

What neurophysiology  
do I need to know?

Dominik Straumann

# Different approaches

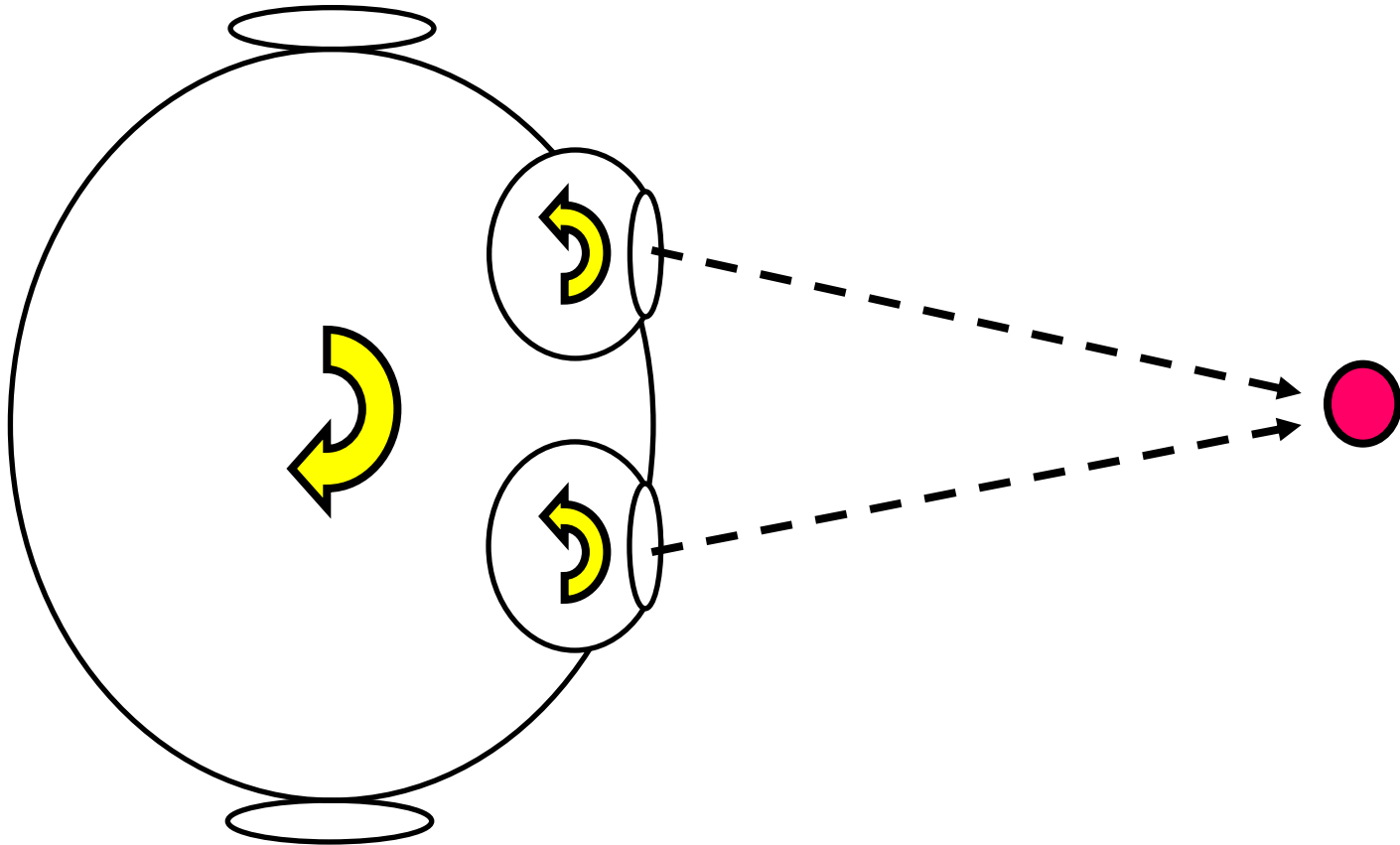
- anatomical approach  
functions of neural structures
- phenomenological approach  
description & explanation of phenomena in  
healthy subjects & patients

# Many topics...

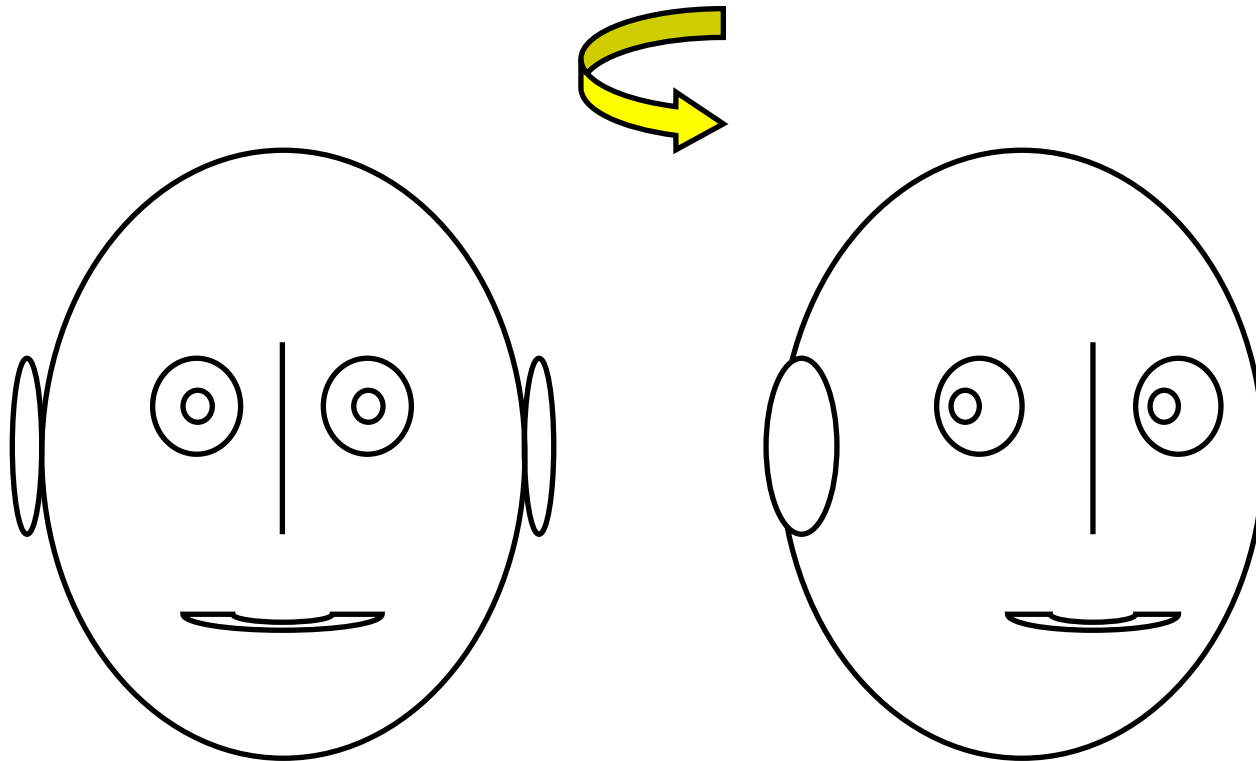
- frequency-dependence of the angular VOR
- acceleration & velocity steps
- velocity-to-position mechanism
- vestibular canal asymmetry
- velocity-to-position
- Alexander's law
- vestibular push-pull mechanism
- Ewald's second law & head impulses
- linear VOR
- tilt vs. translation dilemma, ocular counterroll
- Coriolis stimulation

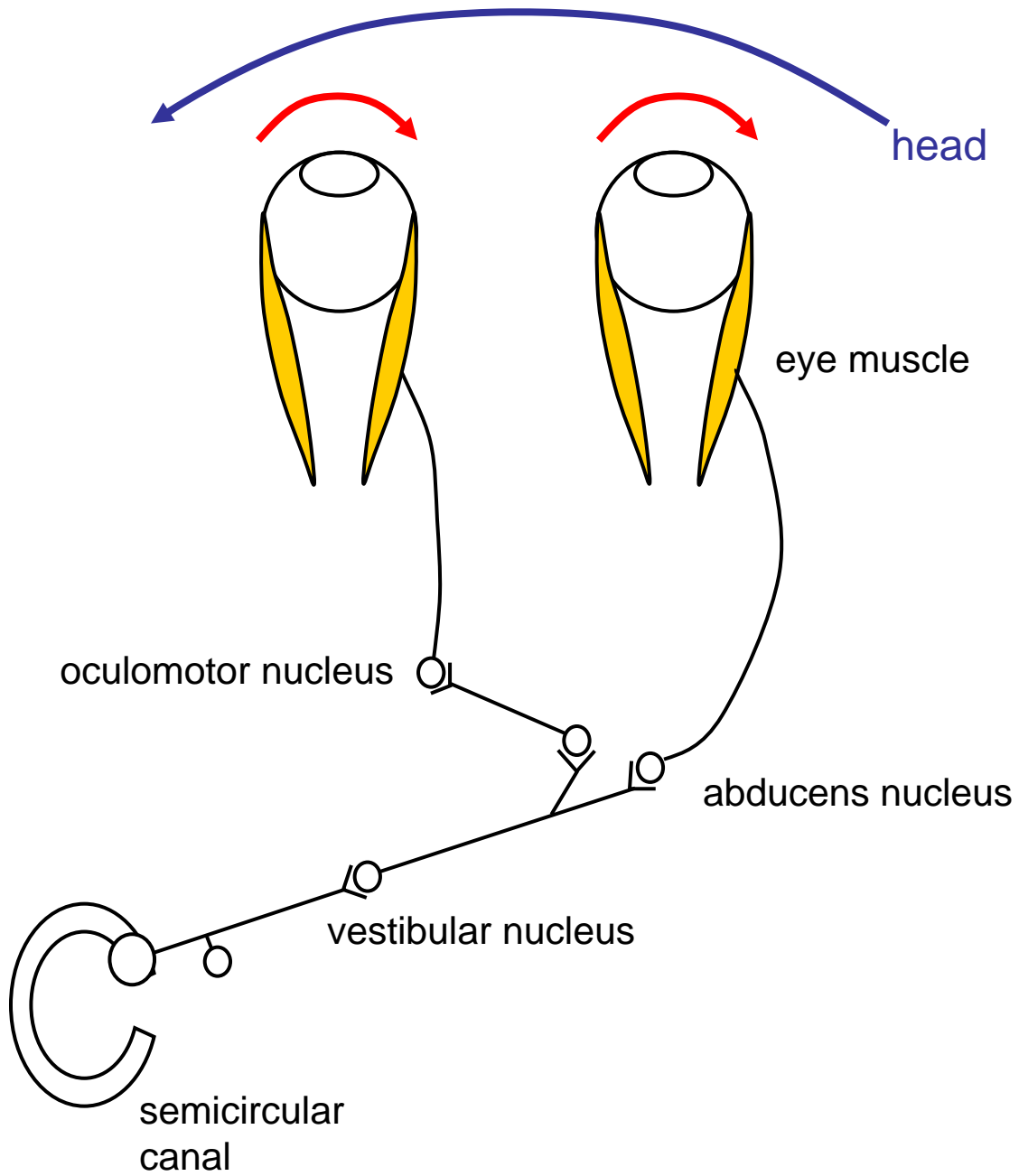
**Let's start!**

# angular Vestibulo-Ocular Reflex (aVOR)



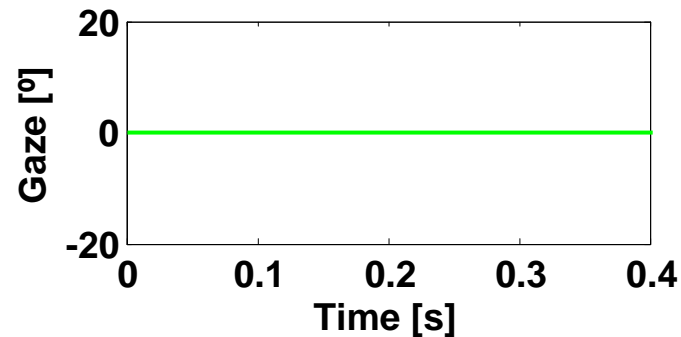
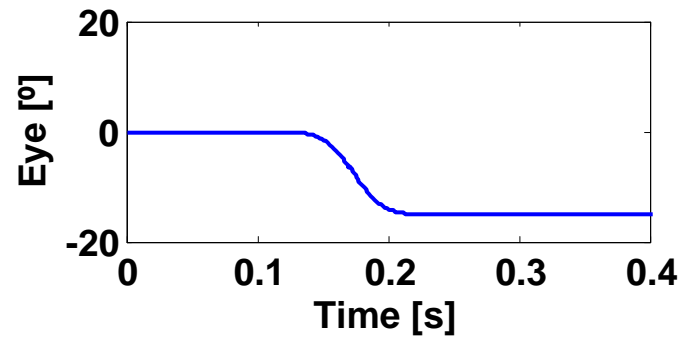
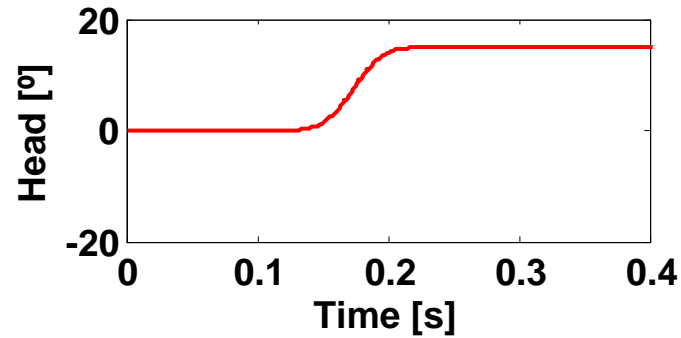
# Gaze stabilization in space





# Head, Eye, Gaze

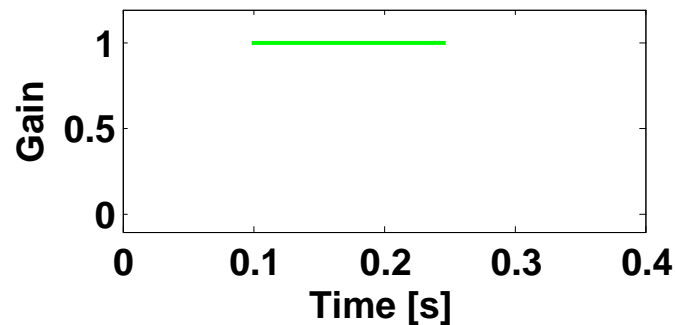
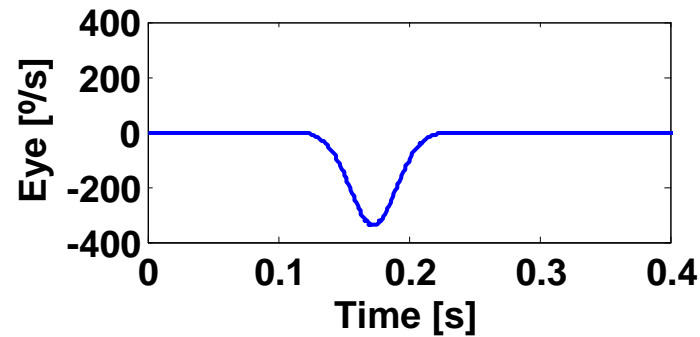
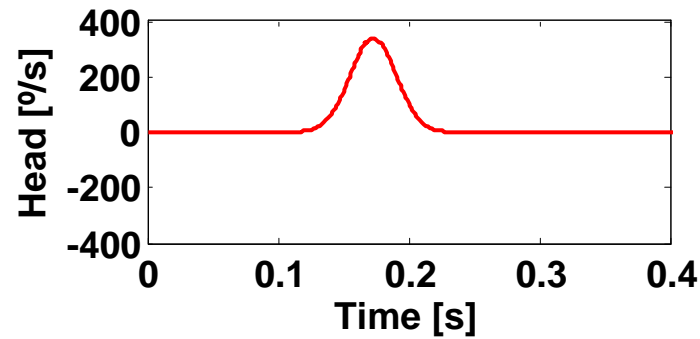
„perfect“ VOR



**gaze = head + eye**  
(„eye-in-space“)

# Velocity, gain

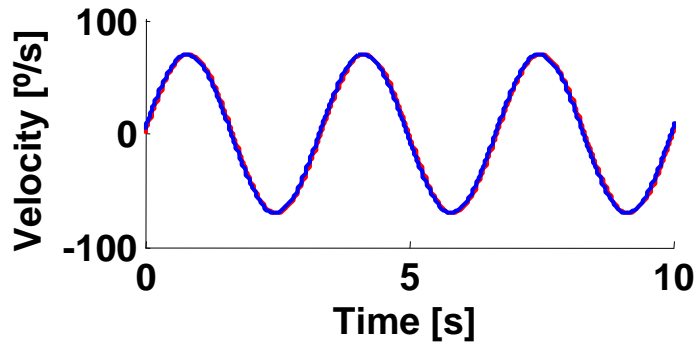
„perfect“ VOR



$$\text{gain} = \frac{\text{eye velocity}}{\text{- head velocity}}$$

# Frequency dependence

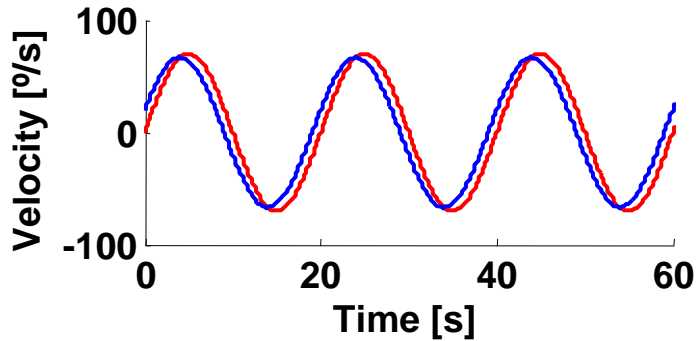
0.3 Hz



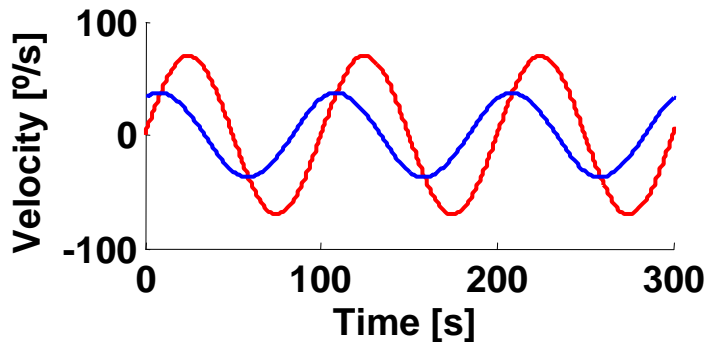
— -head  
— eye

gain  $\approx 1$   
phase  $\approx 0$

0.05 Hz



0.01 Hz

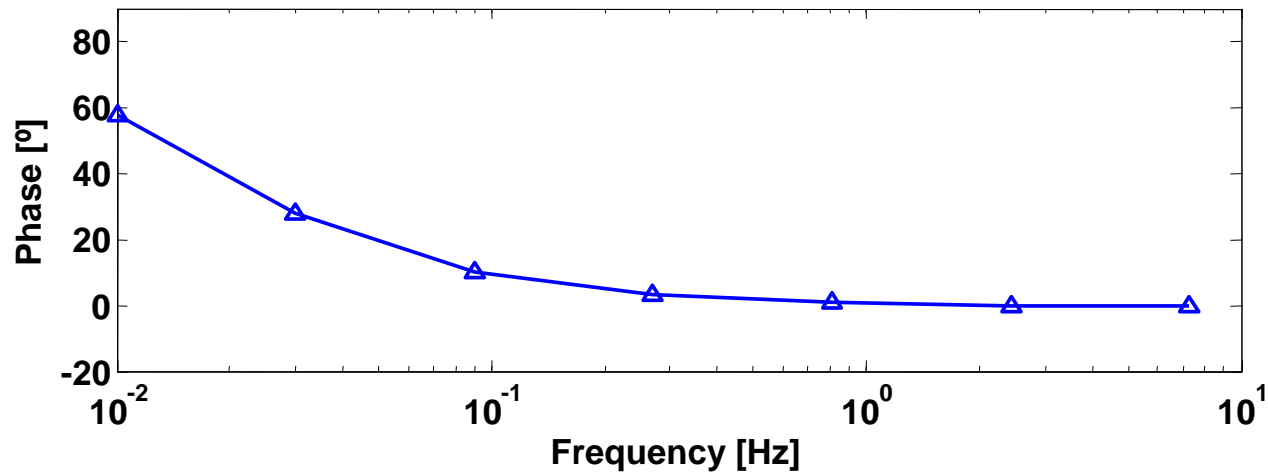
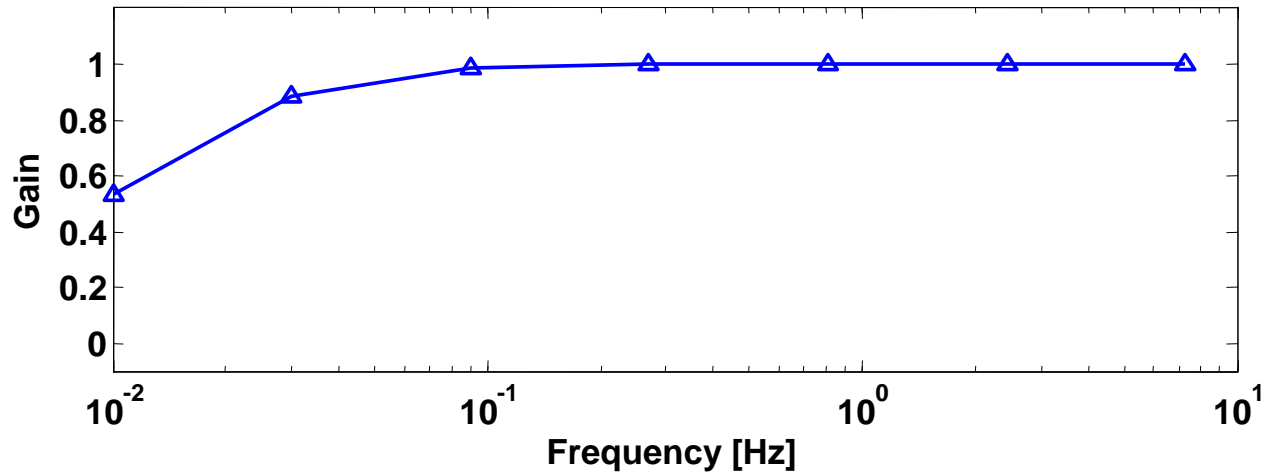


gain  $\downarrow$   
phase lead

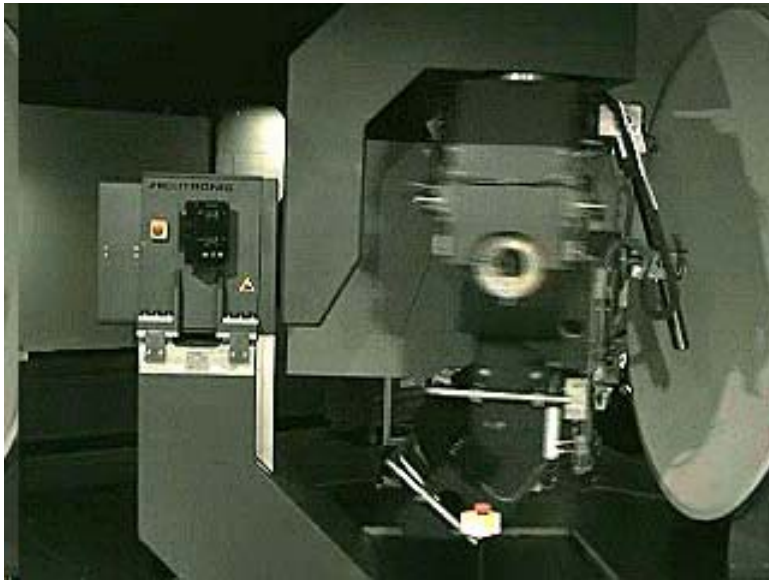
# Bode plot



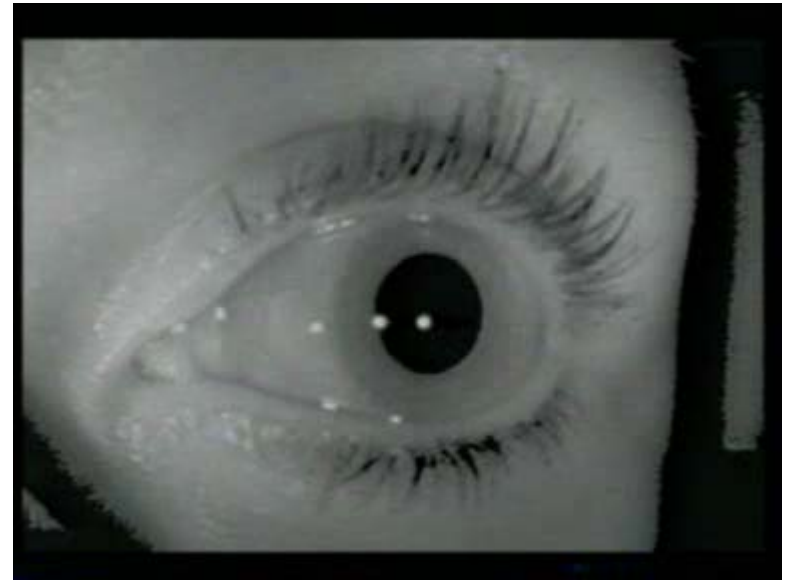
Hendrik Wade Bode  
1905-1982



# Horizontal vestibulo-ocular reflex testing

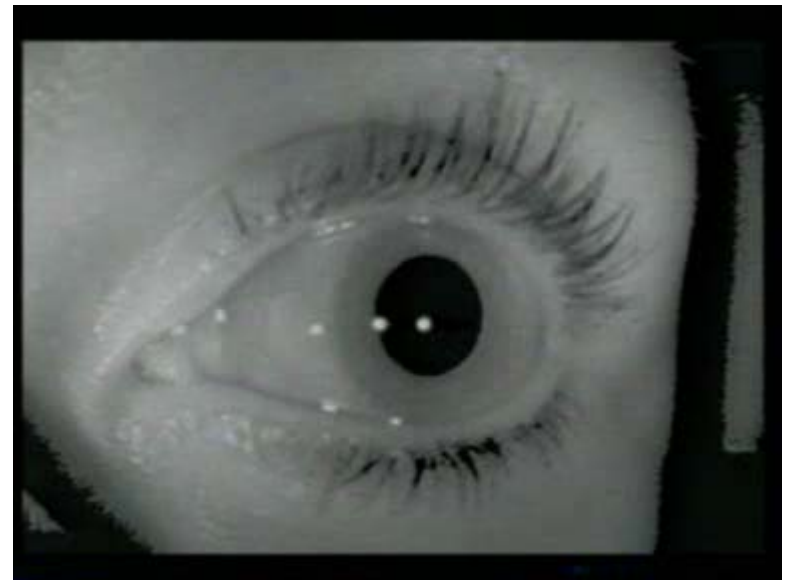
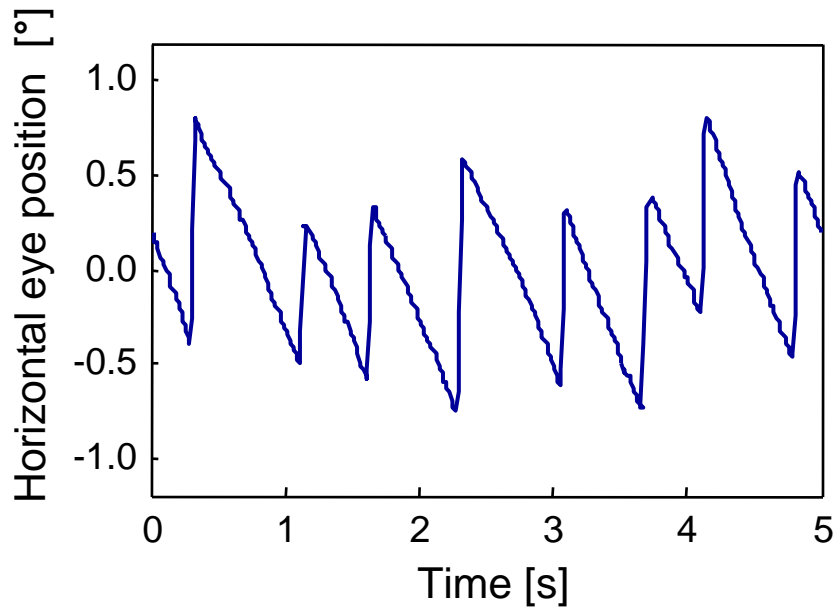


Horizontal rotation



Horizontal nystagmus

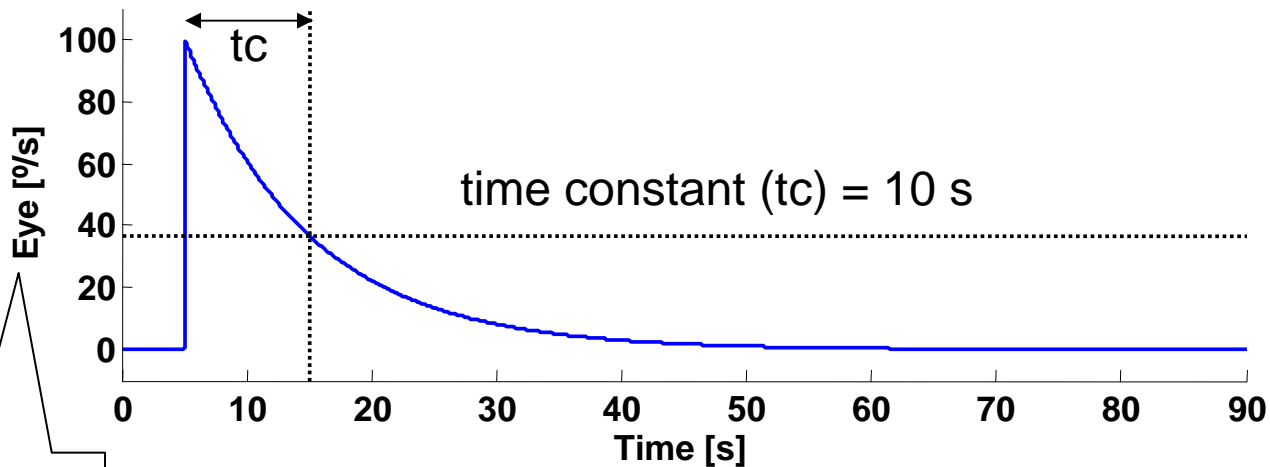
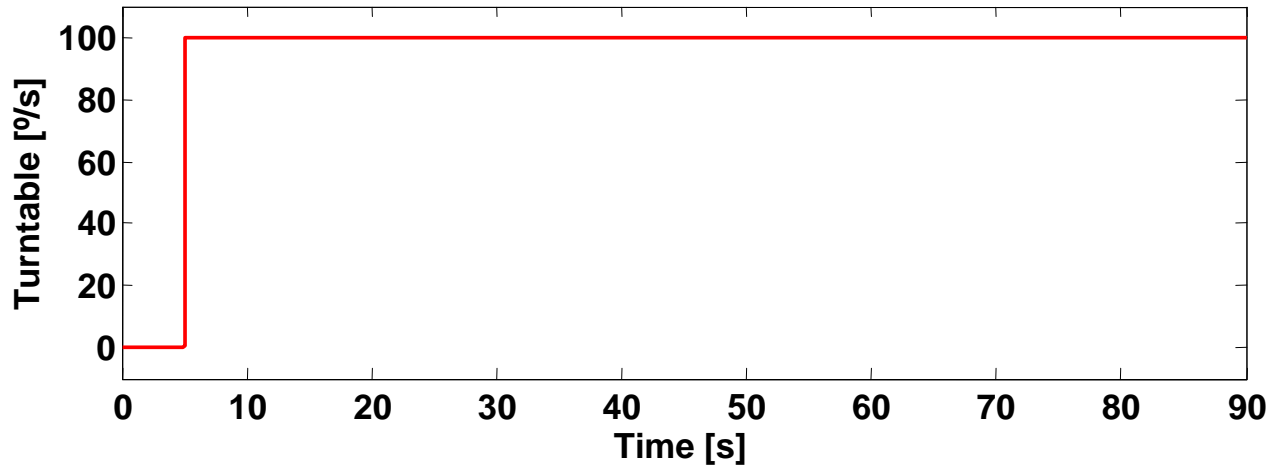
# Horizontal vestibulo-ocular reflex testing



Horizontal nystagmus

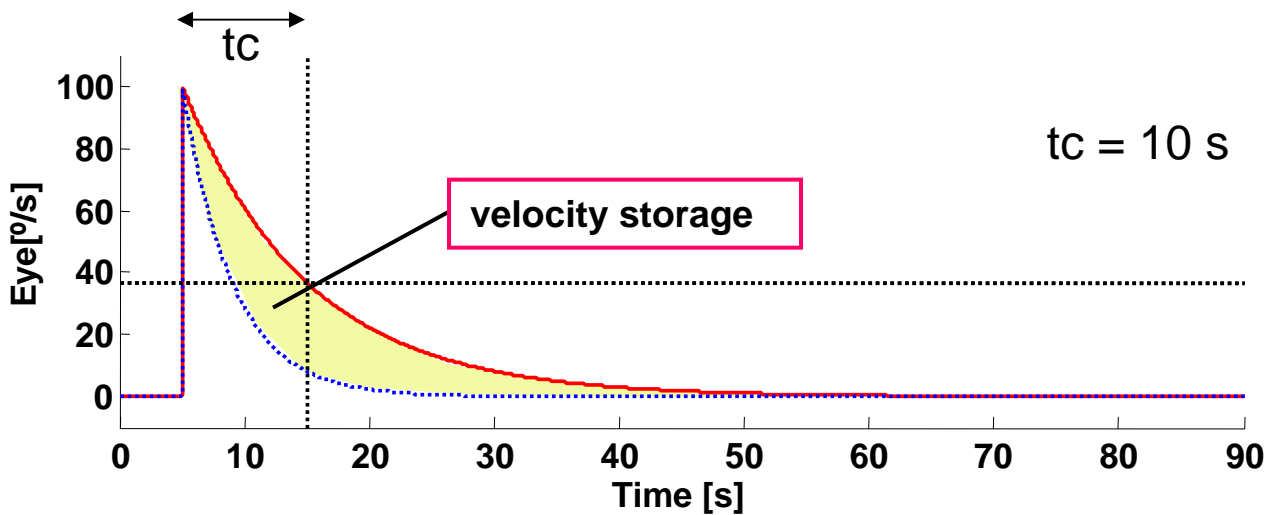
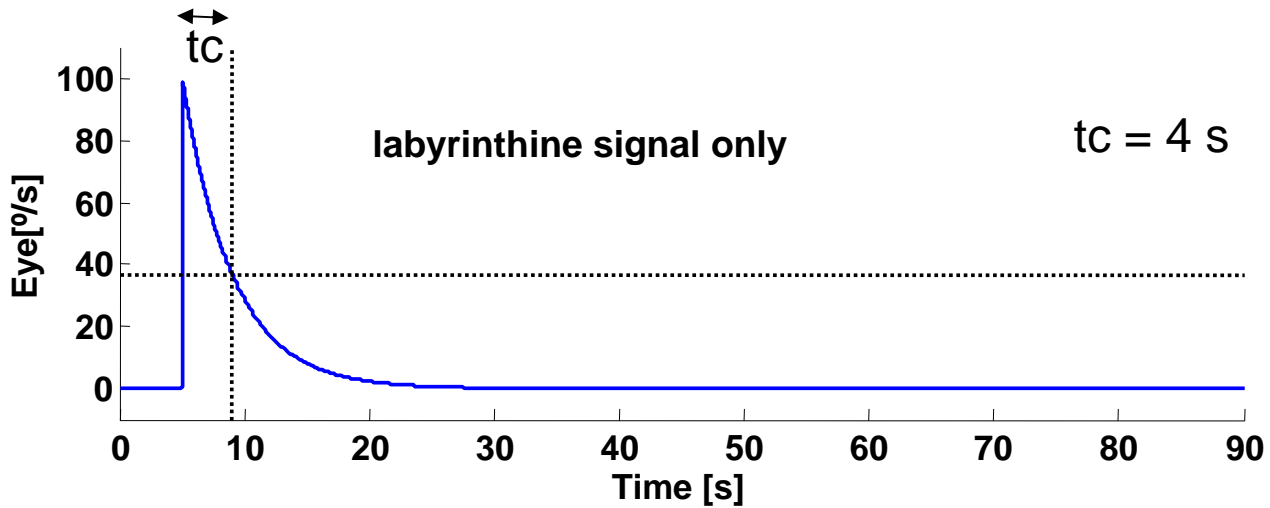
# Velocity step response

in the dark!

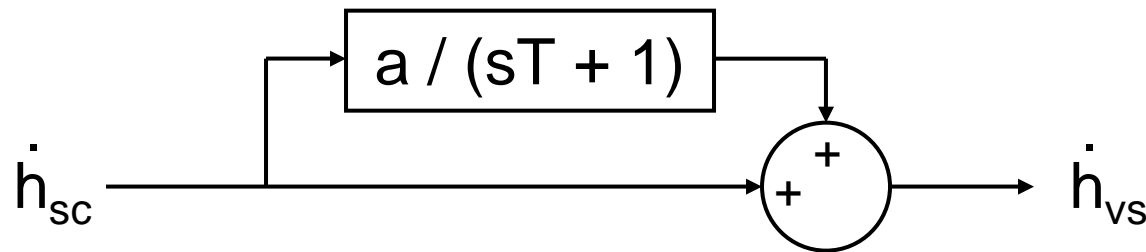


slow-phase  
eye velocity

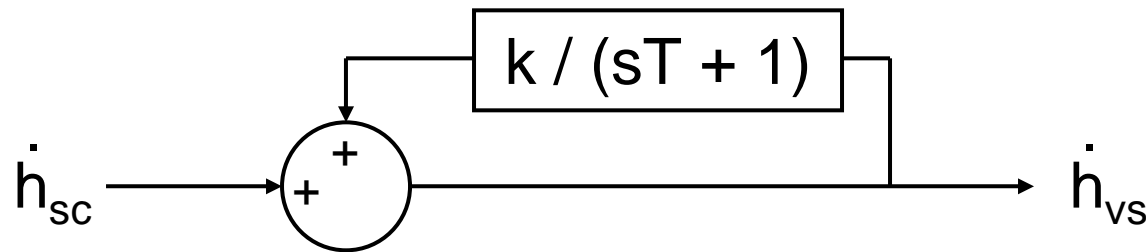
# Responses to velocity step



# Models of velocity storage



feedforward  
leaky integrator  
(Raphan, Cohen)



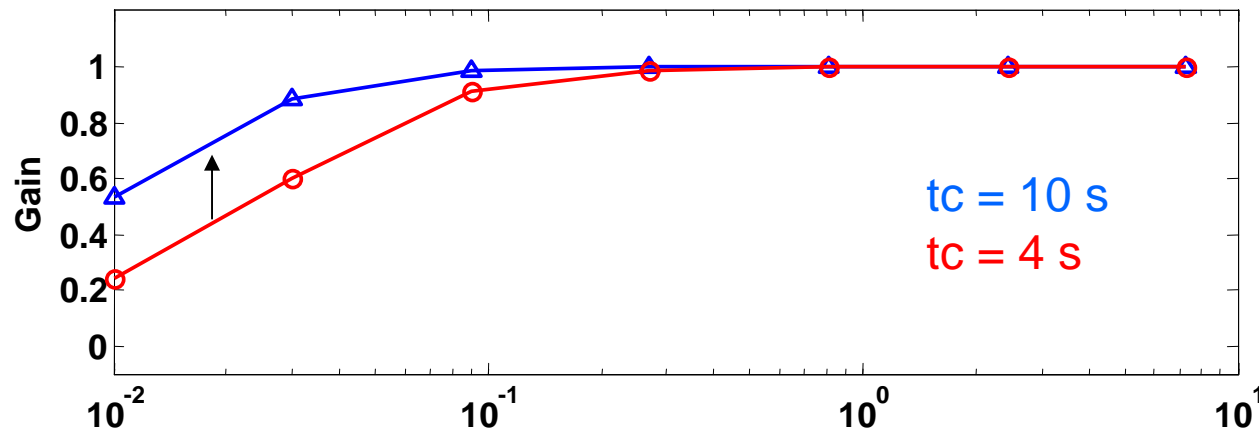
positive  
feedback  
(Robinson)

$\dot{h}_{sc}$ : signal from semicircular canals

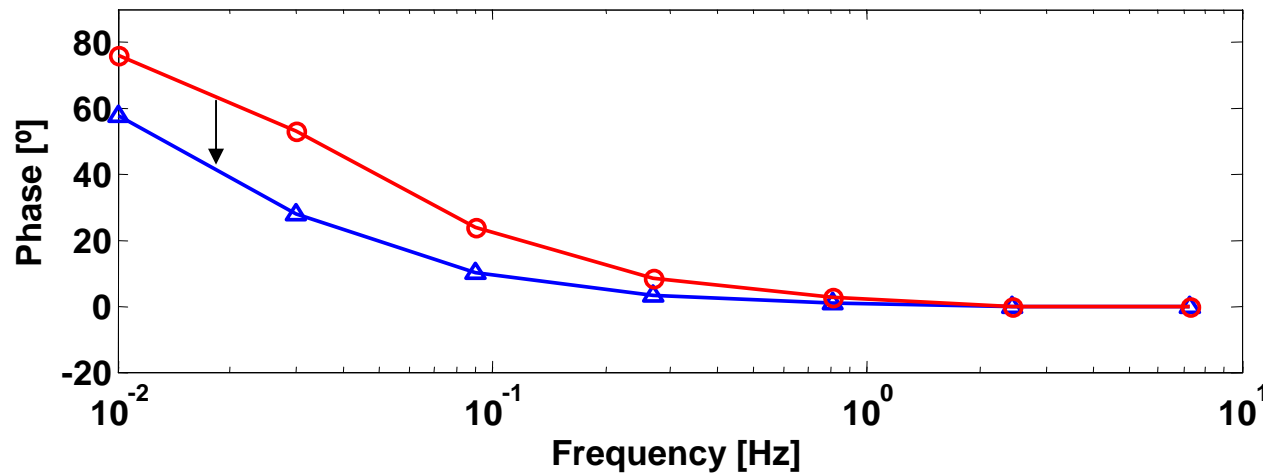
$\dot{h}_{vs}$ : signal from velocity storage

# Bode plot

## Velocity storage

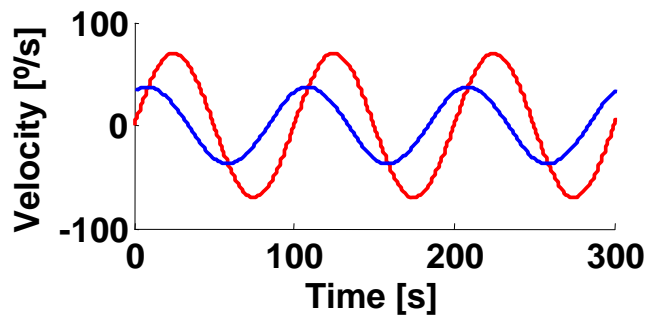
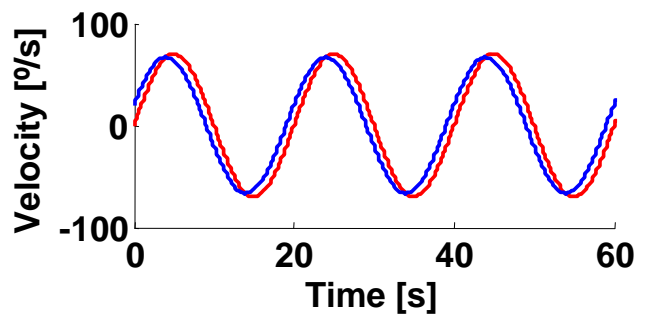
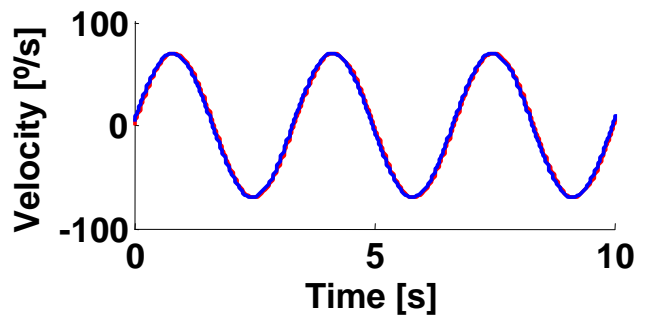


gain  $\uparrow$  at  
lower frequencies



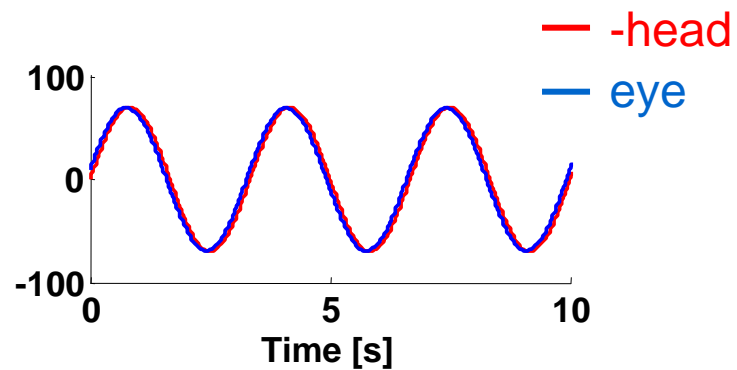
phase  $\downarrow$  at  
lower frequencies

**tc = 10 s**

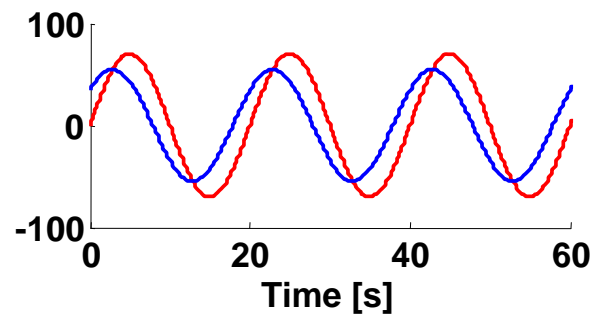


**tc = 4 s**

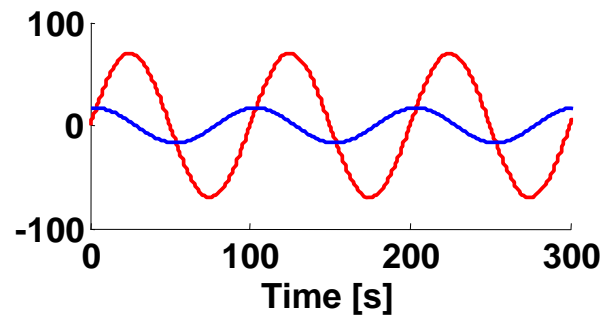
**0.3 Hz**



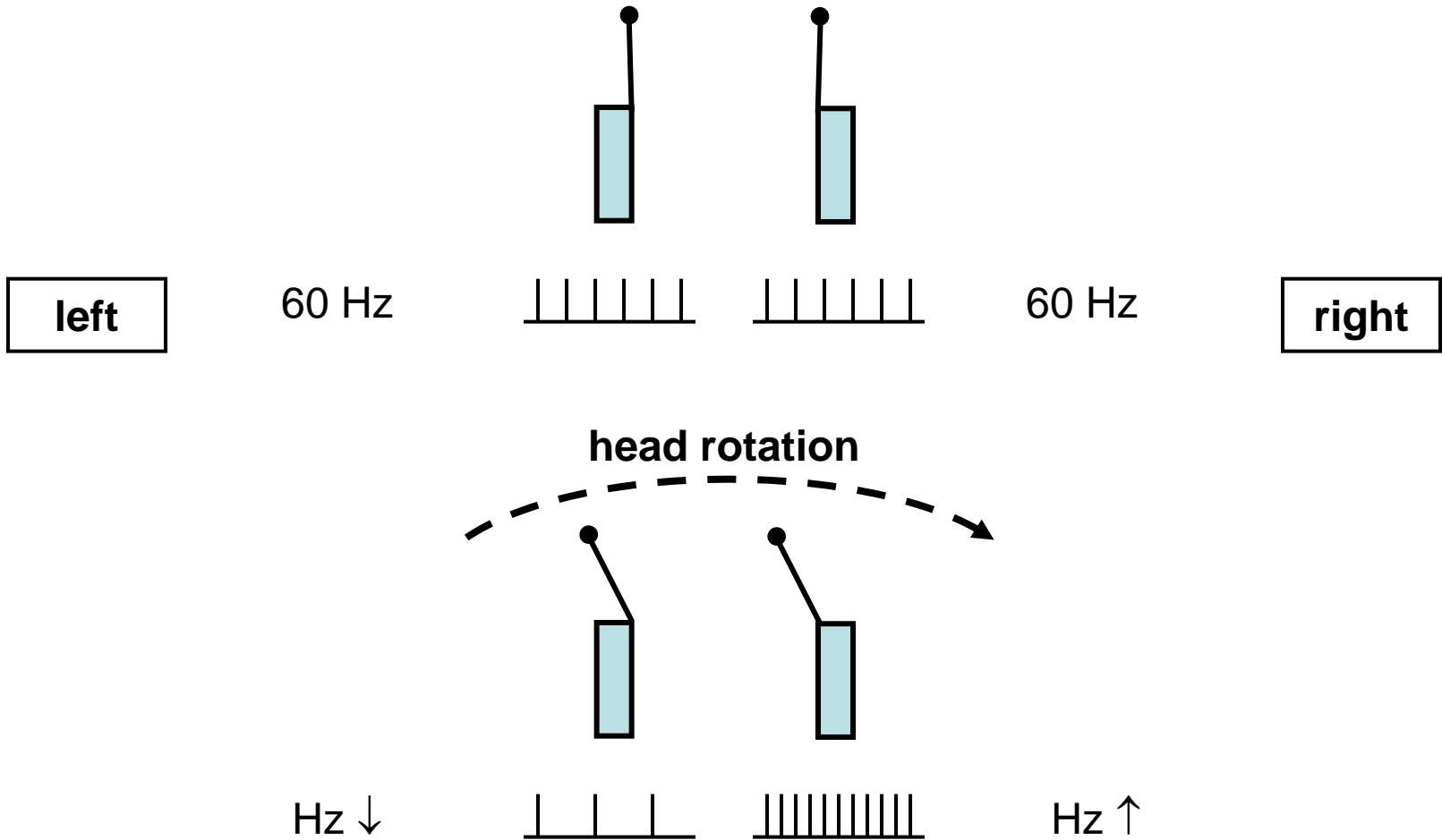
**0.05 Hz**



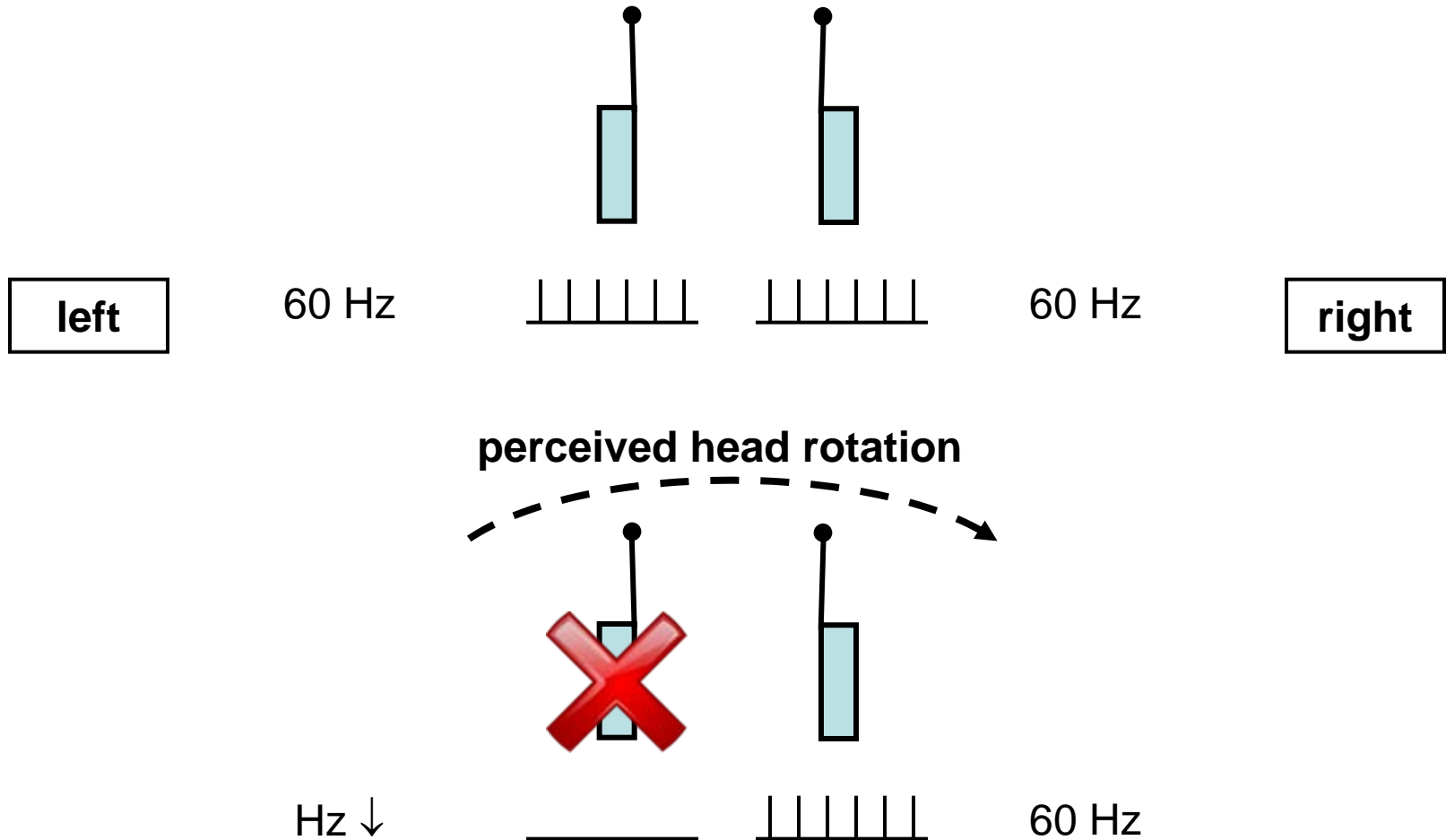
**0.01 Hz**



# Resting rate



# Vestibular tone asymmetry



# Alexander's law

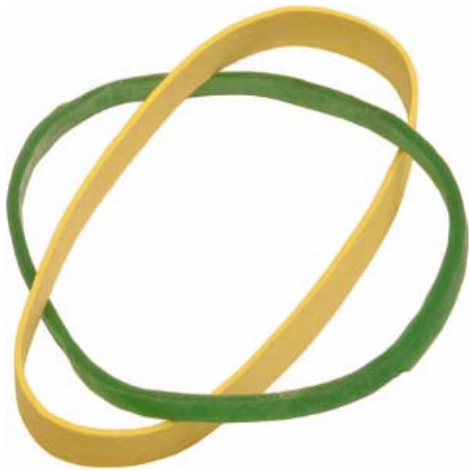
**Spontaneous  
nystagmus**

5 days after vestibular neuritis

# Mechanics of eye plant

- Elasticity

force  $\sim$  eccentricity

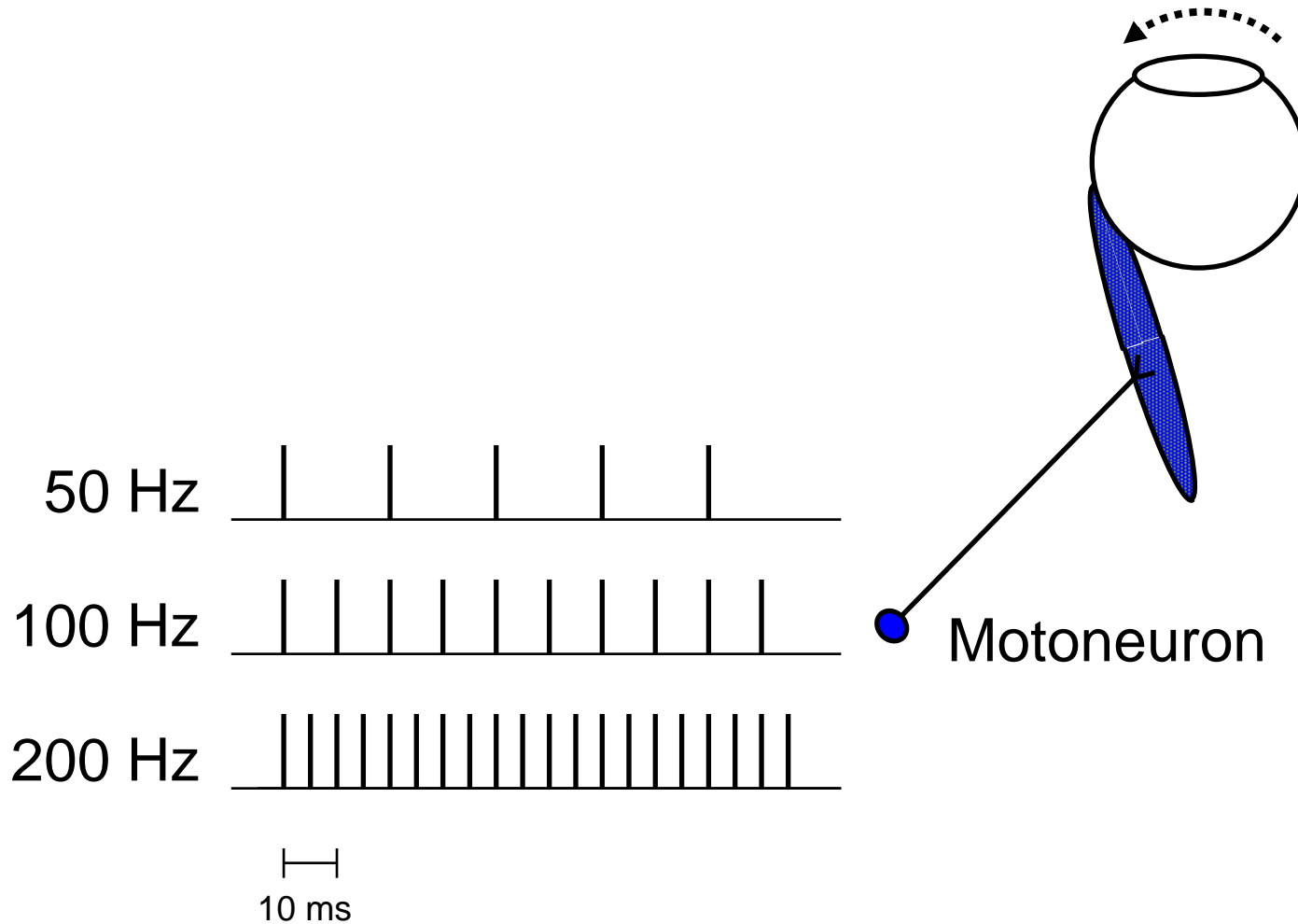


- Viscosity

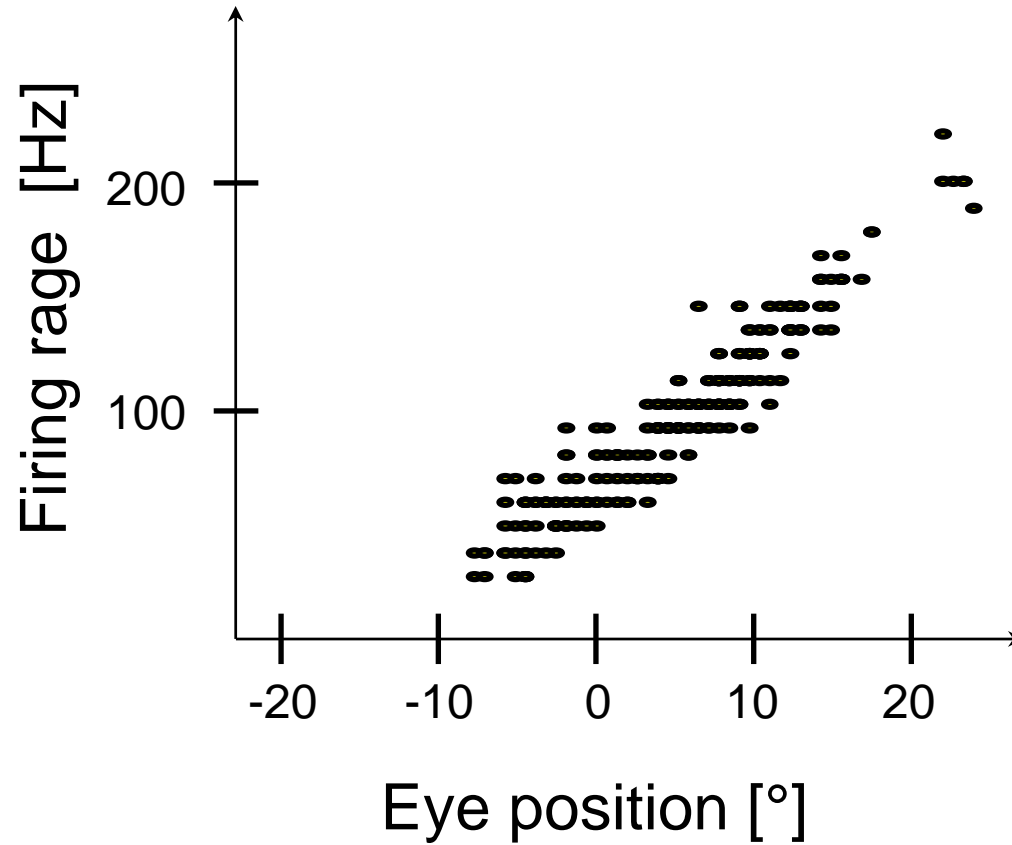
force  $\sim$  velocity

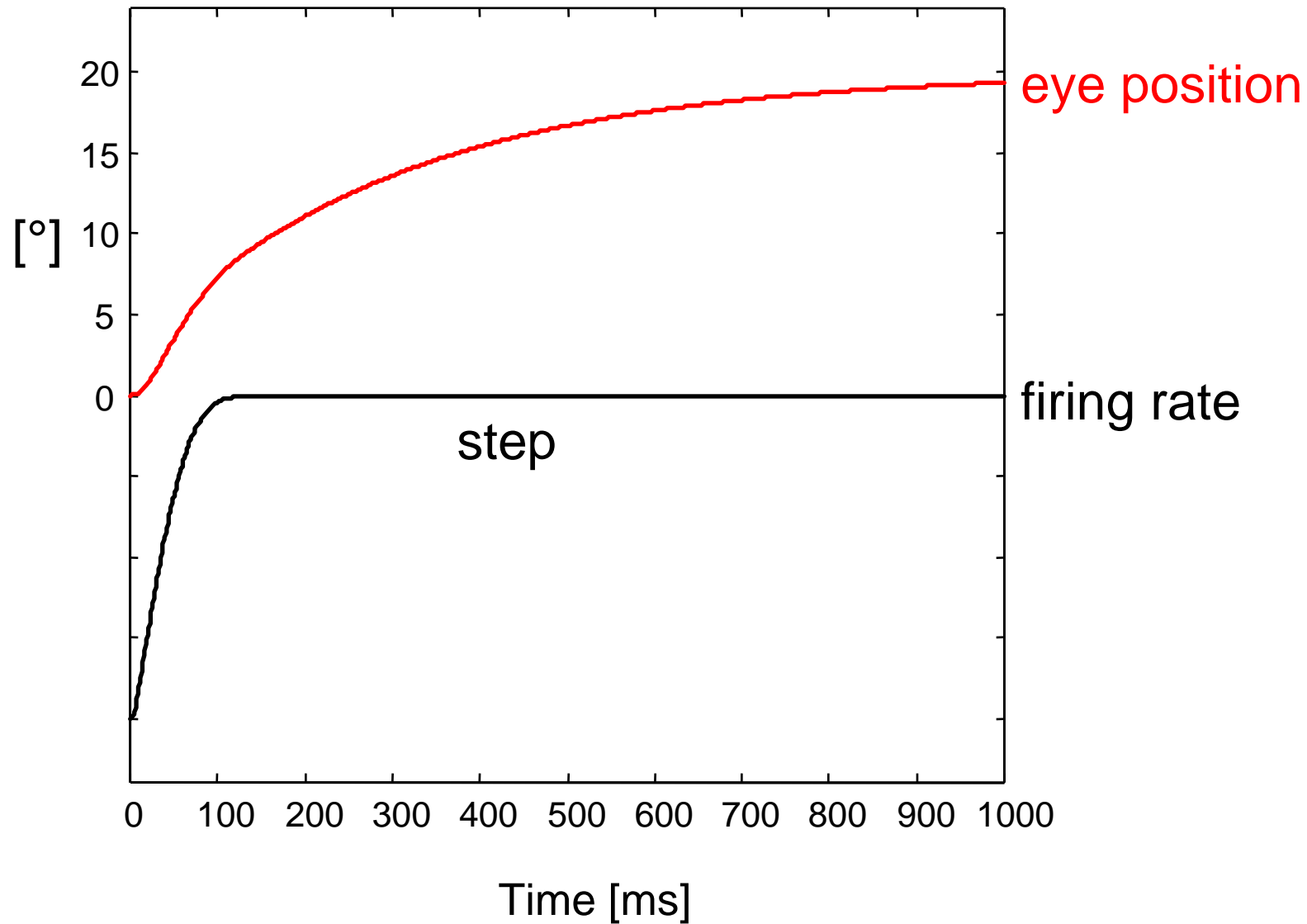


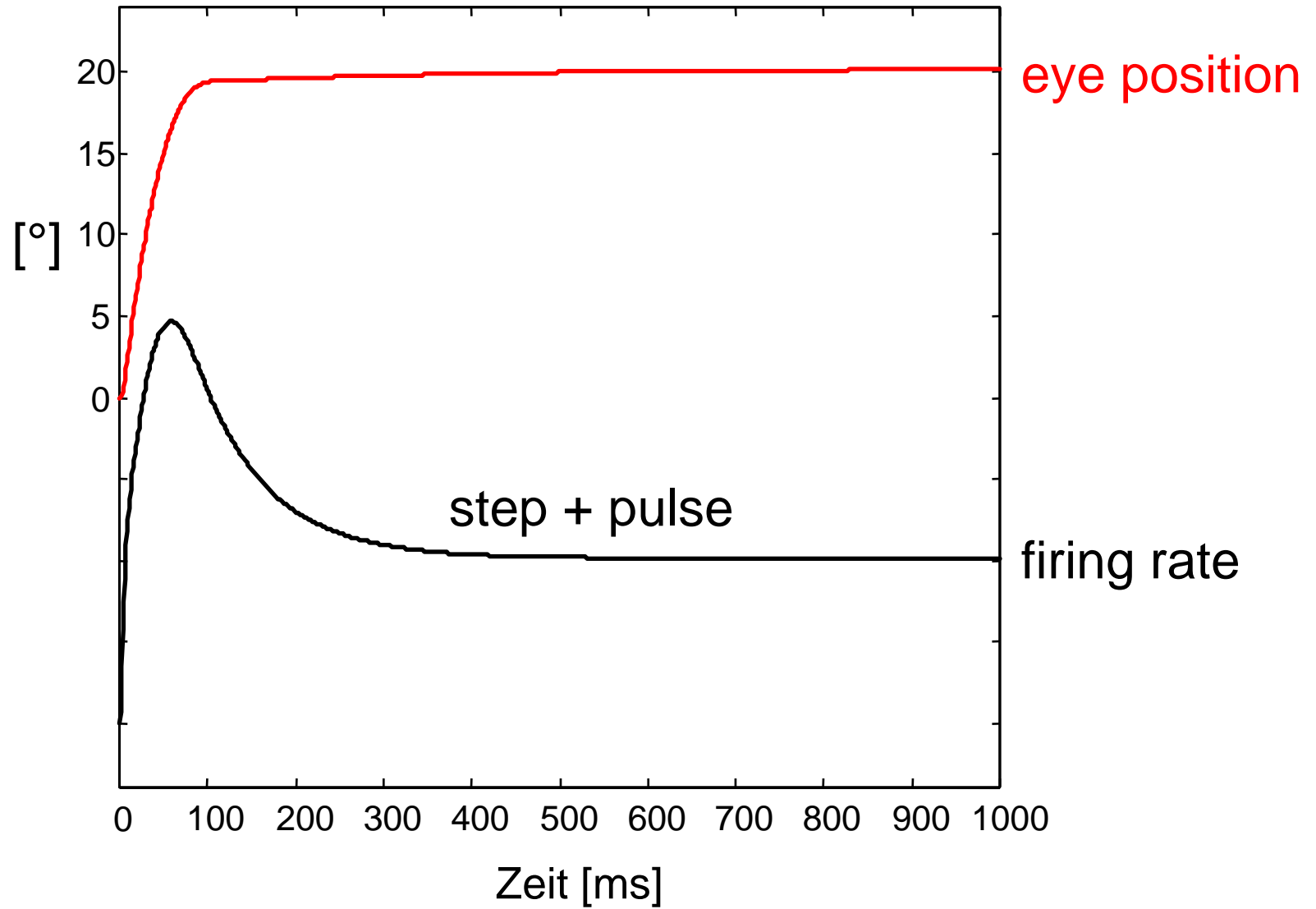
# Firing rate ~ muscle length



# Firing rate $\sim$ eye position







# Superior rectus motoneuron

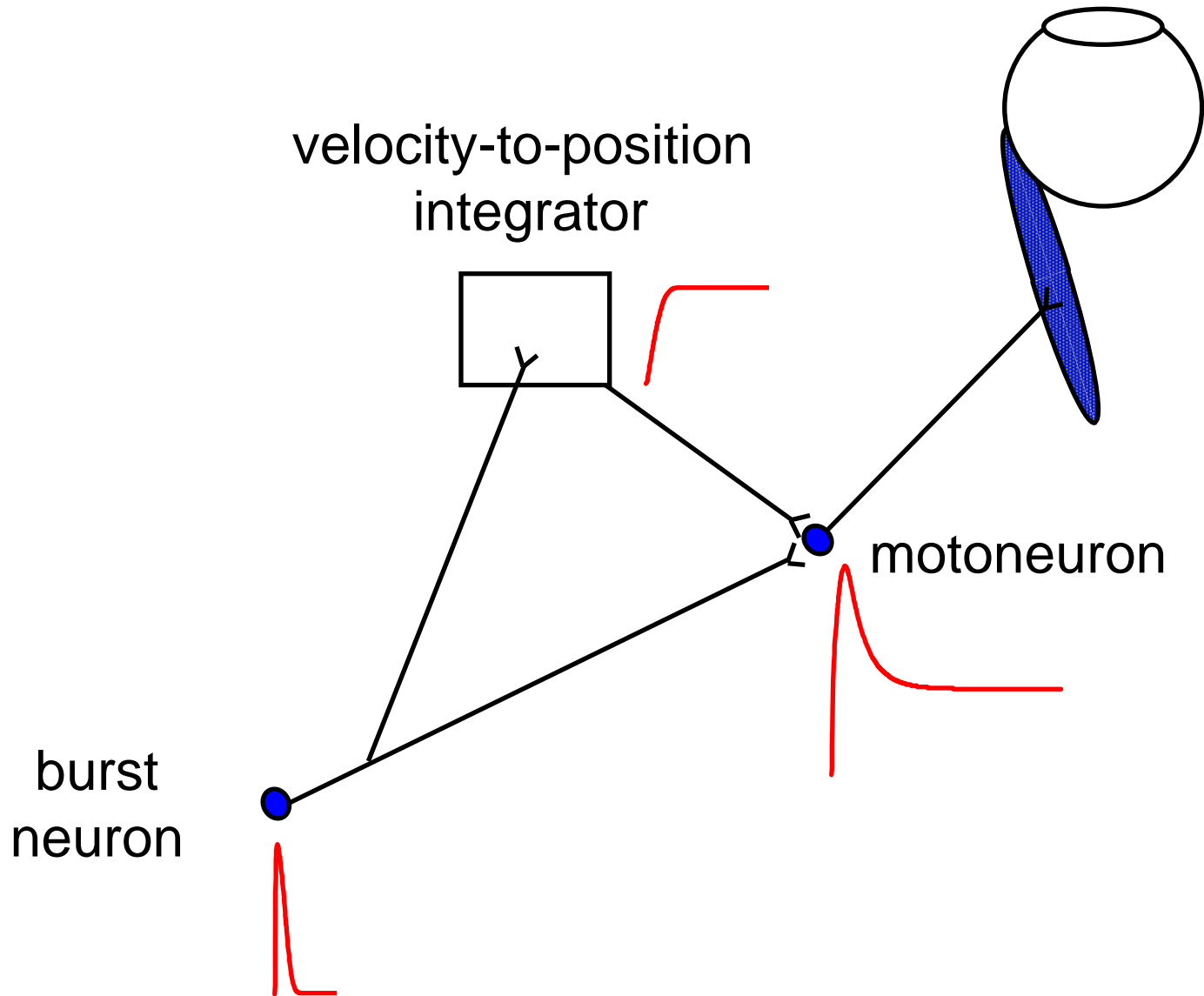


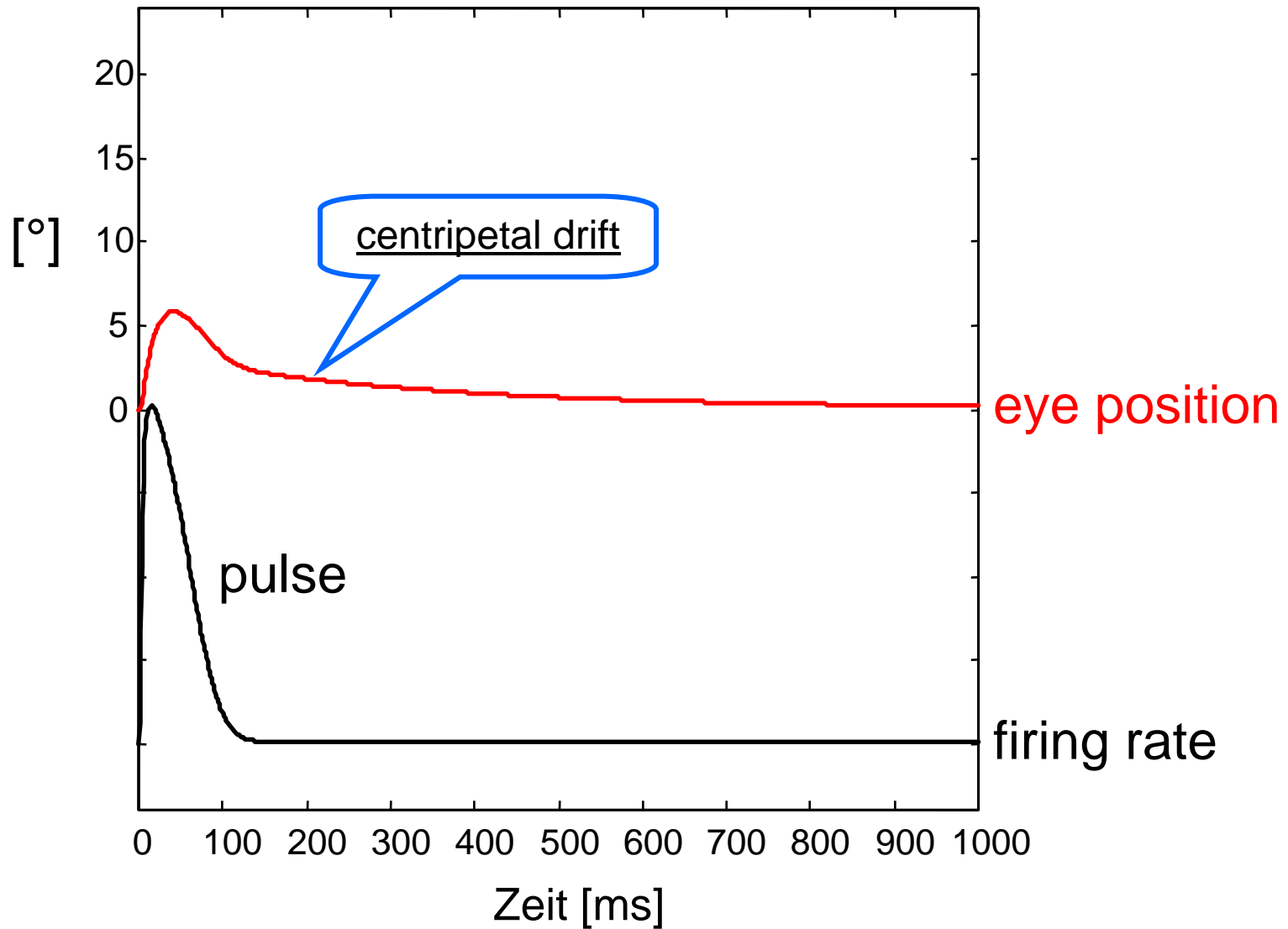
vertical eye position



10°

100 ms





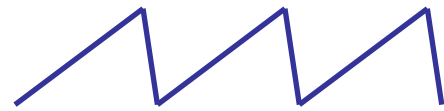
# position independent nystagmus (vestibular)



right gaze

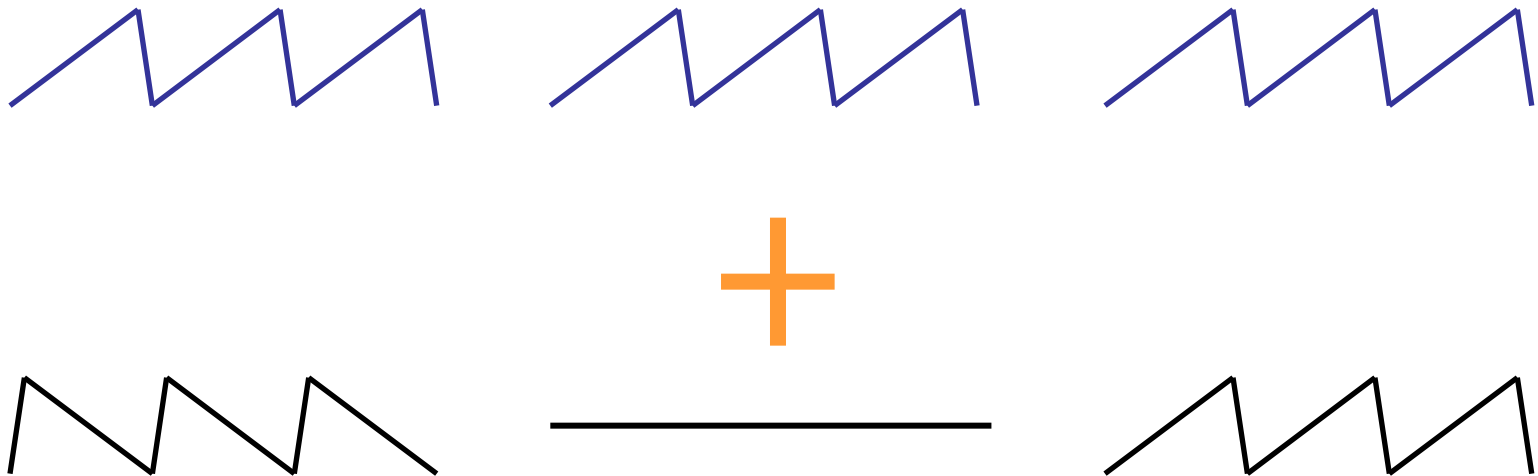


straight ahead  
gaze

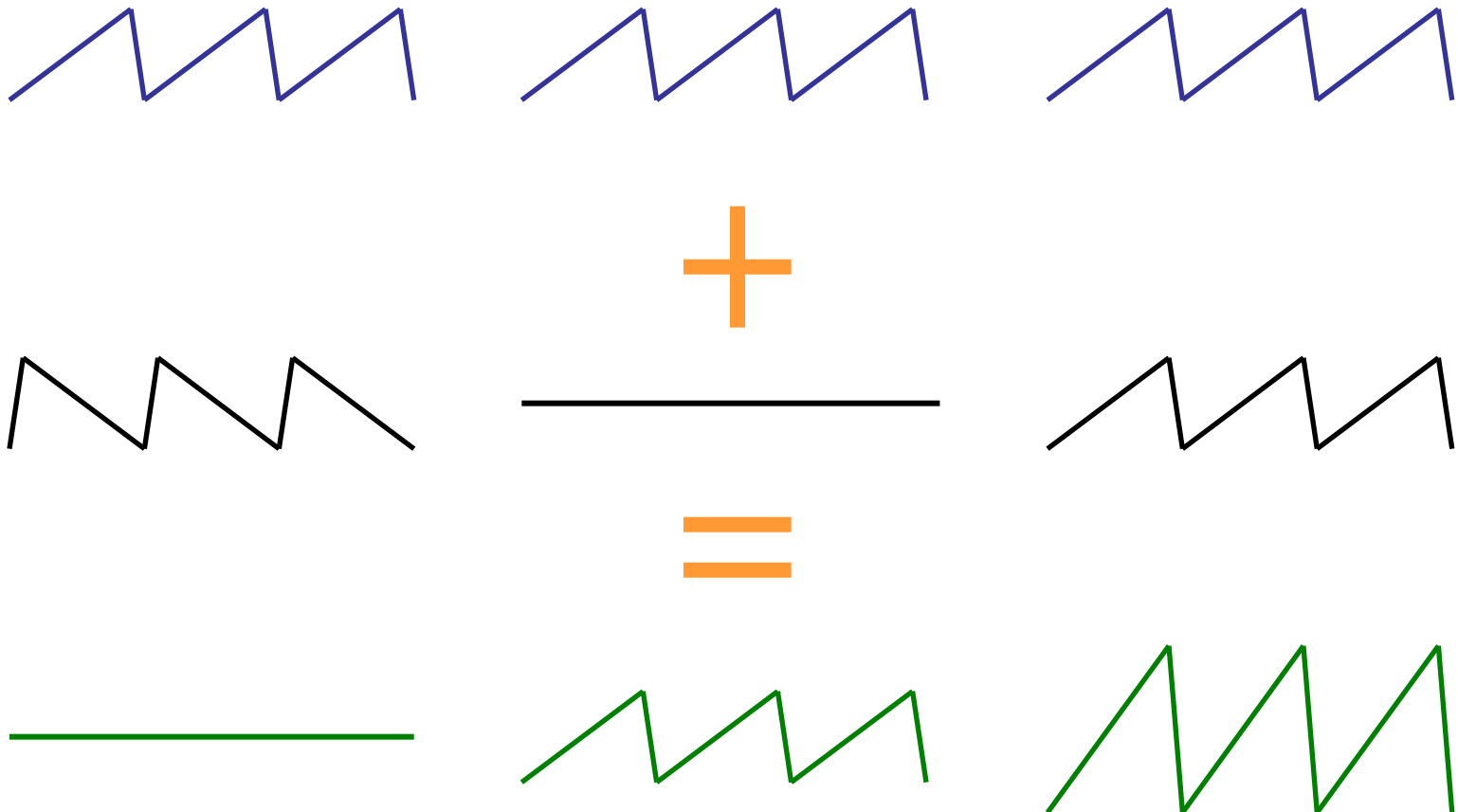


left gaze

position independent nystagmus (vestibular)  
+ gaze-evoked nystagmus (leaky integrator)



position independent nystagmus (vestibular)  
+ gaze-evoked nystagmus (leaky integrator)  
= spontaneous nystagmus according to  
Alexander's law



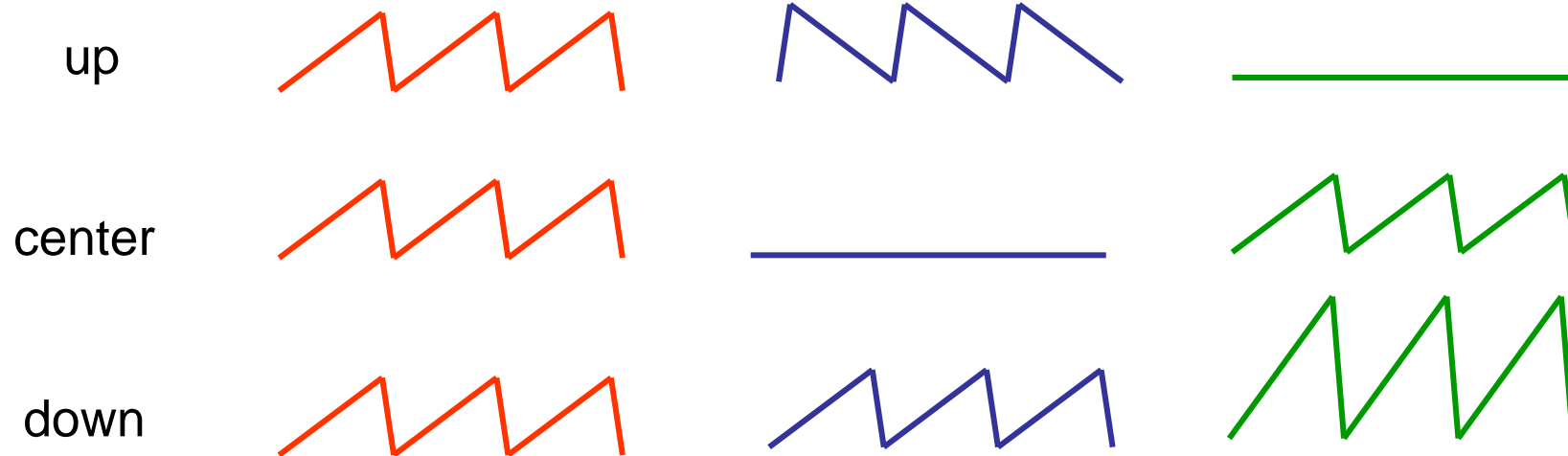
# Alexander's law in downbeat nystagmus



bias drift

gaze-evoked  
drift

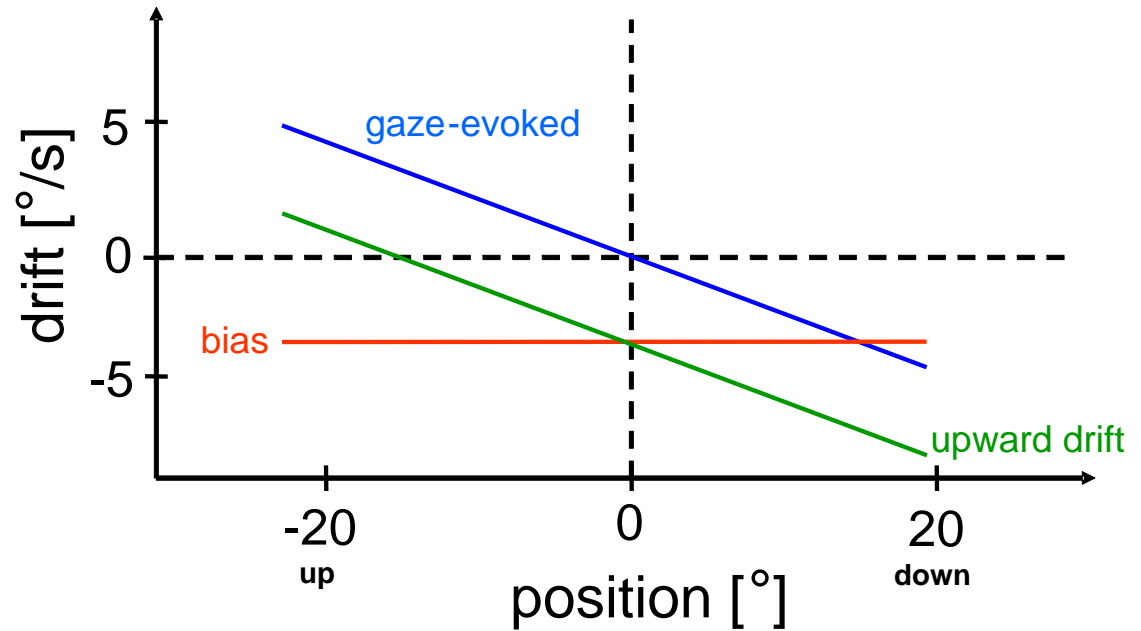
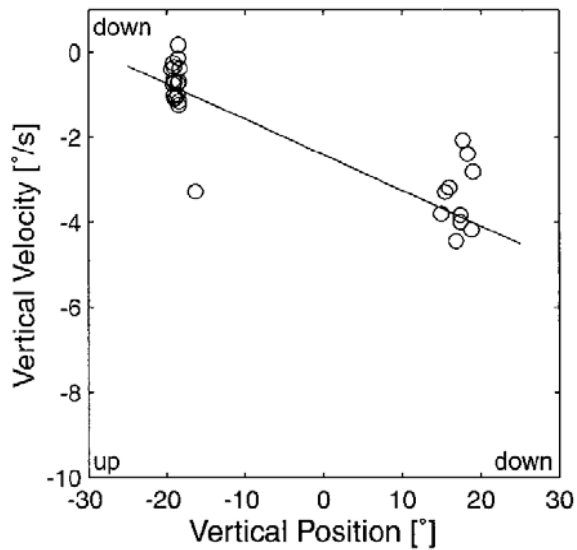
downbeat  
nystagmus



+

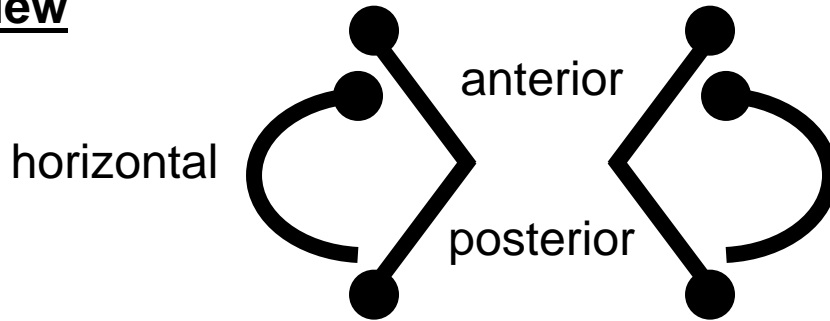
=

# Downbeat nystagmus



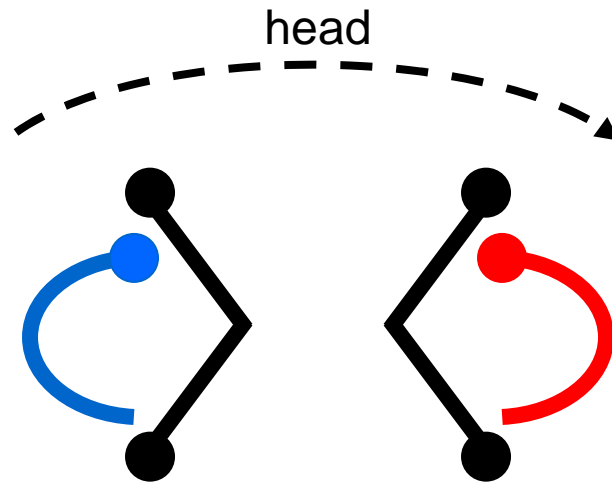
# Push-pull semicircular canals

Top View

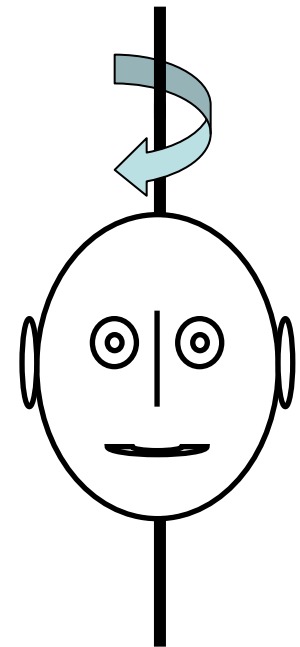


● ampulla

**Right Horizontal –  
Left Horizontal  
(RHLH)**

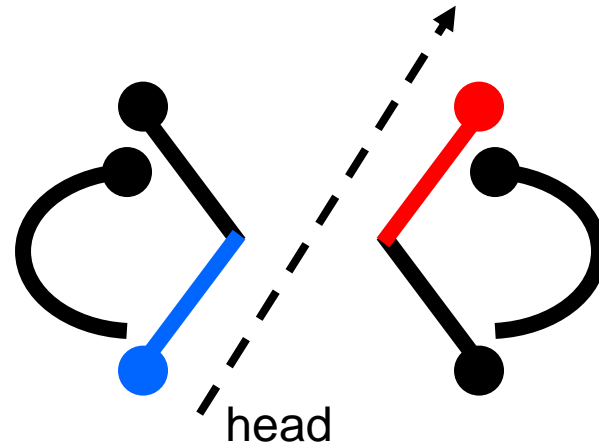


— excitation  
— inhibition

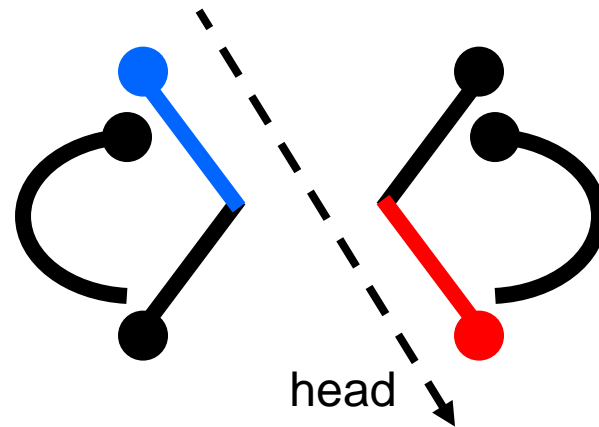


# Push-pull semicircular canals

Right Anterior –  
Left Posterior  
(RALP)

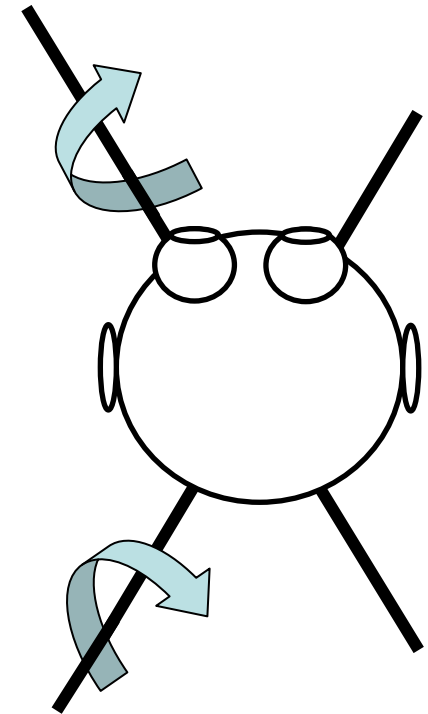


Right Anterior –  
Left Posterior  
(RPLA)



— excitation  
— inhibition

● ampulla



# Ewald's 2<sup>nd</sup> law

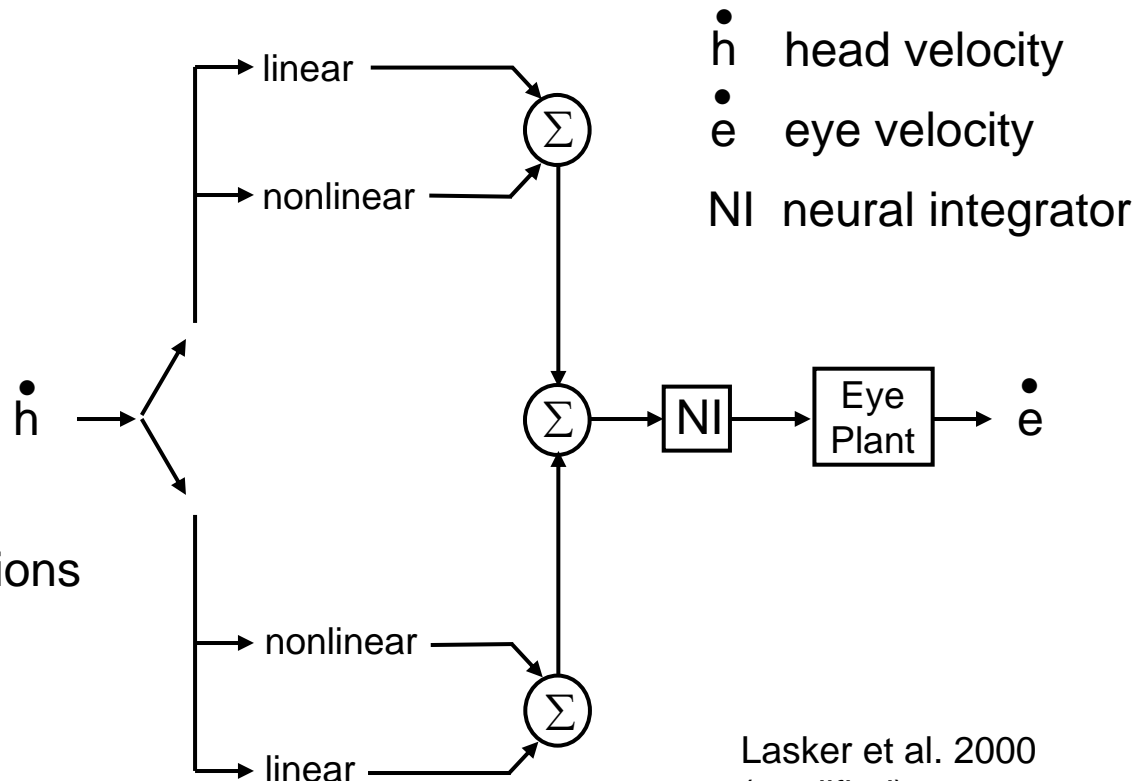
Excitation drives the VOR better than inhibition (1892).

## linear pathway

- excitation  $\approx$  -inhibition
- not cutoff (always  $> 0$  Hz)

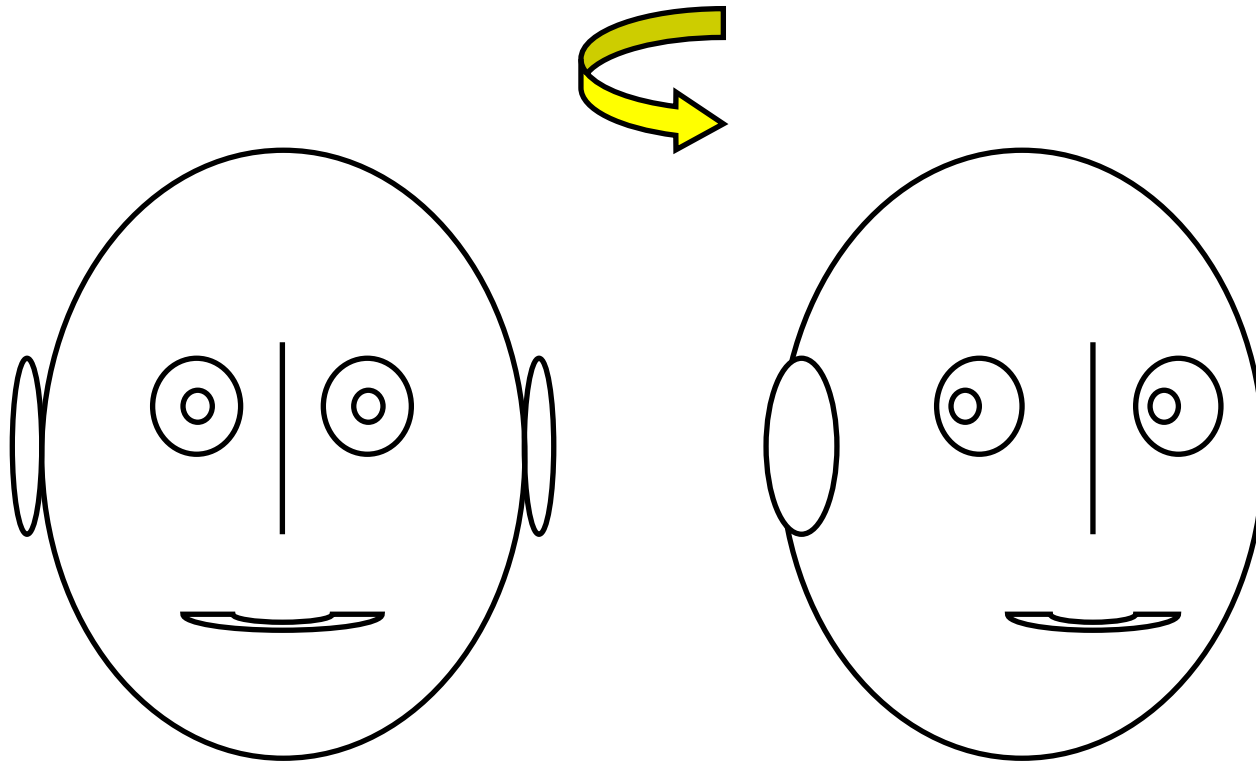
## nonlinear pathway

- excitation only
- sensitive to high accelerations



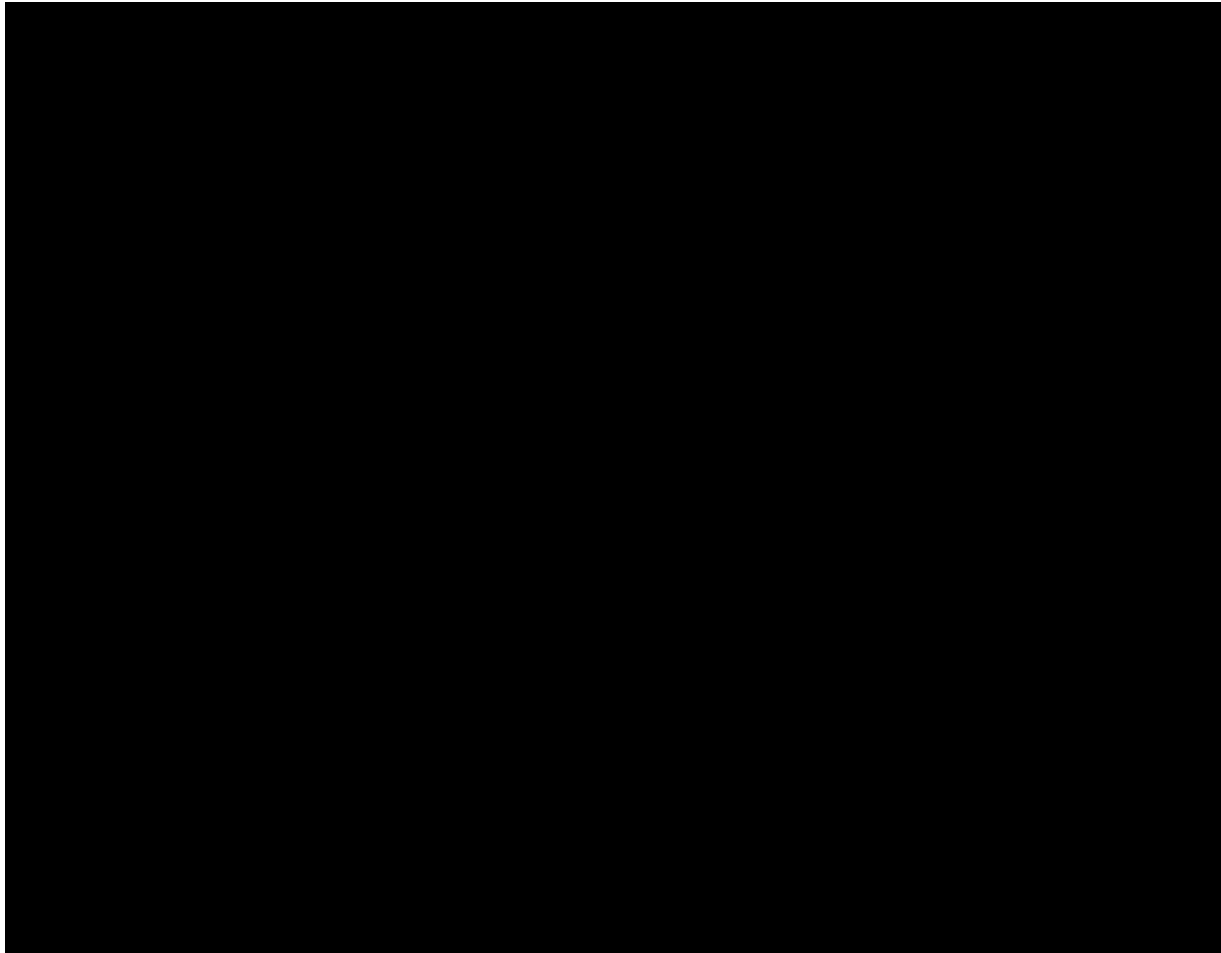
Lasker et al. 2000  
(modified)

# Normal head-impuls test\*

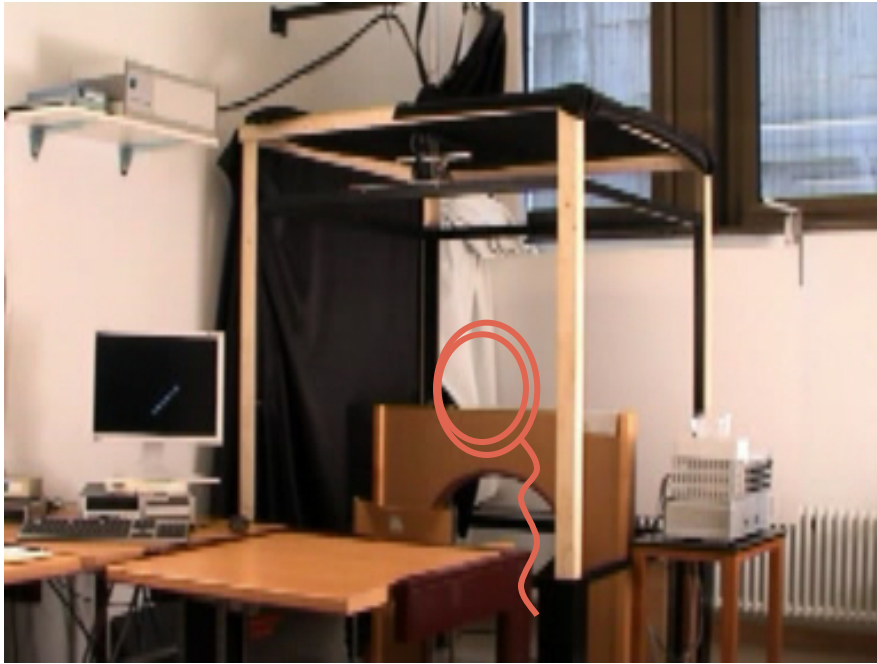


\*Halmagyi G.M., Curthoys I.S (1988)  
Archives of Neurology

# Horizontal head impulses



# Search-coil head impulse test



3D magnetic field

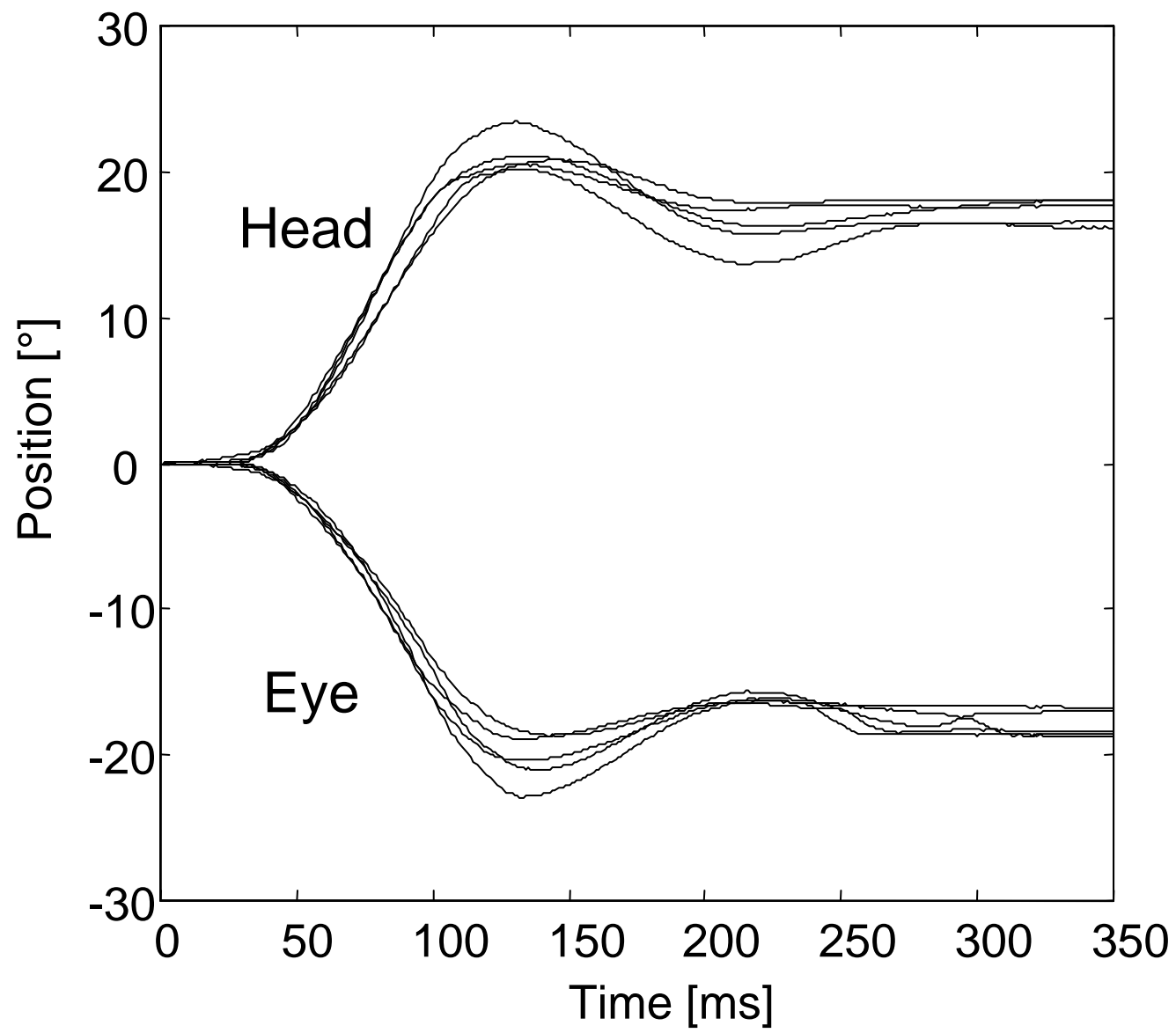


David A. Robinson:  
„dual search coil  
technique“

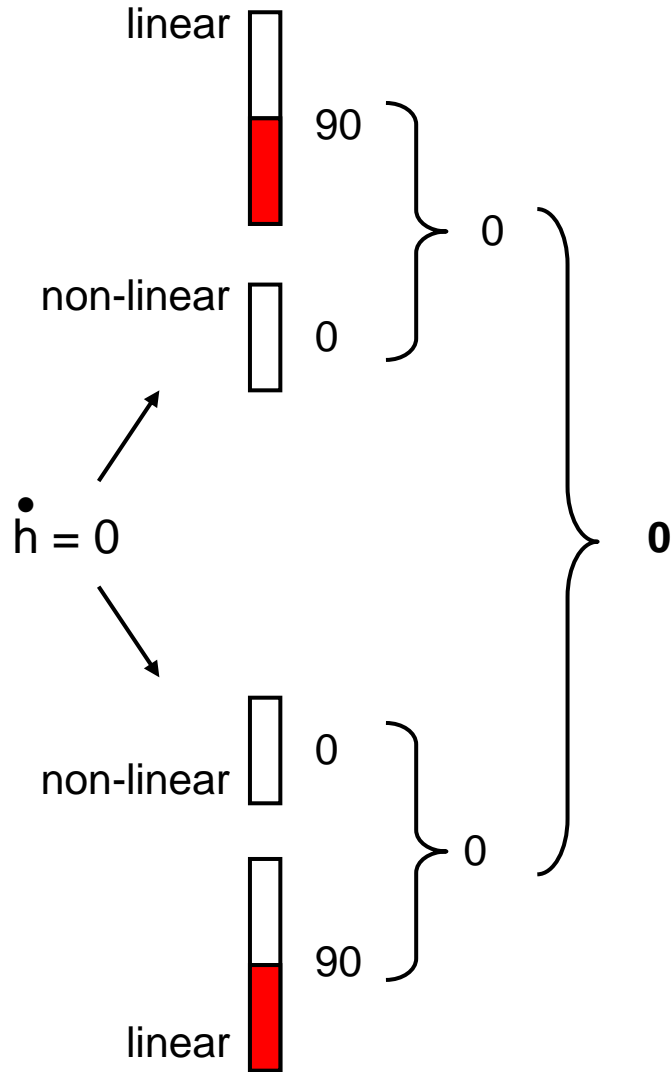


modified silicon anulus  
by Collewijn et al.

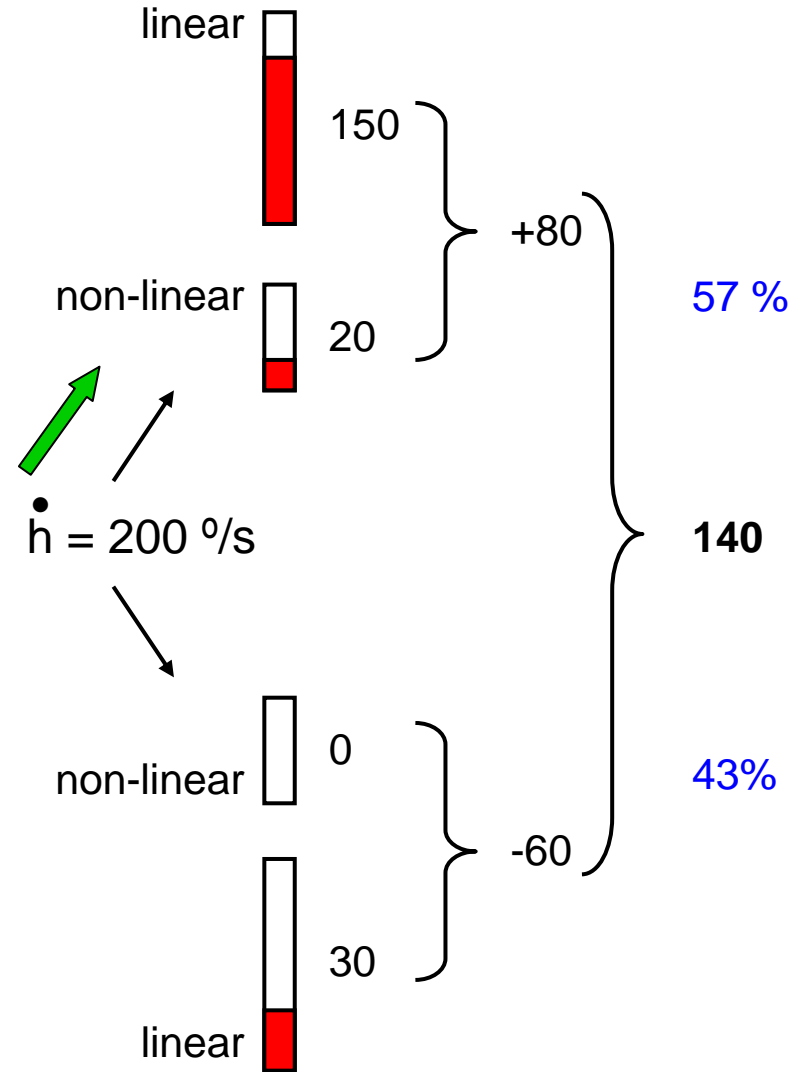
Normal  
response



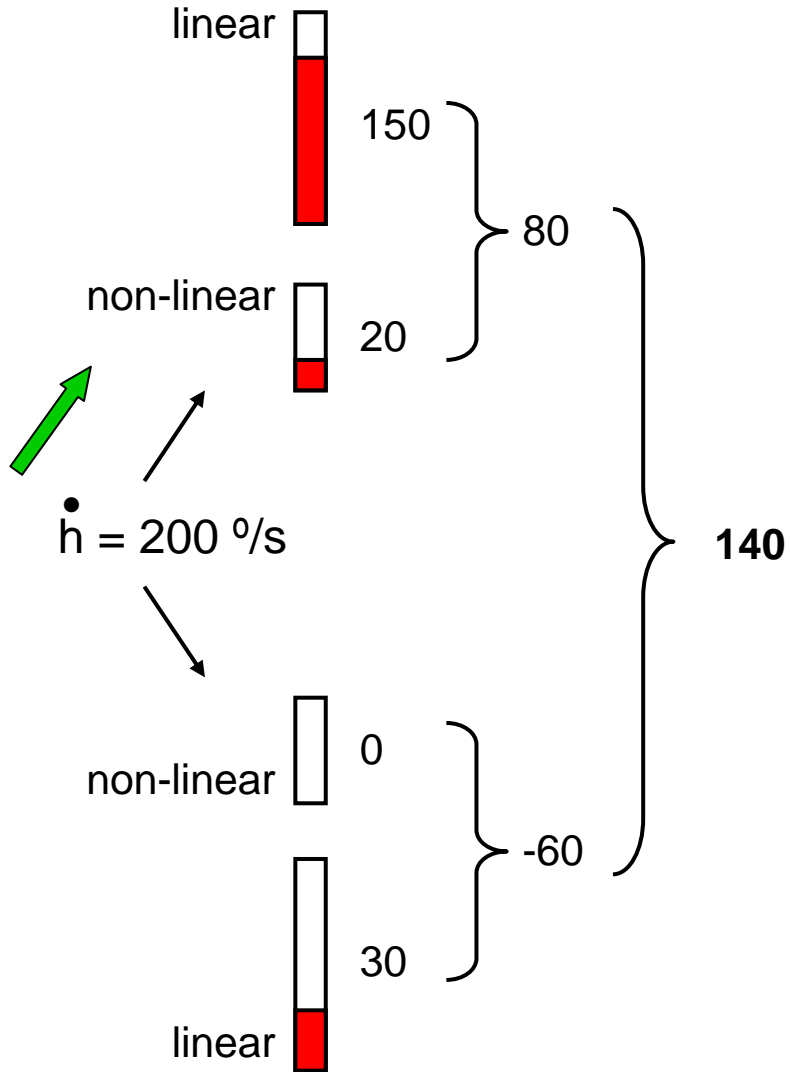
# Head not moving



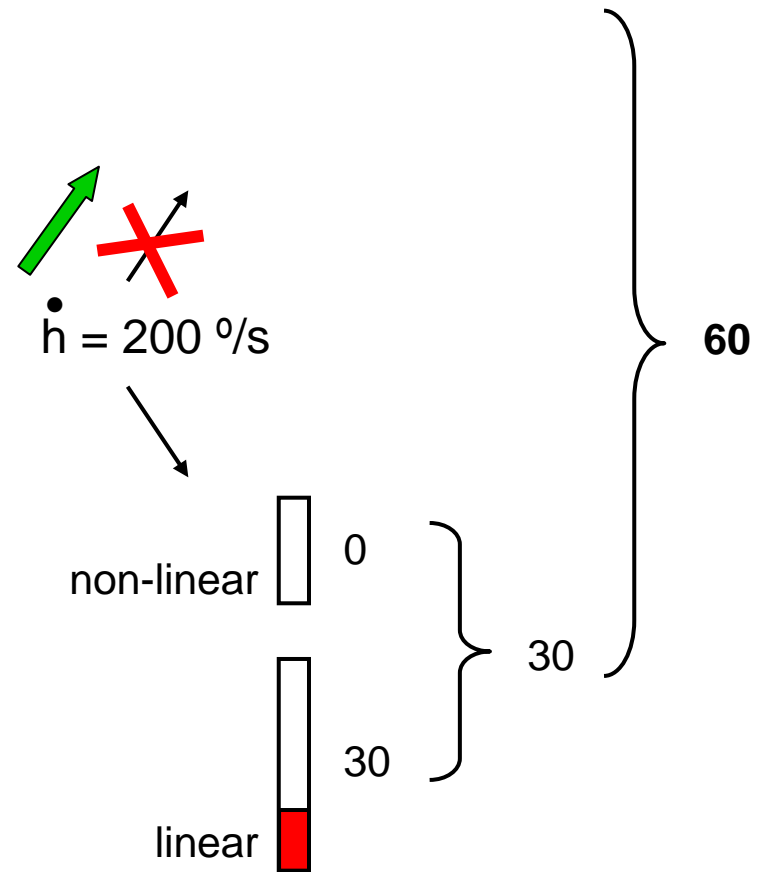
# Head impulse to the right



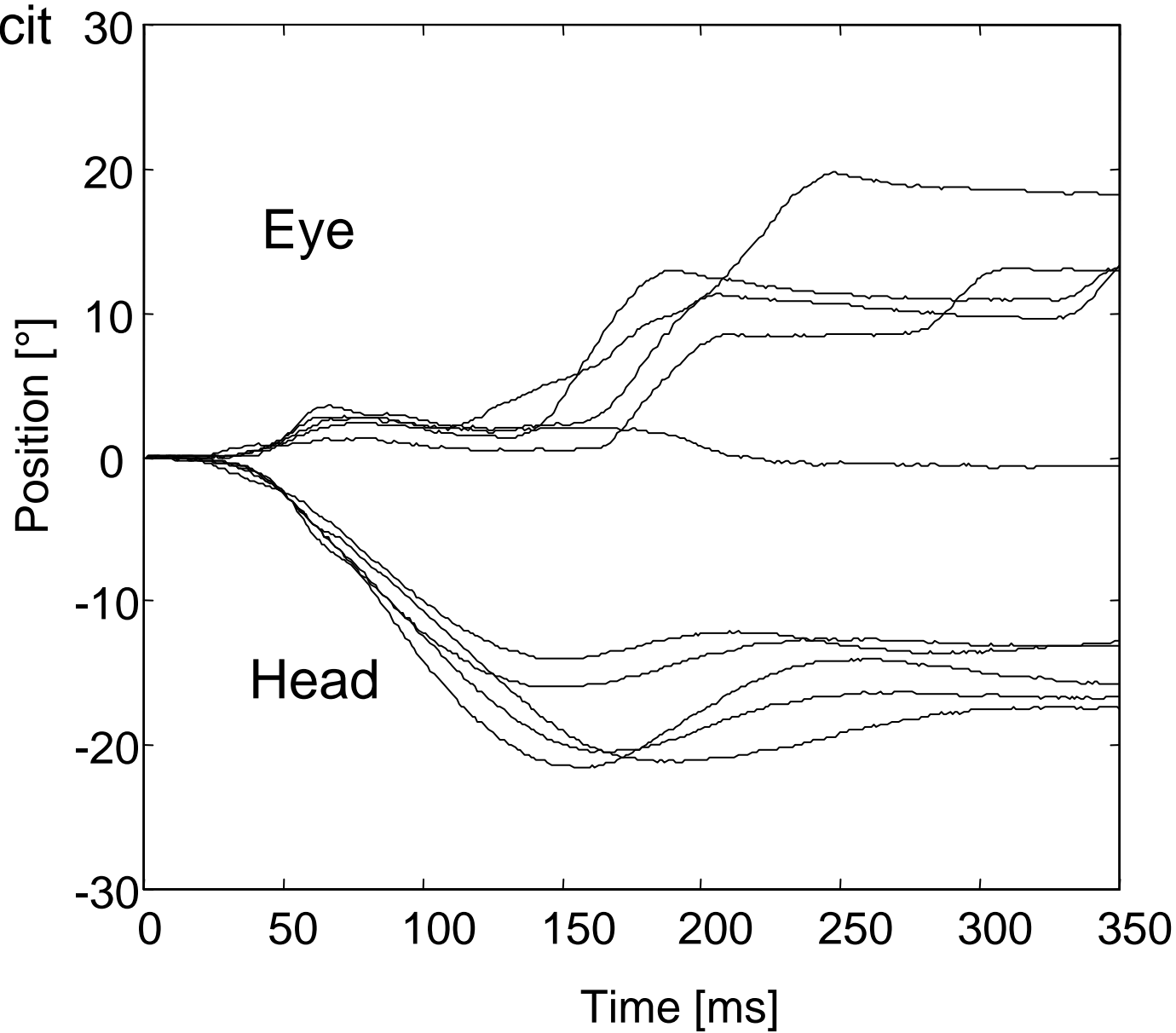
# Head impulse to the right



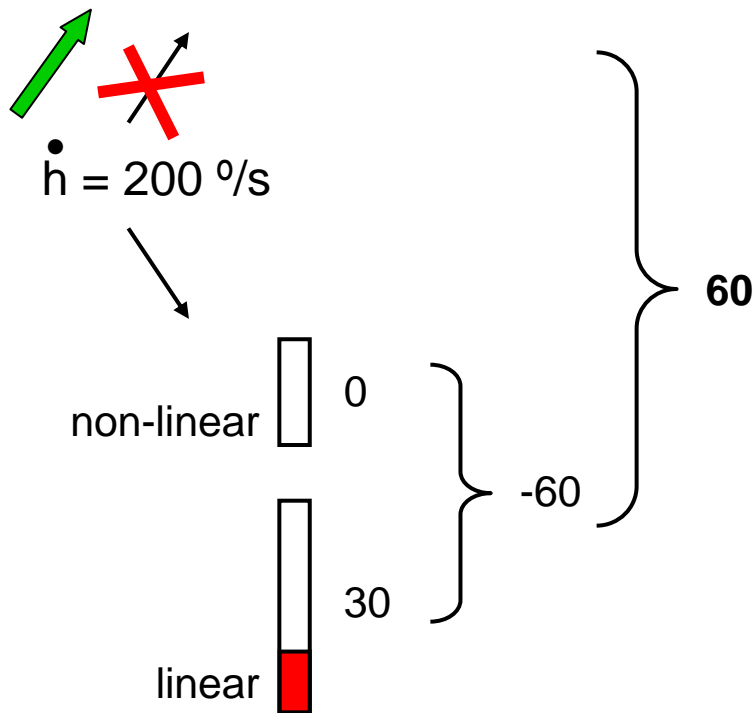
# Head impulse to the right



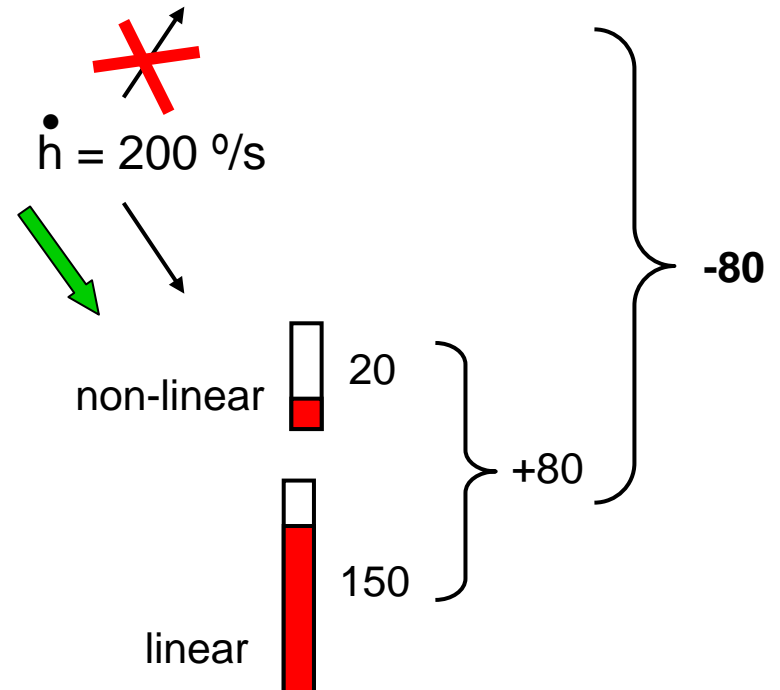
Vestibular deficit  
on the left



## Head impulse to the right

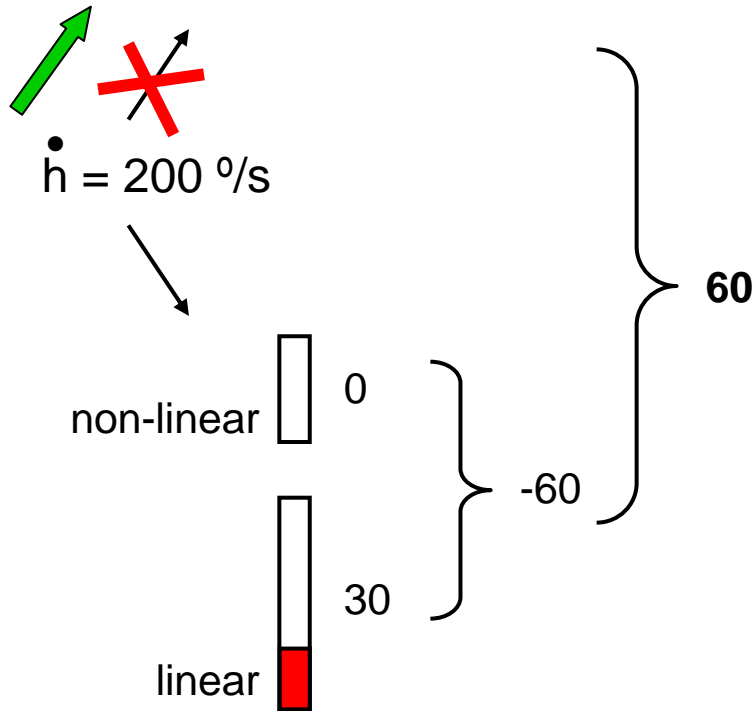


## Head impulse to the left

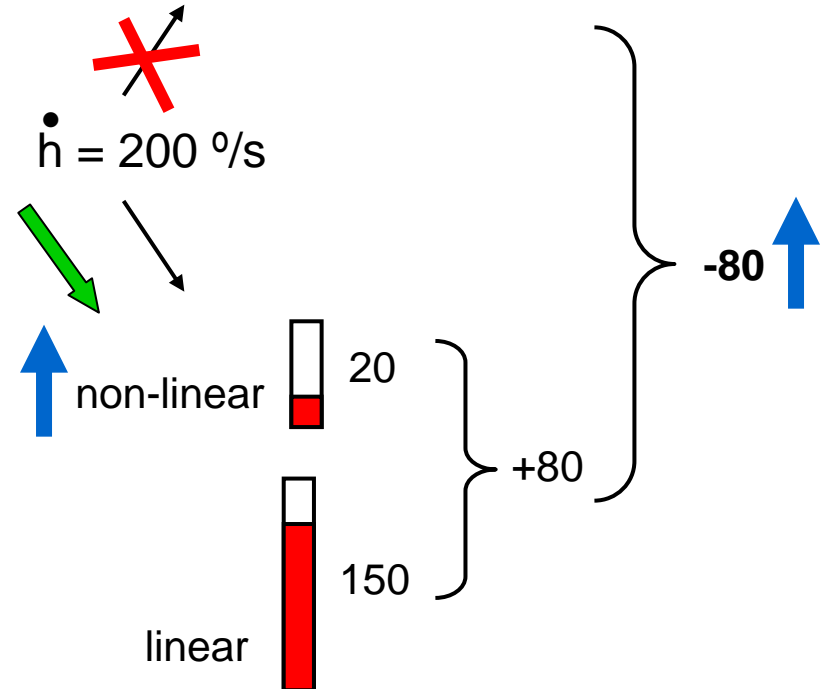


Gain reduction is greater during ipsilesional head acceleration.

## Head impulse to the right



## Head impulse to the left

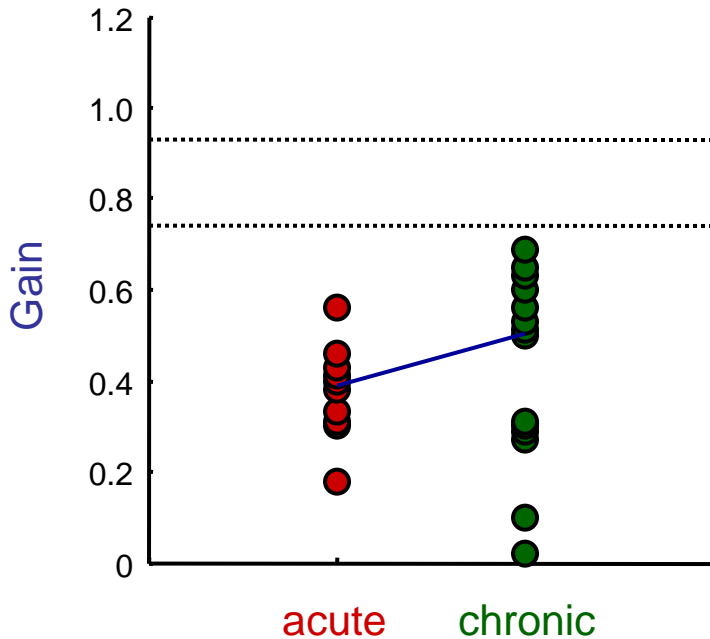


**central enhancement of  
contralesional nonlinear pathway**

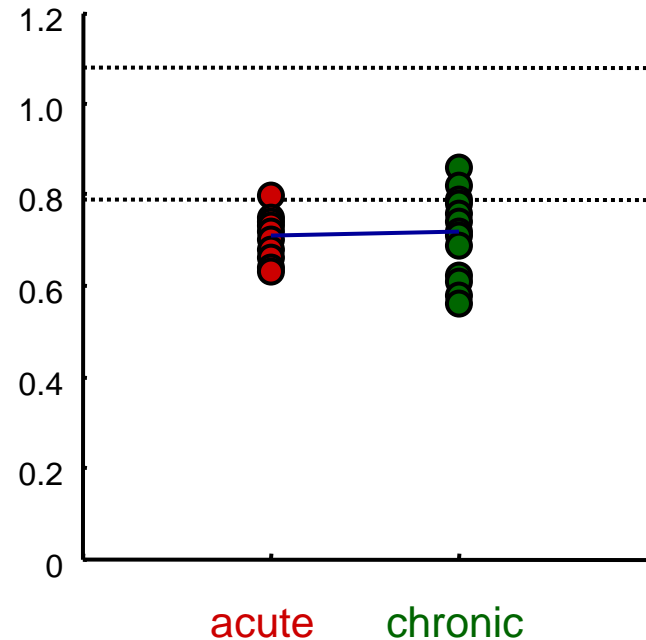
contralesional gain  $\uparrow$   
gain asymmetry  $\uparrow$

# Horizontal head impulse testing

ipsilateral

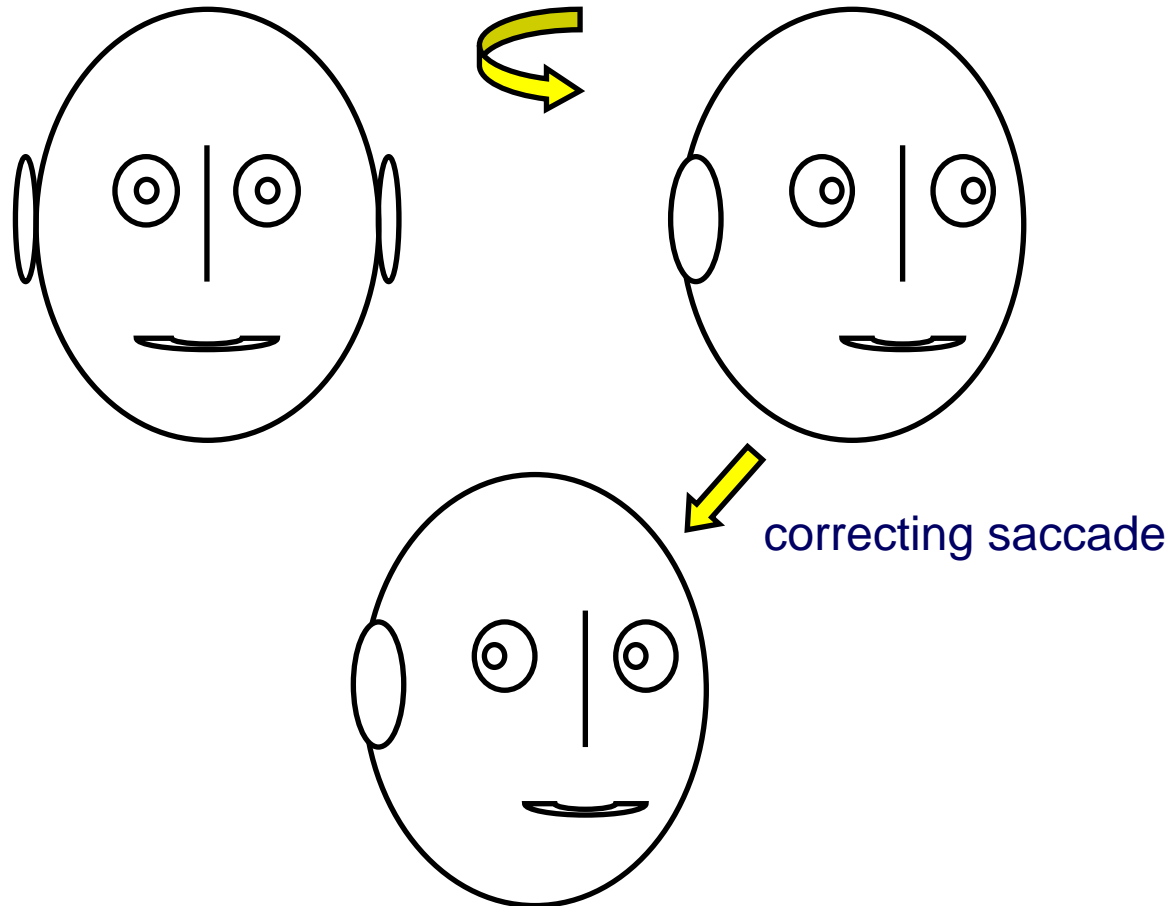


contralateral



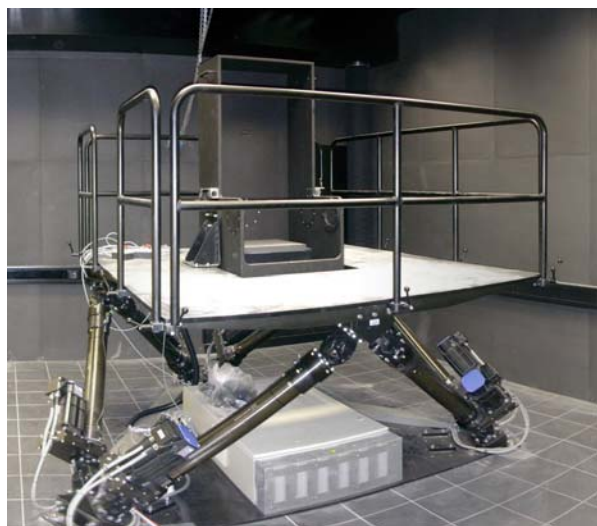
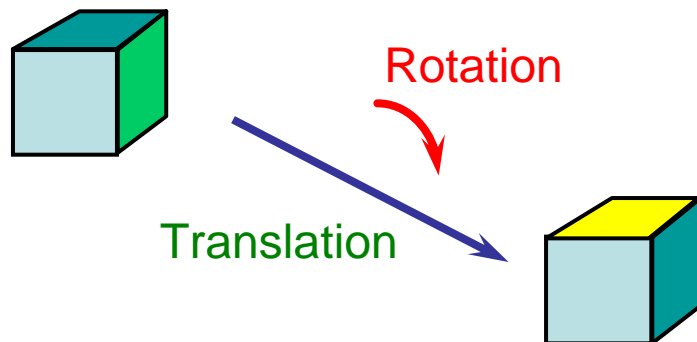
acute: < 3 days  
chronic: > 2 months

# Leftsided vestibular deficit

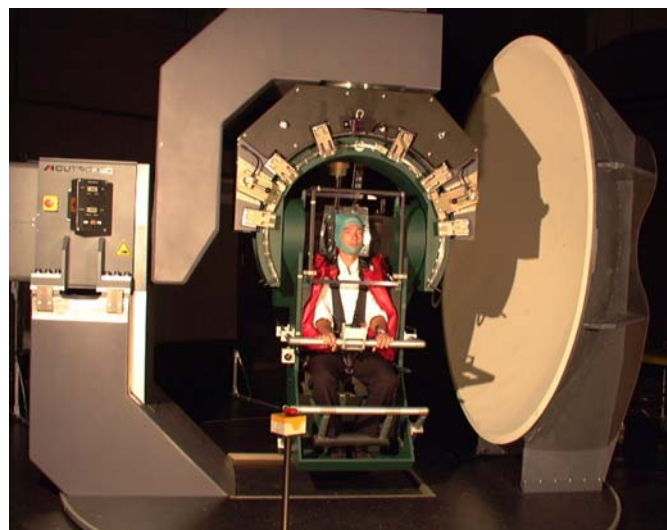


# Pathological head impulse test

**Unilateral  
vestibular  
neuritis**

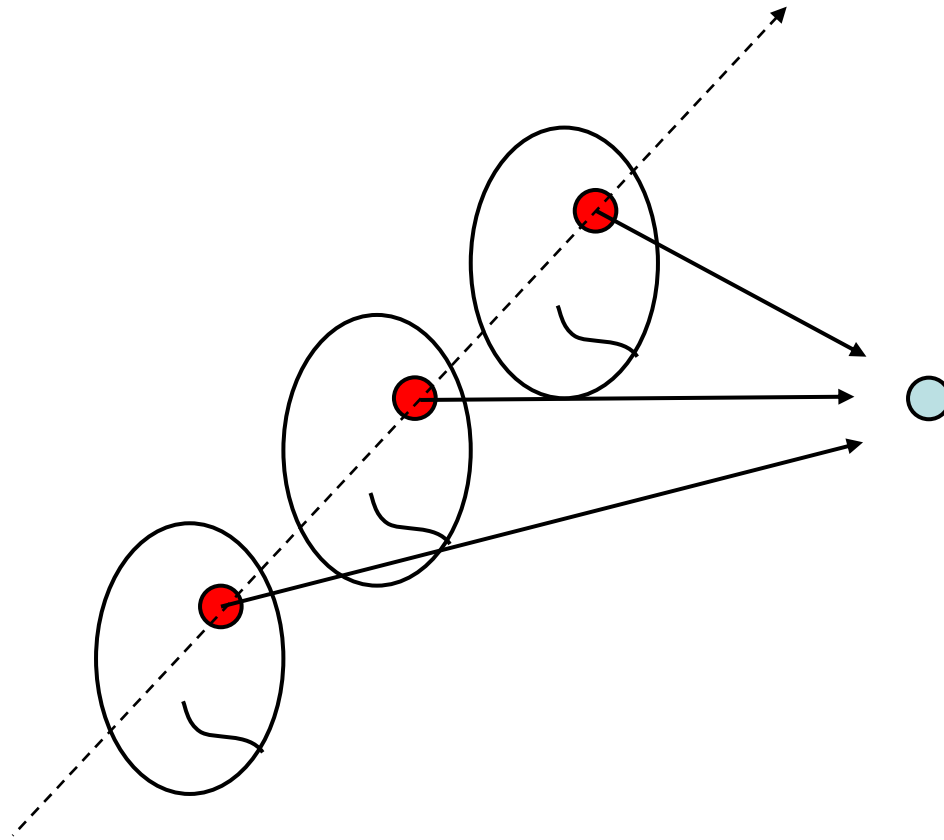


Motion simulator



Turntable

# Linear vestibulo-ocular reflex





SWAY

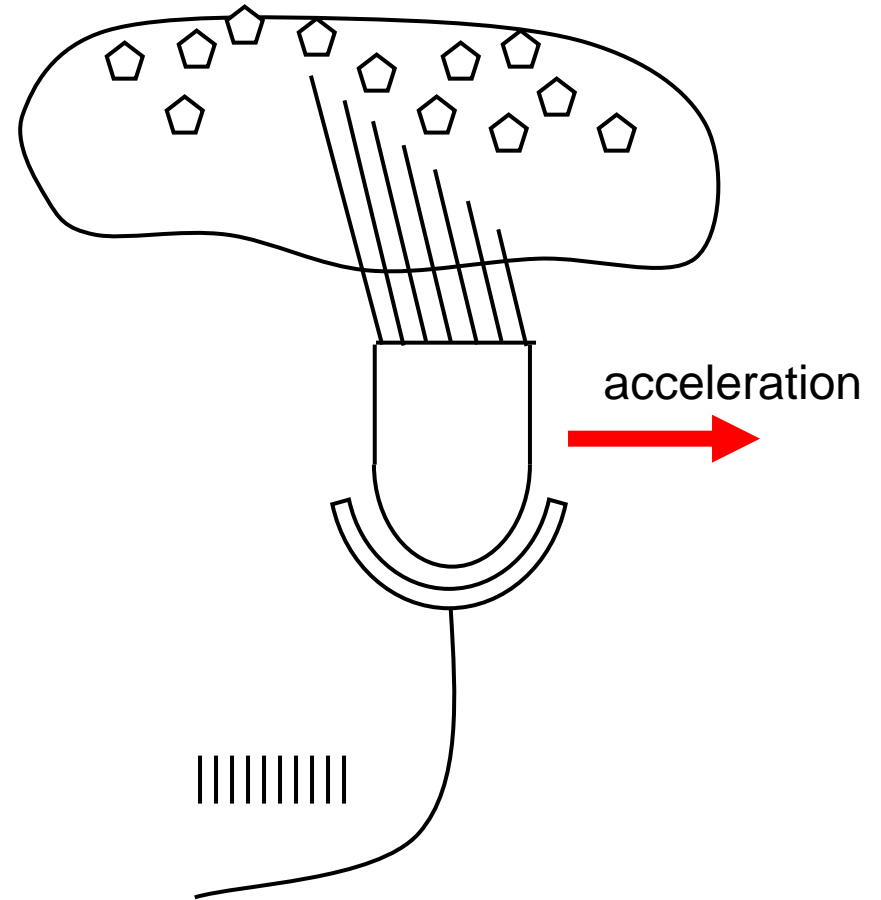
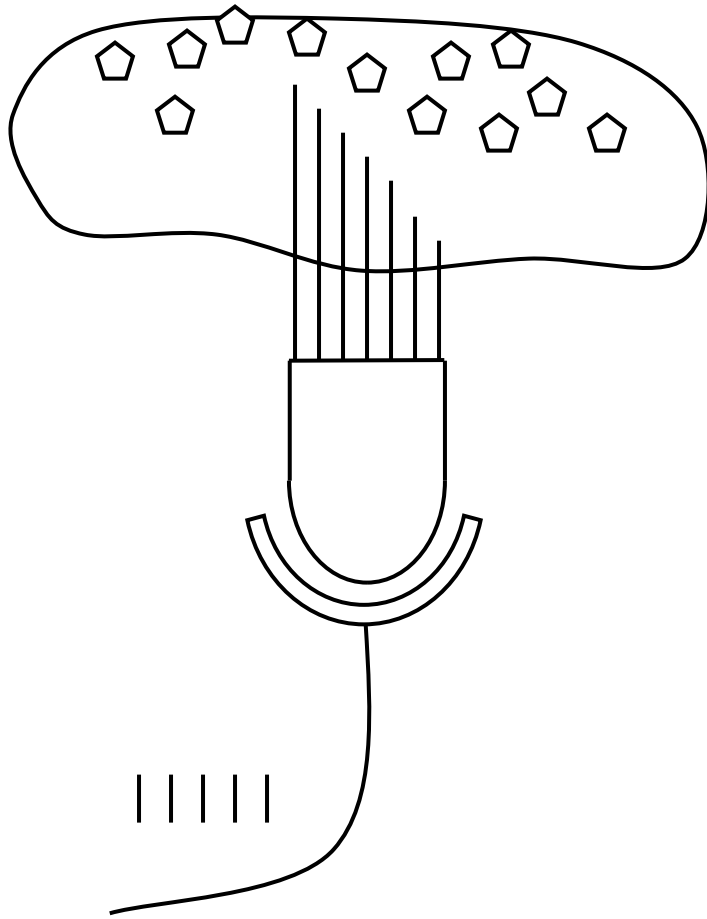


HEAVE



SURGE

# Otolith organs



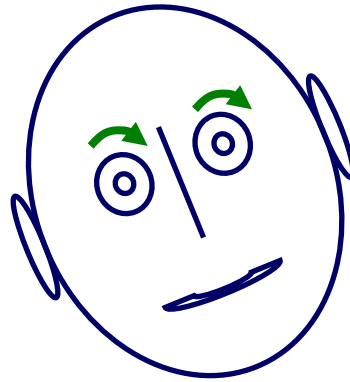
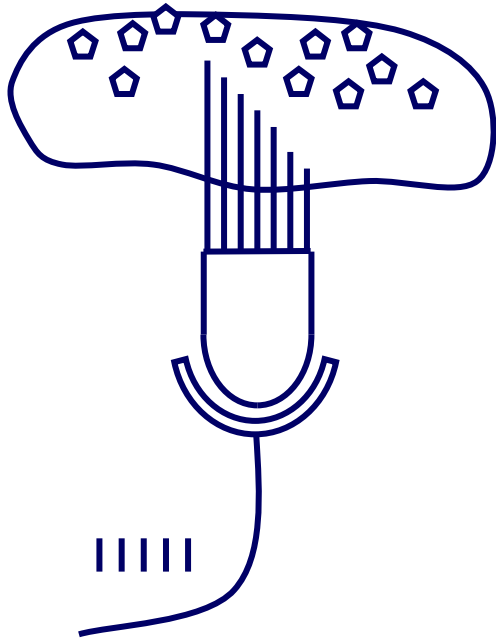
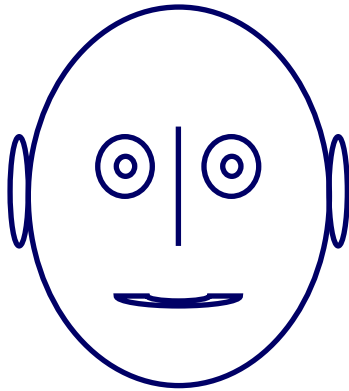
# Tilt translation dilemma



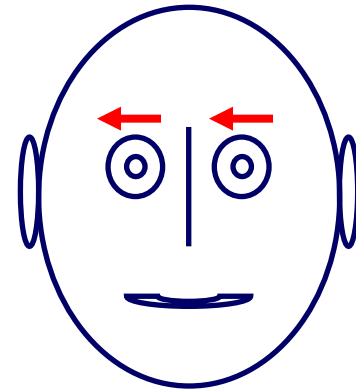
Equivalence principle:

An accelerometer can not distinguish between gravity and linear acceleration.

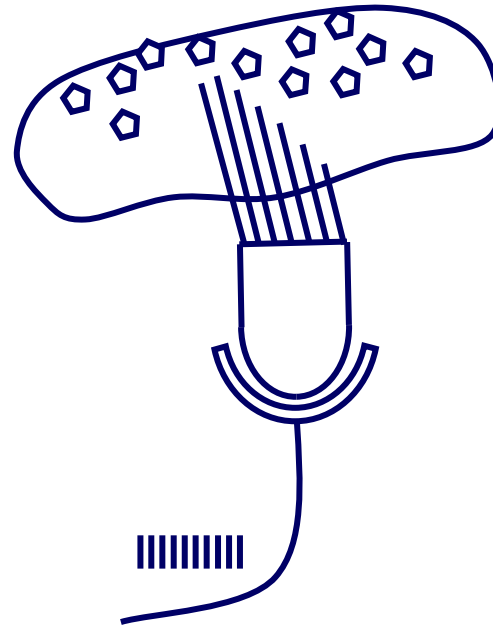
(1907)



or

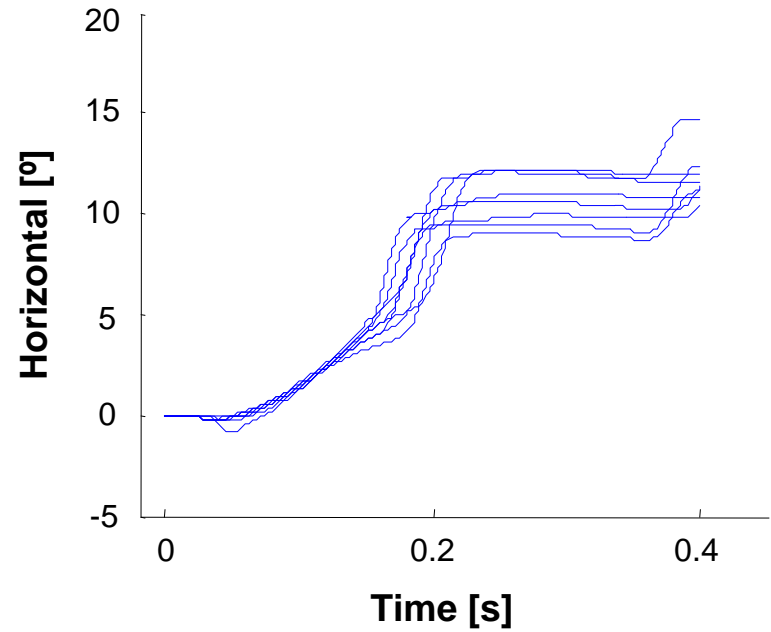
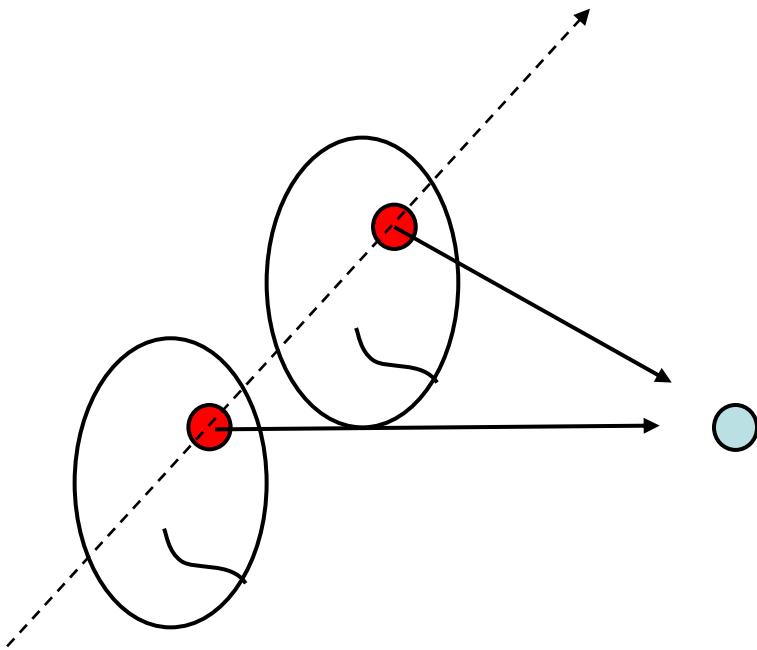


acc →

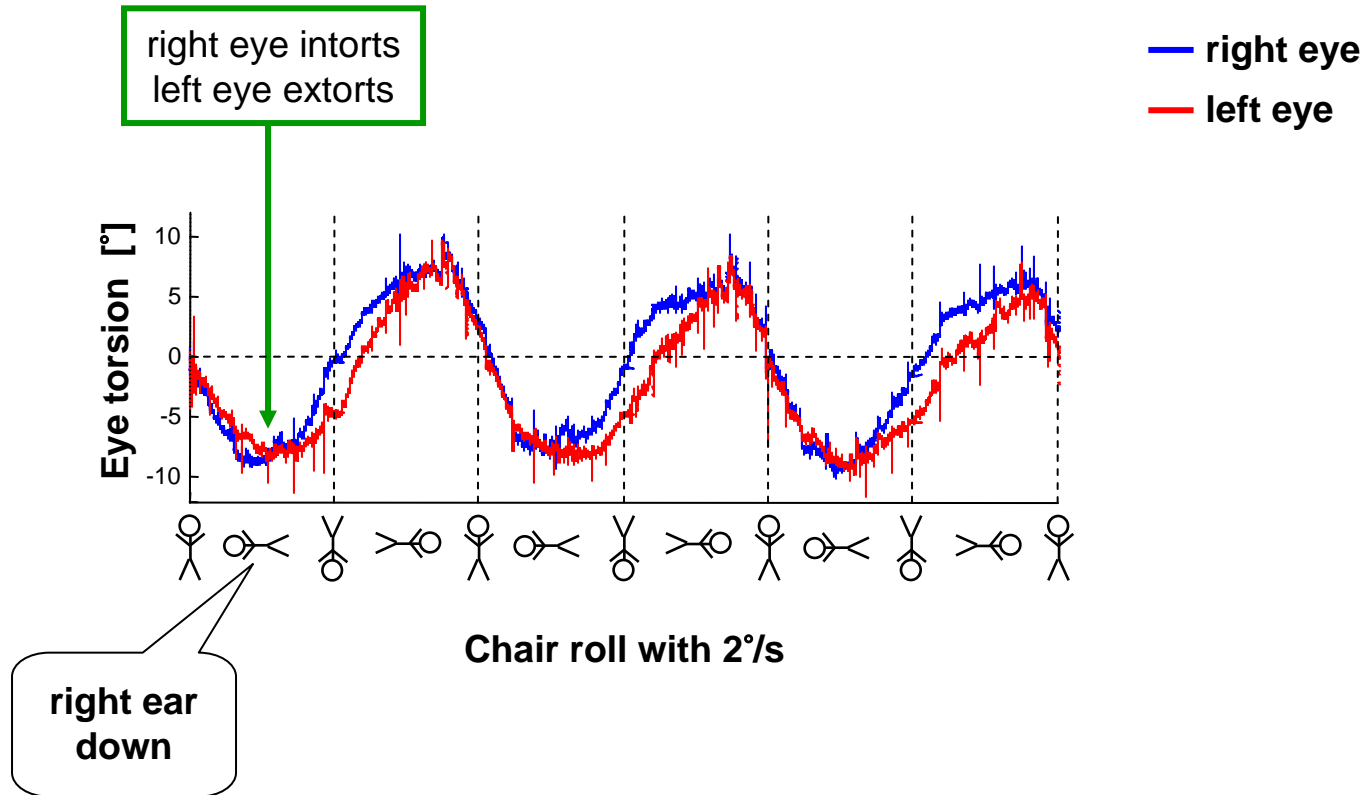


„tilt-translation  
dilemma“

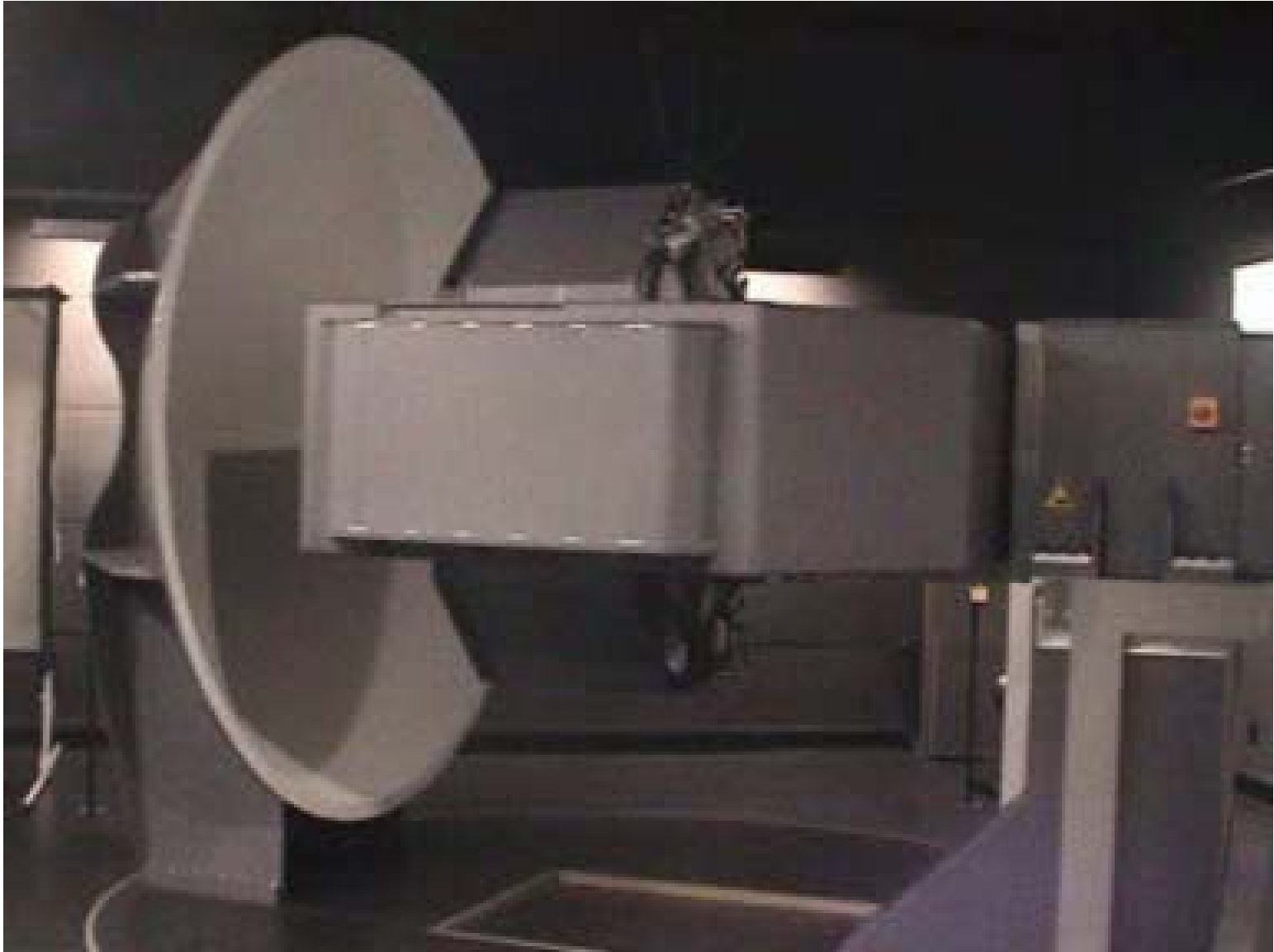
# Horizontal translational VOR



# Static ocular counterroll

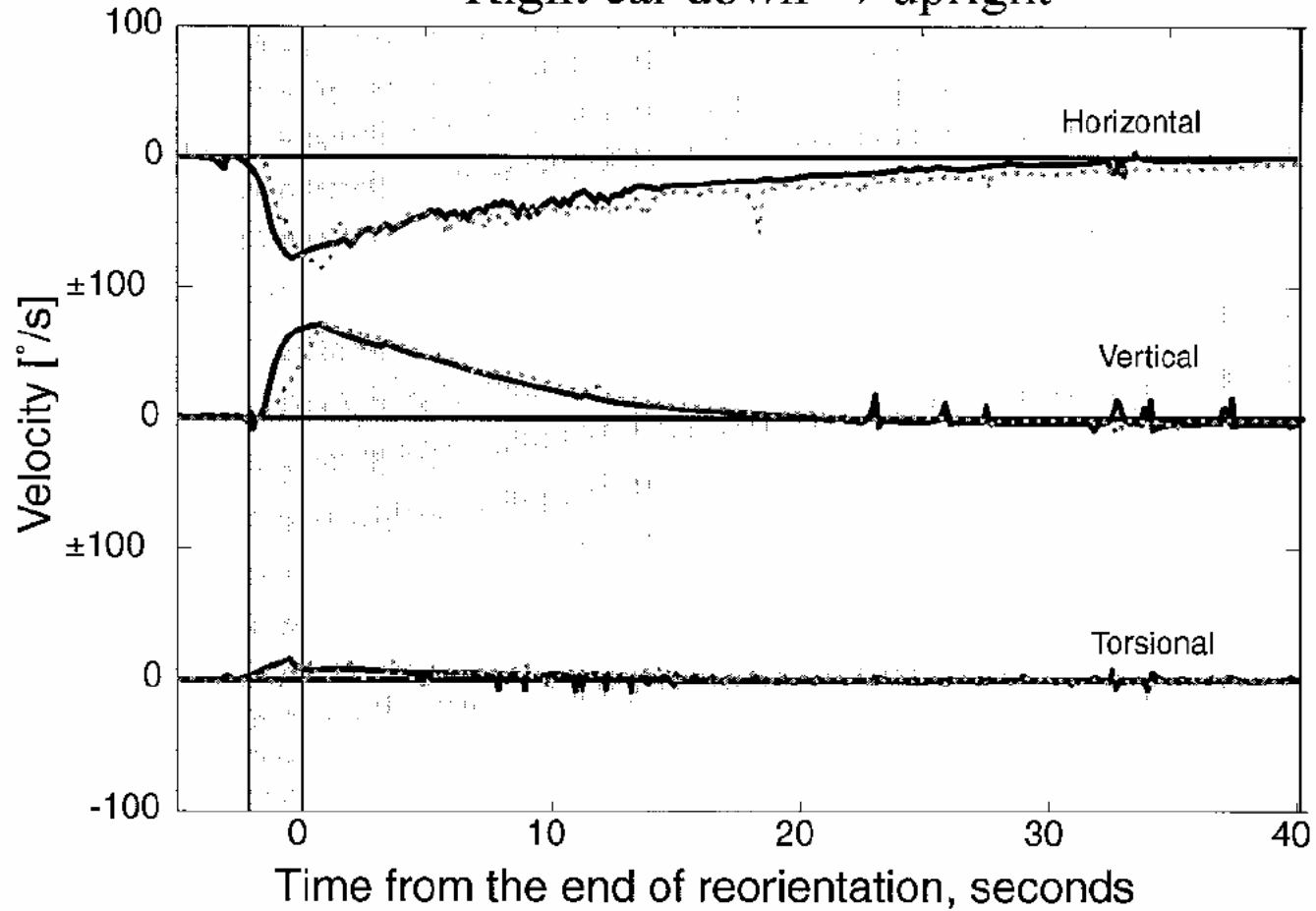


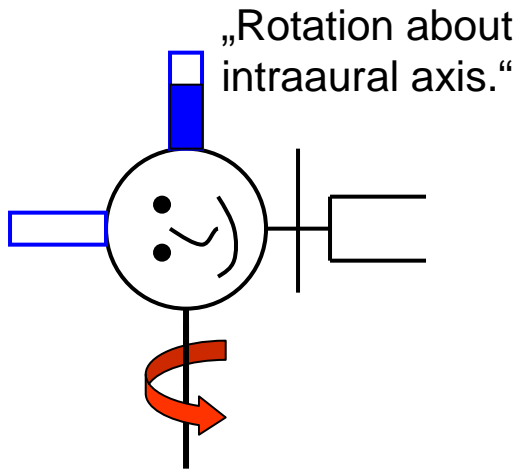
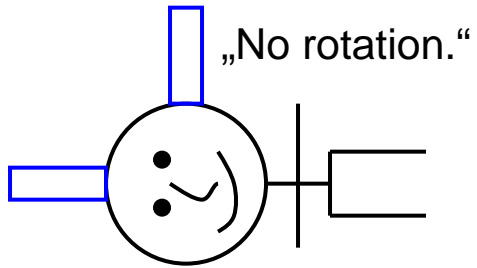
**Yaw rotation on  
office chair**



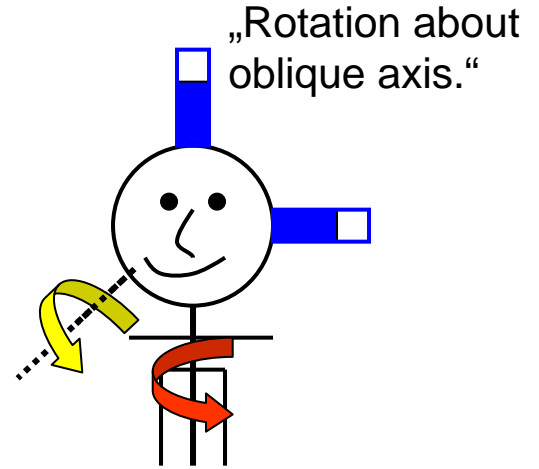
Coriolis-Experiment

# Right ear down → upright

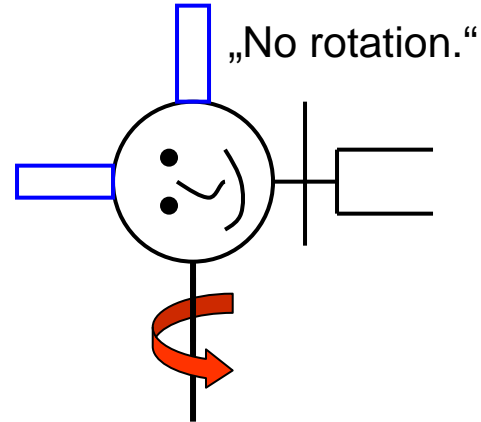


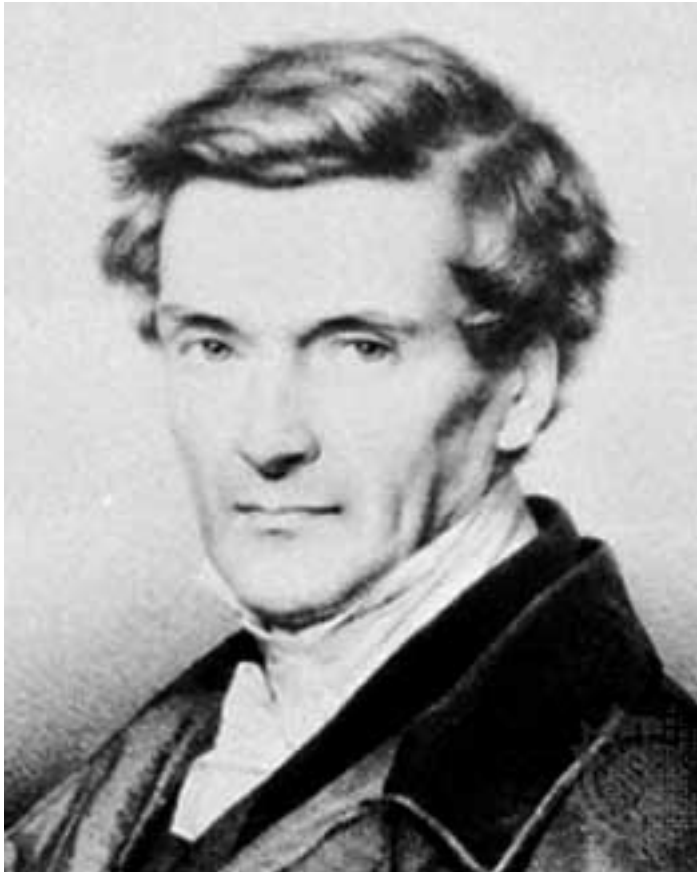


-----  
1 minute  
-----



↑  
Tilt  
|





Gaspard-Gustave de Coriolis  
(Paris, 1792-1843)



Syd Mead

Thank you for your attention!