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## Does the brain perform arithmetical computations with neurally embedded kinematic parameters?

Laurent Goffart, PhD

Exp Brain Res (2001) 139:313–347  
DOI 10.1007/s002210100770

RESEARCH ARTICLE

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### Predictive elements in ocular interception and tracking of a moving target by untrained cats

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 amplitudes 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 assure 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

HOR. ERROR  
end  
start  
saccade

VER. ERROR  
end  
start  
saccade

ERROR < 0 : undershoot  
ERROR > 0 : overshoot

• Static  
• 21°/s

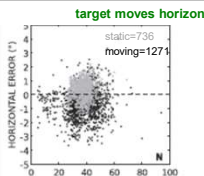
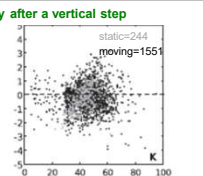
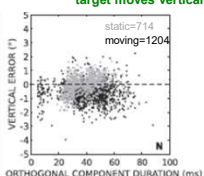
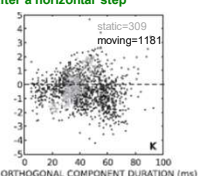
Monkey N      Monkey K

target moves horizontally after a vertical step

target moves vertically after a horizontal step

Comparable errors between saccades toward a static versus moving target

NO SPATIAL LEAD of endpoints for interceptive saccades

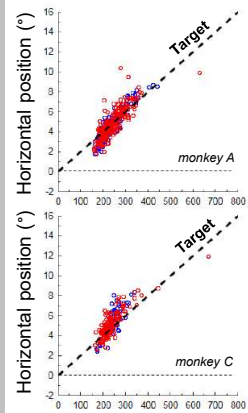
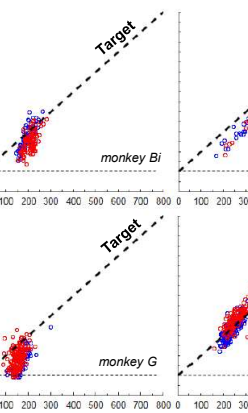
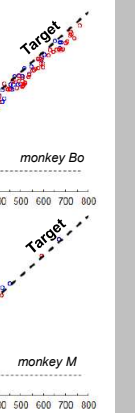





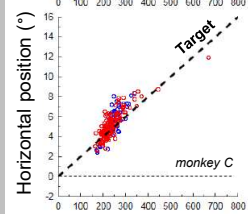
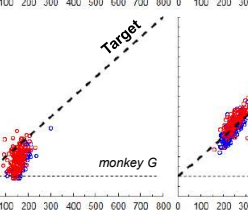
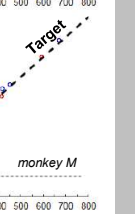
Fleuret, Hugues, Perrinet & Goffart JNP 2011

## No spatial lead either in untrained monkeys

saccade  
end  
start

Constant speed = 20°/s

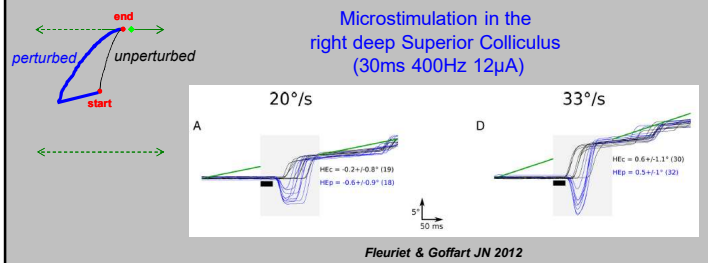




Landing time (ms)      Landing time (ms)      Landing time (ms)

• First session (D1)    • Last session (>10 days after D1)

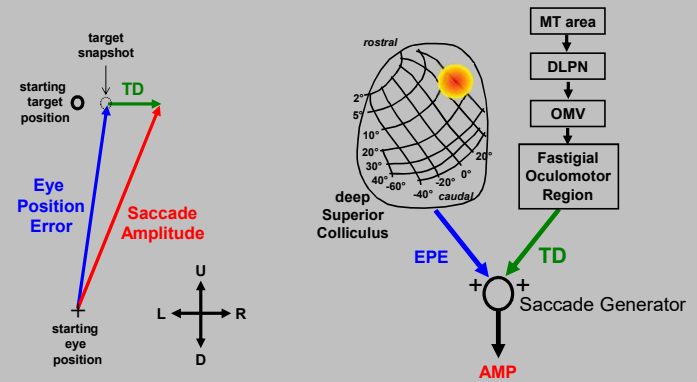
### No spatial lead after perturbation



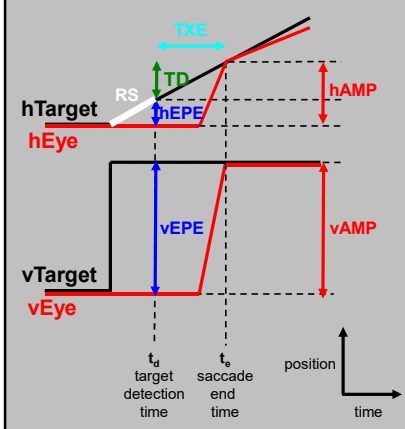
Contrary to the claim that interceptive saccades "would assure a spatial lead of the gaze at the saccade end instead of a precise capture of the target", our observations indicate that interceptive saccades either precisely capture the target, where it is when it is there or they undershoot the target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

### Dual-drive hypothesis (simple version)

Keller et al. JNP 1996  
Optican & Quiaia ANYAS 2002  
Optican Encyclopedia of Neurosc. 2010

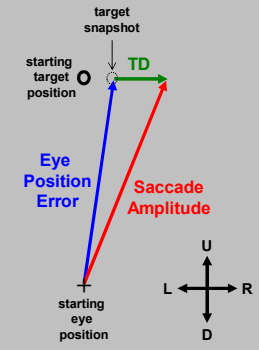


### Dual-drive hypothesis (version complicated)



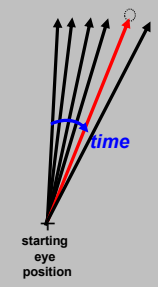
- ASSUMPTIONS :**
1. Snapshot of Eye Position Error (EPE)
  2. Snapshot of Retinal Slip (RS)
  3. Calculation of  $TXE = -\frac{EPE}{RS}$  (eye crossing time)
  4. Sum :  $-EPE + (TXE \times TV_{estim}) = AMP$
- TD**

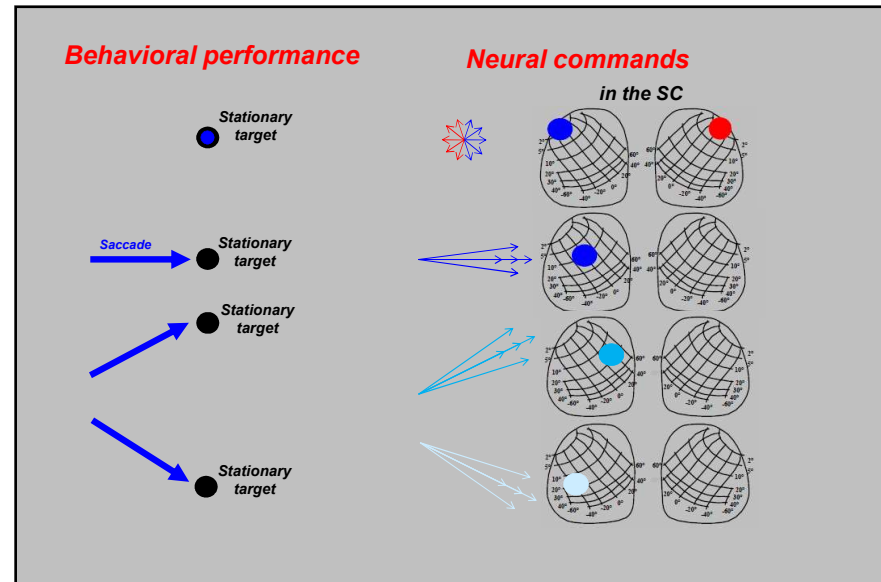
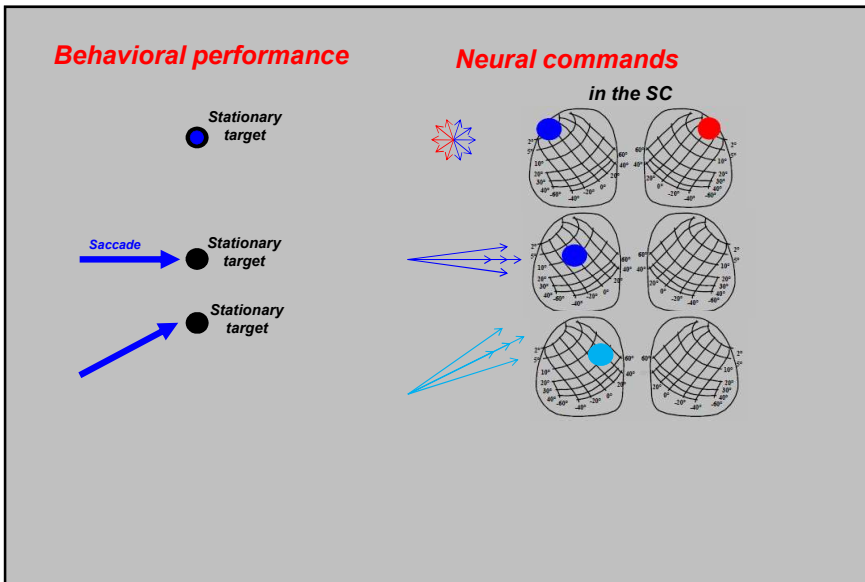
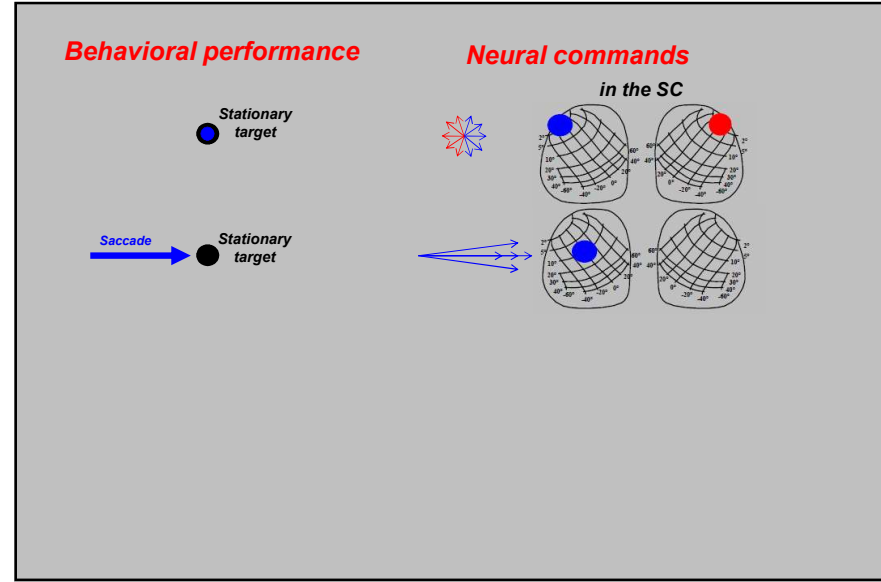
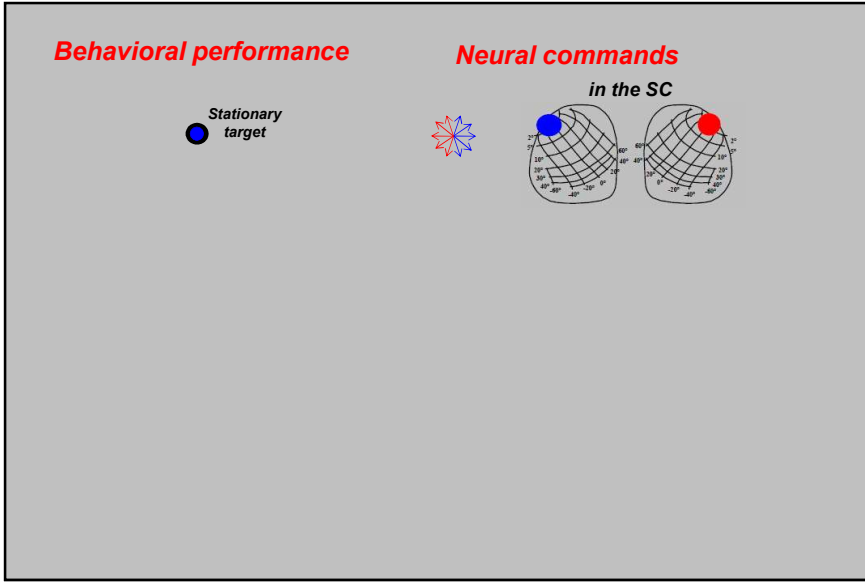
#### Dual drive hypothesis

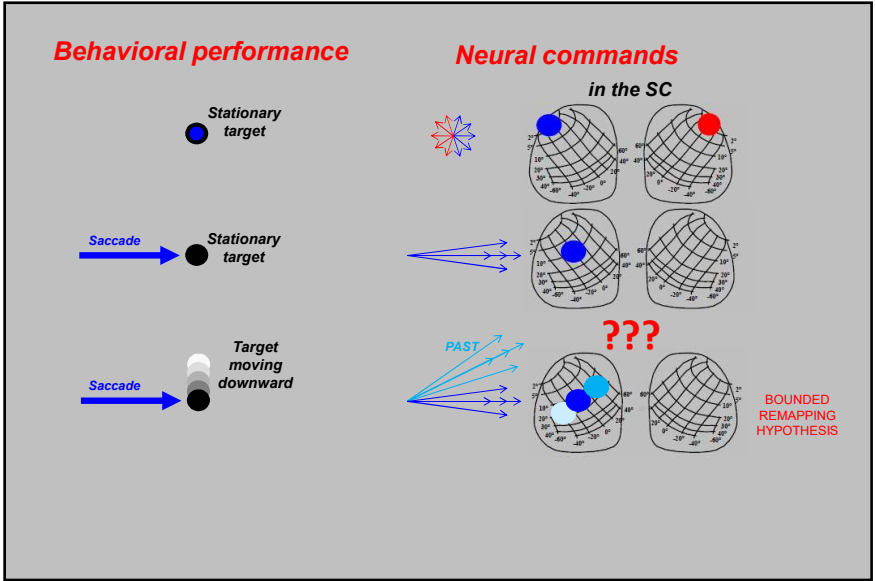
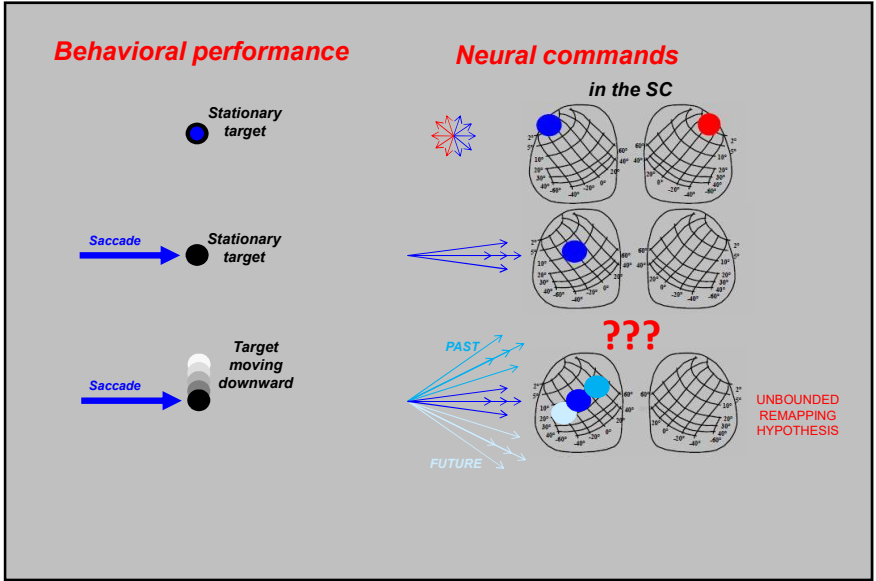
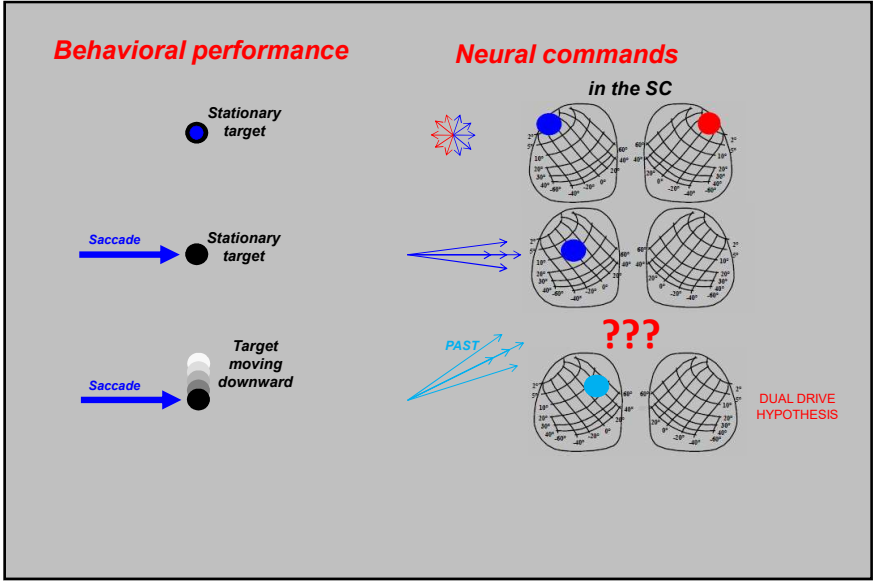
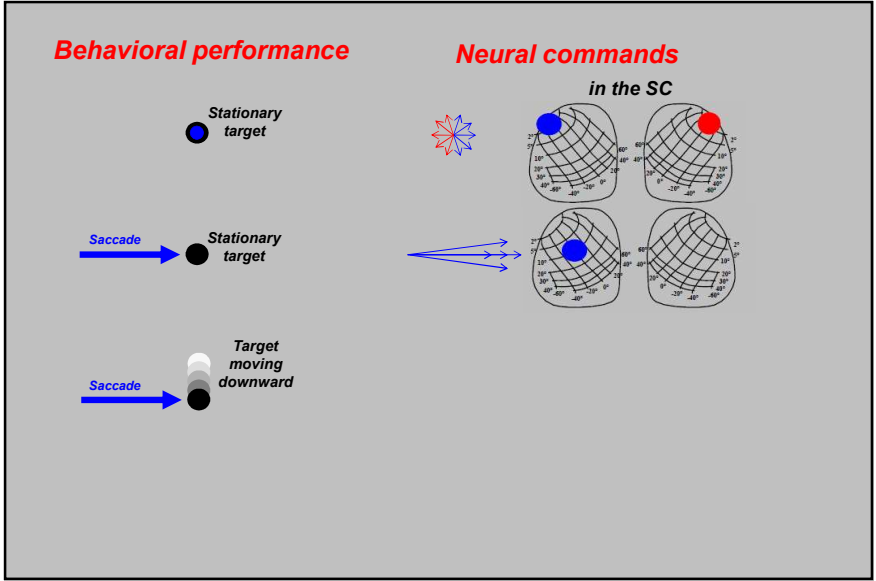


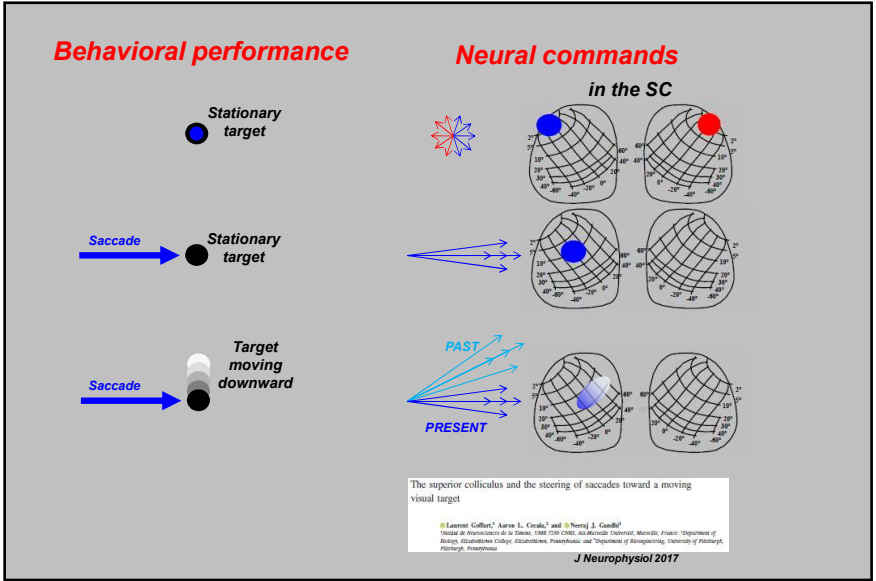
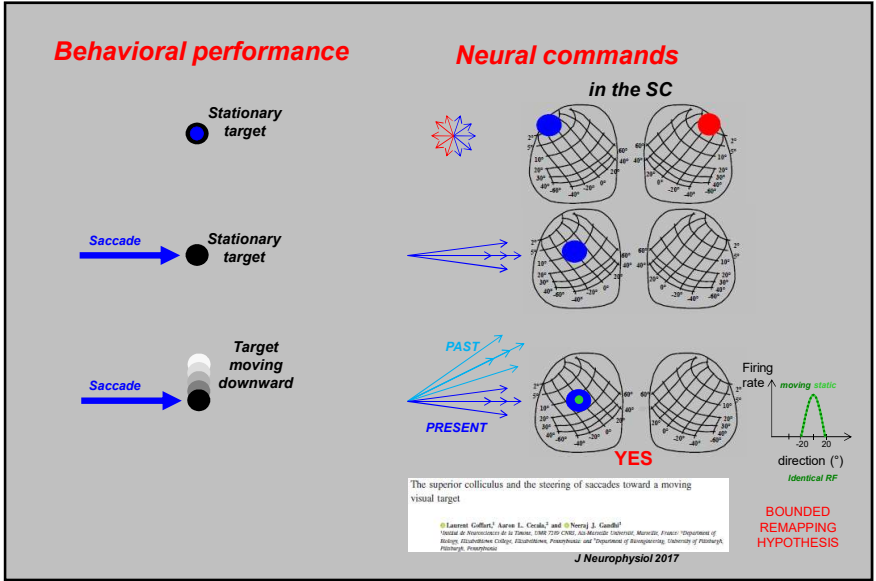
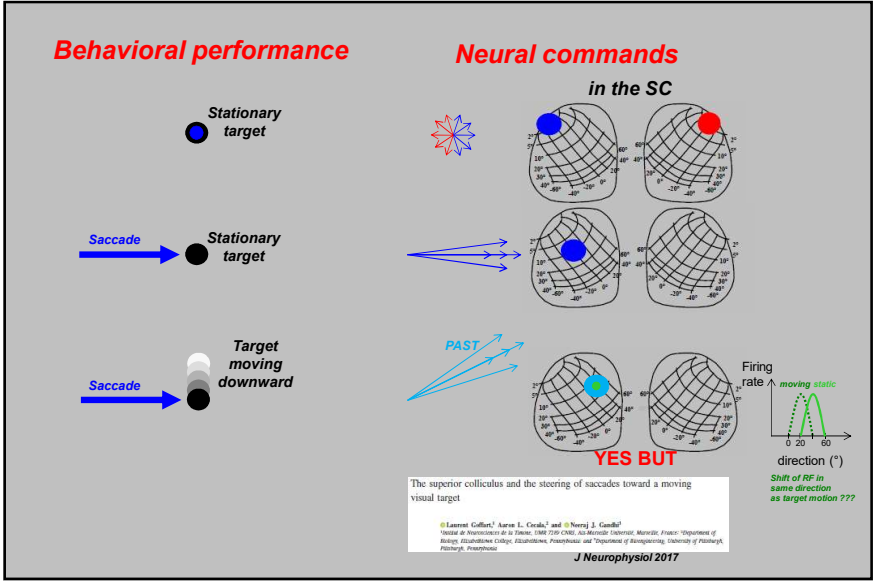
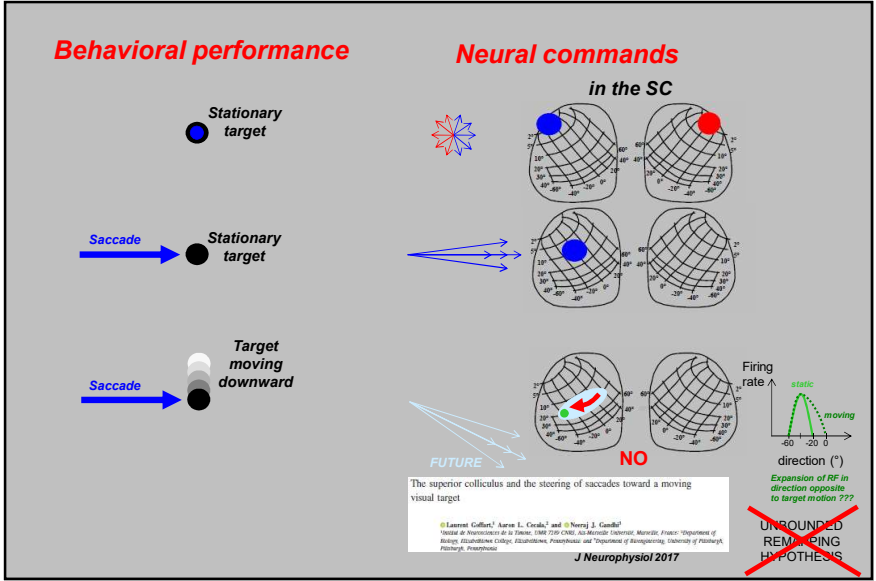
#### Remapping hypothesis "here and now" hypothesis NO SNAPSHOT

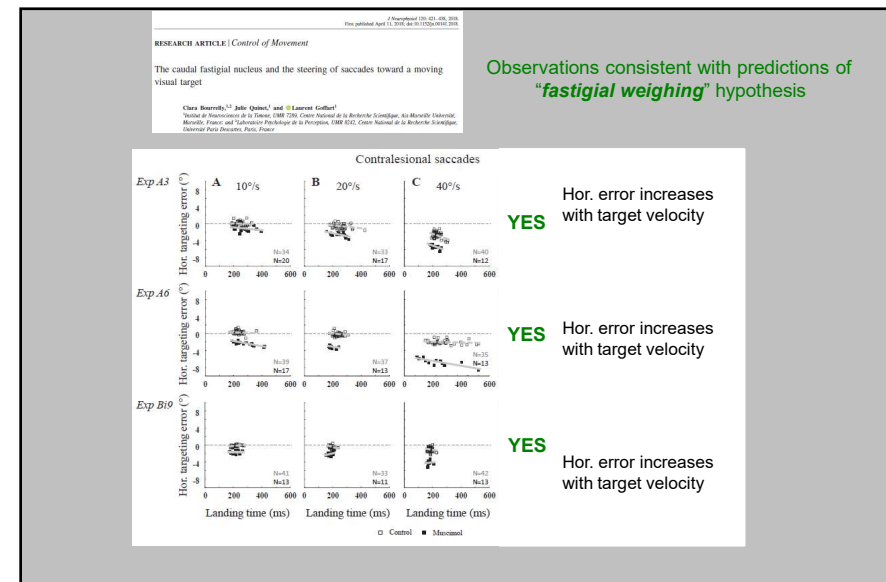
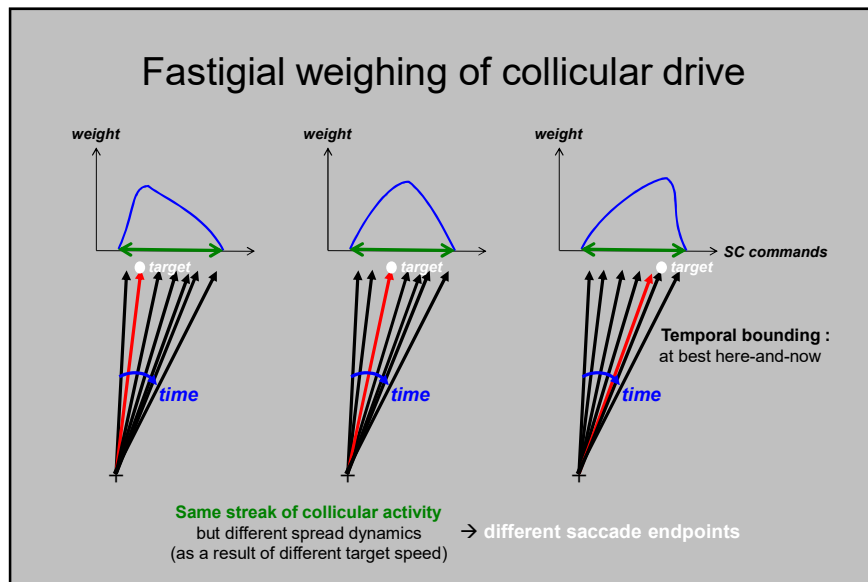
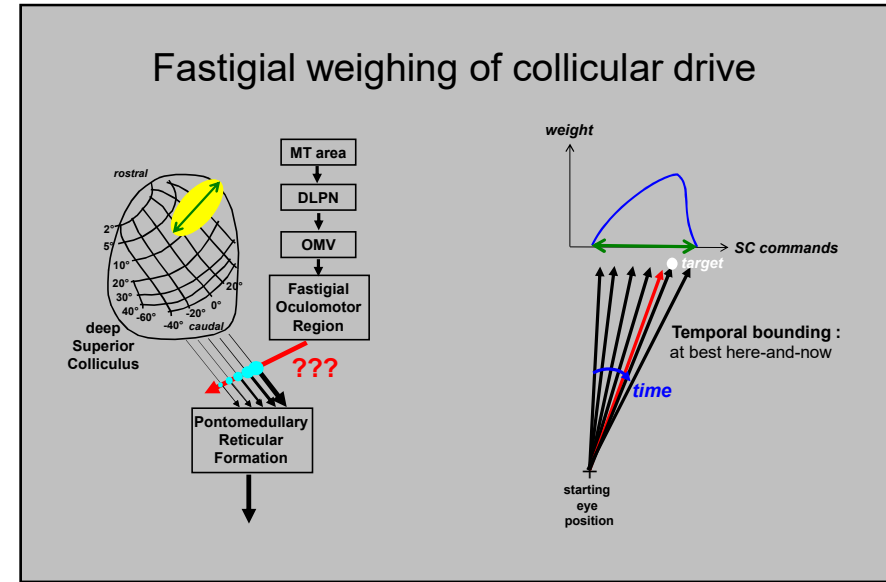
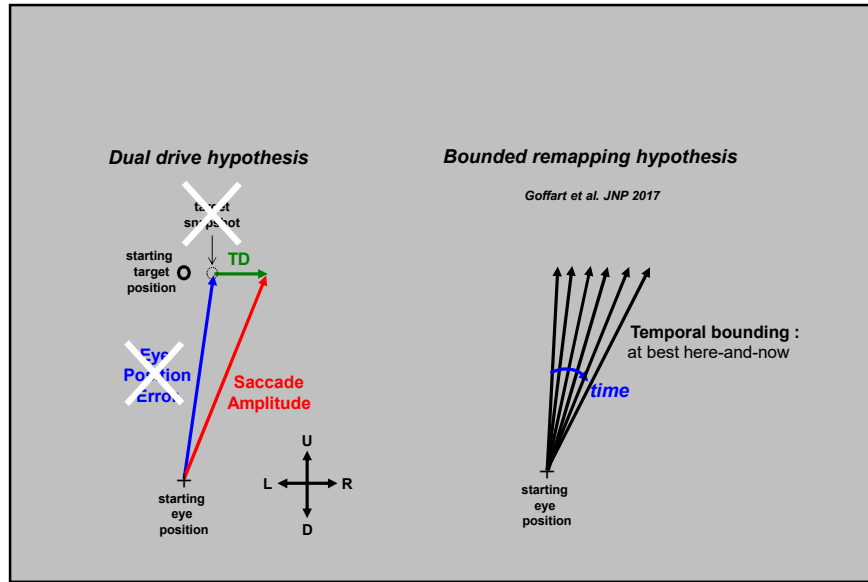
Fleuriet et al. JNP 2011  
Fleuriet & Goffart JN 2012  
Goffart et al. JNP 2017

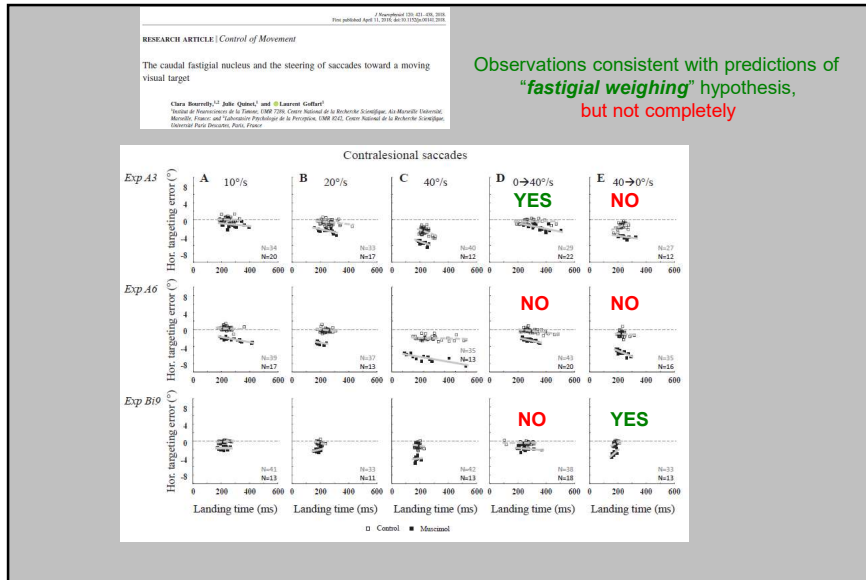








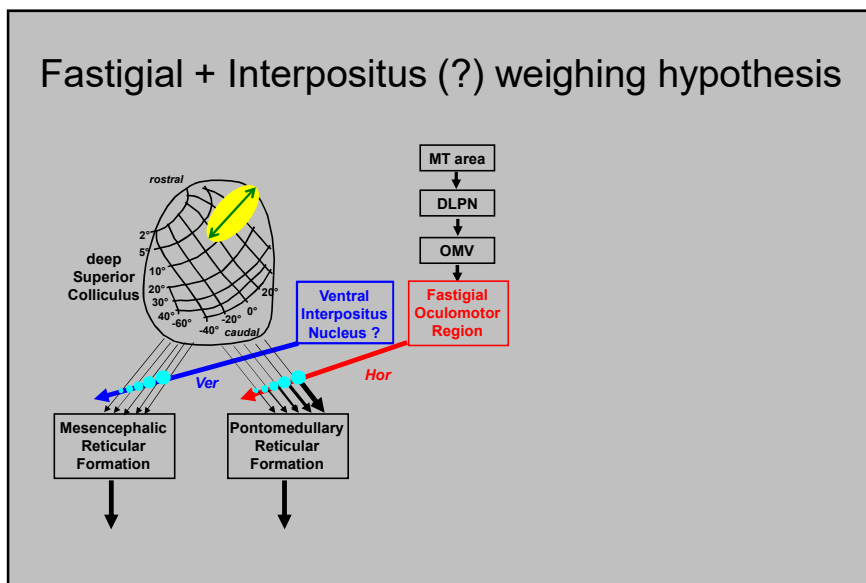




**HOP !!!**

**LIMITATIONS**

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



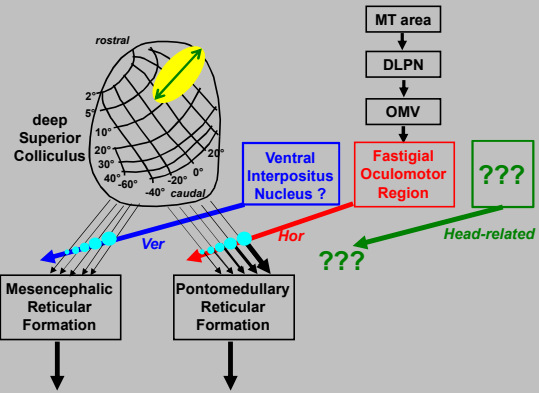
**HOP HOP!!!**

**MORE LIMITATIONS**

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

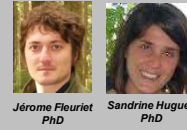
2. SC is a gaze-related structure (eye+head) whereas the CFN is oculomotor (Quinet & Goffart 2005; 2007; 2009; Fuchs et al. 2010)

# Fastigial + Interpositus (?) weighing hypothesis



# ACKNOWLEDGMENTS

## Behavioral studies Collicular perturbation



## Collicular unit recordings



## Fastigial inactivation

