Role of the cerebellum in an attractor model for saccadic control and learning

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Junya Inoue, Akshay Markanday, Peter Thier

Hertie Institute, University of Tübingen, Tübingen, Germany

Hertie-Institut für klinische Hirnforschung

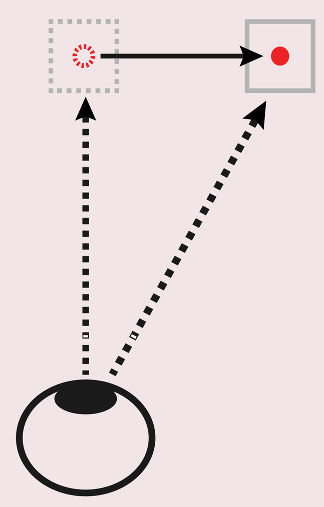
How does the cerebellum control saccades?

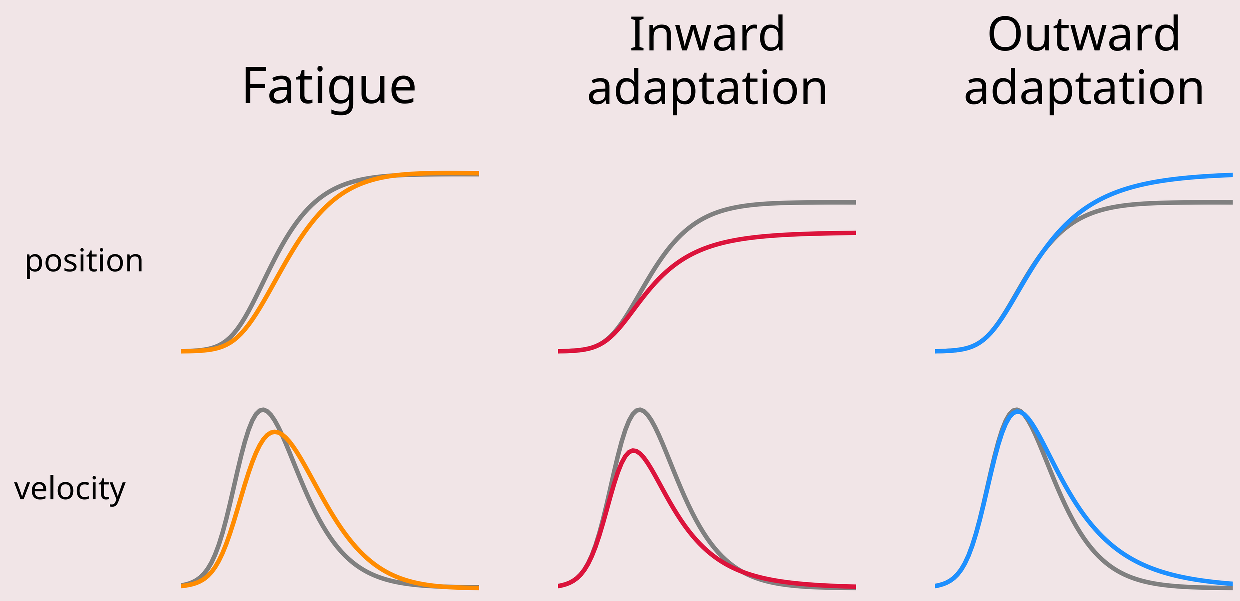
A saccade is a rapid movement ***without sensory feedback***.
However, thanks to the cerebellum, it is still ***fast*** and ***accurate*** and able to ***adapt*** to new environments

The cerebellum adjusts peak velocity (PV), duration and amplitude resorting ***internal model*** of the saccadic eye movement

Question:

How does the cerebellum fine-tune the parameters of this internal model?





	Fatigue	Inward	Outward
Amp.		↓	↑
PV	↓	↓	
dur.	↑		↑

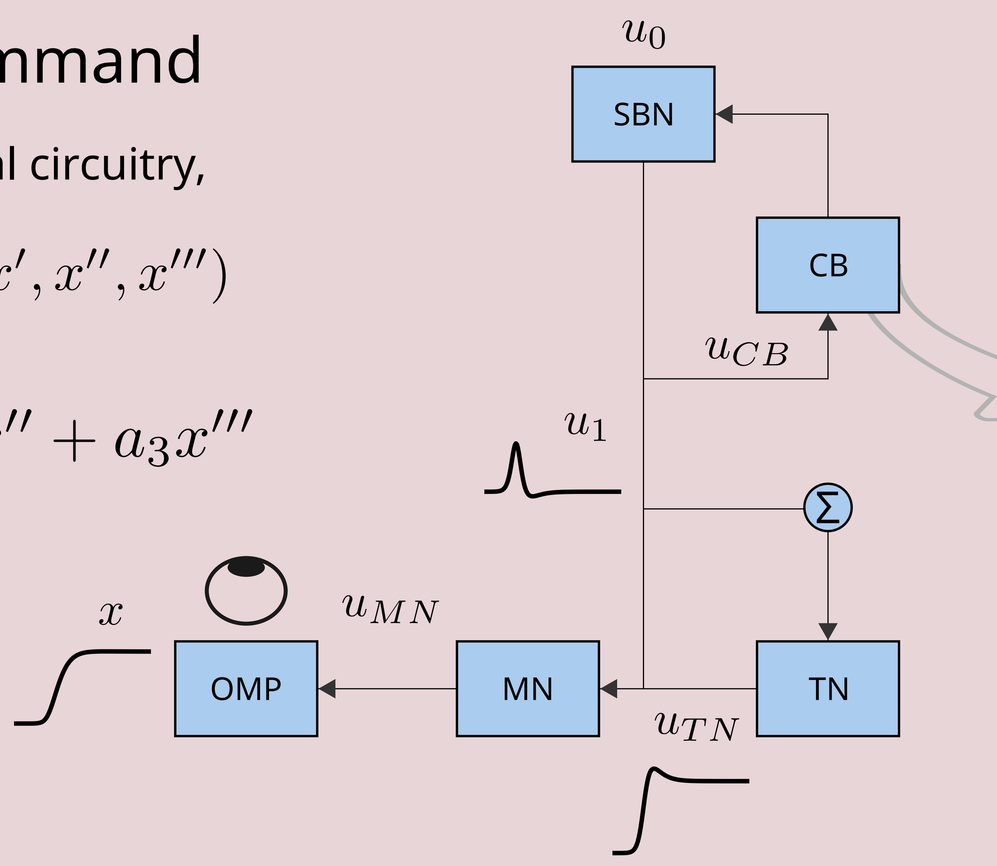
Theoretical approach

What kind of control is required to make a saccade fast and precise?

Estimation of motor command

From biomechanics and neuronal circuitry, estimate motor command u_1 from movement kinematics (x, x', x'', x''')

$$u_{MN} = a_0 x + a_1 x' + a_2 x'' + a_3 x'''$$
$$u_{MN} = \tau u_1 + u_{TN}$$
$$u_{TN} = \int u_1 dt$$

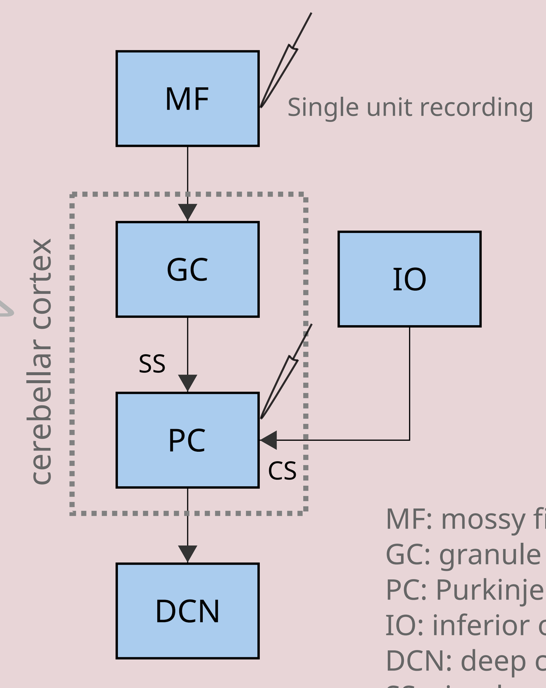


OMP: oculomotor pland
MN: motoneuron
TN: tonic neuron
SBN: saccadic burst neuron
CB: cerebellum

Experimental approach

What is the relationship of the model elements to neurons in the cerebellar cortex?

Cerebellar anatomy

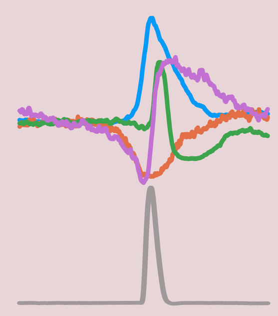


MF: mossy fiber
GC: granule cell
PC: Purkinje cell
IO: inferior olive
DCN: deep cerebellar nucleus
SS: simple spike
CS: complex spike

SS:
- result of cerebellar computation

CS:
- convey error information
- induce learning

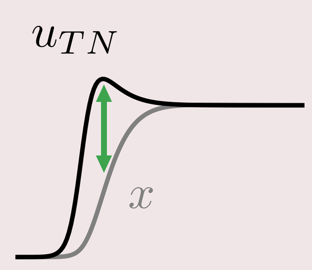
What's the true population activity of PC-SS?
- longer modulation than actual movement
- diverse & complex firing



SS discharge of single PCs

Control strategy

- The difference between x and u_{TN} drives the eye
- u_{TN} transiently overshoots the target
- But finally u_{TN} returns to the target such as to ensure that the eyes reach the target in one stroke
- estimate of kinmatics $\hat{x}$ and $\hat{x}'$ are necessary



Attractor model

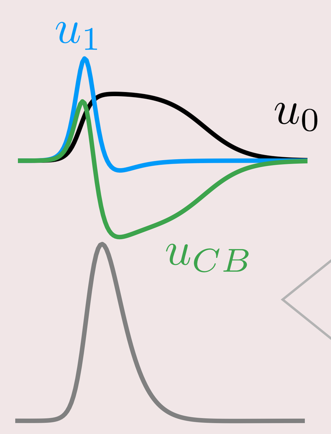
$$u_1 = u_0 w_{burst}((1 - \frac{\hat{x}}{w_{amp}}) - w_{vel}\hat{x}')$$
$$u_{CB} = u_1 - u_0$$

Approximation of current kinematics (***internal model***)

$$u_1(t) \approx a\hat{x}'(t + \Delta t) + b\hat{x}''(t + \Delta t)$$

Model parameters

$$w_{burst}, w_{amp}, w_{vel}, a, b$$



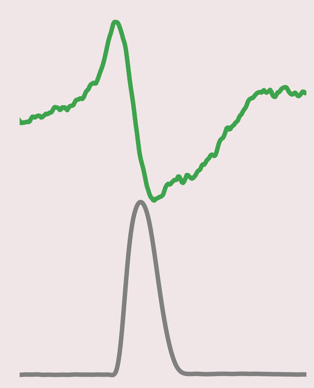
PC clustering by error tuning

CSs convey error information and induce learning

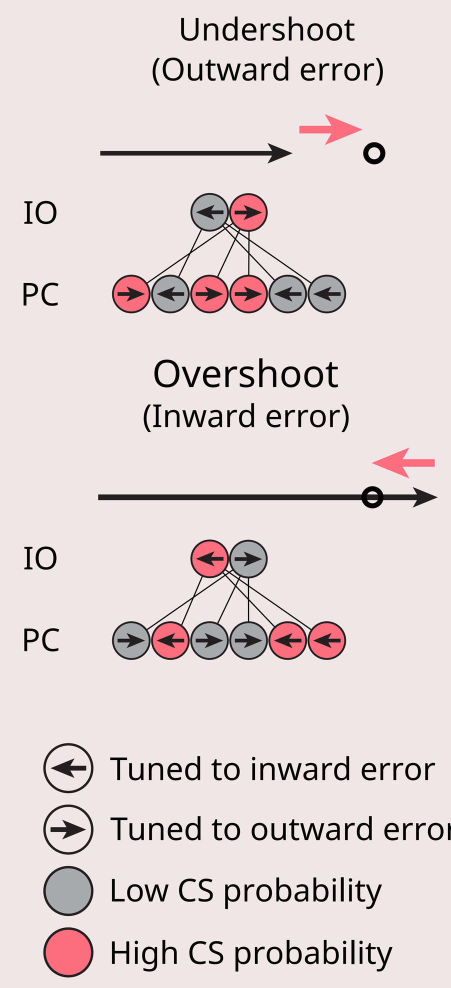
PCs are tuned to specific error directions of CSs (e.g. inward error ⊖ and ⊖ outward error)

They have functionally opposite roles

Net modulation is the difference between the two groups ⊖ and ⊖



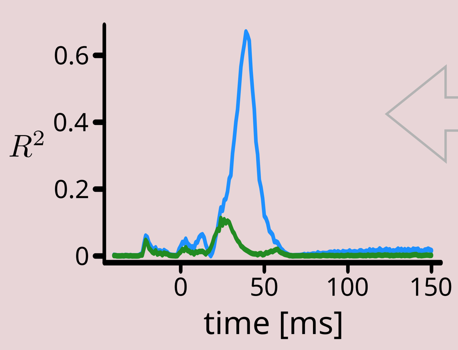
- Early peak (acceleration)
- Late trough (deceleration)



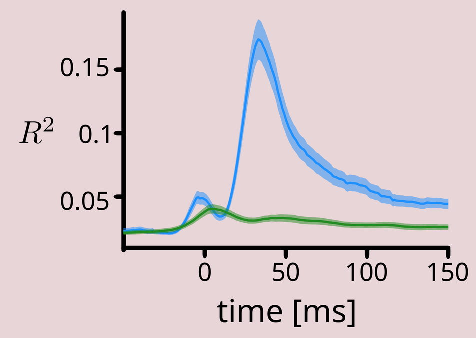
Kinematic encoding

What is the relationship between the motor command & the resulting kinematics?
→ signal dependent noise added to u_0

u_1 is highly correlated to kinematics (PV & duration)
u_{CB} corrects the motor command from noisy u_0



Kinematic encoding



What do MFs and PCs encode?

MF firing is better correlated with saccade kinematics

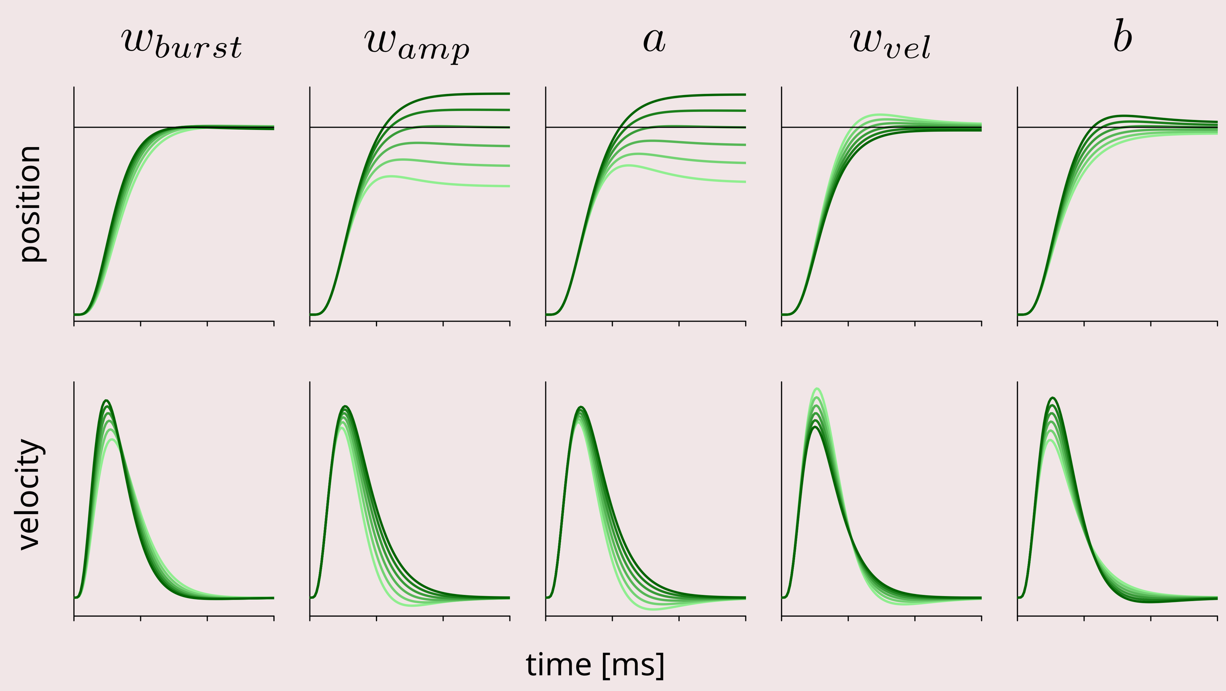
PCs correct the movement

Changing model parameters

Behavioral changes
$w_{amp} \sim a$
$w_{vel} \sim b$

Short-term adaptation
update: (a, b)
internal model parameters

Long-term adaptation
update: (w_{amp}, w_{vel})
downstream network weights



Summary & Conclusion

The attractor model can explain effectively the behavior of the PC-SS discharge
- early acceleration & late deceleration phases of the saccades
- little encoding of saccade kinematics
- PC-SS works as an online correction of the noisy signal

This could be particularly important for the implementation of learning-based changes of saccade amplitudes
- multidimensional parameter updates for short- and long-term adaptation

Contact:
junya.inoue@student.uni-tuebingen.de