

Complexité - désordre (organisateur : J-C S Lévy)  
Université Paris Diderot  
Paris 15-16 janvier 2018

## Neurophysiologie de la synchronisation visuomotrice locale

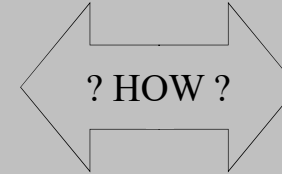
Laurent Goffart<sup>1,2</sup> & Clara Bourrelly<sup>1</sup>

CNRS

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

laurent.goffart.int@gmail.com

Object situated  
"here and now"  
in external world  
rigid object (x,y,z,t)

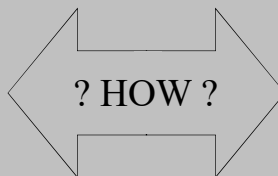


Representation  
spatio-temporally distributed  
in the brain activity  
dynamical flow  
akin to an explosion-contraction

*We do not address a problem related to perception*

*"Je n'emploie jamais le verbe percevoir, ni le substantif perception ... [car] j'ignore si la perception est une sensation ou un jugement"* (Henri Poincaré).

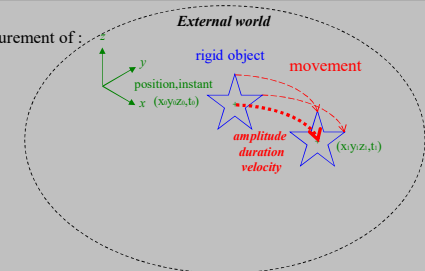
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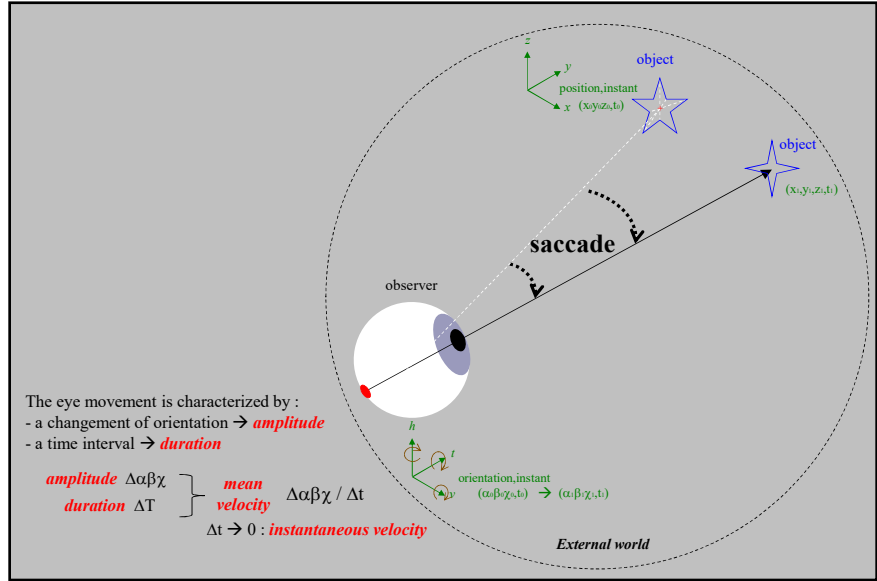
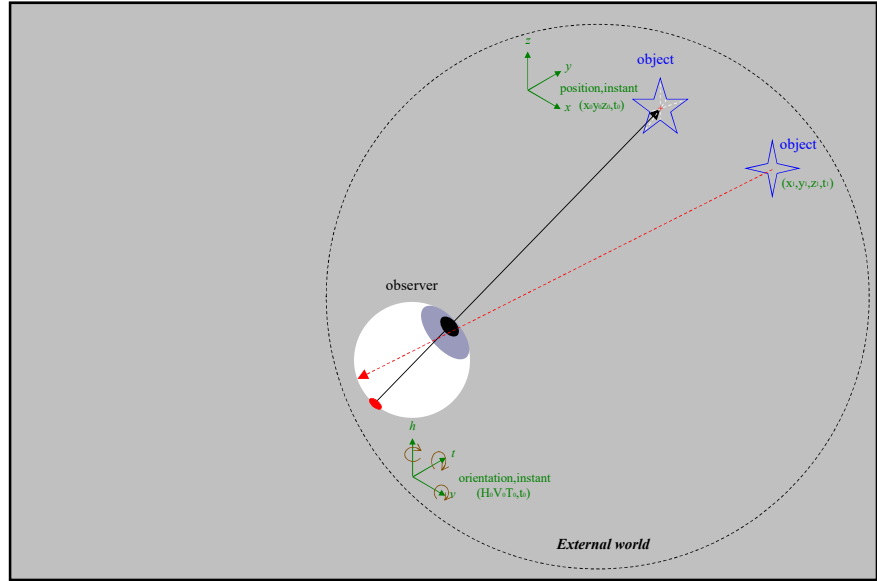
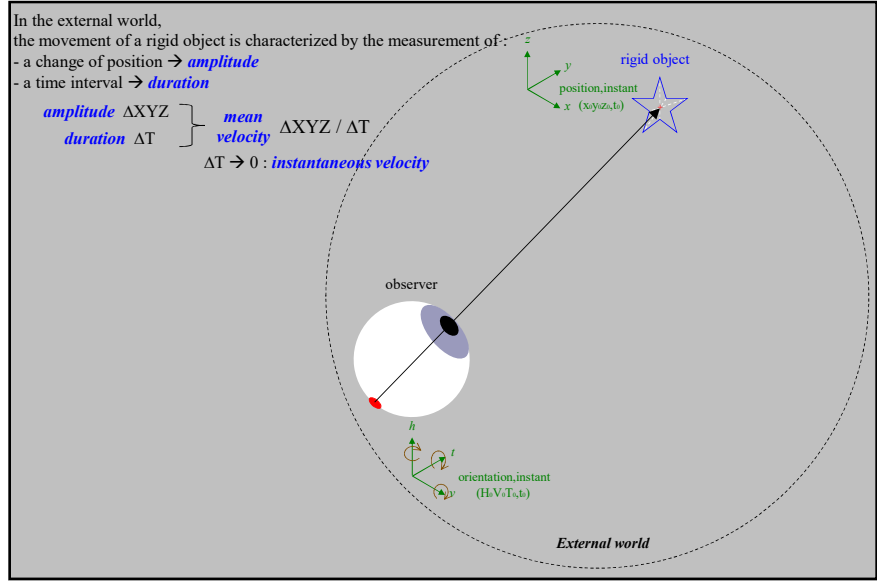
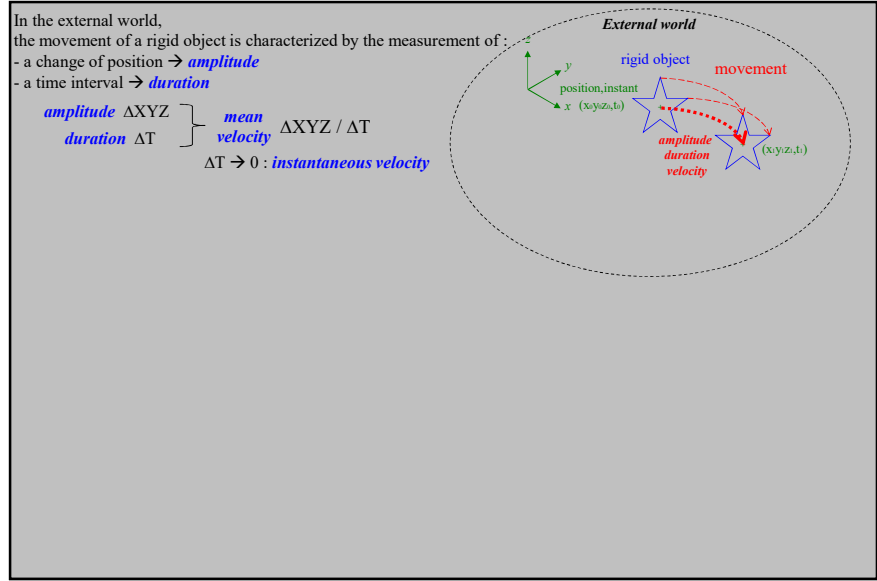


Representation  
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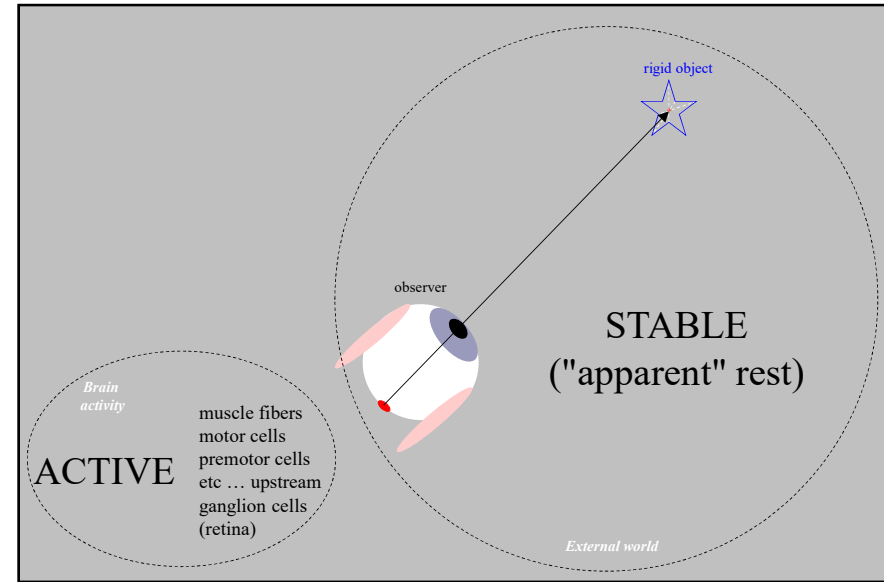
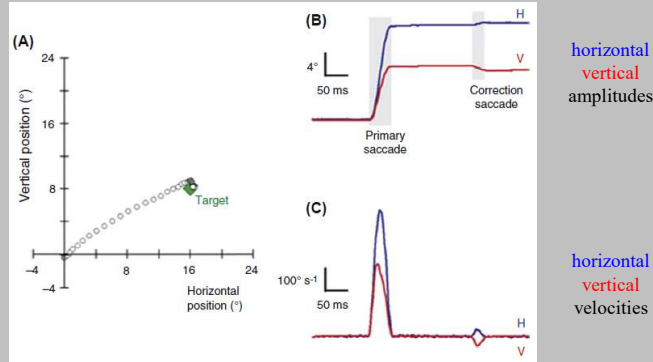
*How does the brain activity endows us with the ability to reach an object  
and to assign a reality to it ?*

In the external world,  
the movement of a rigid object is characterized by the measurement of :  
- a change of position → **amplitude**  
- a time interval → **duration**





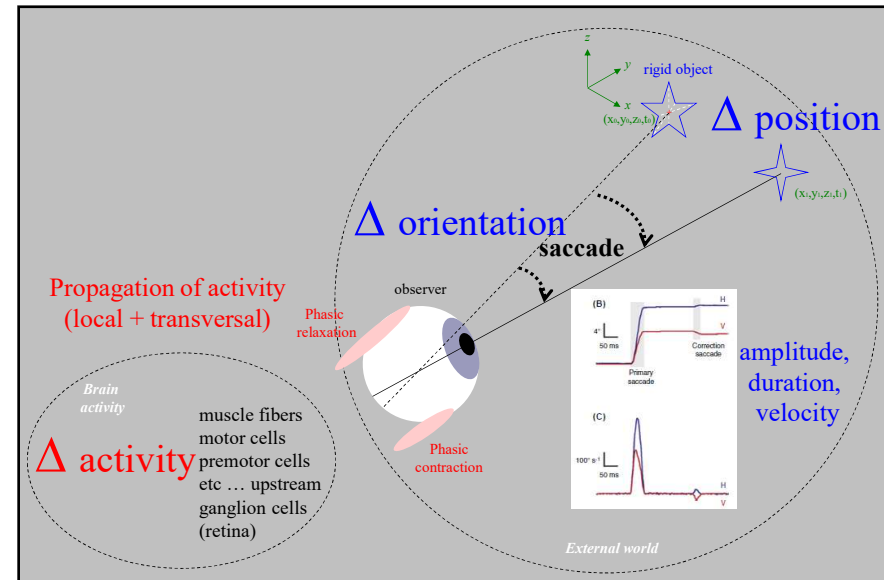
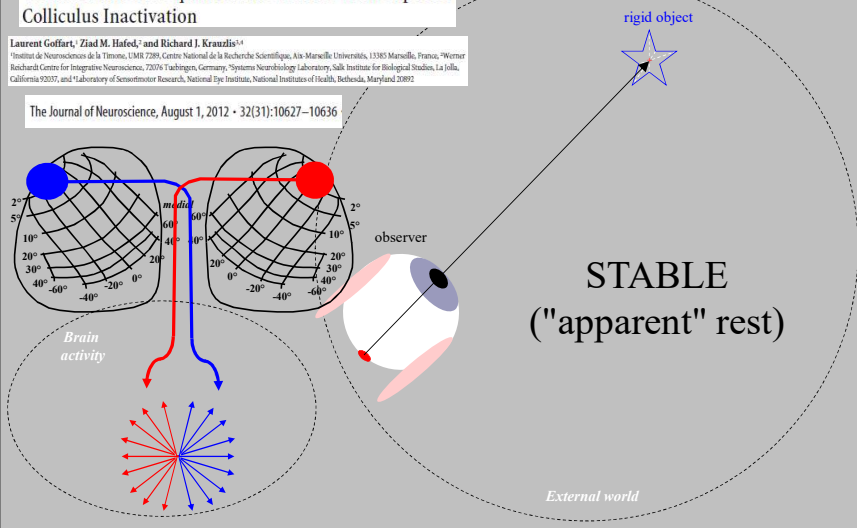
# The saccade toward a visual target



# Visual Fixation as Equilibrium: Evidence from Superior Colliculus Inactivation

Laurent Goffart, Ziad M. Hafed, and Richard J. Krauzlis<sup>1,2</sup>  
<sup>1</sup>Unité de Neurosciences de la Vision, UMR 7289, Centre National de la Recherche Scientifique, Aix-Marseille Université, 13385 Marseille, France; <sup>2</sup>Warner Research Center for Integrative Neuroscience, 720% Taubing, Germany; <sup>3</sup>Systems Neurobiology Laboratory, Salt Institute for Biological Studies, La Jolla, California 92037; and <sup>4</sup>Laboratory of Sensorimotor Research, National Eye Institute, National Institutes of Health, Bethesda, Maryland 20892

The Journal of Neuroscience, August 1, 2012 • 32(31):10627–10636

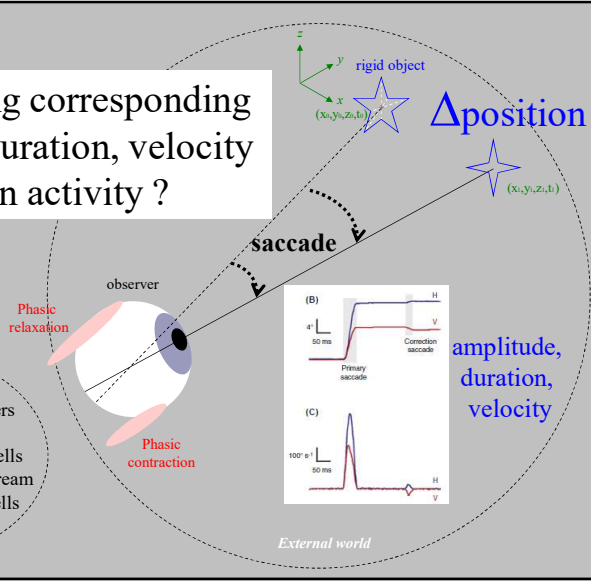


Is there anything corresponding to amplitude, duration, velocity in the brain activity ?

Propagation of activity (local + transversal)

$\Delta$  activity

muscle fibers  
motor cells  
premotor cells  
etc ... upstream  
ganglion cells  
(retina)



Is there anything corresponding to amplitude, duration, velocity in the brain activity ?

"Le cerveau dispose de modèles internes des lois de Newton" (Berthoz, Simplicity 2012)

The fact that we measure and characterize the movements of bodies using concepts from the classical mechanics does not imply that these concepts have corresponding "substrates" in the brain processes.

## The cerebral medium in a few words

Vascularized organ composed of neural and glial cells

**Non homogeneous and non uniform** distribution of neurons :

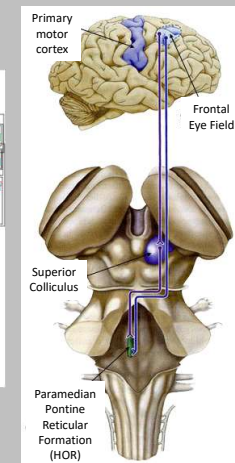
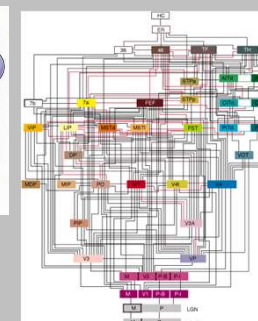
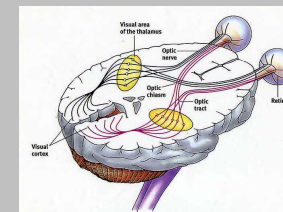
- clusters (nuclei)
- layers (cortical, sub-cortical or peripheral)
- diversity of neuronal shapes

Local connectivity

Distant connectivity through fibers (axons) clumped together into :

- bundles (intra-brain connections)
- sensitive or motor nerves (extra-brain connections)

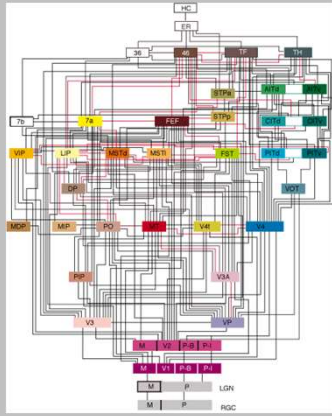
**Asymmetrical propagation** of neural activity but reciprocal connectivity is possible.



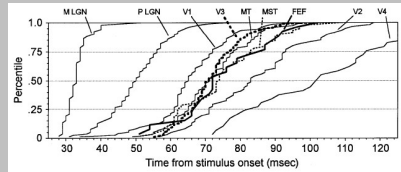
Largely incomplete schema

- Pulvinar
- Nucleus of Optical Tract
- Superior Colliculus
- etc ...

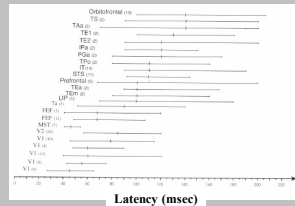
# Spatio-temporally distributed activity



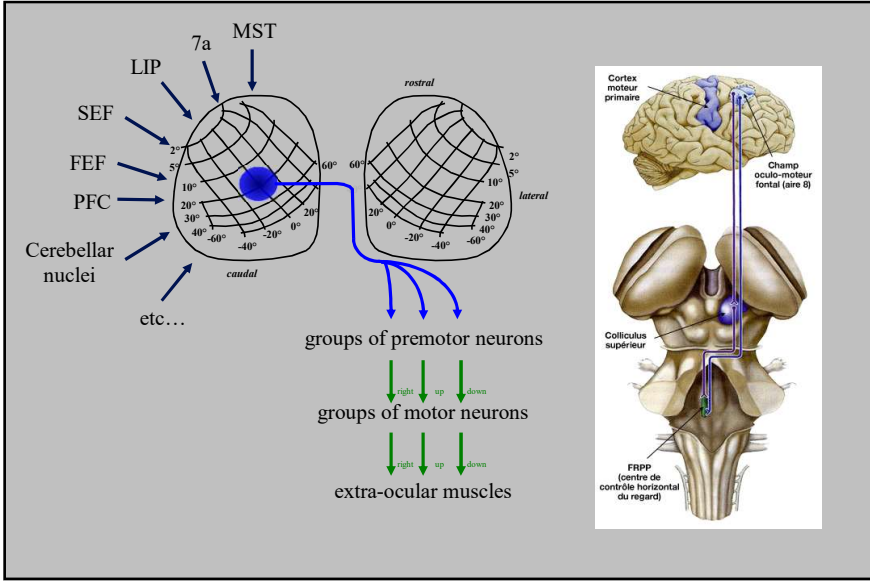
Felleman & van Essen Cerebral cortex 1991



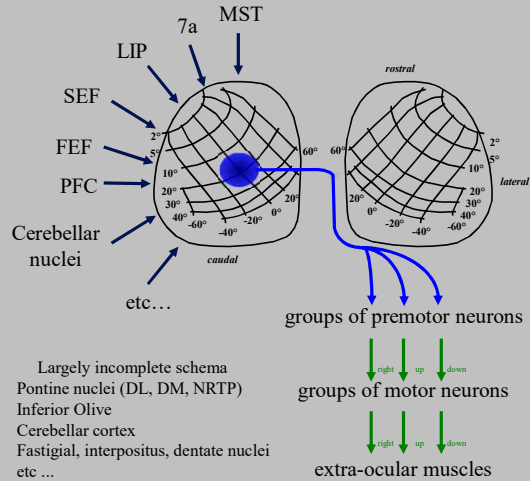
Schmolesky et al. J Neurophysiol 1998



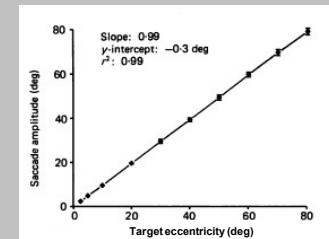
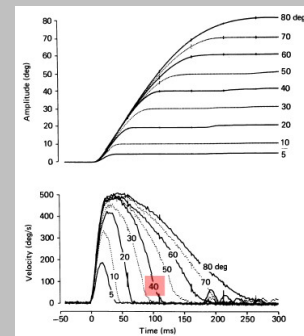
Nowak & Bullier Cerebral cortex: extrastriate cortex in primates 1997



# Converging input to the Superior Colliculus

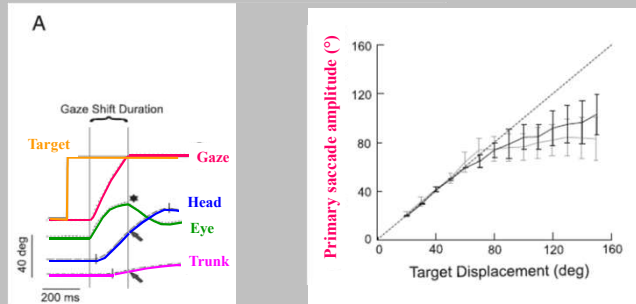


# Eye saccades in the human primate



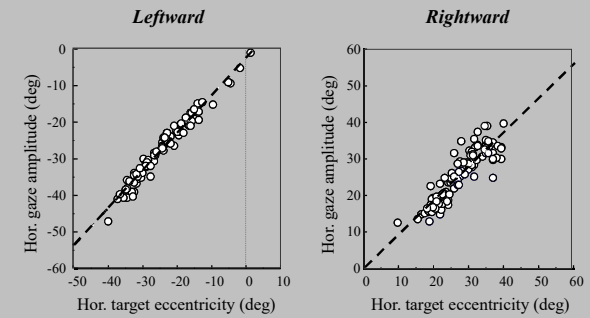
Collewijn et al J Physiol 1988

## Gaze saccades in the non-human primate

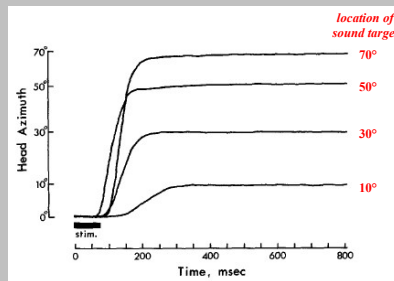


McCluskey & Cullen *J Neurophysiol* 2007

## Gaze saccades in the cat



## Head saccades in the barn owl

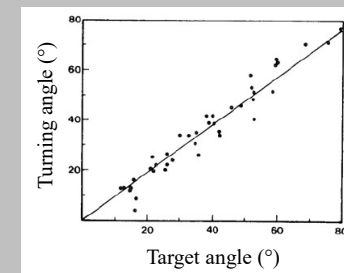


Knudsen, Blasdel & Konishi *J Comp Physiol* 1979

## Head saccades in the salamander

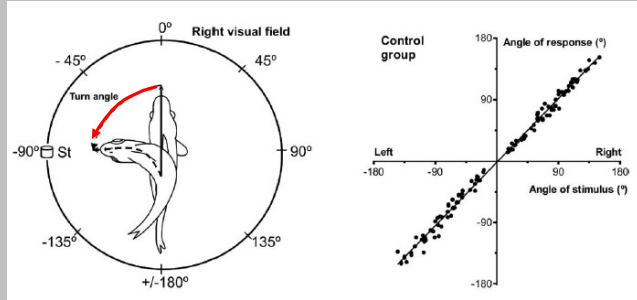


Schülert & Dicke *J. Exp Biol* 2002



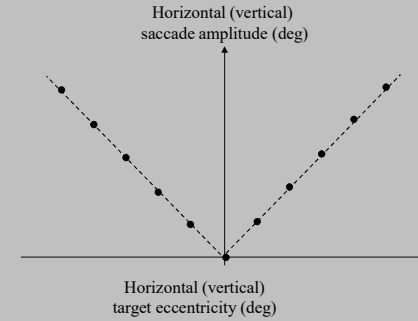
Werner & Himstedt  
*Zool Jb Physiol* 1985

## Body saccades in the goldfish



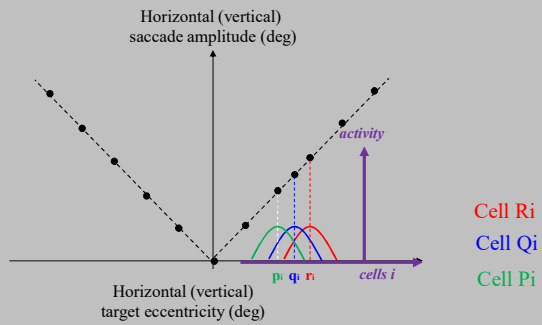
Torres et al. Brain Res Bull 2005

## Metrical relation between two continuums



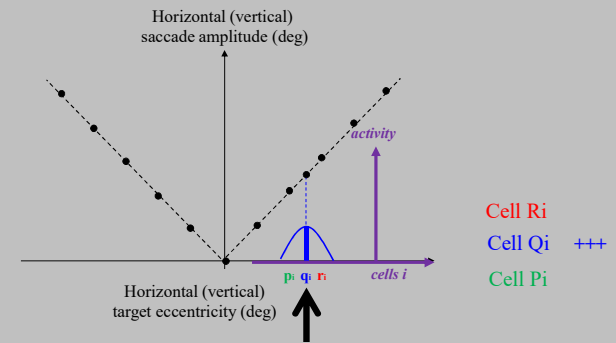
*The notion of continuity is acceptable in the medium of brain functioning because of overlapping response fields*

## Metrical relation between two continuums



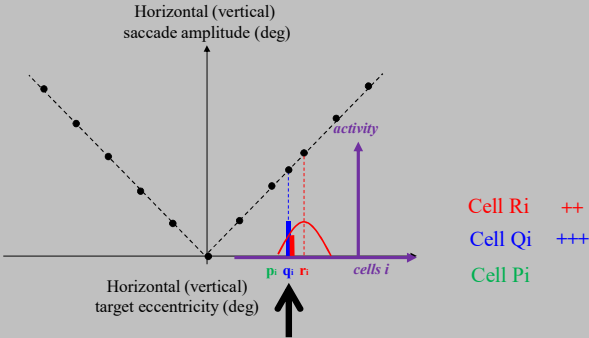
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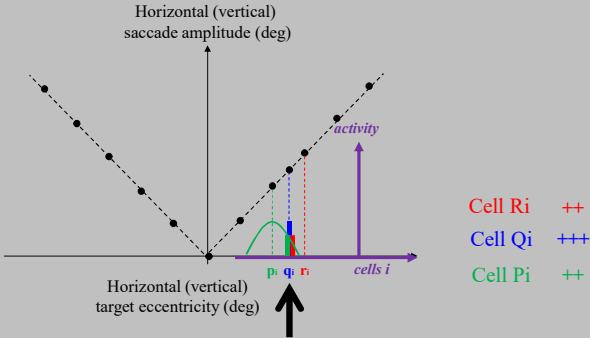
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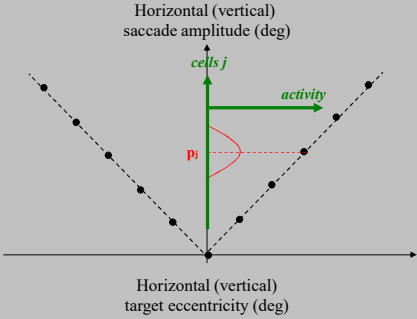
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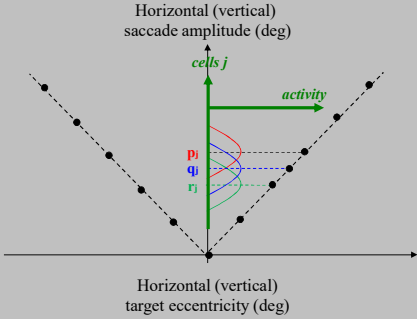
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# Metrical relation between two continuums



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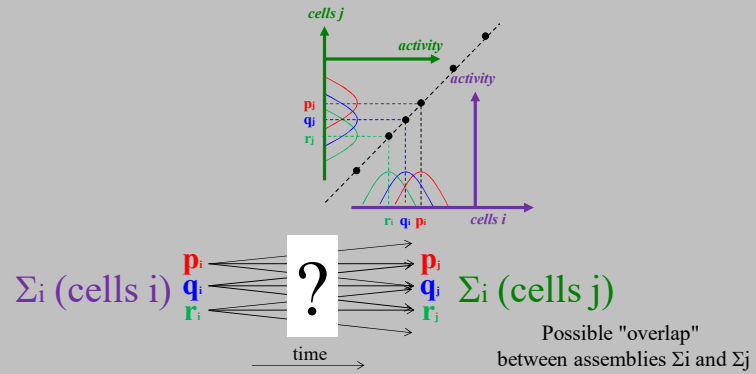
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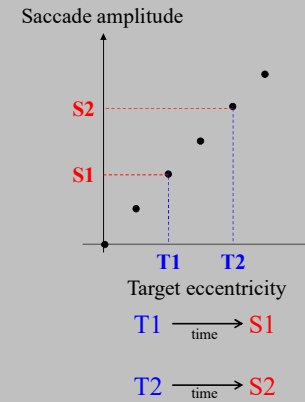
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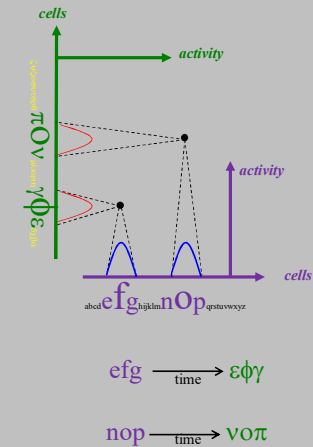
Metrical relation between two continuums  
 →  
 Propagation of activity between cell assemblies



"Newtonian space"

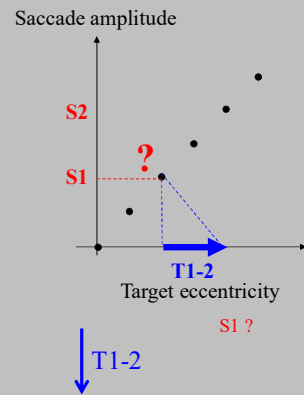


"Brain activity"



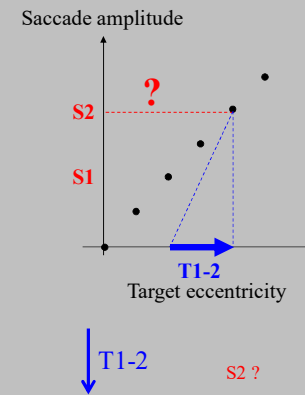
"Newtonian space"

Moving target (brief motion)



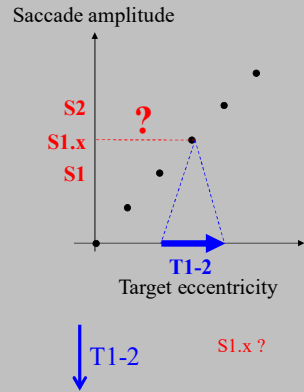
"Newtonian space"

Moving target (brief motion)



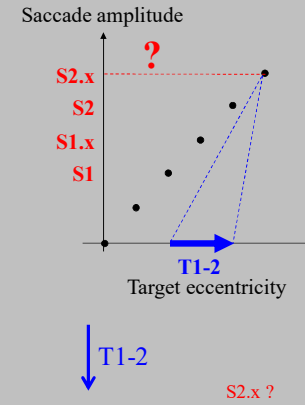
# "Newtonian space"

## Moving target (brief motion)



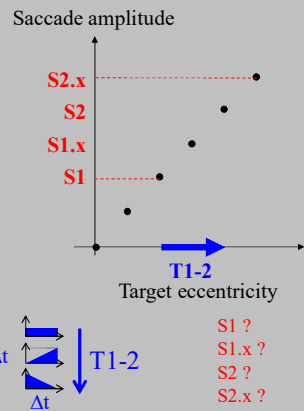
# "Newtonian space"

## Moving target (brief motion)



# "Newtonian space"

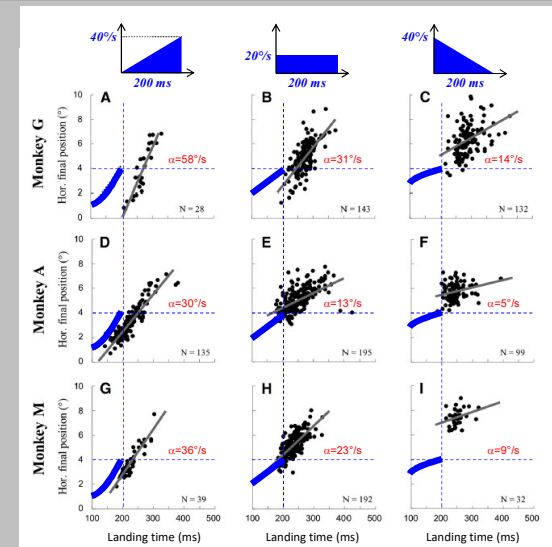
## Moving target (brief motion)

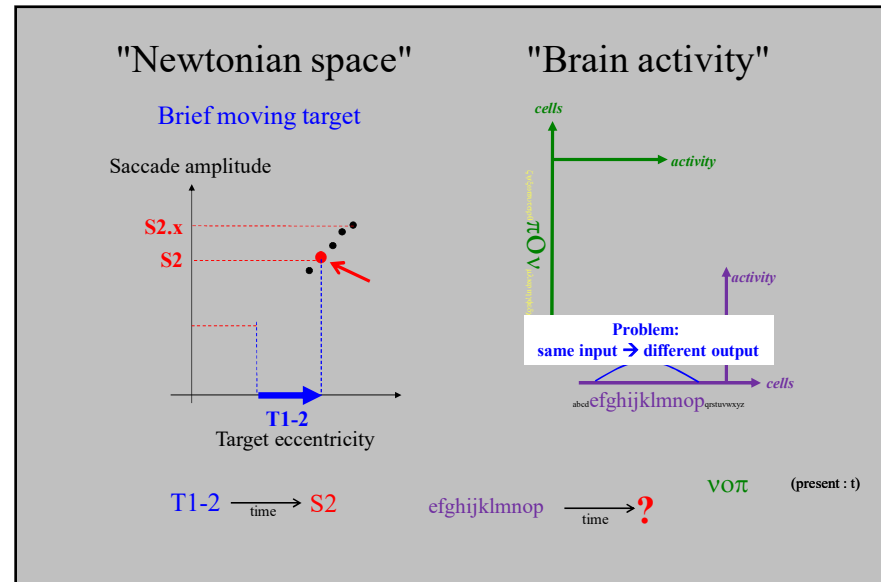
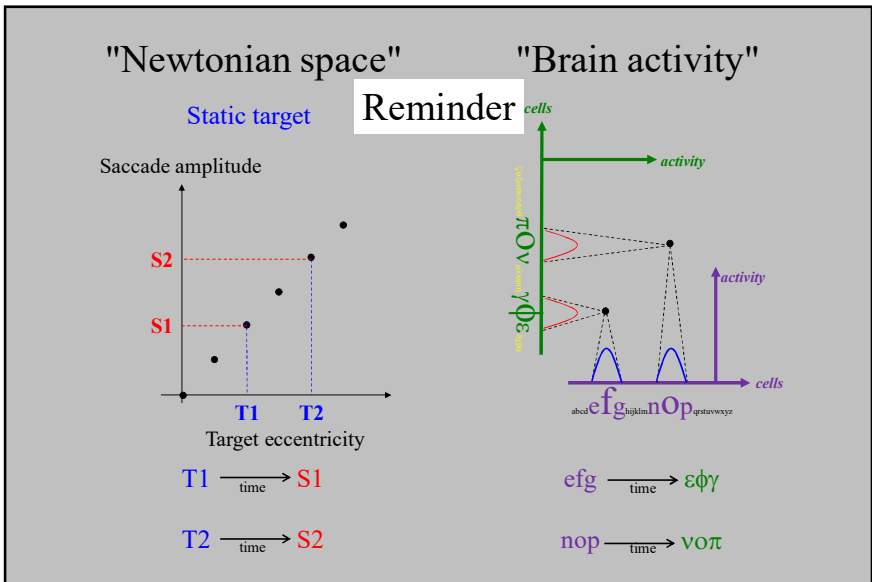
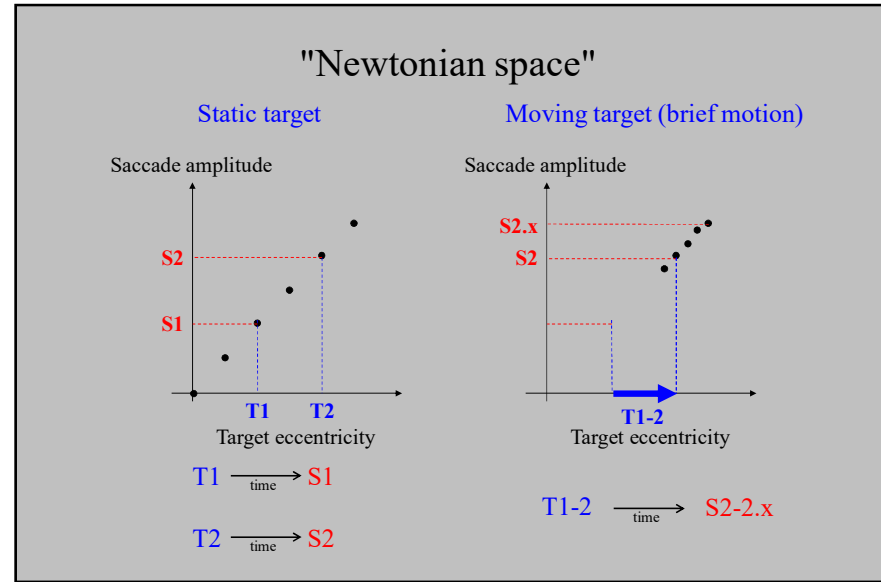
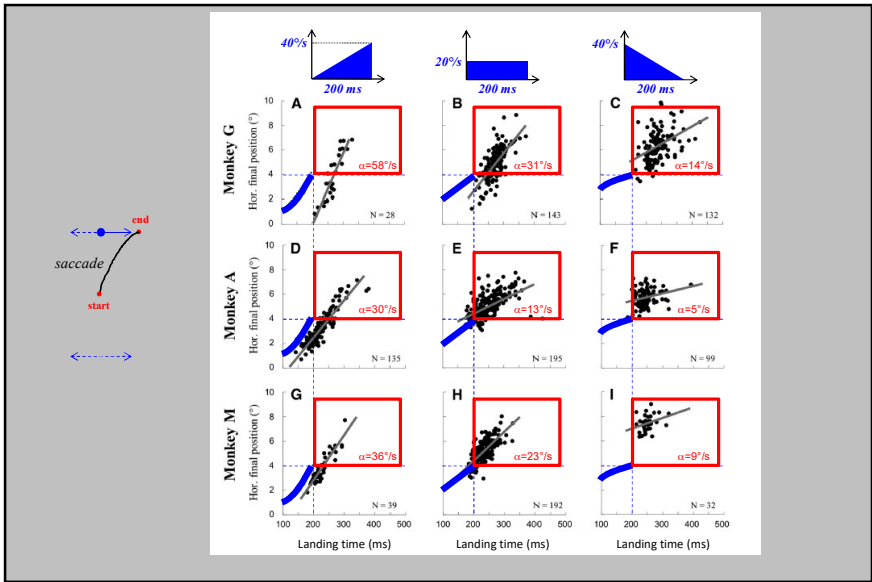


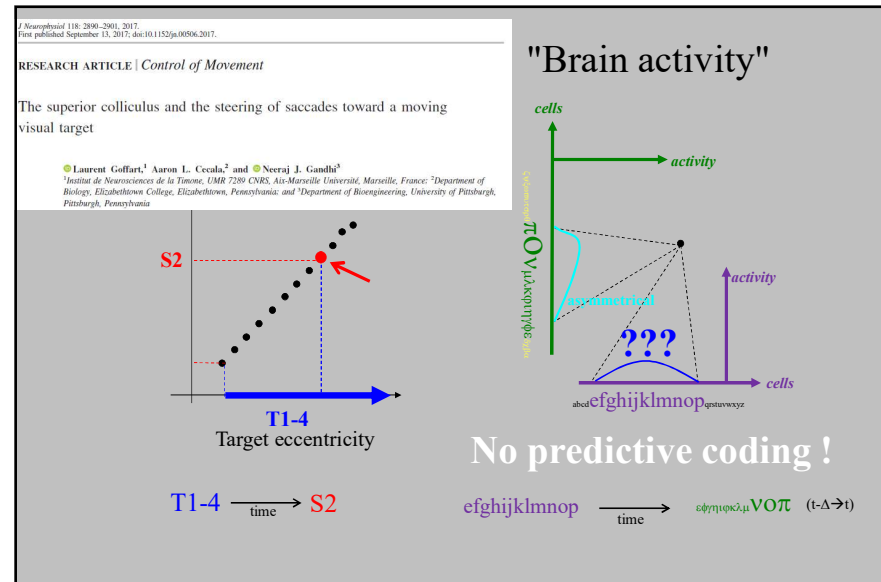
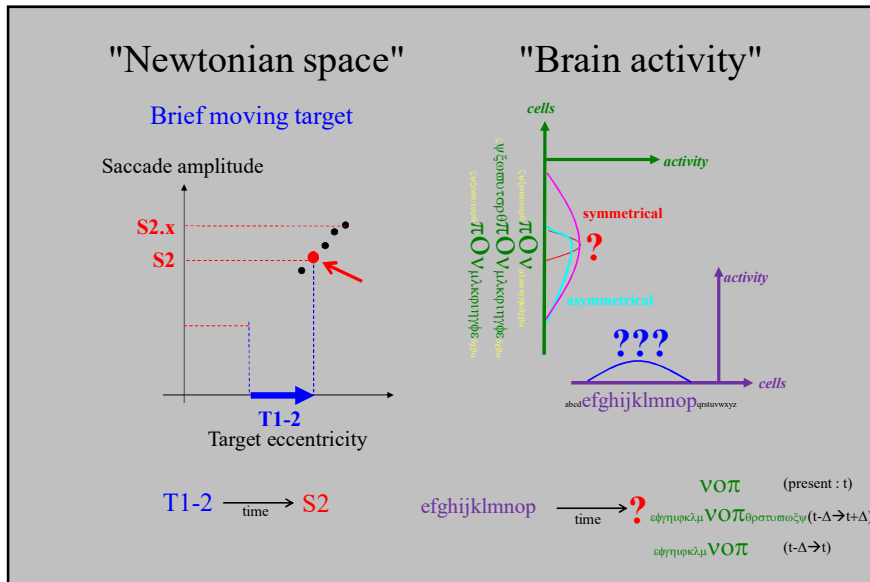
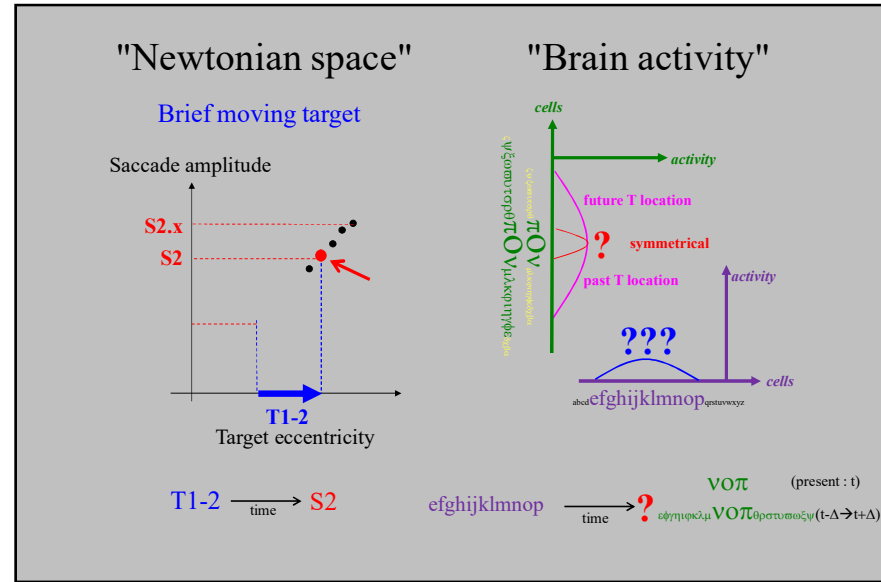
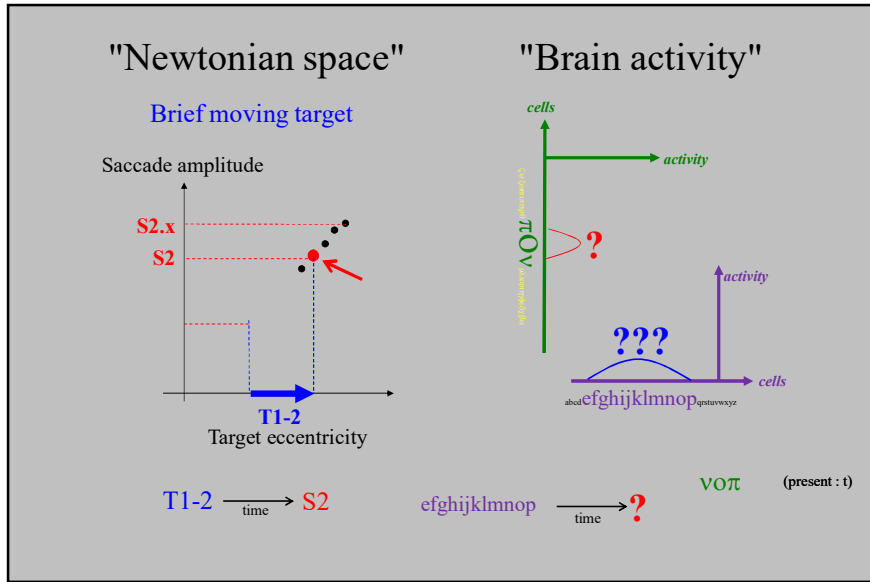
Does the Brain Extrapolate the Position of a Transient Moving Target?

Julie Quiñet and Laurent Goffart  
 Institut de Neurosciences de la Timone, Unité Mixte de Recherche, 7289 Centre National de la Recherche Scientifique, Aix-Marseille Université, 13385 Marseille Cedex 5, France

The Journal of Neuroscience, August 26, 2015 • 35(34):11780–11790



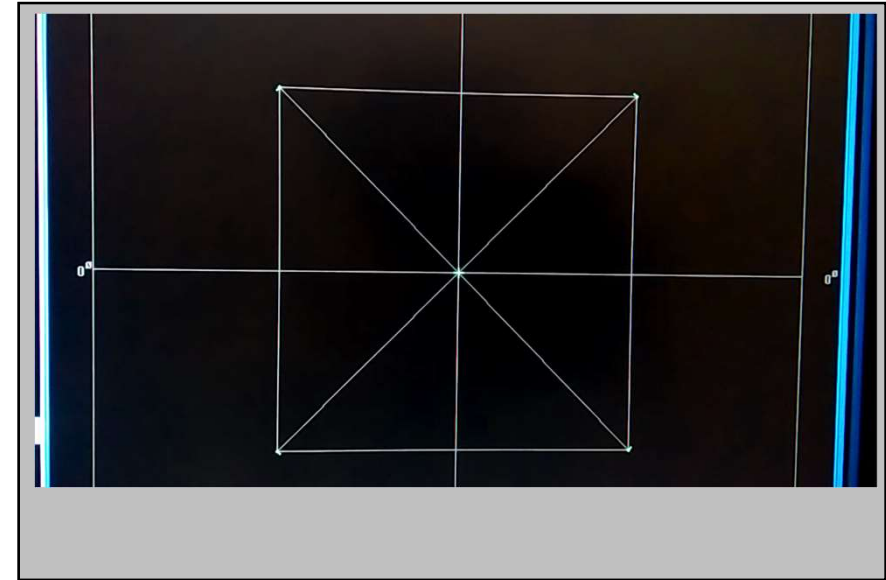
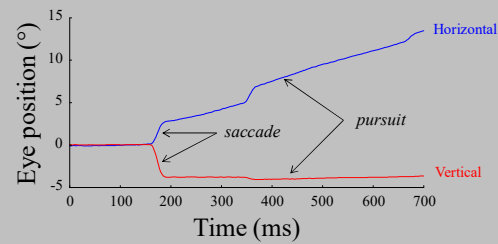




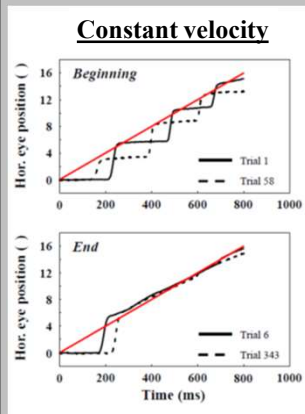
## Two types of eye movement in response to the constant and uniform motion of a target

rapid : saccade  
slow: smooth pursuit

*Largely distinct populations of neurons*



## Learning to track a moving target

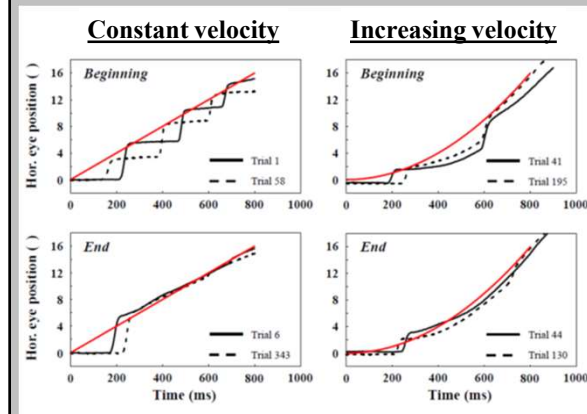


*J Neurophysiol* 116: 2739-2751, 2016.  
First published September 28, 2016; doi:10.1152/jn.0019.2016.

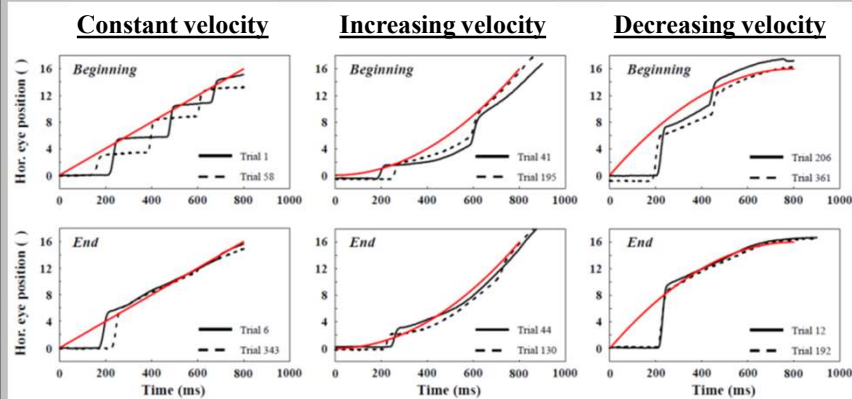
Learning the trajectory of a moving visual target and evolution of its tracking in the monkey

Clara Bourrelly,<sup>1,2</sup> Julie Quinet,<sup>1</sup> Patrick Cavanagh,<sup>2</sup> and Laurent Goffart<sup>1</sup>  
<sup>1</sup>Institut de Neurosciences de la Timone, UMR 7289, Centre National de la Recherche Scientifique, Aix-Marseille Université, Marseille, France; and <sup>2</sup>Laboratoire Psychologie de la Perception, UMR 8242, Centre National de la Recherche Scientifique, Université Paris Descartes, Paris, France

## Learning to track a moving target



## Learning to track a moving target



## Synchronization instead of prediction

Synchronizing the tracking eye movements with the motion of a visual target: **12**  
Basic neural processes

Laurent Goffart<sup>\*1</sup>, Clara Bourrelly<sup>\*1</sup>, Julie Quinet<sup>\*</sup>  
<sup>\*</sup>Institut de Neurosciences de la Timone, UMR 7289, Centre National de la Recherche Scientifique, Aix-Marseille Université, Marseille, France  
<sup>1</sup>Laboratoire Psychologie de la Perception, UMR 5342, Centre National de la Recherche Scientifique, Université Paris Descartes, Paris, France  
<sup>1</sup>Corresponding author: Tel.: 33 4 91 32 40 52; Fax: 33 4 91 32 40 56, e-mail address: laurent.goffart.int@gmail.com

*Progress in Brain Research*, vol. 236, pp 243-268, 2017.

Any neural event involves a population of neurons  
 Neural transmission is facilitated by synchronized excitatory input  
 Increasing to size of the population of neurons favors the probability of synchronized activity  
 The population activity is asymmetrically distributed and gradually adjusted through learning

## Conclusion

According to several contemporary authors, the Newtonian laws of mechanics would be internalized in the inner functioning of the brain. Yet this formalism assumes that the measured phenomenon happen in a homogeneous, uniform and inert receptacle (mathematical space) characterized by two disjoined things : space and time.

BUT the medium of neuronal processes is not homogeneous, not isotropic, not infinite, not inert, not permanent and the functional elements corresponding to objects are not rigid.

If the position of a rigid object in the world can be described (measured) by spatial (position xyz) and temporal (instant t) coordinates, in the medium of brain functioning, a target is re-presented by flows of activity which propagate transversally (from the ganglion cells in the retina to the motor neurons and muscle fibers) and spread laterally (at the level of each relay).

If one considers a simple light spot, well delimited in the visual field, the visuomotor flows, to which the spot is associated, consist of an "**arborescent expansion**", spatially and temporally (persistence), followed by a "**contraction**" where duration mostly matters, a duration which can be "enlarged" insofar as the eye movements can be accompanied by a movement of the head.

In other words, if the trajectory of a rigid body in the world can be described by a thickless line (a time function), its re-presentation in the brain activity is "spatially" and "temporally" different ; it is diffusing and elastic.

The cerebral medium is **not** inert and permanent either ; it is plastic and changing. The ability to pursue with gaze a target here and now, to **synchronize** the eye movements with the target motion is not a spontaneous behavior ; it requires a learning during which the brain functioning changes (augmentation of resources).

## Conclusion (end)

For several years, a confusion has been made in the neurosciences of movement between the measurement and the measured phenomenon.

The limitations of measurement and the associated theoretical notions have led to imagine wrong options.

The gaze is neither a point nor a line, the visual field is neither homogeneous nor isotropic.

The neuronal processes unfold and determine the actual movement ; removing the notion of "future" from the axioms does not lead to contradictions (not yet ☺). This viewpoint considers that the brain and the behavior evolved in a world filled with uncertainties. It is more adaptive to generate movements which fit with the present conditions than with those imagined to happen in the future.

The extrapolation presents an horizon beyond which the neural representation stagnates and starts disintegrating

## Acknowledgements



*Julie Quinet*  
*PhD*



*Clara Bourrelly*  
*PhD*



European Research Council  
Established by the European Commission  
Grant POSITION  
(head: Patrick Cavanagh)



Fondation  
Berthe Fouassier  
(Julie Quinet)



FONDATION  
RECHERCHE  
MÉDICALE  
(Clara Bourrelly)



**for supporting the freedom  
to challenge the dogmas  
and move beyond the frontiers**