice." *J. Neurosci.* 34 (21): 7203–15. doi:10.1523/JNEUROSCI.2791-13.2014. http://www.ncbi.nlm.nih.gov/pubmed/24849355.

De Zeeuw, Chris I, and Christopher H Yeo. 2005. "Time and Tide in Cerebellar Memory Formation." *Curr. Opin. Neurobiol.* 15 (6): 667–74. doi:10.1016/j.conb.2005.10.008. http://www.ncbi.nlm.nih.gov/pubmed/16271462.

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