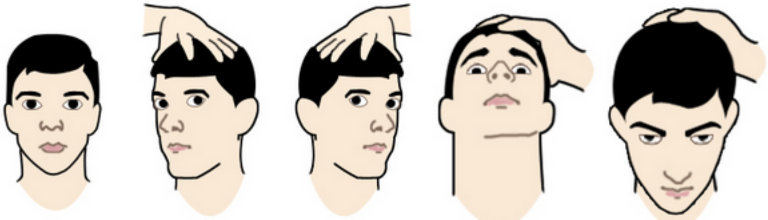
ADDING NUCLEO-OLIVARY INHIBITION TO A BOTTOM-UP COMPUTATIONAL MODEL OF THE VESTIBULO-OCULAR REFLEX TO CONTROL GAZE STABILIZATION

Xavier Duran, supervised by Ivan Herreros and Paul Verschure

July 6, 2015

Master in Cognitive Systems and Interactive Media



[1]

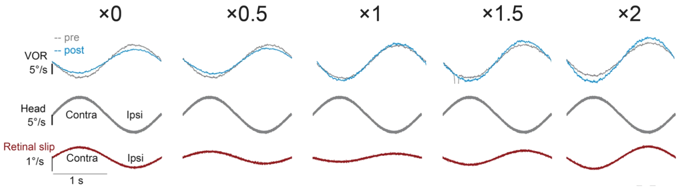
This reflex functions to **stabilize images** on the retinas during **head movement** by producing **eye movements** in the direction opposite to head movement, thus preserving the image on the center of the visual field.

[1] http://bit.ly/1Ox3Qd6

VOR adaptation is controlled by the cerebellum

- CS: head movement
- US: retinal slip (error or teaching signal)
- CR: corrective eye movements

[Cohen et al., 2004]



[Guo et al., 2014]

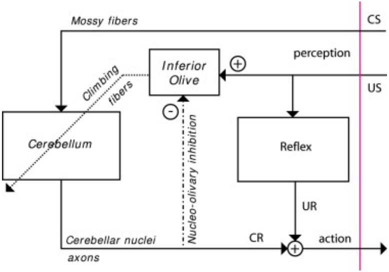
EXTINCTION OF THE LEARNED ADAPTATION

- old memories may no longer be useful, and in some cases may be maladaptive
- learned adaptation is extinguished when no longer necessary
- head movements (US) in the absence of visual stimulation (CS) cause a loss of the learned eye movement response (CR)
- changes in the amplitude, or gain of the VOR
- is mediated by an active, extinction-like process (not by passive forgetting)

[Cohen et al., 2004]

- Climbing fibers bring the CS (retinal slip)
- Inhibition of climbing fibres serves as a teaching signal for extinction

[Medina et al., 2002]



- Cost-optimization
- Error-based learning
- The gain of the NOI is what determines the amplitude of the response on adaptive reflexes

[Emken et al., 2007, Herreros and Verschure, 2013]

PROBLEM STATEMENT

State of the art computational models of the vestibulo-ocular reflex don’t define a physiological mechanism for extinction

Would nucleo-olivary inhibition explain extinction in the vestibulo-ocular reflex computational models?

Fingerprints

- NOI has a role in the eye-blink reflex (similar cerebellar circuitry) [Herreros and Verschure, 2013]
- There is extinction of the adaptive response in the absence of peripheral error
- VOR adaptation has a non-perfect performance, with a residual error proportional to the amount of cerebellar action required

Adding nucleo-olivary inhibition on a detailed bottom-up state of the art vestibulo-ocular reflex computational model would offer a more parsimonious explanation of the experimental behavior of the reflex.

METHODS

This computational model is made bottom-up from physiological and behavioral observations

- Plasticity on the cerebellar cortex
  - quick
  - short-term
  - error-based learning
- Plasticity on the brainstem
  - slow
  - long-term

[Clopath et al., 2014]

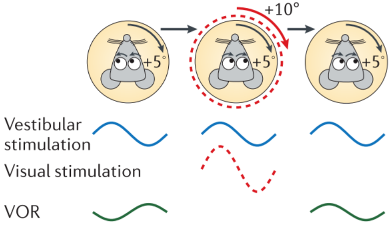
- learned adaptation at the cerebellar cortex is slowly transfered to the brainstem
- cortical plasticity remains flexible to further adaptations
- savings help faster response on reacquisition

Extinction on Clopath's model

- Weakly modulated by head movement (vestibular signal)
- Weights on cortical plasticity experiment a linear decay to their initial value

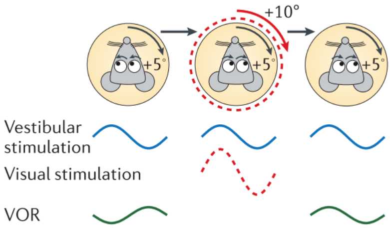
Extinction on NOI model

- Extinction is defined as proportional to cortical output [Najac and Raman, 2015]



[Gao et al., 2012]

- Day 1: VOR cancellation
- Day 2: VOR reversal with gain -0.5
- Day 3 and 4: Phase reversal with gain -1



[Gao et al., 2012]

- Day 1: VOR cancellation
- Day 2: VOR reversal with gain -0.5
- Day 3 and 4: Phase reversal with gain -1
- One week of light deprivation with vestibular stimulation

RESULTS

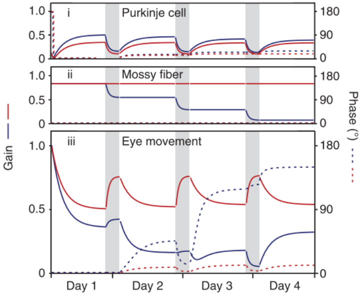


Figure 1: Experimental results

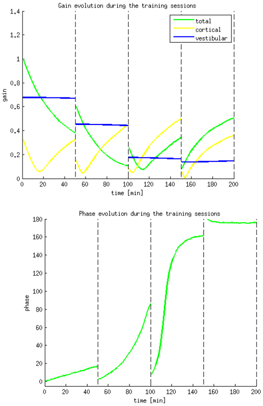


Figure 2: Gain and phase on NOI model simulations

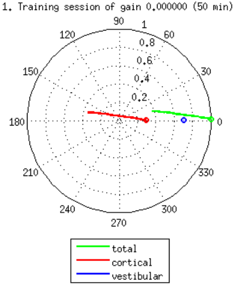


Figure 3: Gain and phase on NOI model simulations

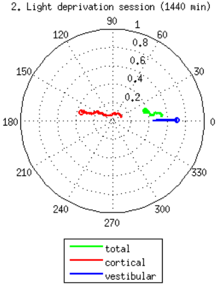


Figure 4: Gain and phase on NOI model simulations

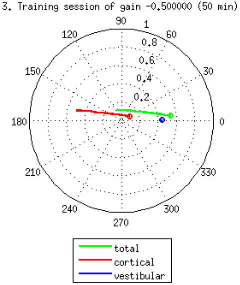
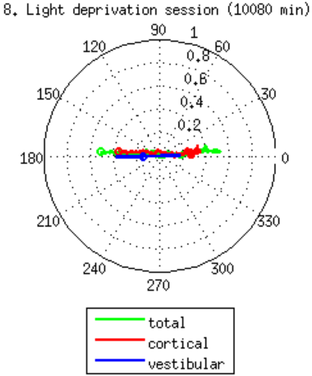


Figure 5: Gain and phase on NOI model simulations

WHAT HAPPENS ON THE DARK?

- Cortical
  - Extinguishes progressively to a baseline
- Nuclear
  - Continues transference from cortical memory
- Total
  - Extinction and transference go in different directions
  - On the dark adaptation continues consolidating until an inflextion point where extinction overtakes transference
  - After a long period on the dark, all cortical memory is consolidated on the brainstem and cortical contribution is at its baseline



Limitations of the model

- control isn't perfect
- there's always some modulation on the cortical signal
- nuclear transference

CONCLUSIONS

- NOI explains extinction on VOR adaptation
- Extinction is triggered when vestibular information is available
- Teaching or error signal is modulated by cortical response (OCNO loop)
- Savings

More detailed bottom-up models

- transgenic mouse lines
- better electro-physiological recordings
- models with distributed plasticity

REFERENCES

Clopath, C., Badura, A., De Zeeuw, C. I., and Brunel, N. (2014).
A cerebellar learning model of vestibulo-ocular reflex adaptation in wild-type and mutant mice.
J. Neurosci., 34(21):7203–15.

Cohen, M. R., Meissner, G. W., Schafer, R. J., and Raymond, J. L. (2004).
Reversal of motor learning in the vestibulo-ocular reflex in the absence of visual input.
Learn. Mem., 11(5):559–565.

Emken, J. L., Benitez, R., Sideris, A., Bobrow, J. E., and Reinkensmeyer, D. J. (2007).
Motor adaptation as a greedy optimization of error and effort.
J. Neurophysiol., 97(6):3997–4006.

Gao, Z., van Beugen, B. J., and De Zeeuw, C. I. (2012).
Distributed synergistic plasticity and cerebellar learning.

Thank you