



50 years of building new worlds through knowledge
Aix-Marseille Université

Tèmes journées Complexité - désordre
Université Paris Diderot
Paris 13-14 janvier 2020

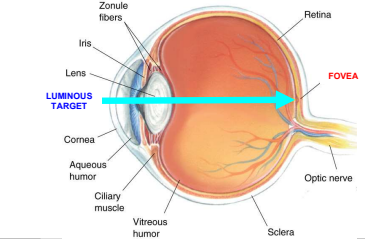


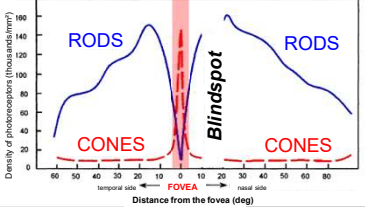

Are kinematic parameters embedded within the brain activity while an accurate movement is being achieved ?

Laurent Goffart^{1,2}
CNRS

1 : Institut de Neurosciences de la Timone, Marseille, France
2 : Centre Gilles Gaston Granger, Aix-en-Provence, France

Looking at a visual target

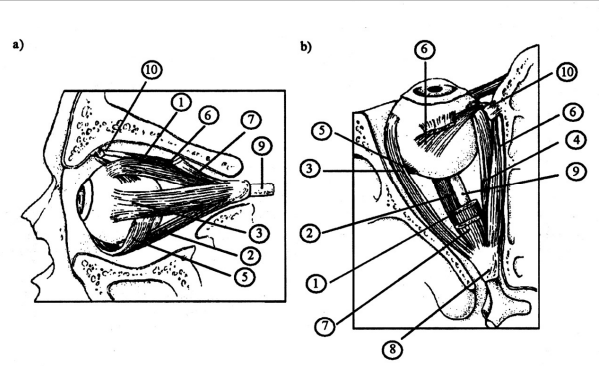




Non-homogeneous retina

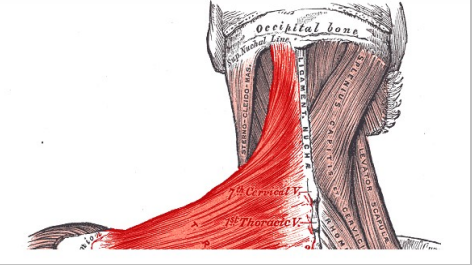
Projection of target onto the fovea

↔ proper extraocular muscles contraction (gaze direction)

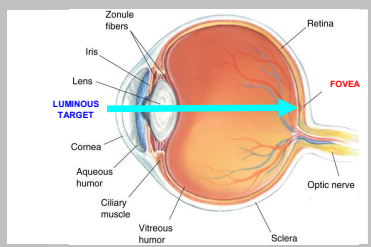


Foveal projection of target

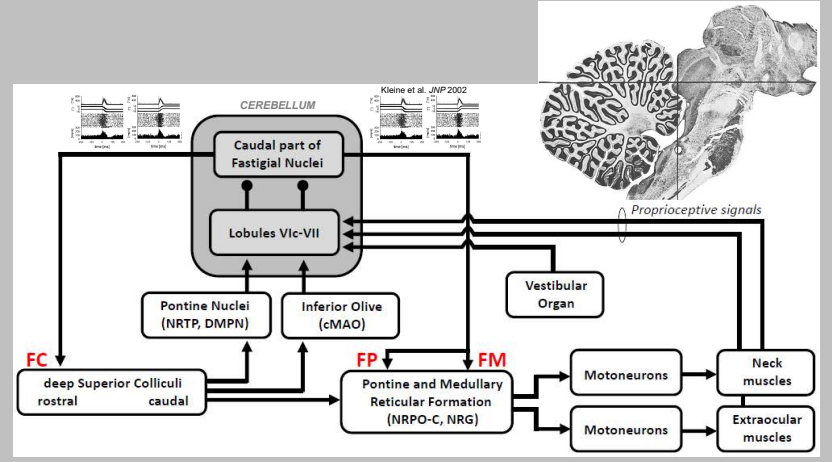
↔ proper contraction of neck muscles (head direction)



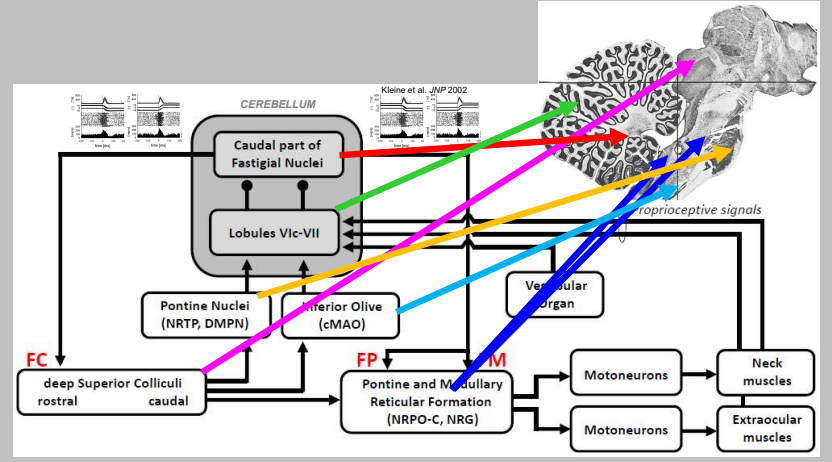
Looking at a visual target IS contracting multiple muscles



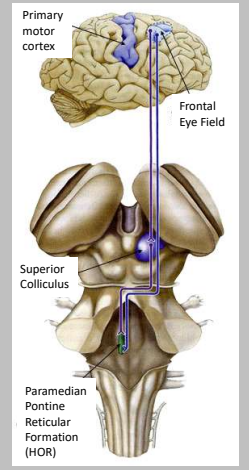
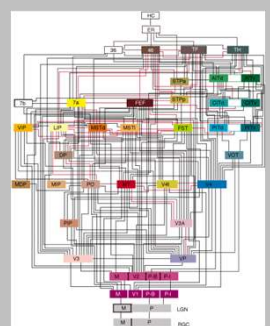
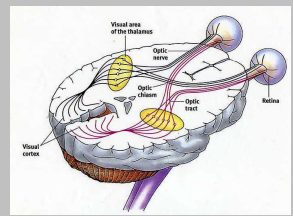
Adjustment of eye and head orientations : neural control



Adjustment of eye and head orientations : neural control



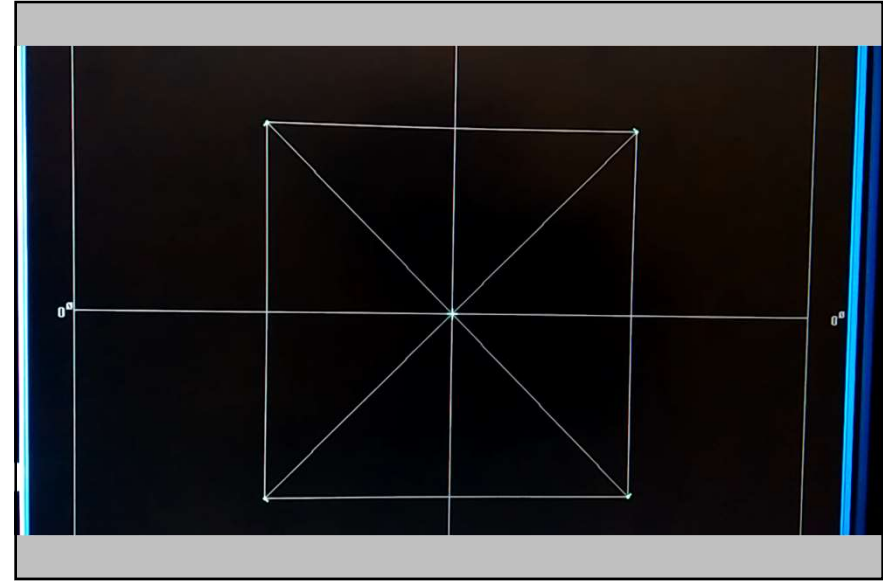
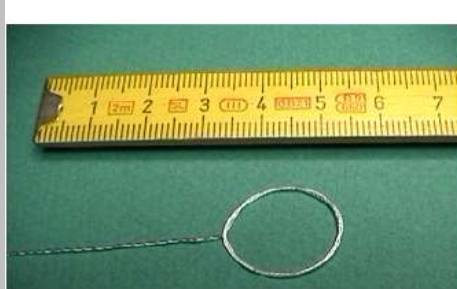
From the retina to premotor commands



- Largely incomplete schema
- Pulvinar
 - Nucleus of Optical Tract
 - Superior Colliculus
 - etc ...

Recording of eye movements

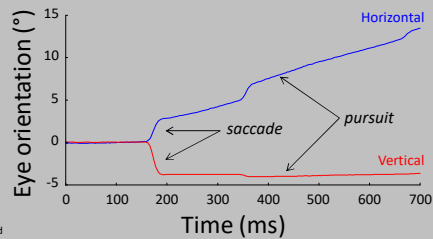
- Electro-magnetic induction
- Scleral coil
- 2 magnetic fields : H and V



Two types of eye movement in response to the motion of a visual target

- rapid : saccade
- slow : pursuit

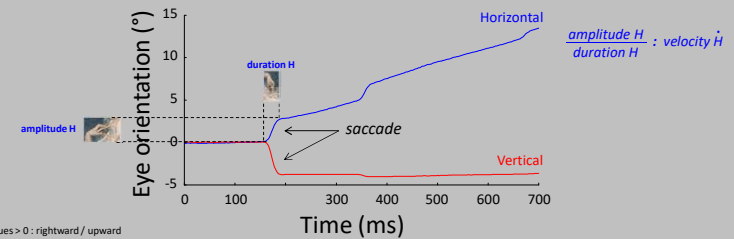
*same muscles and motor nuclei BUT largely distinct cerebral populations
two premotor input : PHASIC (burst) and TONIC*



values > 0 : rightward / upward
value = 0 : straight ahead
values < 0 : leftward / downward

Two types of eye movement in response to the motion of a visual target

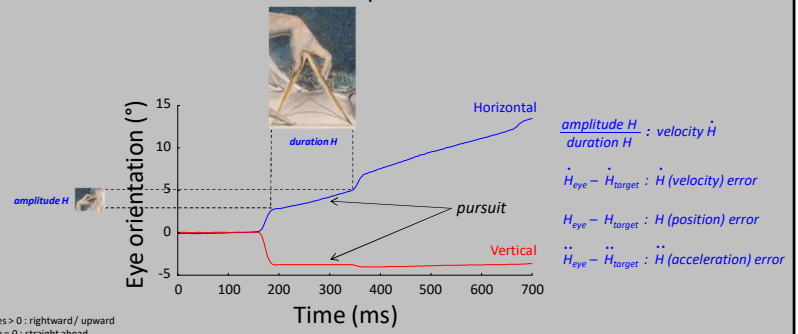
- rapid : saccade



values > 0 : rightward / upward
value = 0 : straight ahead
values < 0 : leftward / downward

Two types of eye movement in response to the motion of a visual target

rapid : saccade
slow : pursuit

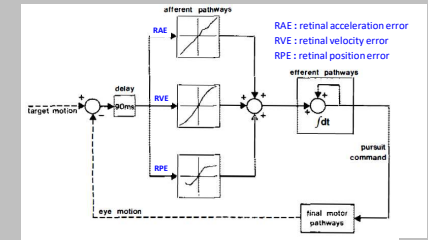


values > 0 : rightward / upward
value = 0 : straight ahead
values < 0 : leftward / downward

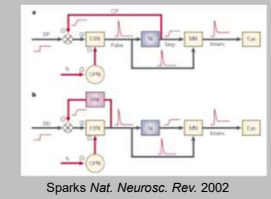
Dividers, physical quantities and mathematics in the brain ?



CIRCUIT FOR PURSUIT

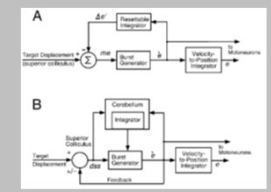


CIRCUIT FOR SACCADE



Motor Error = Desired - Current Positions (DP - CP)

Motor Error = Desired - Current Eye Displ. (DD - CD)



Motor Error = Target - Eye Displ. (TD - ED)

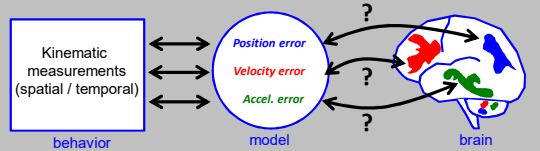
\dot{e} : eye velocity

Target Displacement Initial Motor Error

Dividers, physical quantities and mathematics in the brain ?



QUESTIONING THE BRAIN-MODEL ISOMORPHISM



The fact that we measure and model the movement of the eyeball (a rigid body) with kinematic notions does not imply an equivalence in the brain, and notably that the firing of neurons ought to "encode" (i.e., emit signals related to) amplitude, velocity or acceleration of the eye movement.

Major concern

SPACE-TIME REPRESENTATION IN THE BRAIN. THE CEREBELLUM AS A PREDICTIVE SPACE-TIME METRIC TENSOR

A. PELLIONISZ and R. LLINÁS
Department of Physiology and Biophysics, New York University Medical Center,
550 First Avenue, New York, NY 10016, U.S.A.

Understanding of brain function is often limited by the tacit acceptance of concepts known to be basically inappropriate. An example is the tenet that the brain, in its internal workings, utilizes space-time reference frames similar to those used in classical mechanics.

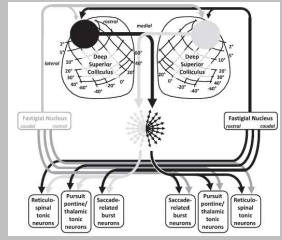
However, the utilization of separate systems of coordinates for space and time hinges upon the concept of simultaneity. Since within the brain there is no 'instantaneous' simultaneity agent comparable to the light, the classical usage of separate space and time coordinates is inapplicable in the case of describing the inner workings of the CNS.

Neuroscience 1982

Alternative viewpoint

REVIEW | *The Role of Eye Movements in Perception, Cognition, and Action*
 Neurophysiology of visually guided eye movements: critical review and alternative viewpoint
 Laurent Goffart,^{1,2} Clara Bourrelly,³ and Jean-Charles Quinton³
Journal of Neurophysiology 2018

CHAPTER
 Kinematics and the neurophysiological study of visually-guided eye movements
 Laurent Goffart^{1,2,3,4}
Progress in Brain Research 2019



No movement = equilibrium
 Movement = restoration of equilibrium

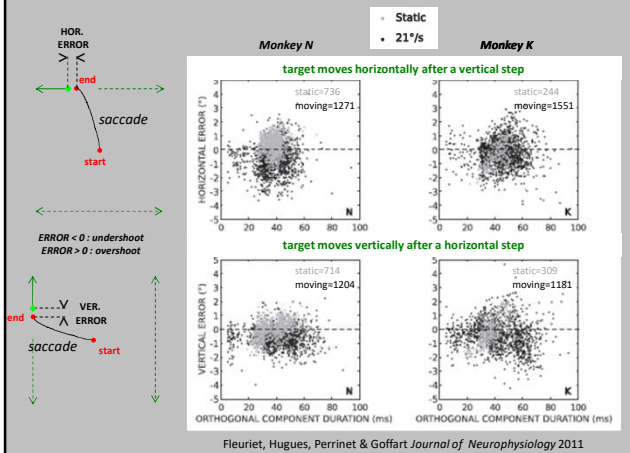
RESEARCH ARTICLE | *Control of Movement*
 Gaze direction as equilibrium: more evidence from spatial and temporal aspects of small-saccade triggering in the rhesus macaque monkey
 Ziad M. Hafed^{1,2*} and Laurent Goffart^{3*}
Journal of Neurophysiology in press

Interceptive saccades

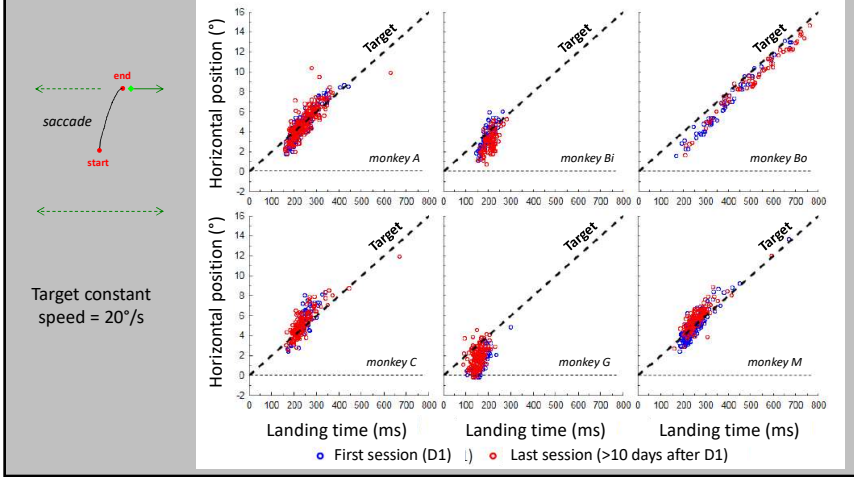
RESEARCH ARTICLE
 Predictive elements in ocular interception and tracking of a moving target by untrained cats
 F. Xilom, J. Petit, A. Grassein, A. Berthier

Abstract We presented a mechanical target moving at constant velocity to awake, nontrained, head-restrained cats, in order to study how naive animals pursue objects moving at a high speed with their gaze. Eye movements were recorded while the target was moving in different directions at a constant velocity (20–80°/s) through the center of the visual field. We observed two oculomotor strategies: cats either made an interception saccade (IS) toward the target but opposite to its motion, or tracked it in the direction of motion. They used the interception strategy more frequently when the gaze position error at the onset of target motion was large, and the tracking strategy when it was small. Interception was always achieved by single saccades, which were faster than tracking saccades (TS). During tracking, cats generated sequences of two to six saccades separated by “smooth” eye movements. Tracking quality varied considerably from trial to trial. When the level of motivation was high, cats would track the target at 80% over up to 75% of the oculomotor range, with relatively small position errors. We compared ISs and TSs with respect to their metric properties and timing. The amplitude of ISs positively correlated with position error existing 100 ms before saccade onset, but saccade vectors were directed to a point ahead of the target along the target’s track. We conclude that, in programming the ISs, target motion is used to predict the future target position so as to assume a spatial lead of the gaze at the saccade end, instead of attempting a precise capture of the target. The amplitude of TSs did not depend on preceding position errors. TSs were usually small at the onset of the first saccade, as if cats would wait till the target arrived near the line of sight. A majority of primary TSs were initiated before the target arrived near the direction of gaze. Thus they had a direction, opposite to the position error sampled 100 ms before the saccade, but the same as the direction

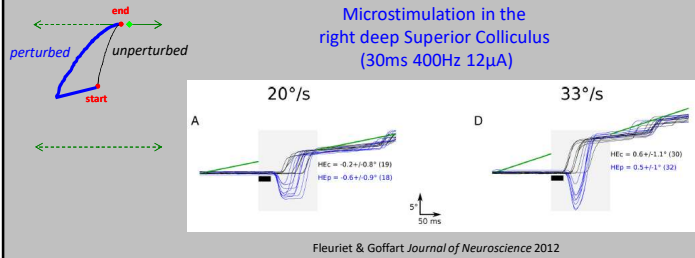
Accuracy and precision of saccades



No spatial lead either in untrained monkeys

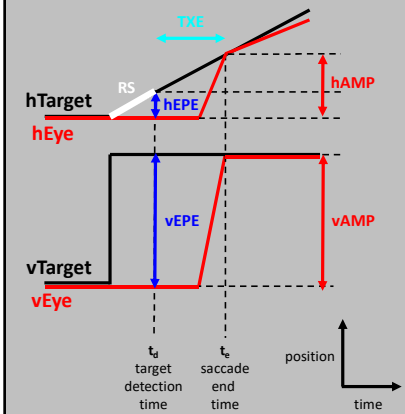


No spatial lead after perturbation



Contrary to the claim that interceptive saccades "would assure a spatial lead of the gaze at the saccade end instead of a precise capture of the target", our observations indicate that interceptive saccades either precisely capture the target, where it is when it is there or they undershoot the target (lag).

Dual-drive hypothesis



ASSUMPTIONS :

1. Snapshot of Eye Position Error (EPE)
2. Snapshot of Retinal Slip (RS)
3. Calculation of $T_{XE} = \frac{EPE}{RS}$ (eye crossing time)

"eye crossing time," which is the time necessary for the eye to cross the target at constant eye velocity ($T_{XE} = -PE/RS$). For saccade trials, T_{XE} was evaluated on the basis of the retinal slip and position error 125 ms before saccade onset

Predictive chronometric control ?

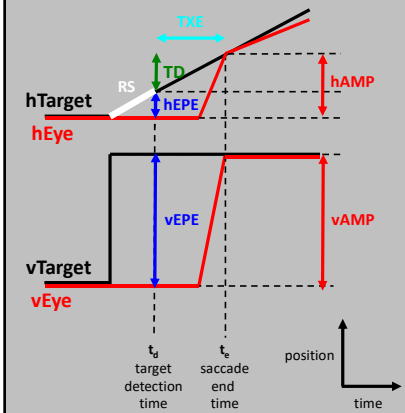
"Apparently, in cats as in humans, to determine an appropriate strategy, the saccadic system takes into account the initial position and velocity of the target and the initial position of the eyes. Based on these variables, the system "predicts" the time remaining till the "collision" of the target with the line of sight." (Klam, Petit, Grantyn & Berthoz EBR 2001)

"The oculomotor system uses a prediction of the time at which the eye trajectory will cross the target, defined as the "eye crossing time" (TXE). The eye crossing time, which depends on both position error and velocity error, is the criterion used to switch between smooth and saccadic pursuit, i.e., to trigger catch-up saccades." (de Brouwer, Yuksel, Blohm, Missal & Lefèvre JNP 2002)

"eye crossing time," which is the time necessary for the eye to cross the target at constant eye velocity ($T_{XE} = -PE/RS$). For saccade trials, T_{XE} was evaluated on the basis of the retinal slip and position error 125 ms before saccade onset

CONCERN : HOW is the "PREDICTED TIME" (ms) translated into "AMPLITUDE" (deg) ?

Dual-drive hypothesis



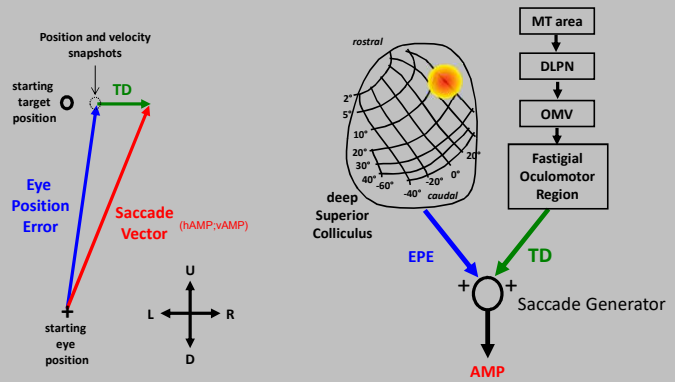
ASSUMPTIONS :

1. Snapshot of Eye Position Error (EPE)
2. Snapshot of Retinal Slip (RS)
3. Calculation of $T_{XE} = \frac{EPE}{RS}$ (eye crossing time)
4. Calculation of $-EPE + (T_{XE} \times TV_{estim}) = AMP$

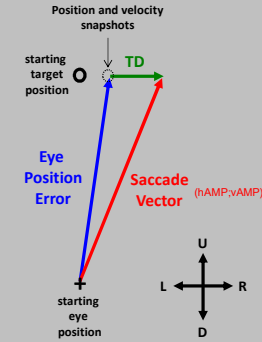
Target Displacement TD

Dual-drive hypothesis

Keller et al. *J Neurophysiol* 1996
 Optican & Quaiia ANYAS 2002
 Optican *Encyclopedia of Neuroscience* 2010



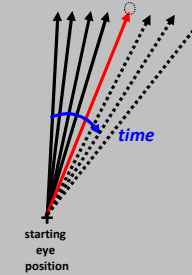
Dual drive hypothesis



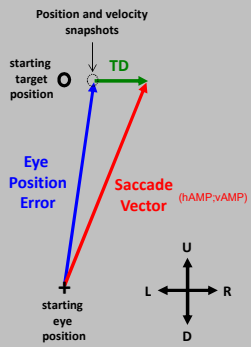
Remapping hypothesis

NO SNAPSHOT

Fleuriet et al. *J Neurophysiol* 2011



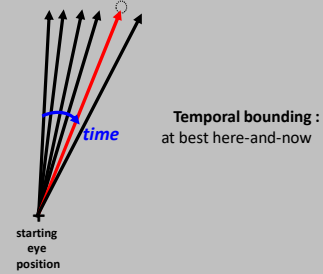
Dual drive hypothesis



Remapping hypothesis "here and now" hypothesis

NO SNAPSHOT

Fleuriet et al. *Journal of Neurophysiology* 2011
 Fleuriet & Goffart *Journal of Neuroscience* 2012
 Goffart et al. *Journal of Neurophysiology* 2017

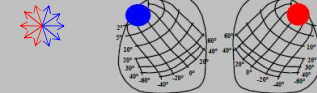


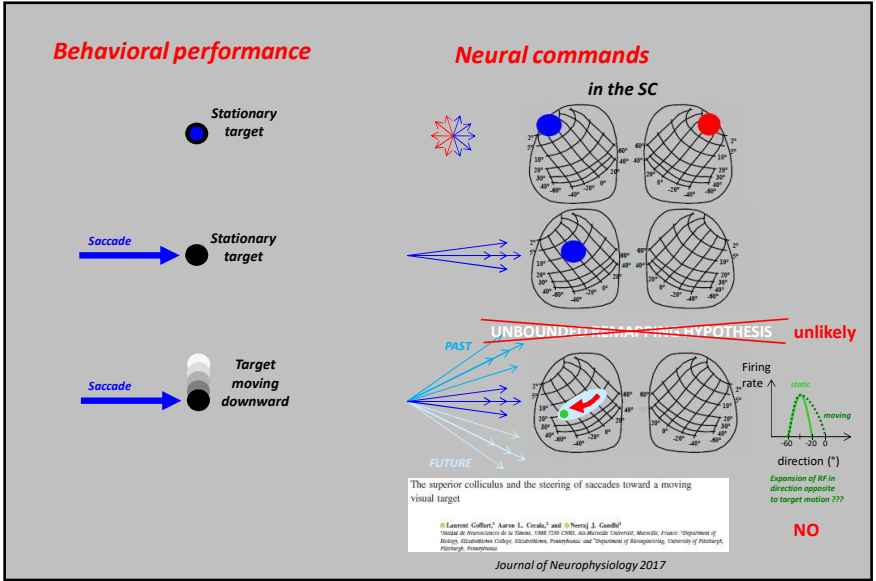
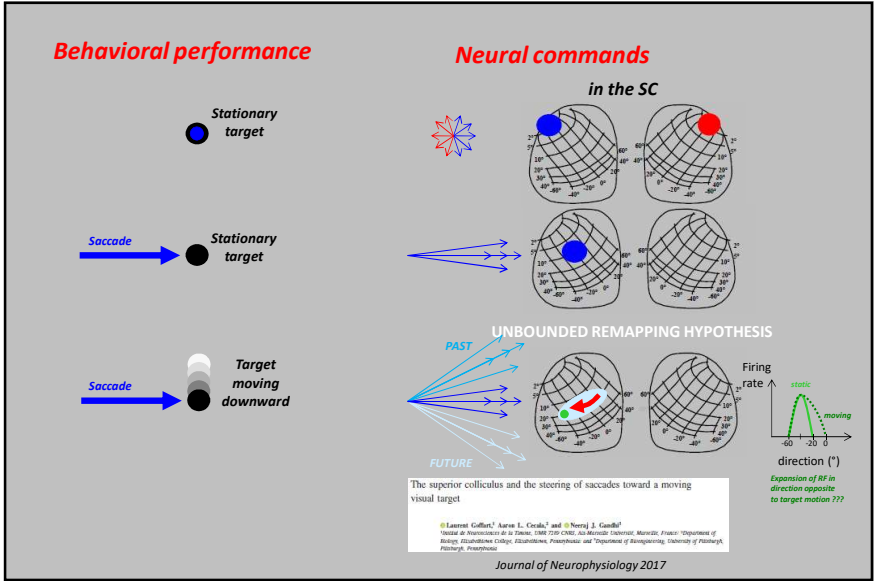
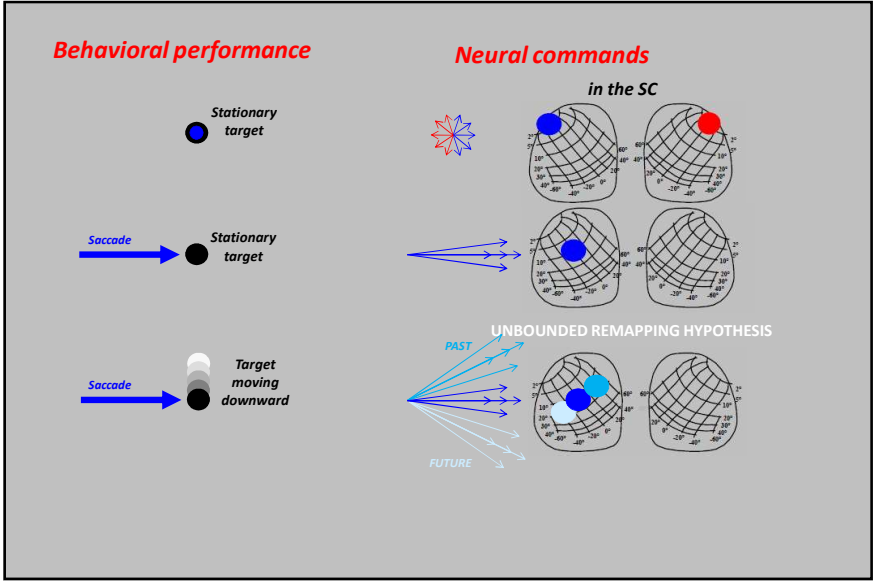
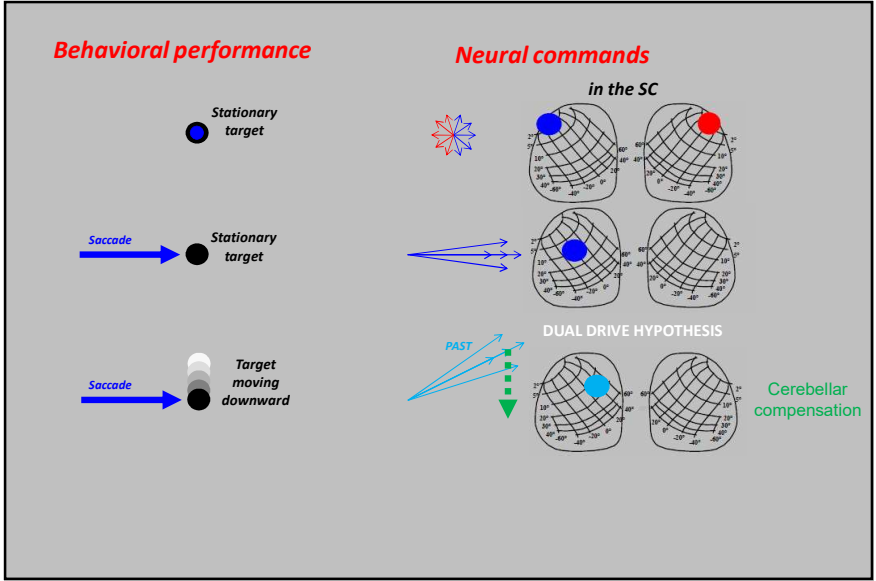
Behavioral performance

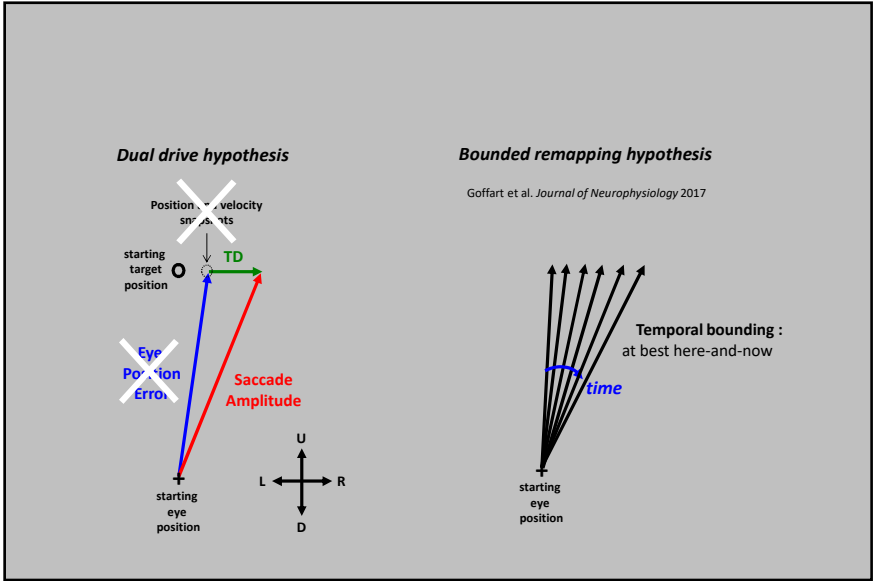
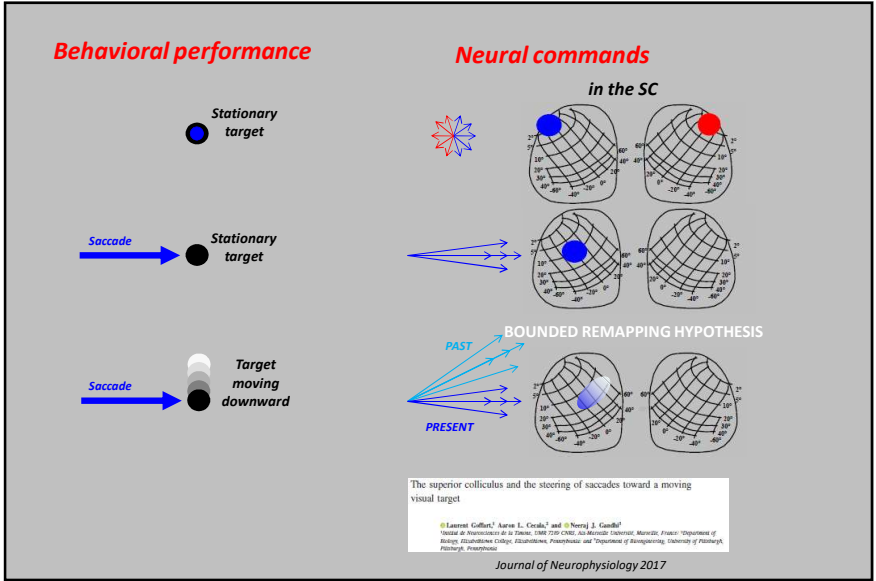
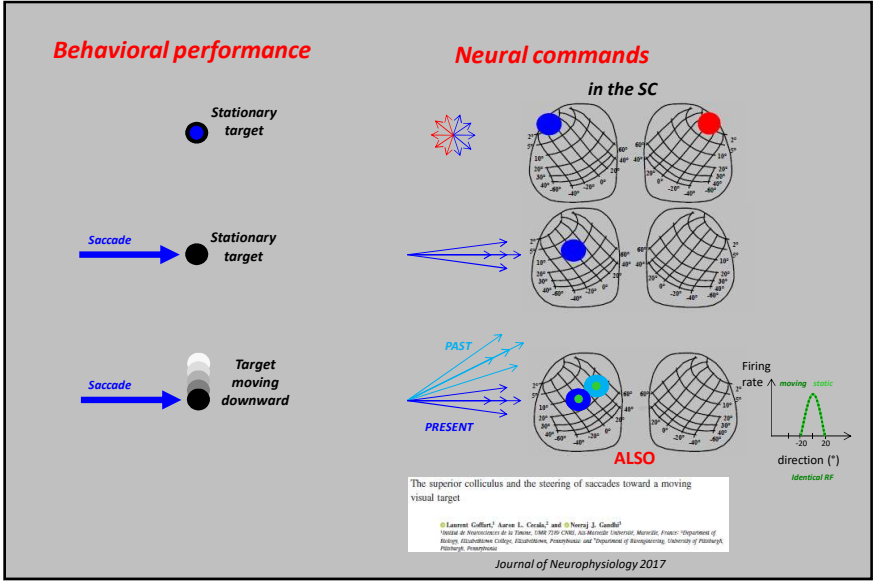
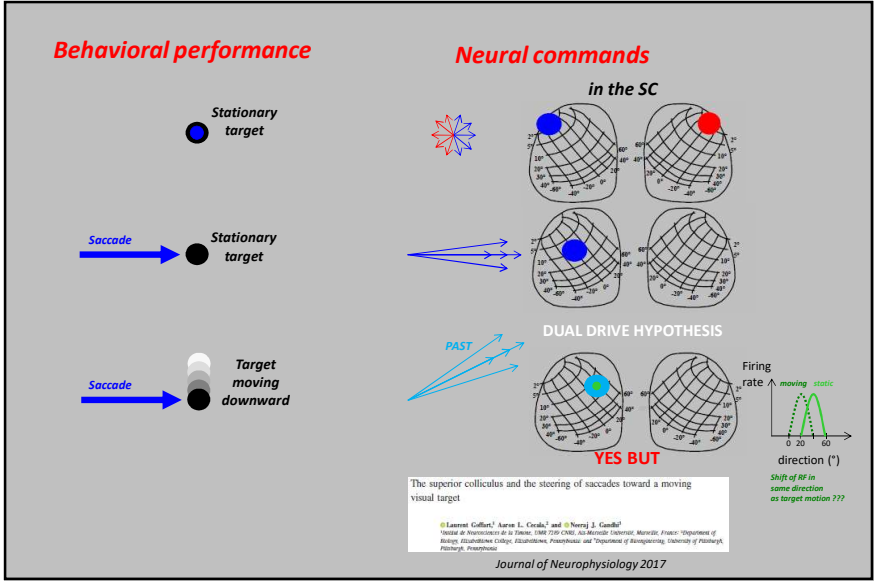
Stationary target

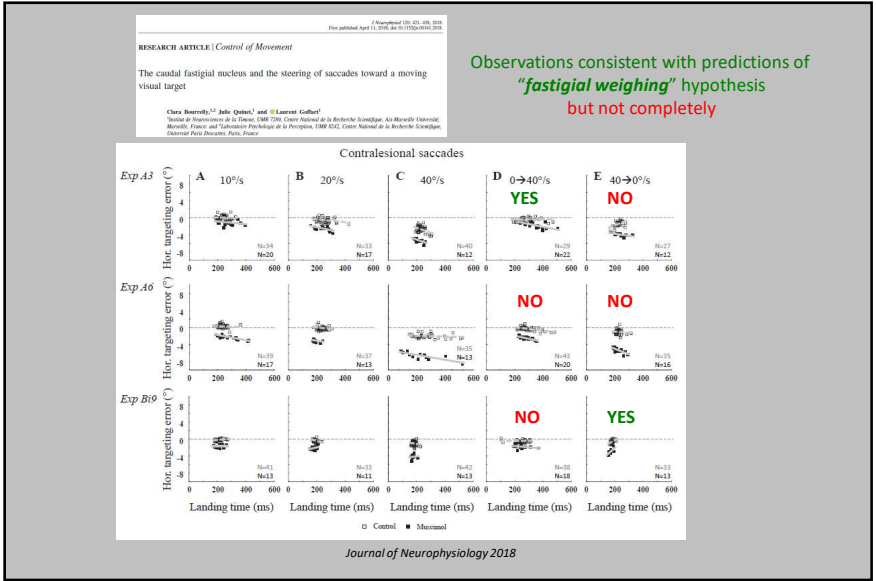
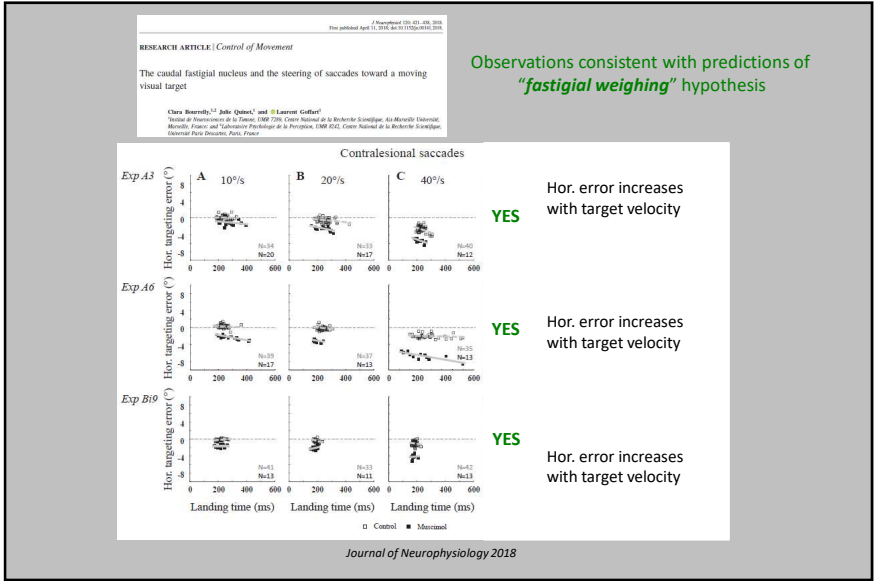
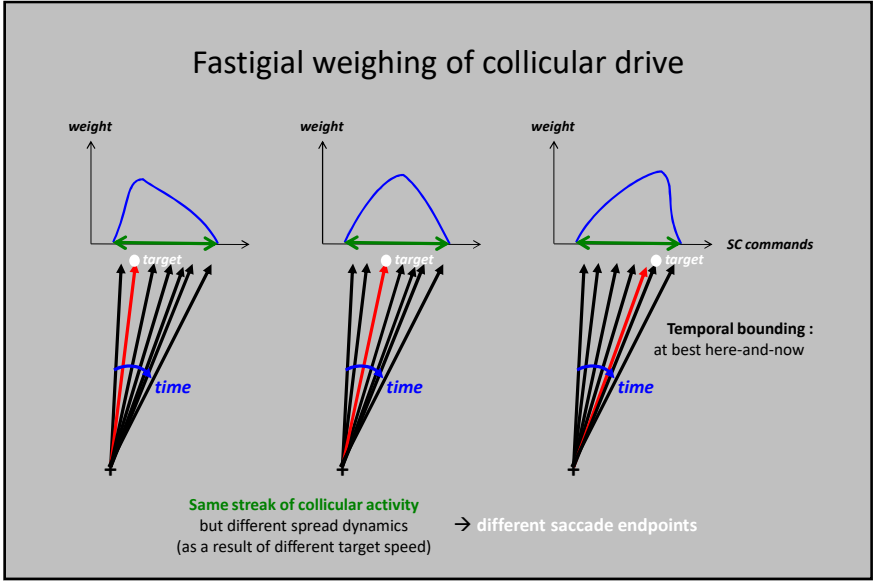
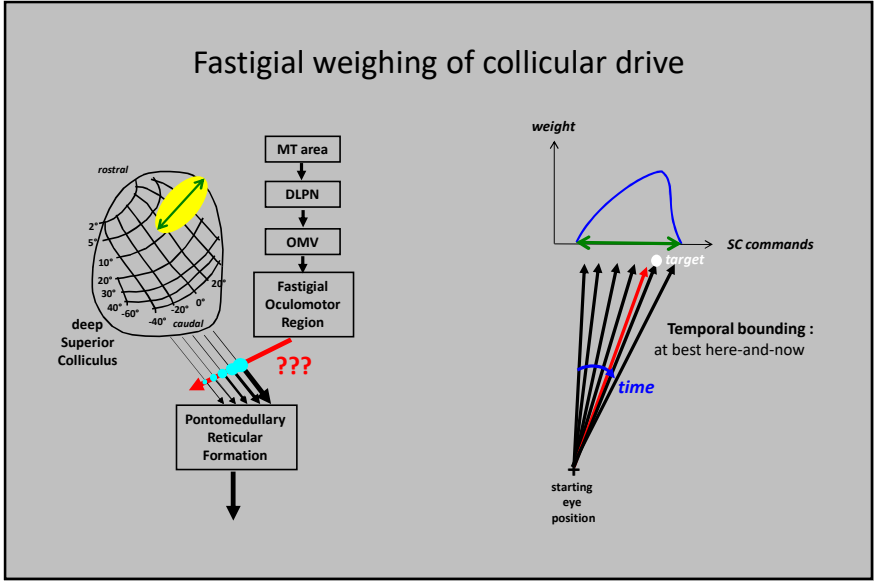
Neural commands

in the SC









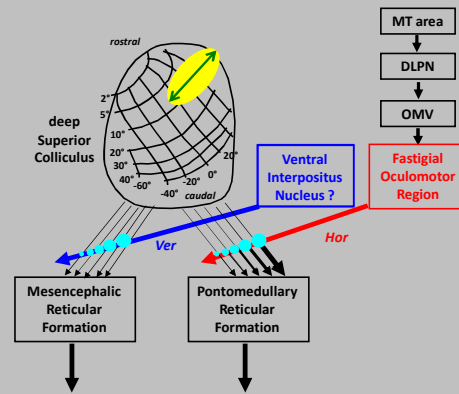


LIMITATIONS



1. CFN is primarily involved in the adjustment of the horizontal component of saccades (Goffart et al. 2003; 2004)

Fastigial + Interpositus (?) weighing hypothesis

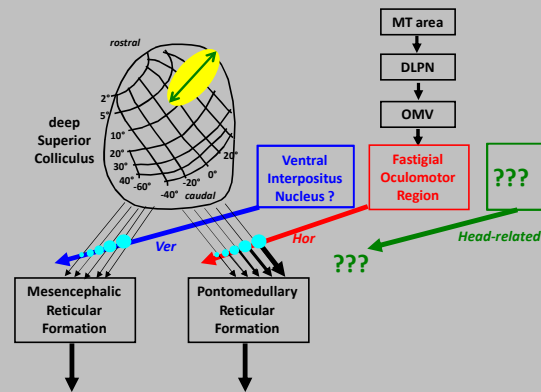


MORE LIMITATIONS



1. CFN is primarily involved in the adjustment of the horizontal component of saccades (Goffart et al. 2003; 2004)
2. SC is a gaze-related structure (eye+head) whereas the CFN is eye-movement-related (Quinet & Goffart 2005; 2007; 2009; Fuchs et al. 2010)

Fastigial + Interpositus (?) weighing hypothesis



ACKNOWLEDGMENTS

Behavioral studies Collicular perturbation



Jérôme Fleuriet
PhD



Sandrine Hugues
PhD

Collicular unit recordings



Neeraj Gandhi
PhD



Aaron Cecala
PhD

Fastigial inactivation



Julie Quinet
PhD



Clara Bourrelly
PhD



NO LIMITATIONS
FOR QUESTIONS

Questioning the "roots" of certainty strengthens the foundations of knowledge

Old dogmas and new axioms in brain theory

András J. Pellionisz

Department of Physiology & Biophysics, New York University Medical
Center, New York, N.Y. 10010

There may be no more important task for theory in any branch of science than removing old dogmas – those that are proven inappropriate yet linger – and replacing them with new axioms. This task is acutely important in neuroscience, which is presently undergoing a metamorphosis from a largely descriptive ("soft") science where the fundamental assumptions are taken for granted into an exact discipline with its own mathematized brain theory, in which case the axioms must be explicit. The process of identifying implicit fundamental assumptions, followed by the adoption of proper axioms and the removal of inappropriate dogma, is a most difficult and often thankless job. The ground must nevertheless be cleared if one expects to build a sound, mathematical brain theory on the foundation of a newly established set of axioms.

to linger = "persist"



Behav Brain Sci 1986