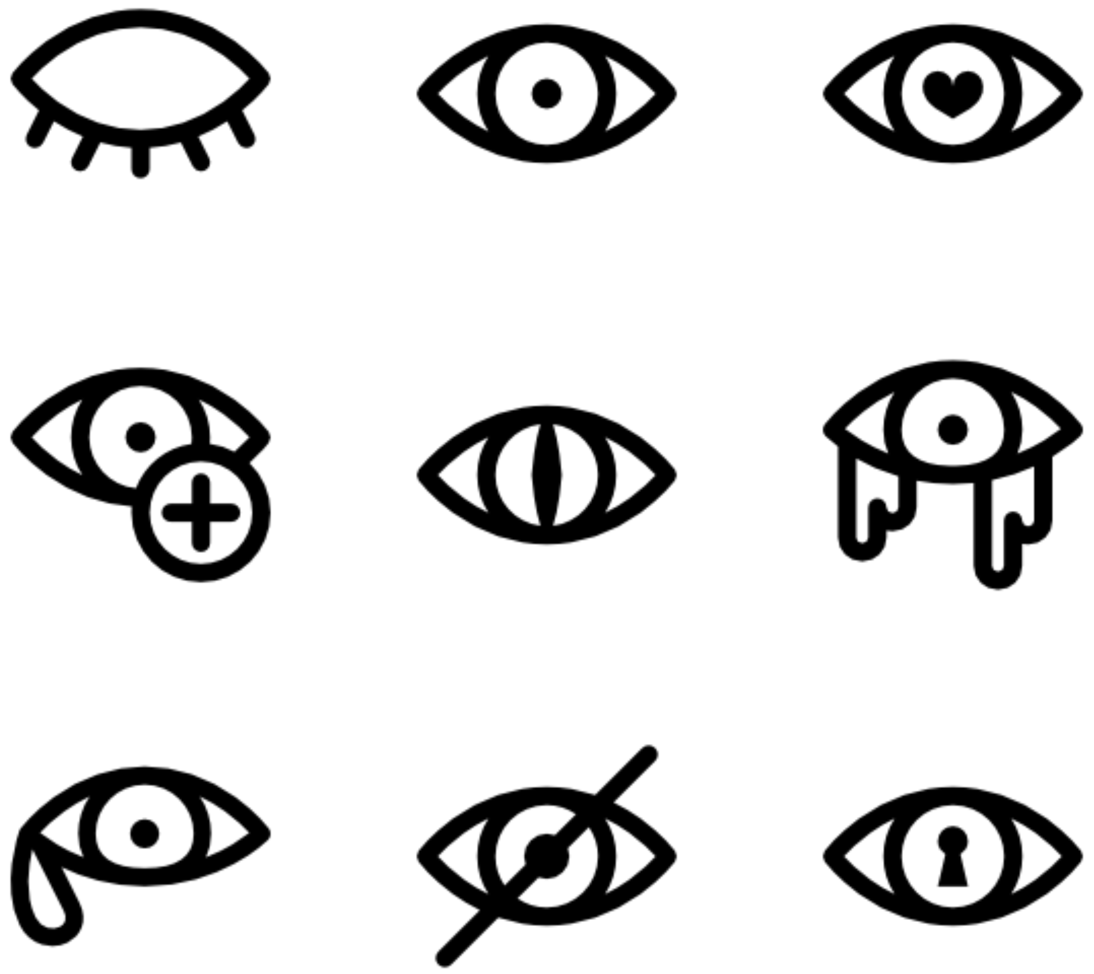
EPOS Eyetracking Course



start

This Course: Timeline

Day 01

Introduction to Oculomotor Control

- Eye Anatomy
- Types of Eye Movements
- Brain Areas
- Visual Stability

Eye Tracking in Practice

- Experimentation (Lab)
- Data Analysis (Laptop)

Day 02

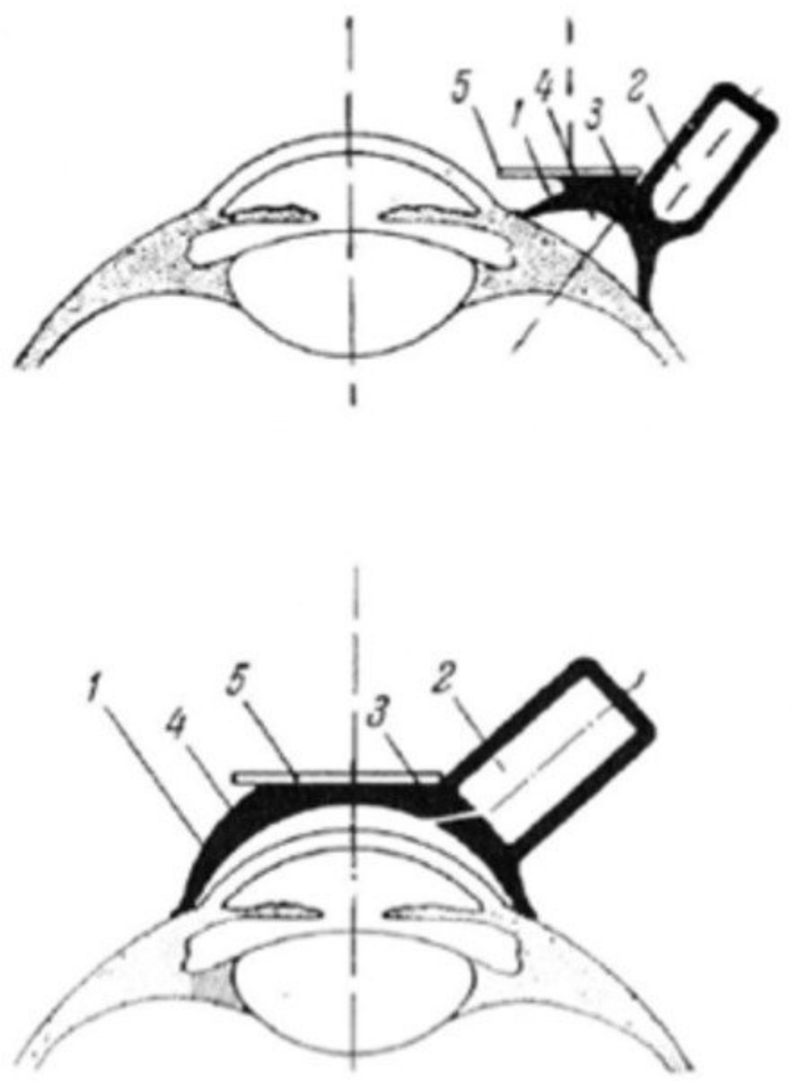
Introduction to the Pupil

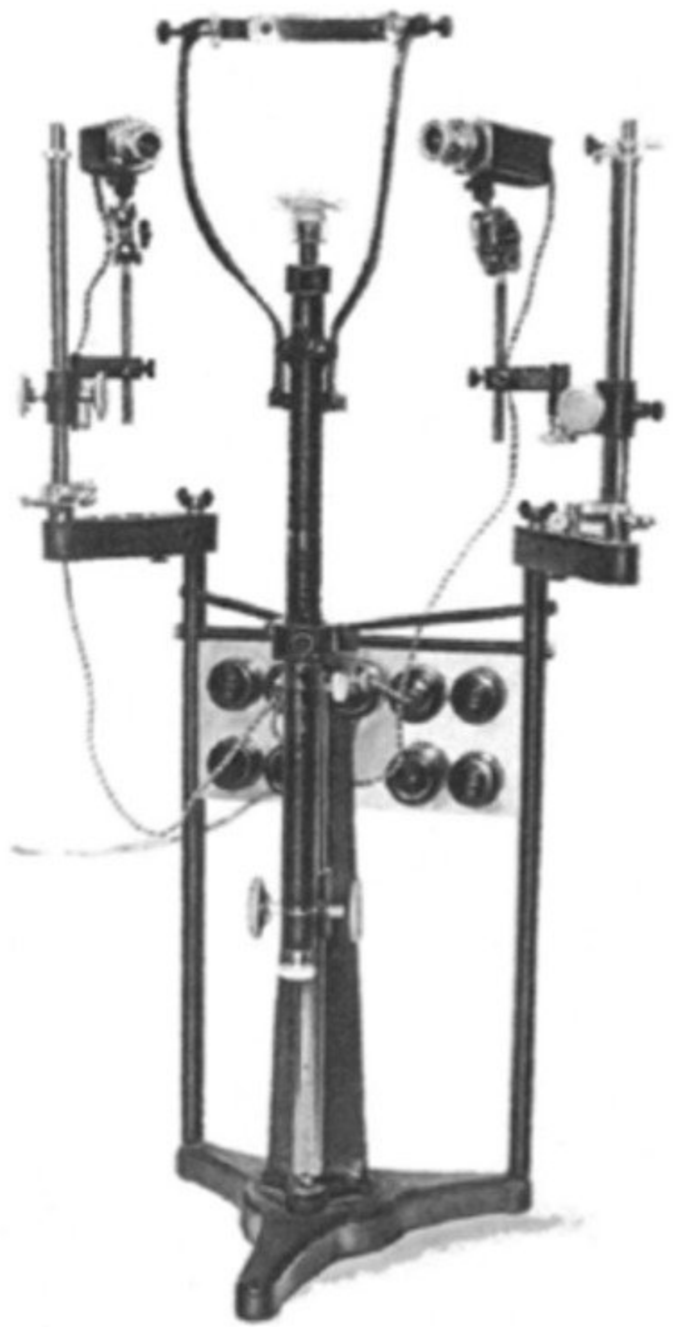
- Pupil responses to light
- Pupil as a gauge on Brain State

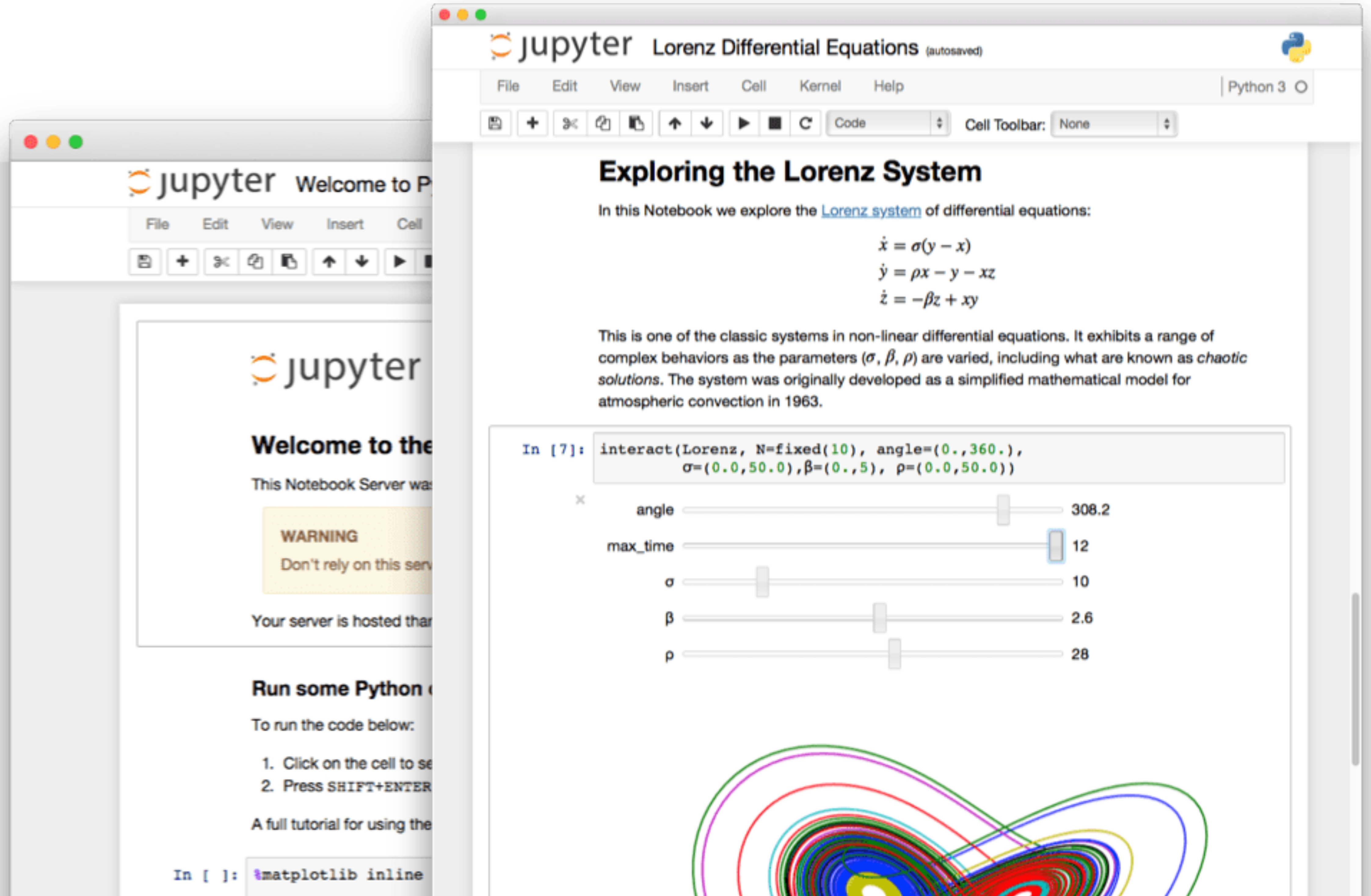
Eye Tracking in Practice

- Experimentation (Lab)
- Data Analysis (Laptop)

next







Lectures: *Background*

Practicals: *Experimentation*

- Learn how to do eye tracking
- Perform actual experiments

Practicals: *Analysis*

- Open-Source tools
- Python Notebooks
- Entire course on GitHub: https://github.com/tknapen/eyetracking_course

Only two days:

ready-made experiments & analyses

Meant to give you a starting point for your own experiments

Why Eyetracking?

"Oculus Animi Index" *Cicero*

Neuroscience: By recording the eye, we learn about the brain.

We learn about what the brain finds important, because it will look there.

We learn about the observer's internal state from the pupil

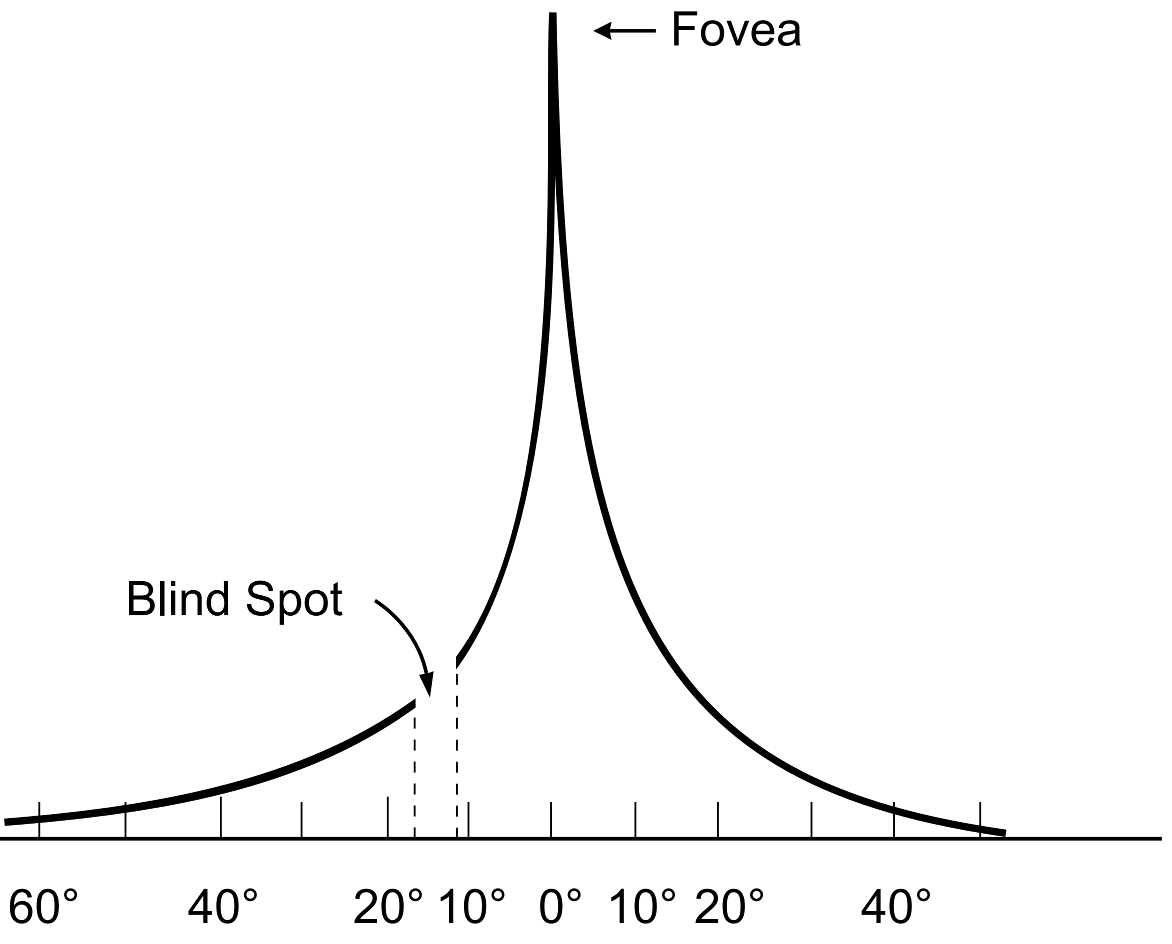
The interaction between action and sensation is extremely close:

An eye movement moves a primary sense organ!

This Lecture:

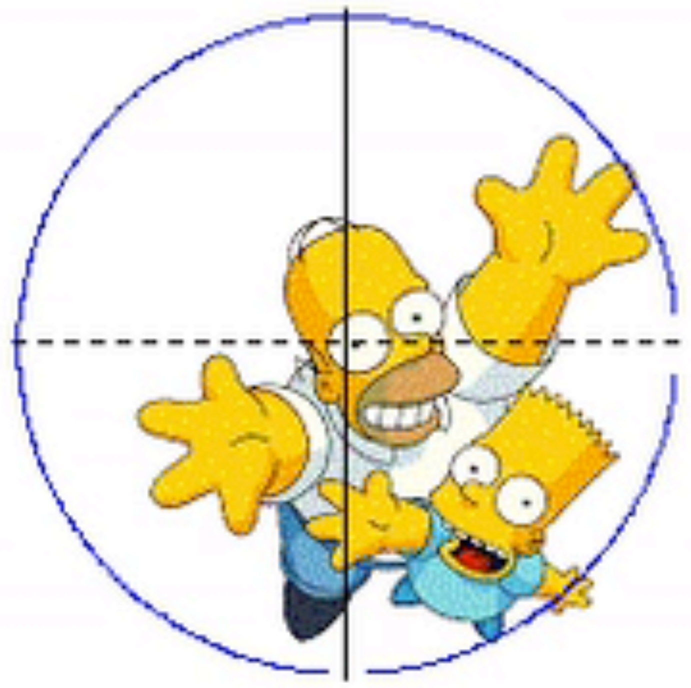
- Different types of eye movements
- Anatomy of the eye muscles
- How does the brain cause these eye movements:
  motor control and neural circuits

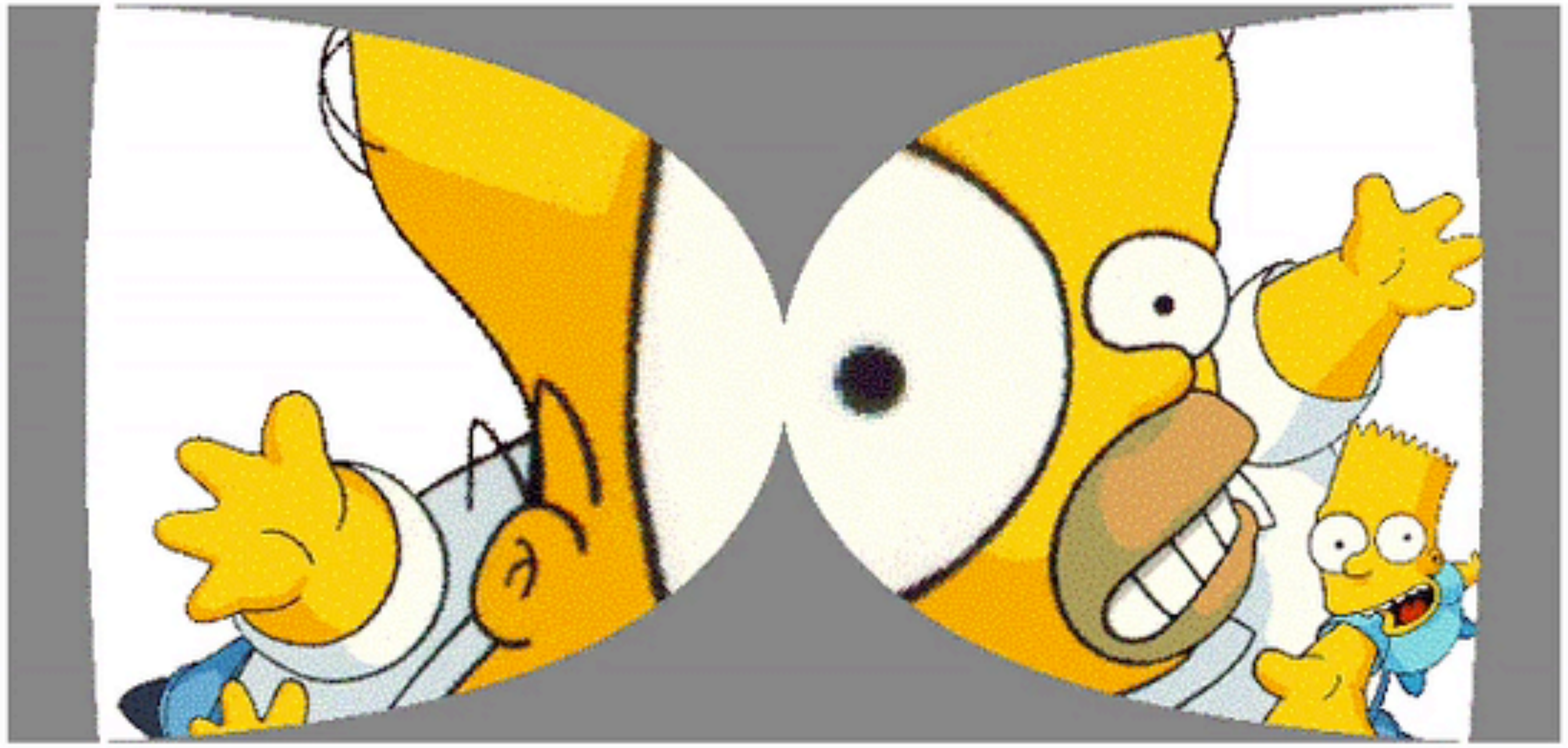
Why make eye movements??



One reason:
*We're almost blind outside the **Fovea***

We need to move the Fovea around in order to process visual information





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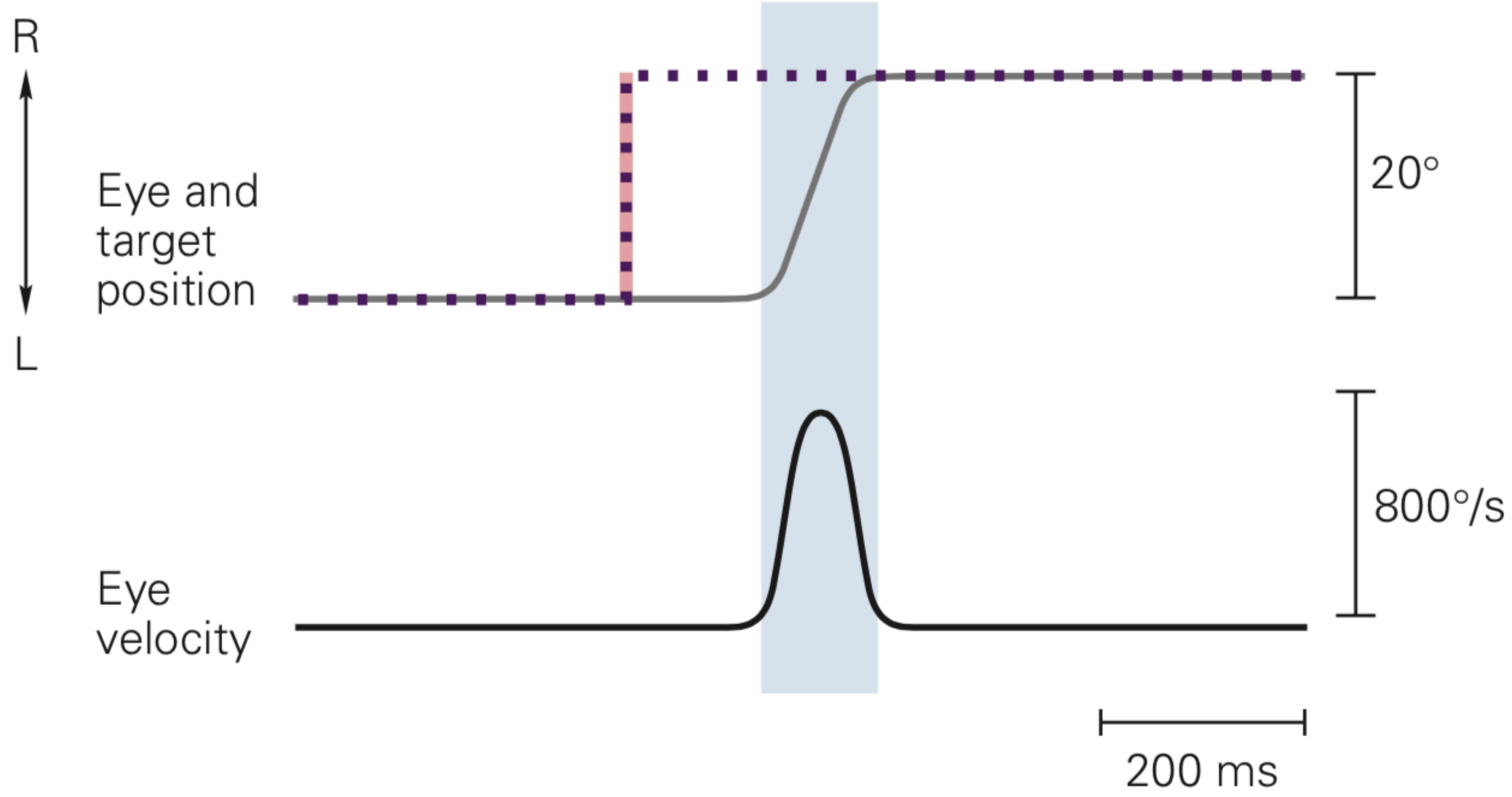
Different eye movements



Yarbus, 1967

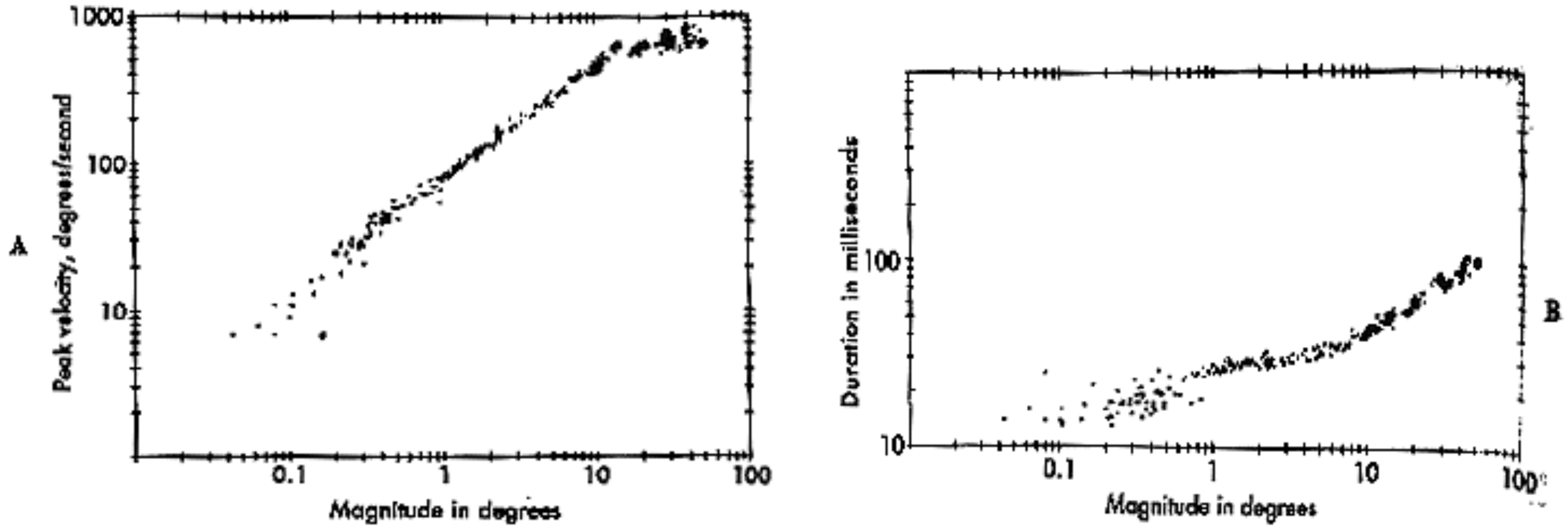
Saccades:

Used to scan the Scene in front of us
Ballistic (Fire-and-Forget) Eye Movements from Fixation to Fixation
We make ~3 saccades per second,
but are almost never aware of them
Fastest (Eye) Movements we make (up to 900 °/s)

Memory-guided saccades: *We can make saccades to things that are not there: implies high-level brain mechanisms are involved*

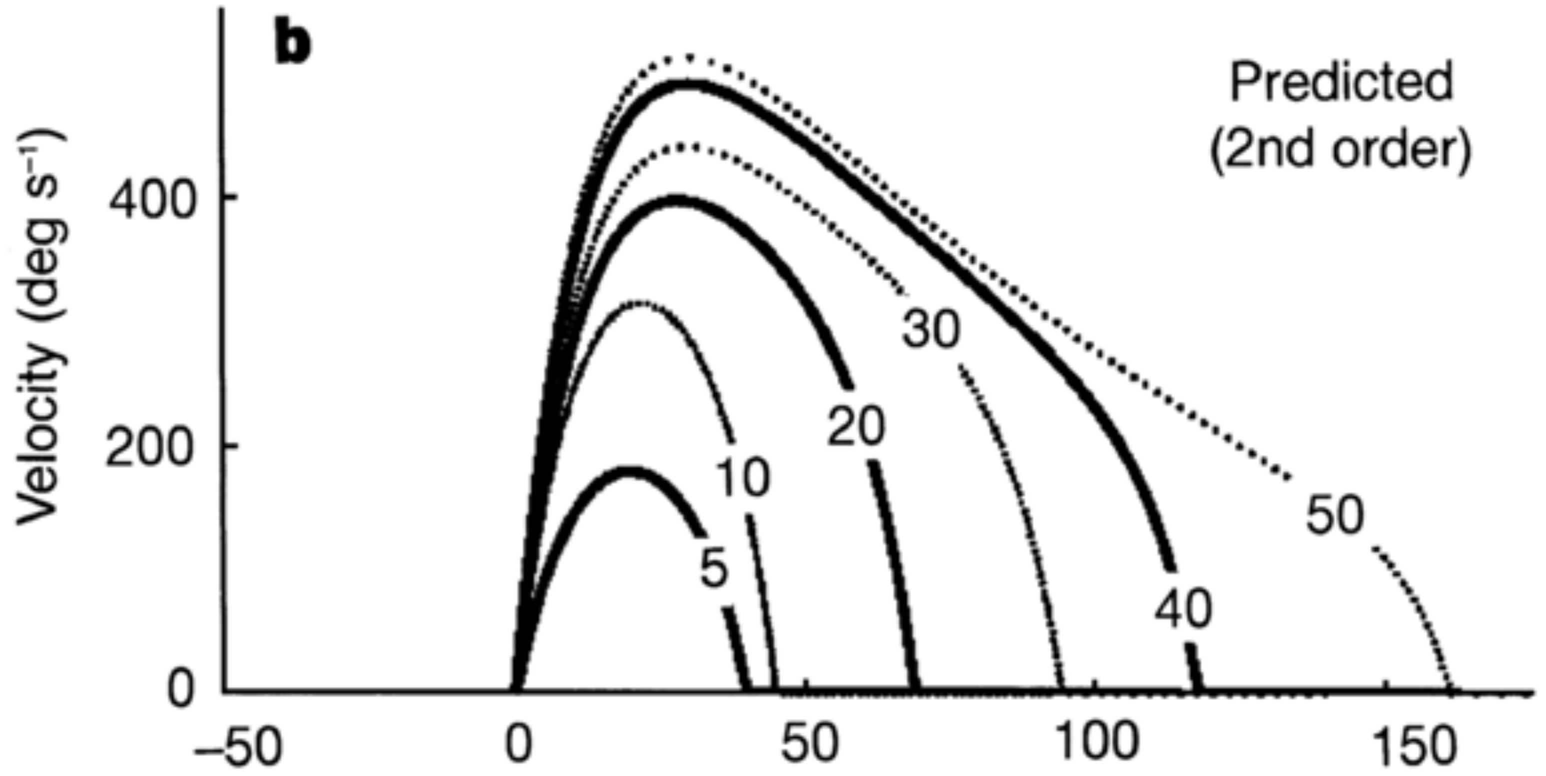
next

Saccades



Main Sequence: *The larger a saccade, the faster it is*
The larger a saccade, the longer it takes

Stereotypical velocity profile



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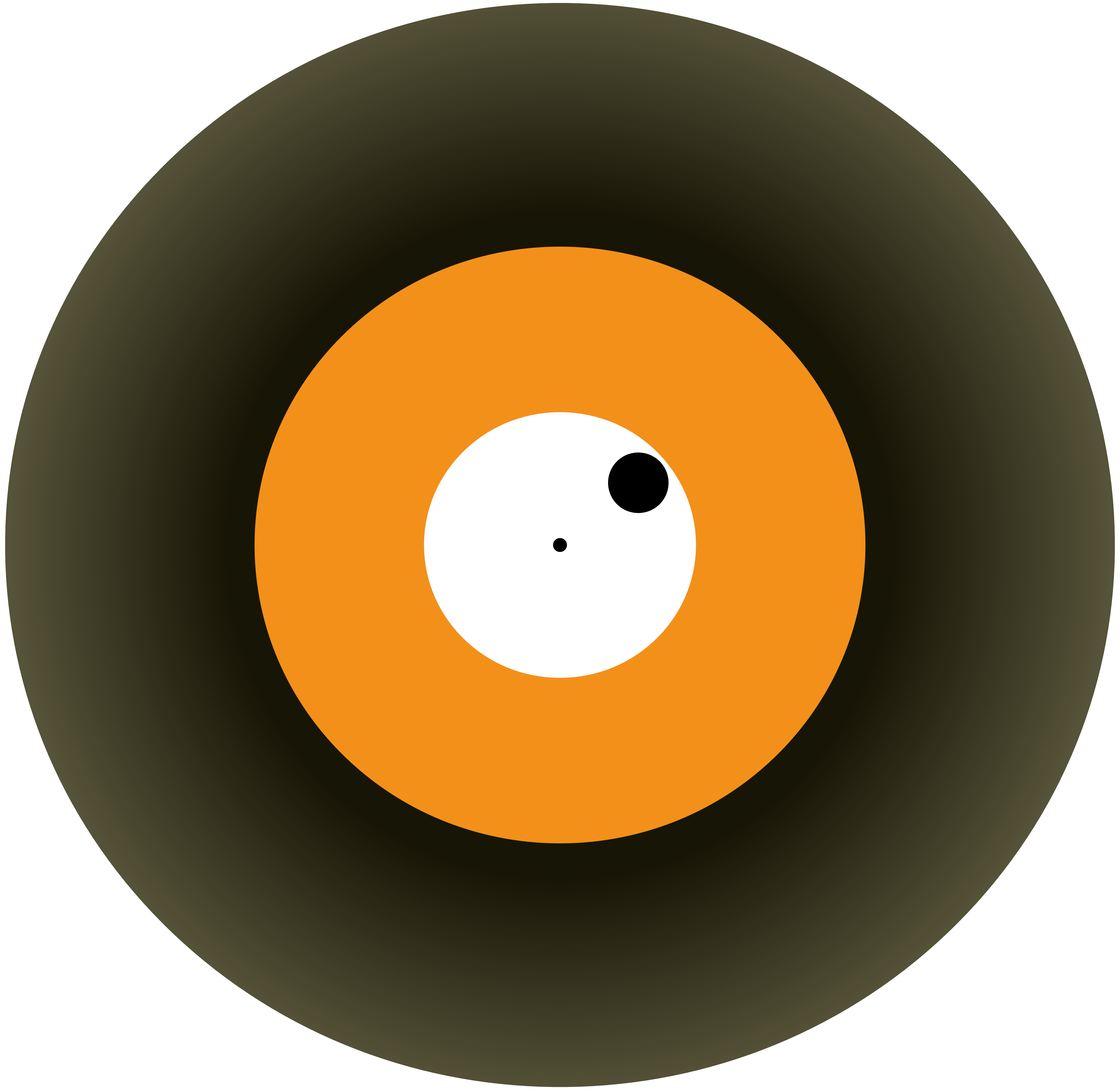
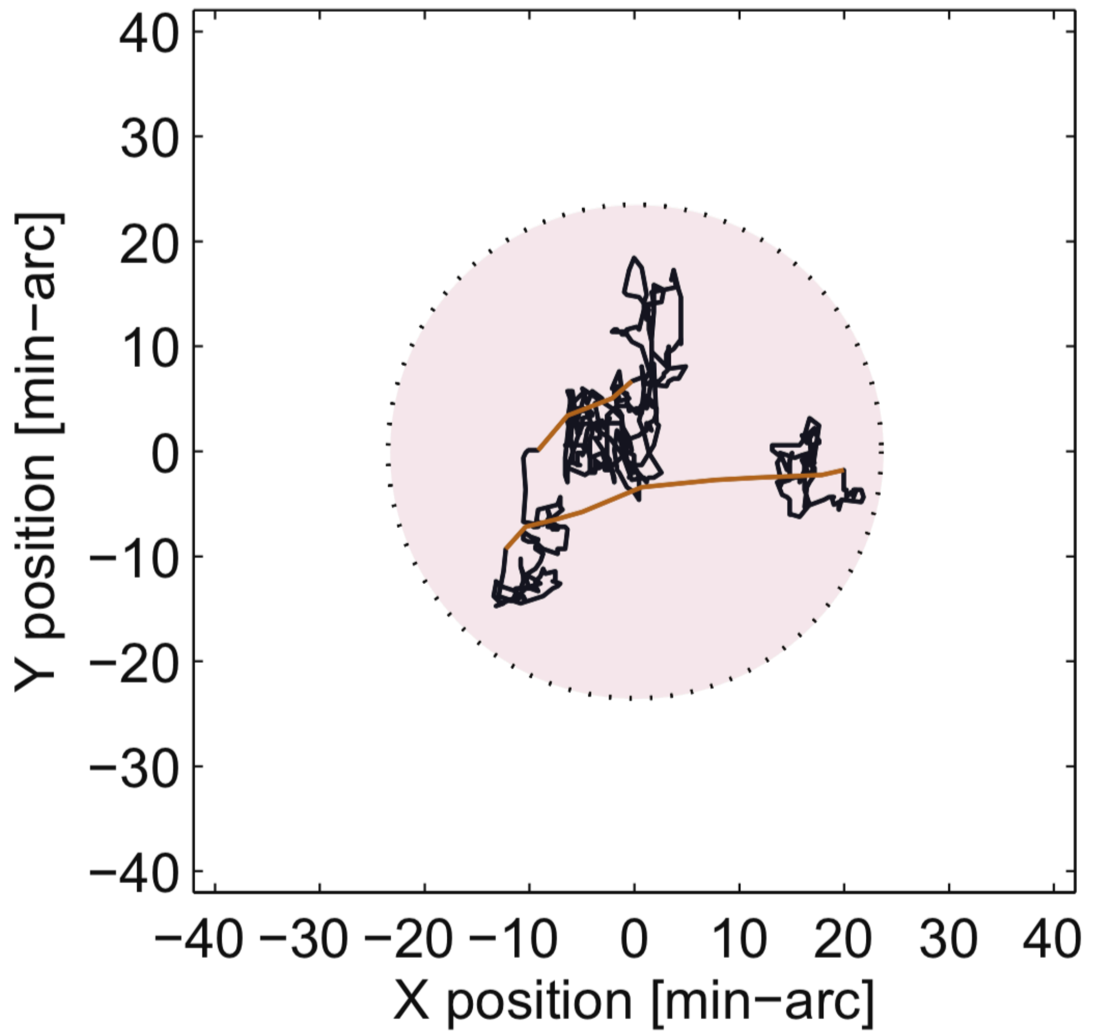


Micro Saccades



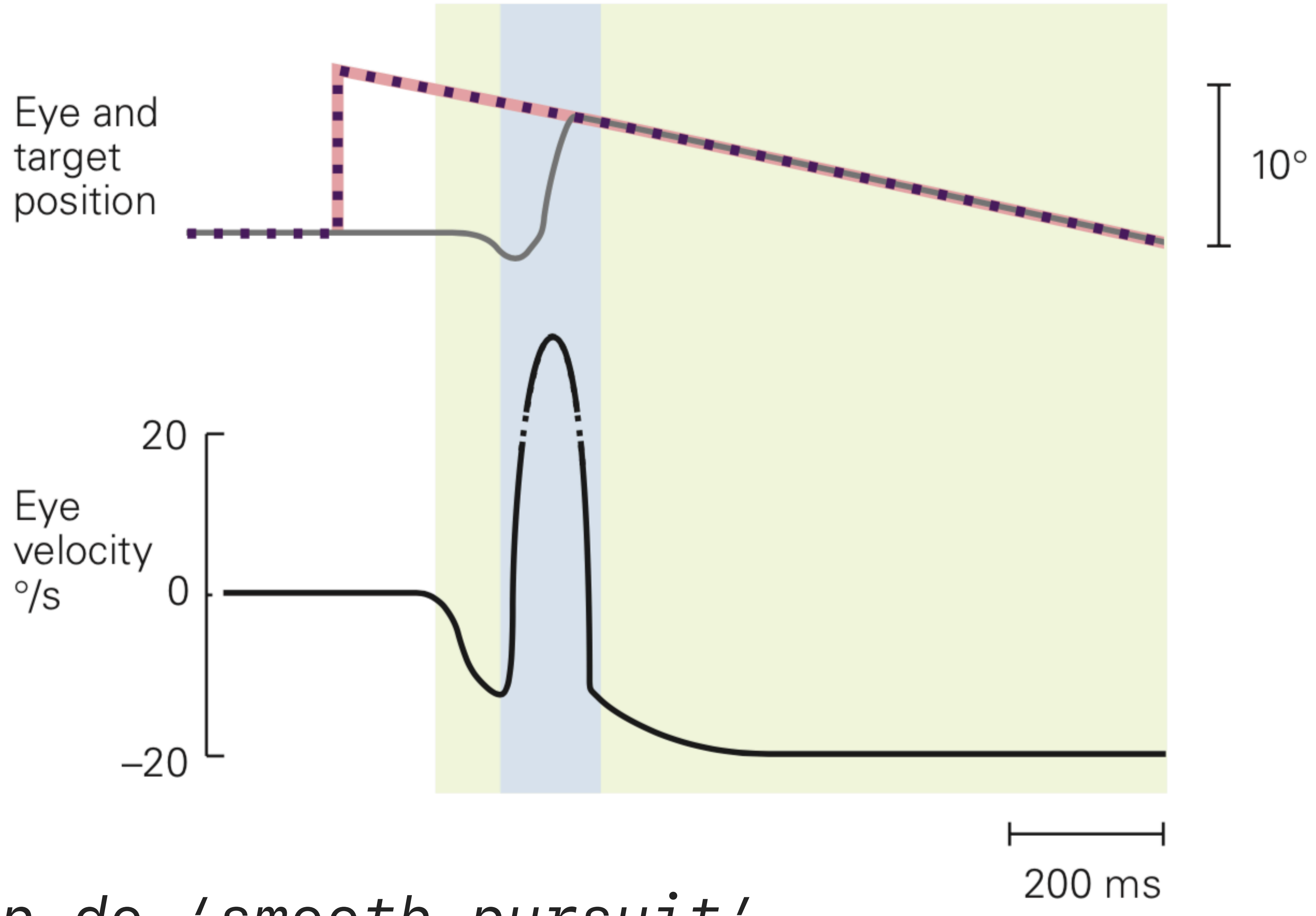
During fixation, the eye is not still.
The eye drifts, and then we make ***Microsaccades***

Microsaccades are usually categorised as all saccade-like eye movements with amplitude <1º

Main Sequence

MS are very brief (<10 ms), so need a fast eye tracker (<250Hz)!
MS are very small, so need a high-precision eye tracker!

Smooth Pursuit



Humans & other 'higher' animals can do 'smooth pursuit'

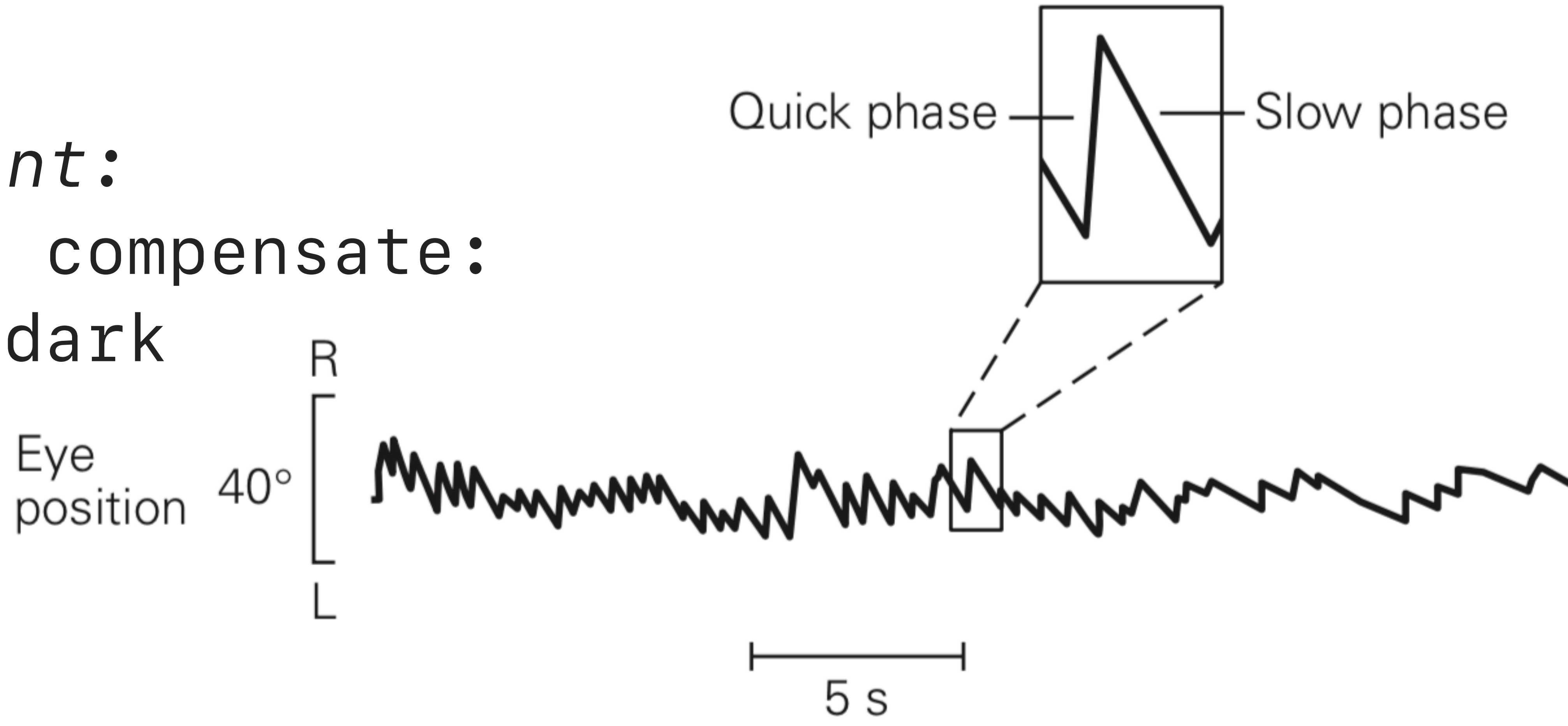
Track a moving target, precisely and without delay.
(Gain 1 and phase lag 0)

Requires continuous updating and integration of motor commands and predictions of motion of a target: Complicated Stuff!

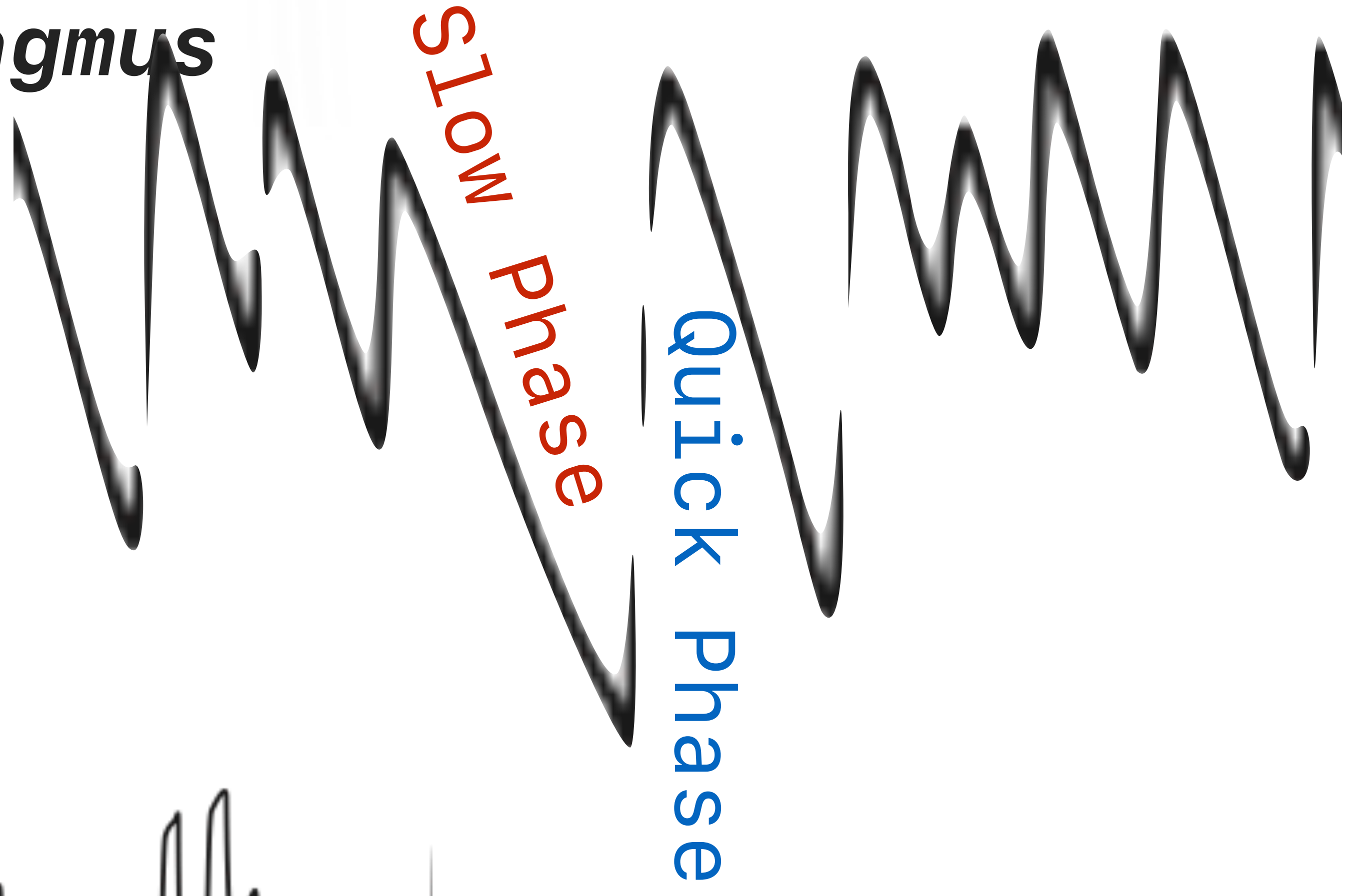
Highest temporal rates of change that can be followed:
around 1 Hz

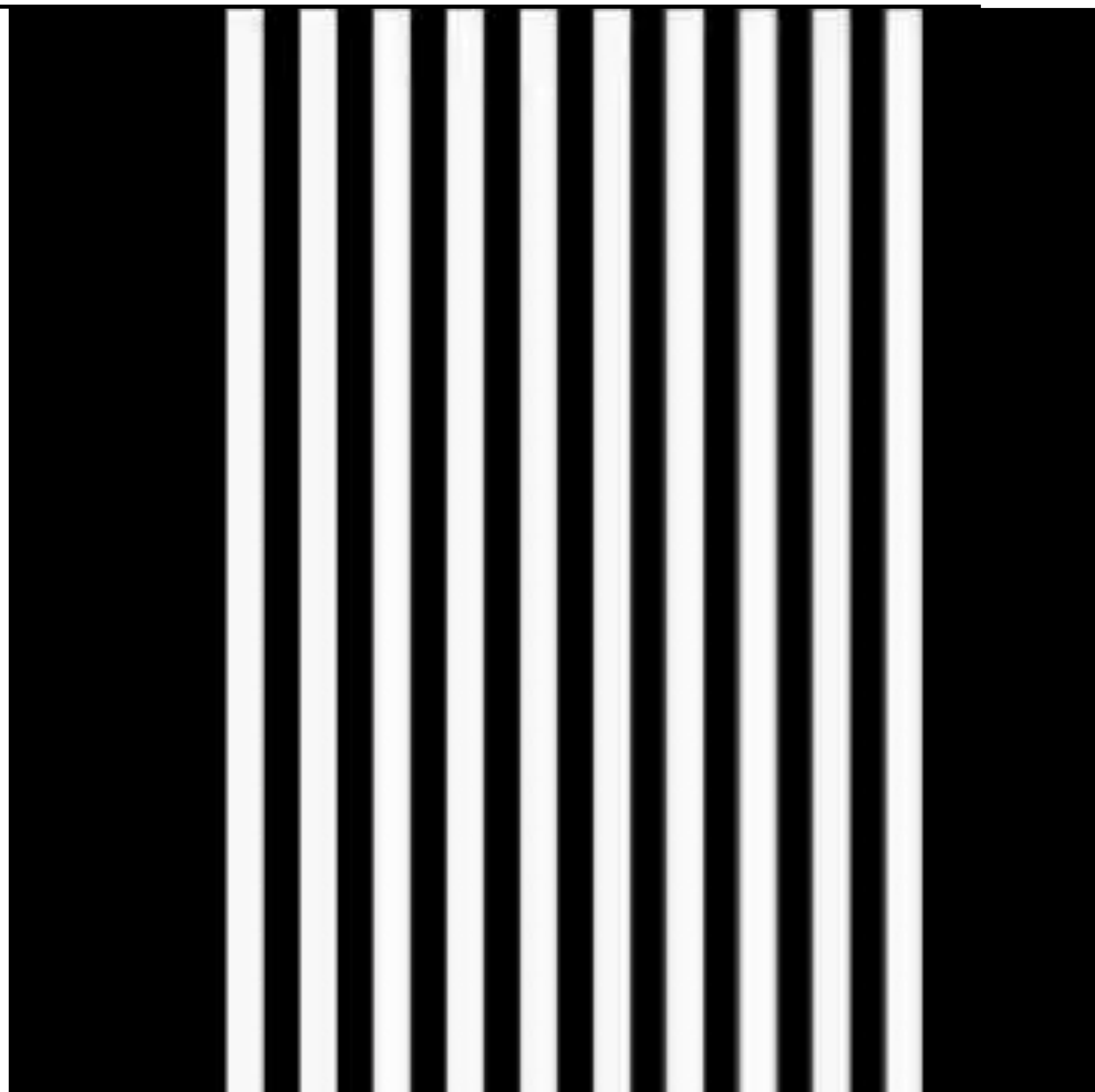
Reflexes and Nystagmus

Keeping the eyes steady is important:
If the body moves, the eyes try to compensate:
Vestibular Nystagmus, even in the dark

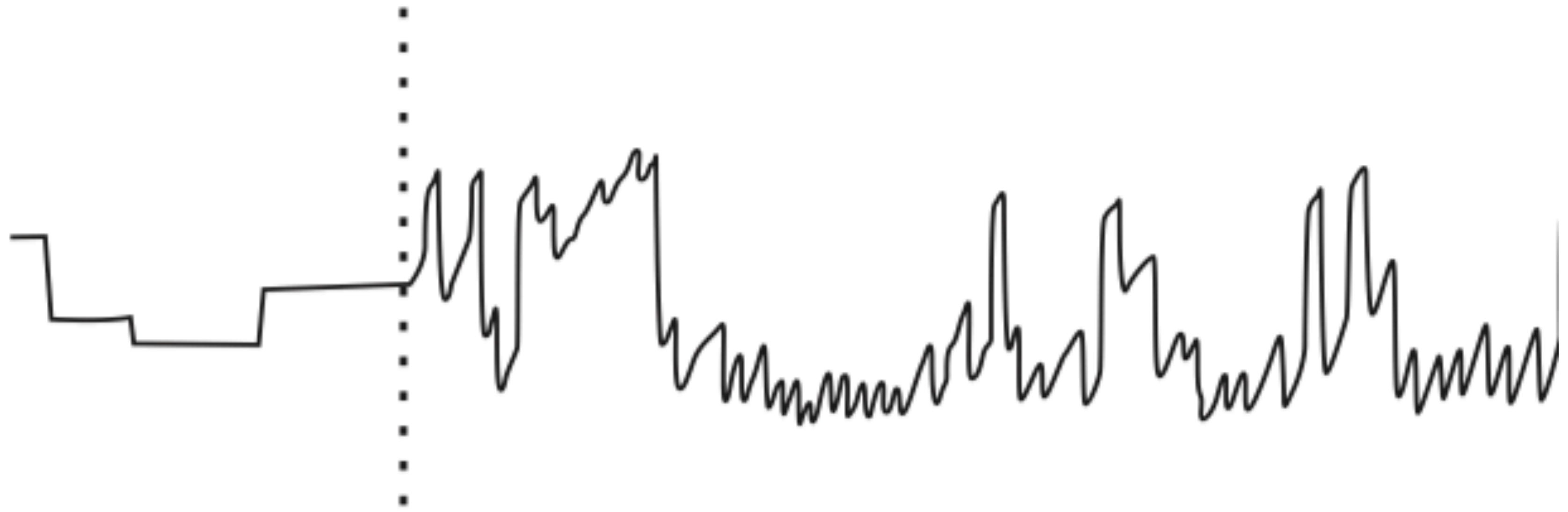


Large moving patterns will induce involuntary following:
Opto-Kinetic Nystagmus





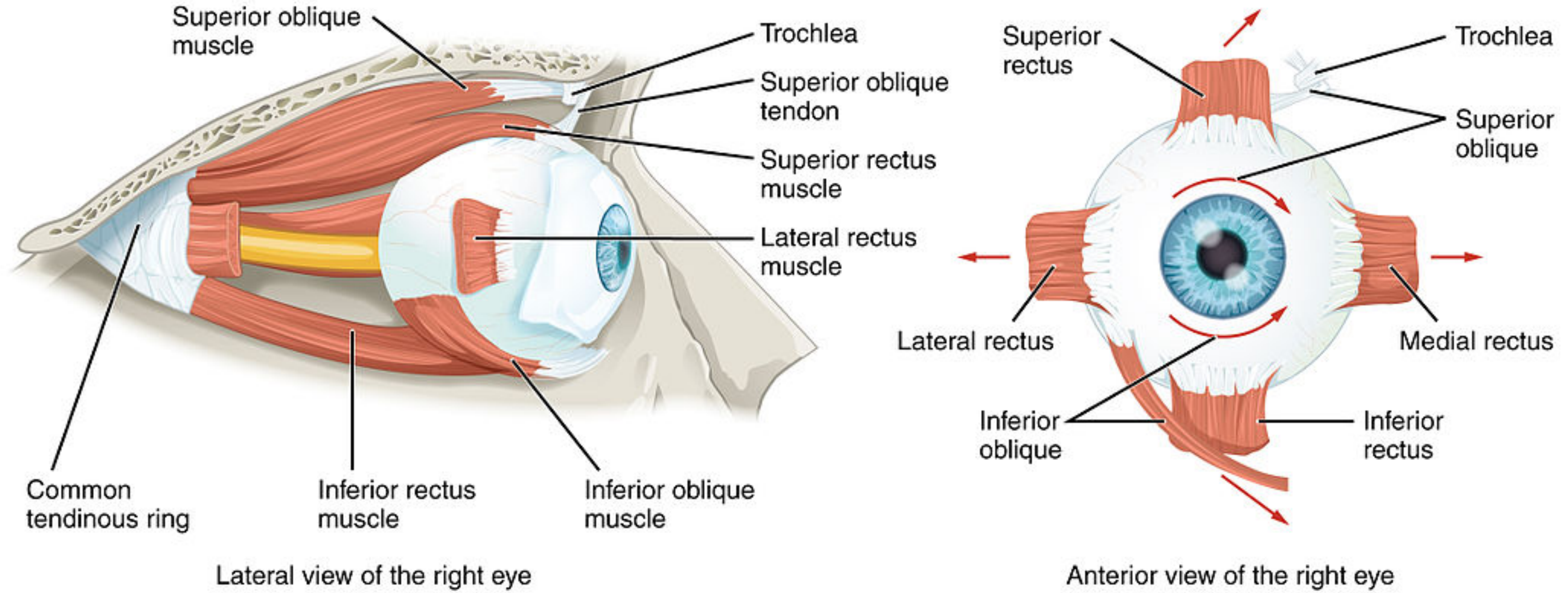
HE position



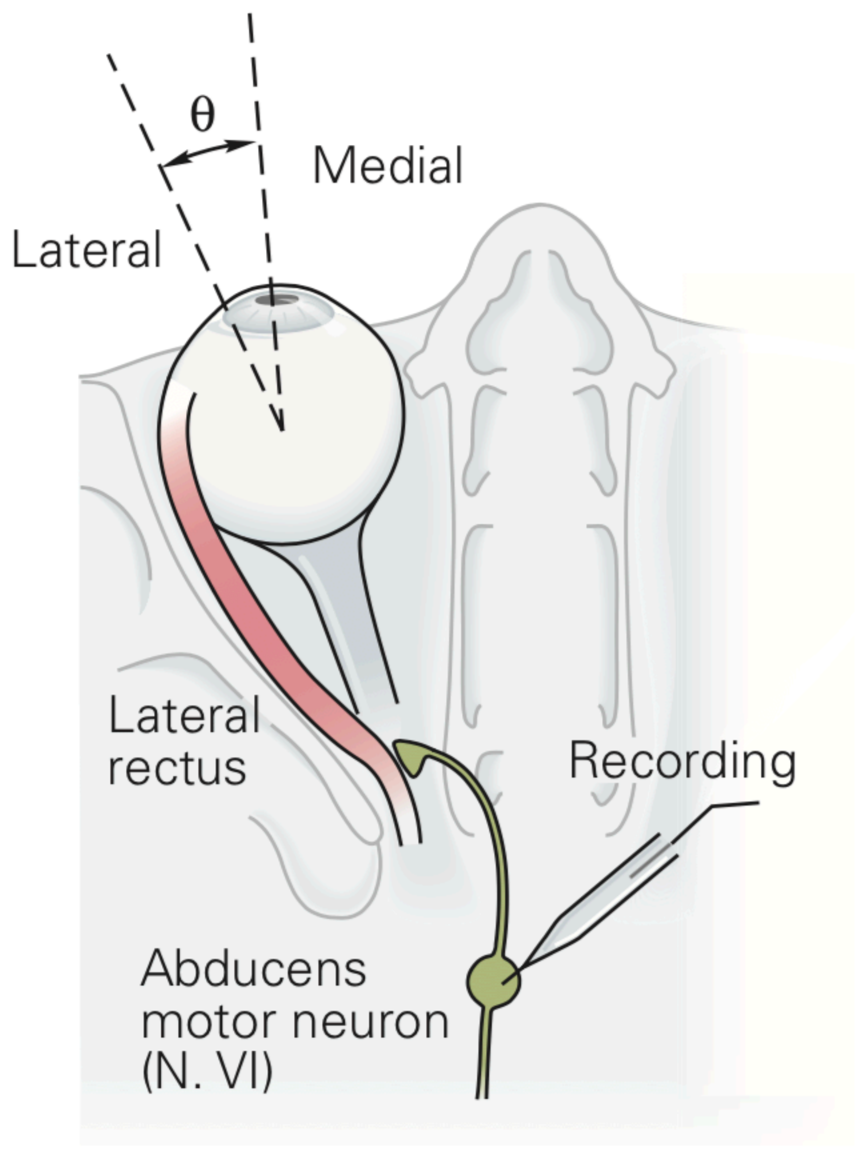
The eye muscles

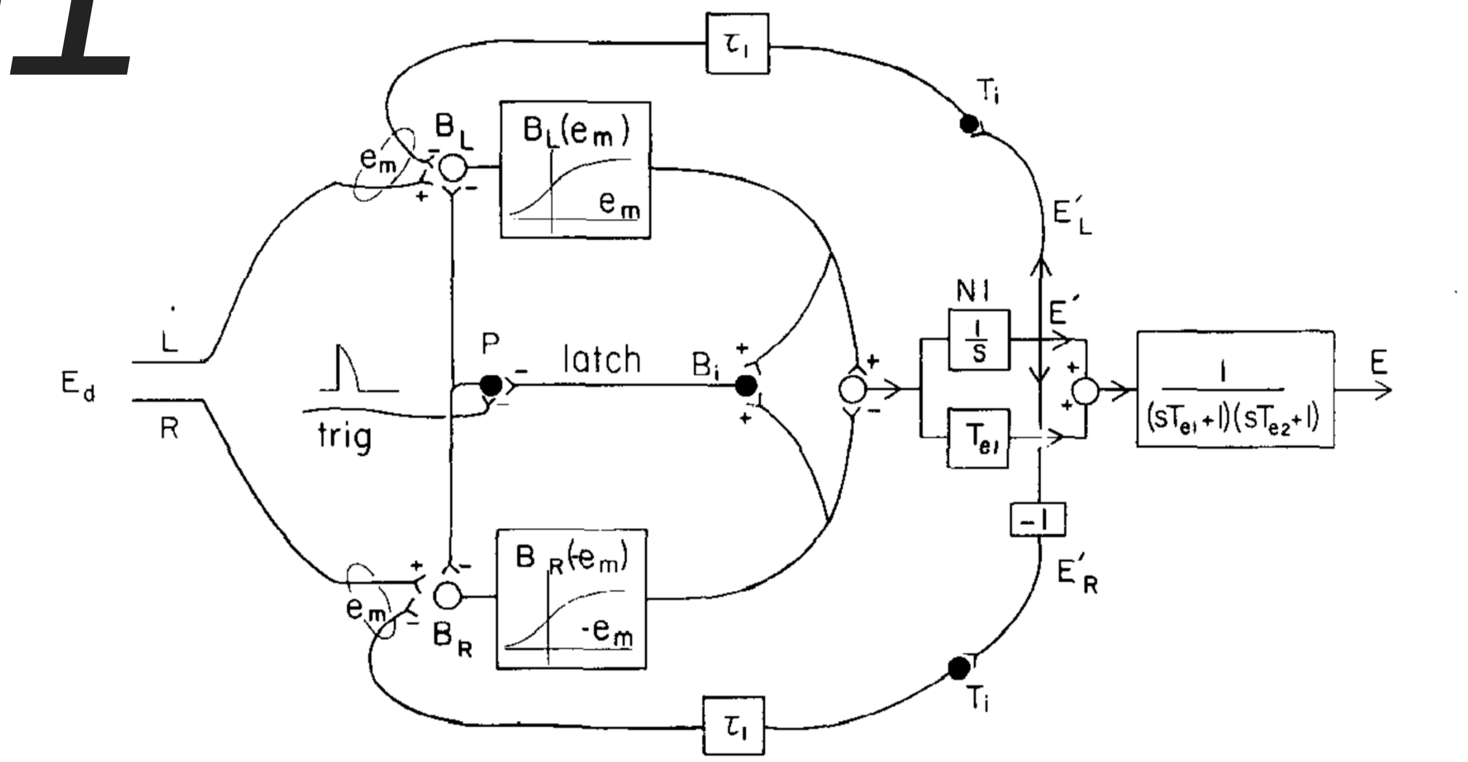
The eye socket is a ball joint:
Six muscles rotate the eye, 4 for up, down, left & right, and 2 for torsional directions of motions. These are:

1. Up: *Superior Rectus*
2. Down: *Inferior Rectus*
3. Lateral / Temporal: *Lateral Rectus*
4. Medial / Nasal: *Medial Rectus*
5. Torsional / CW: *Superior Oblique*
6. Torsional / CCW: *Inferior Oblique*

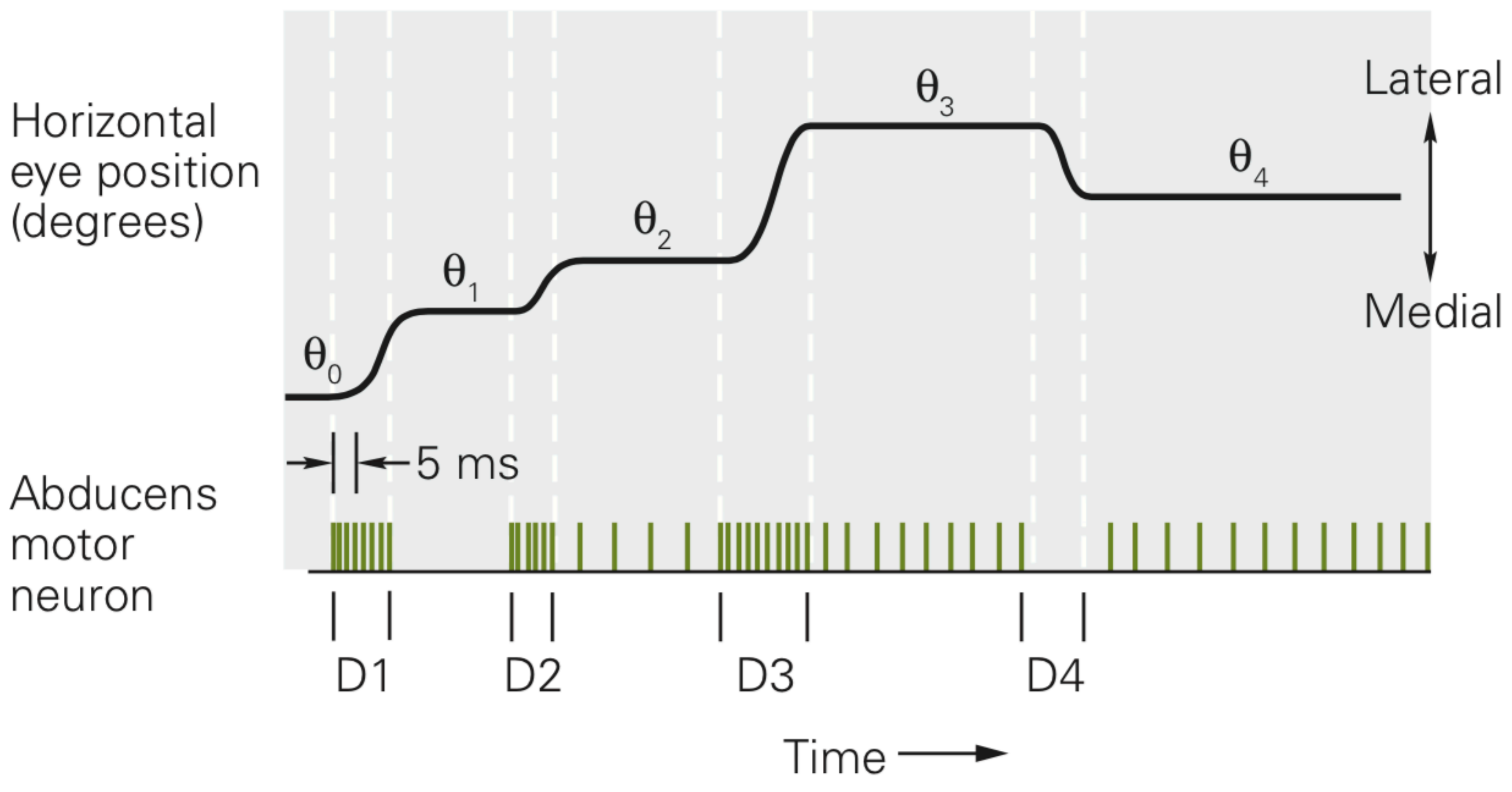


Neural Oculomotor Control





Saccade generator model,
Robinson, 1982

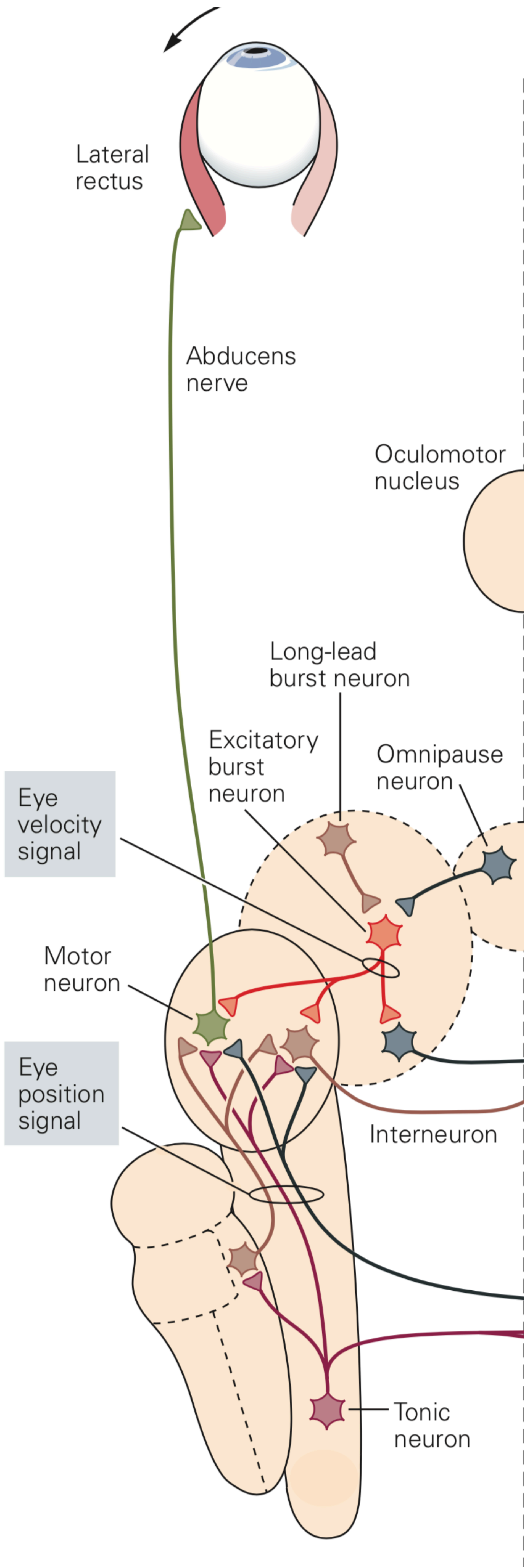


The mechanical mass-spring system of eye ball and its musculature is called **"the plant"**. Oculomotor mechanics are well described by relatively simple mass-spring control models.

Brainstem regions that innervate the eye muscles perform this control.

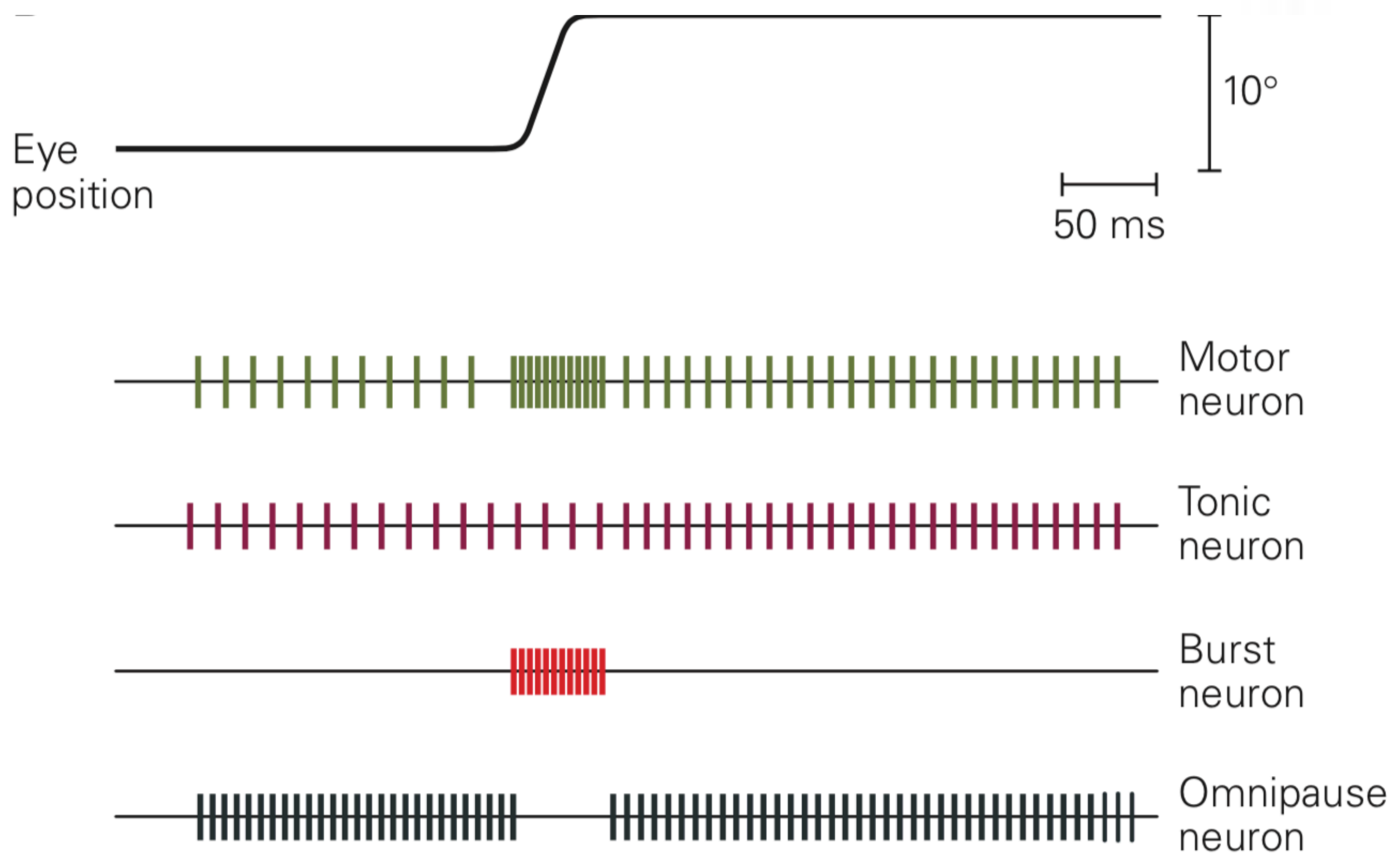
Lowest Level:
Abducens to Lateral Rectus

The more motor neurons fire, the higher the tension in the muscle.

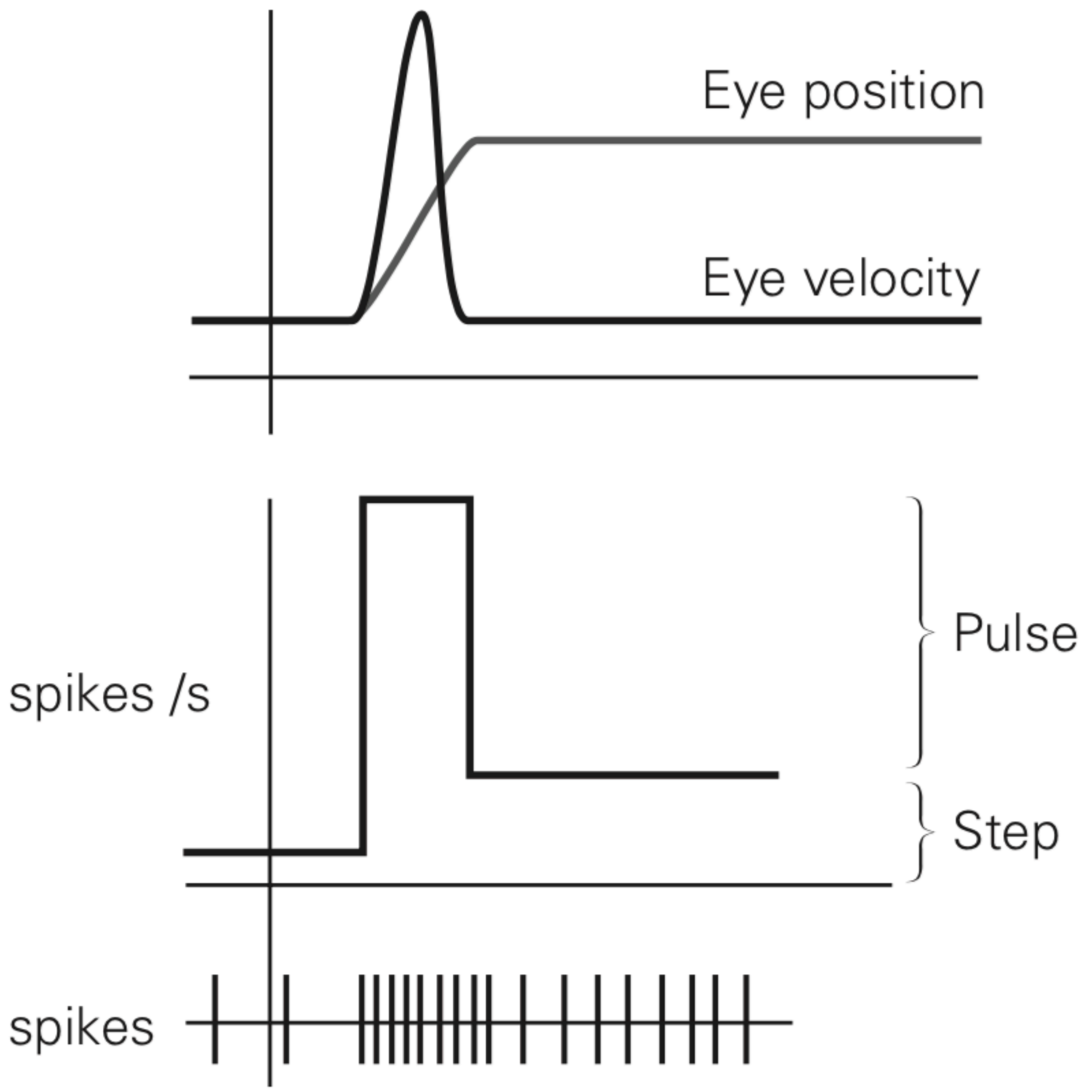


All-or-none saccades are created by antagonism between ***burst neuron*** and ***omnipause neuron***

*Different **directions of eye movements** are encoded in terms of **neuronal timing of spiking** of different types of neurons*

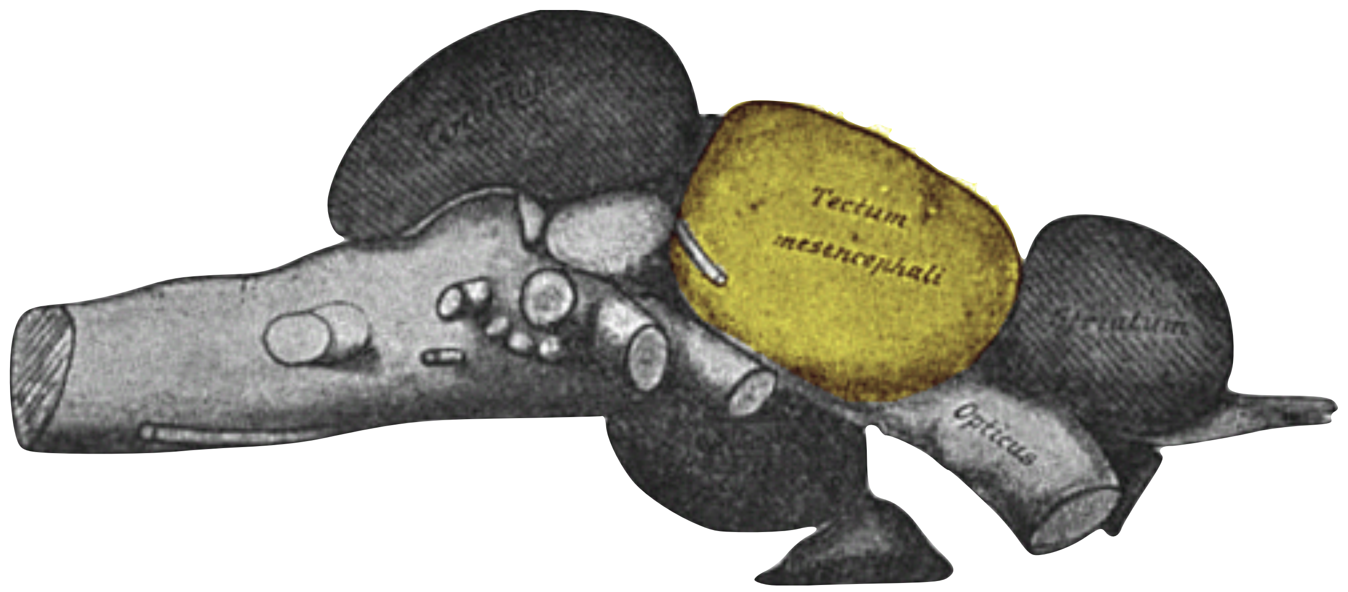


For a saccade, we need to change velocity fast to move the eye, and then keep the eye where we want it. Perform ***pulse-step input***

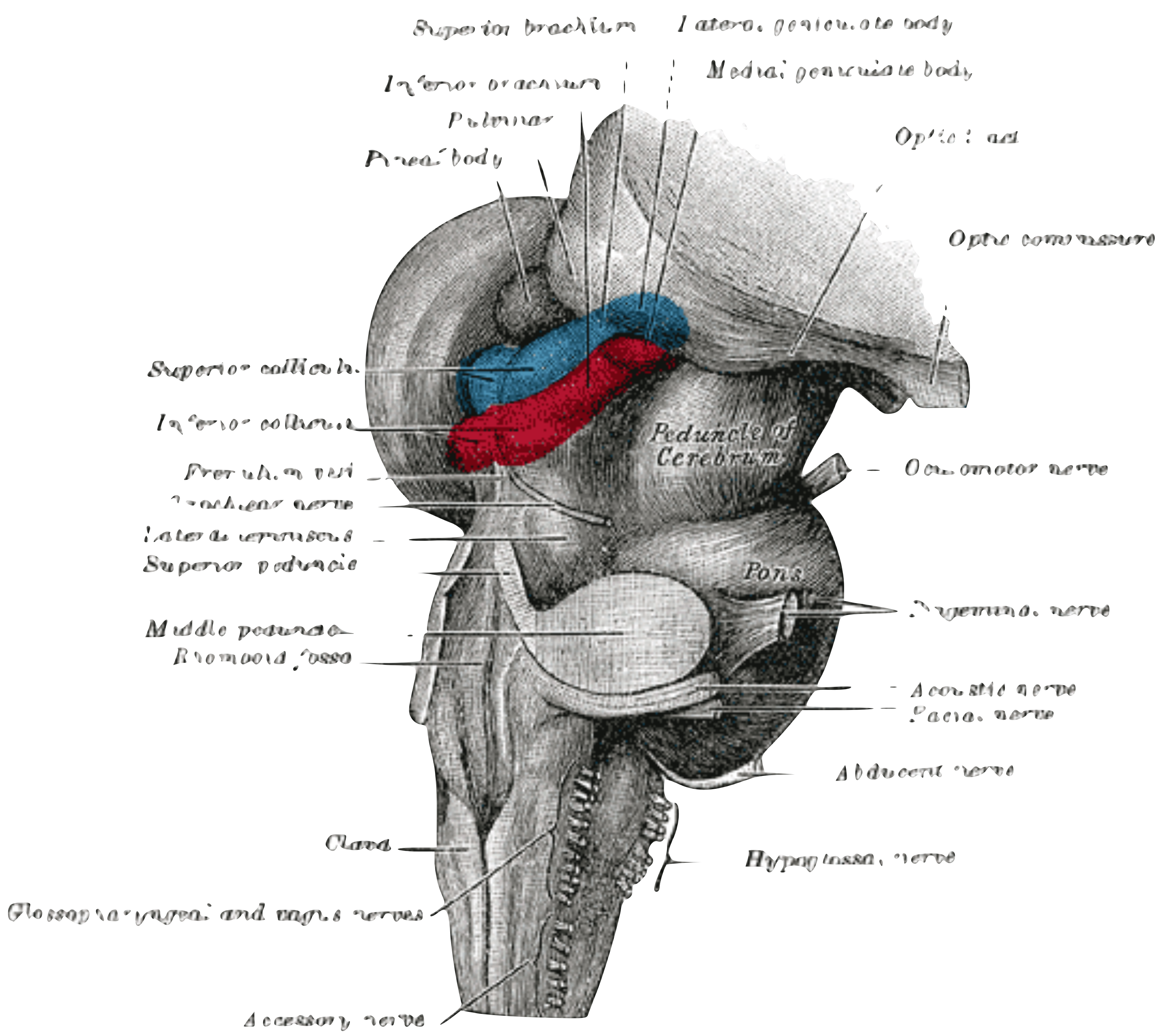


Superior Colliculus

Optic Tectum



Superior & ***Inferior*** **Colliculus**



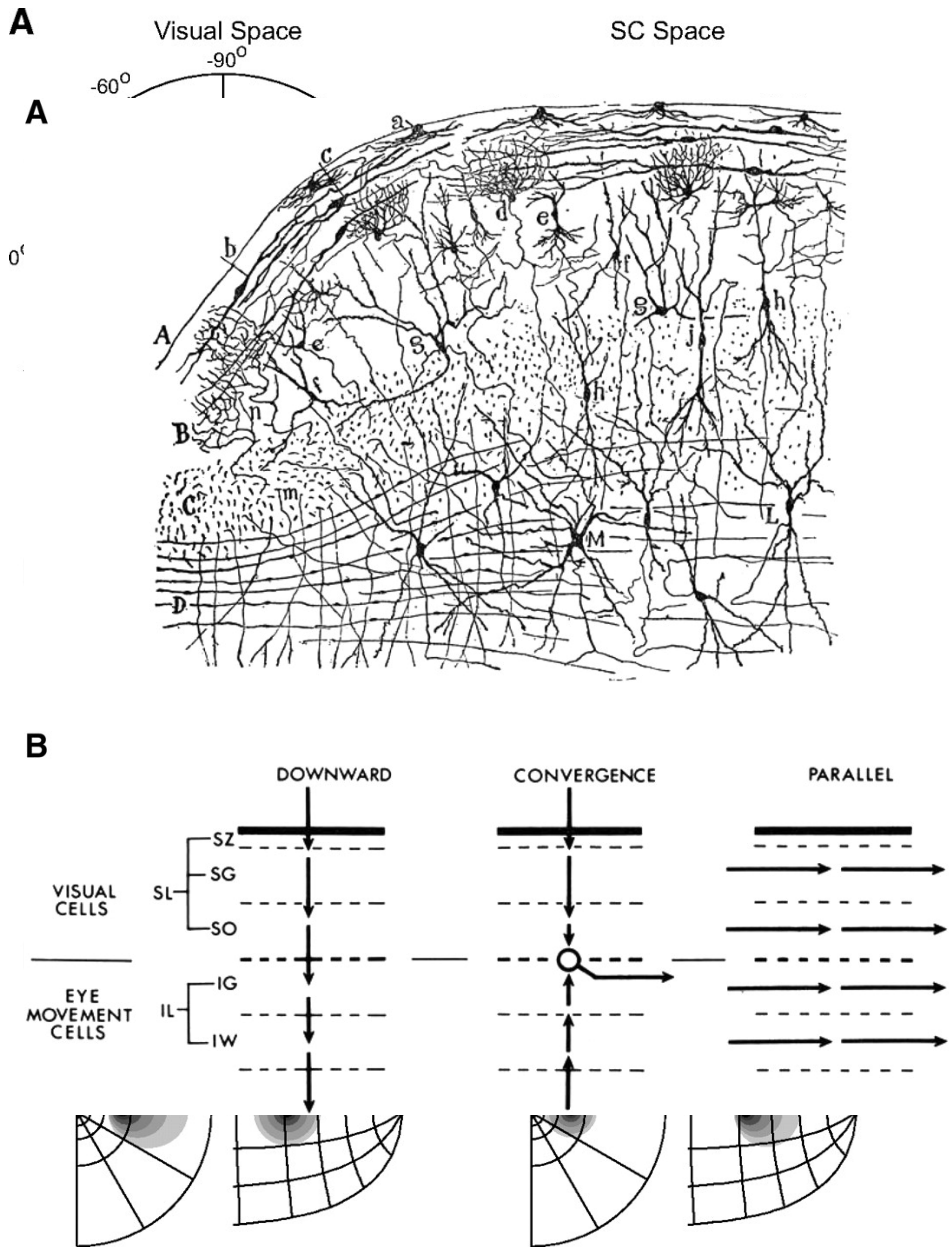
The gateway between higher-order processing and the brainstem

Evolutionarily very old:

present in fish (see Cod)

Lies on top of brainstem, pairs with inferior colliculus:

Goal: ***Aim/Direct sensory organs to visual and auditory stimuli***



Superior Colliculus

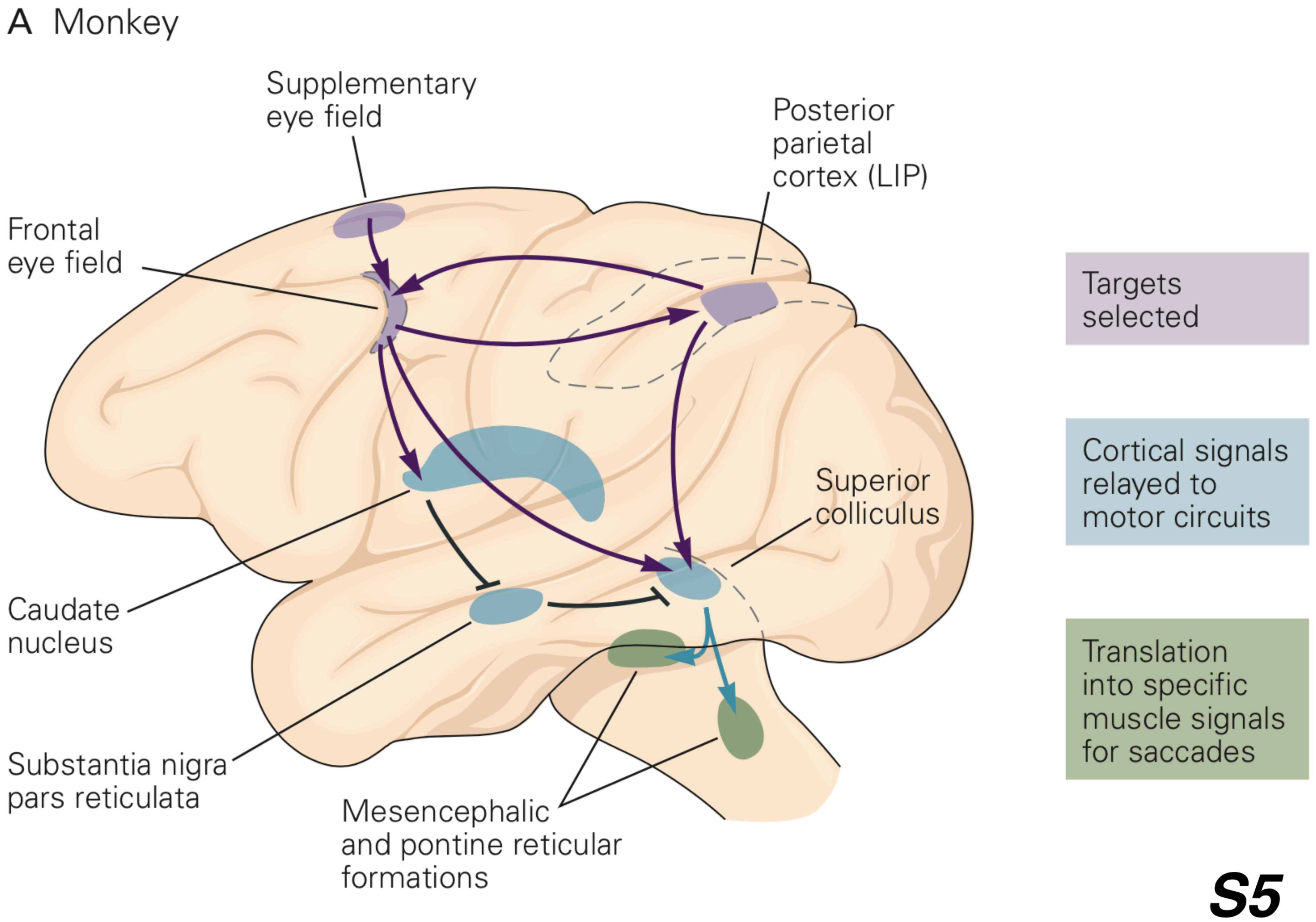
SC has layers: *superficial layers* are ***visual***, *intermediate layers* are ***oculomotor***

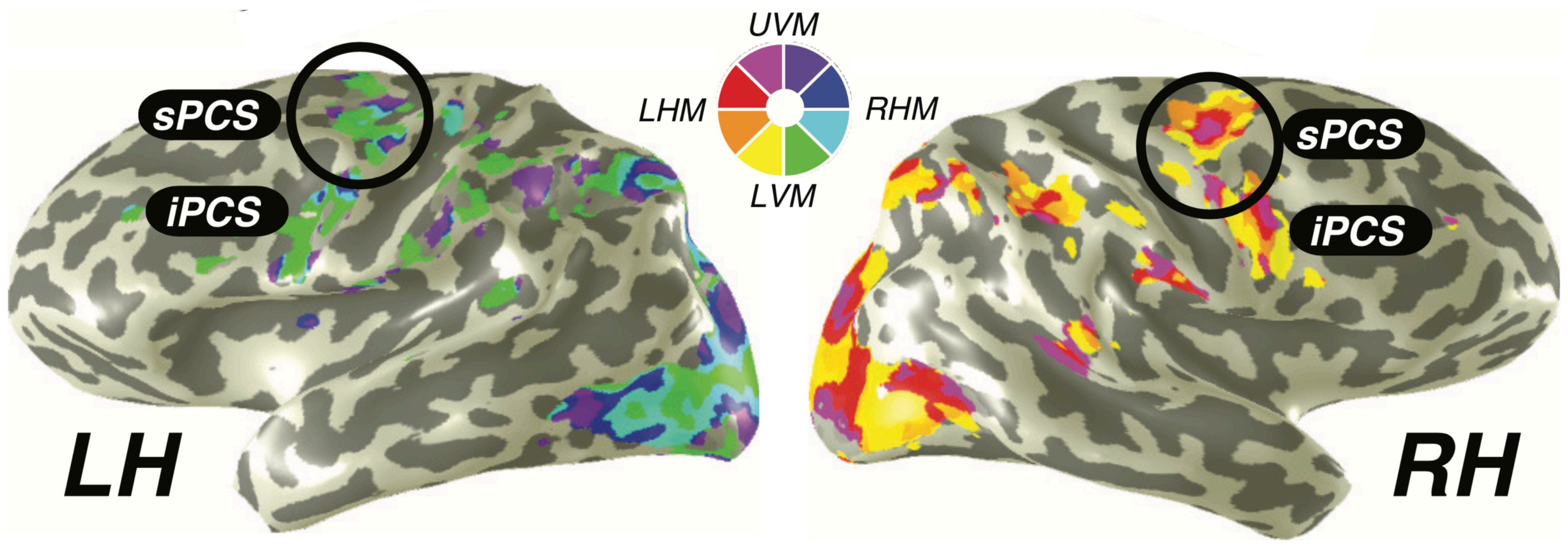
Very early sensorimotor integration!

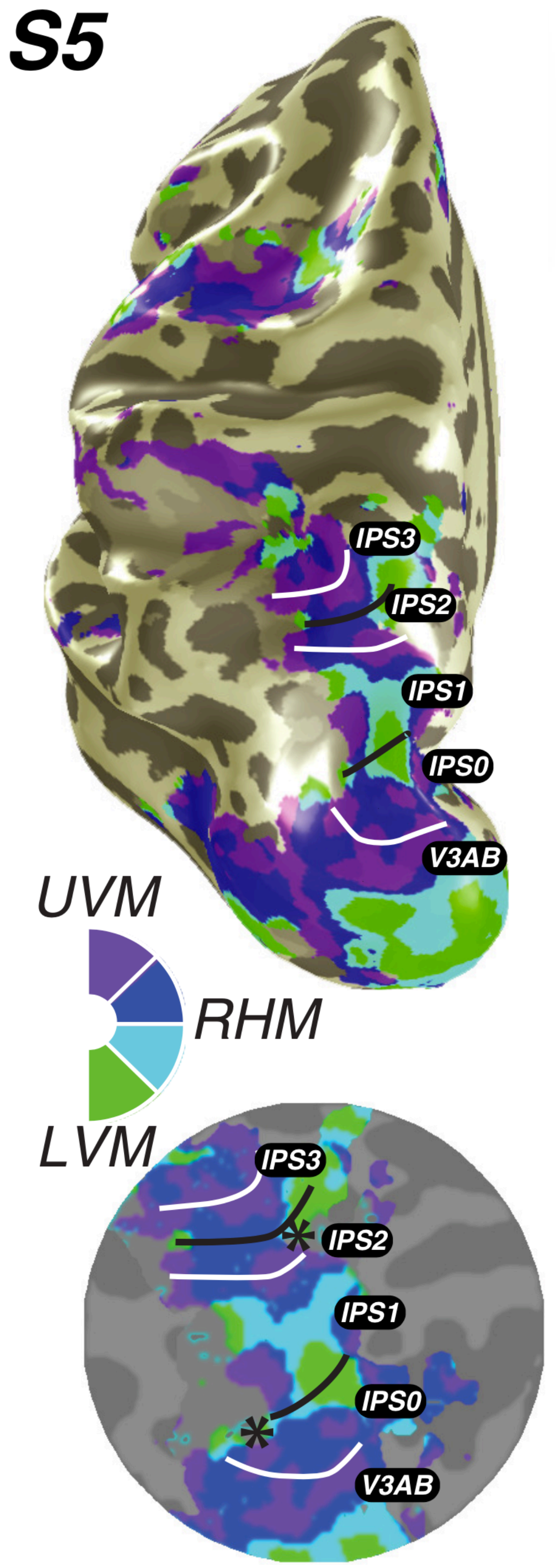
Superior colliculus represents visual space in a ***retinotopic manner***

Bridges *visual coordinates* ***(cortical processing)*** and *motor coordinates* ***(brainstem processing)***.

Saccade–generating circuit







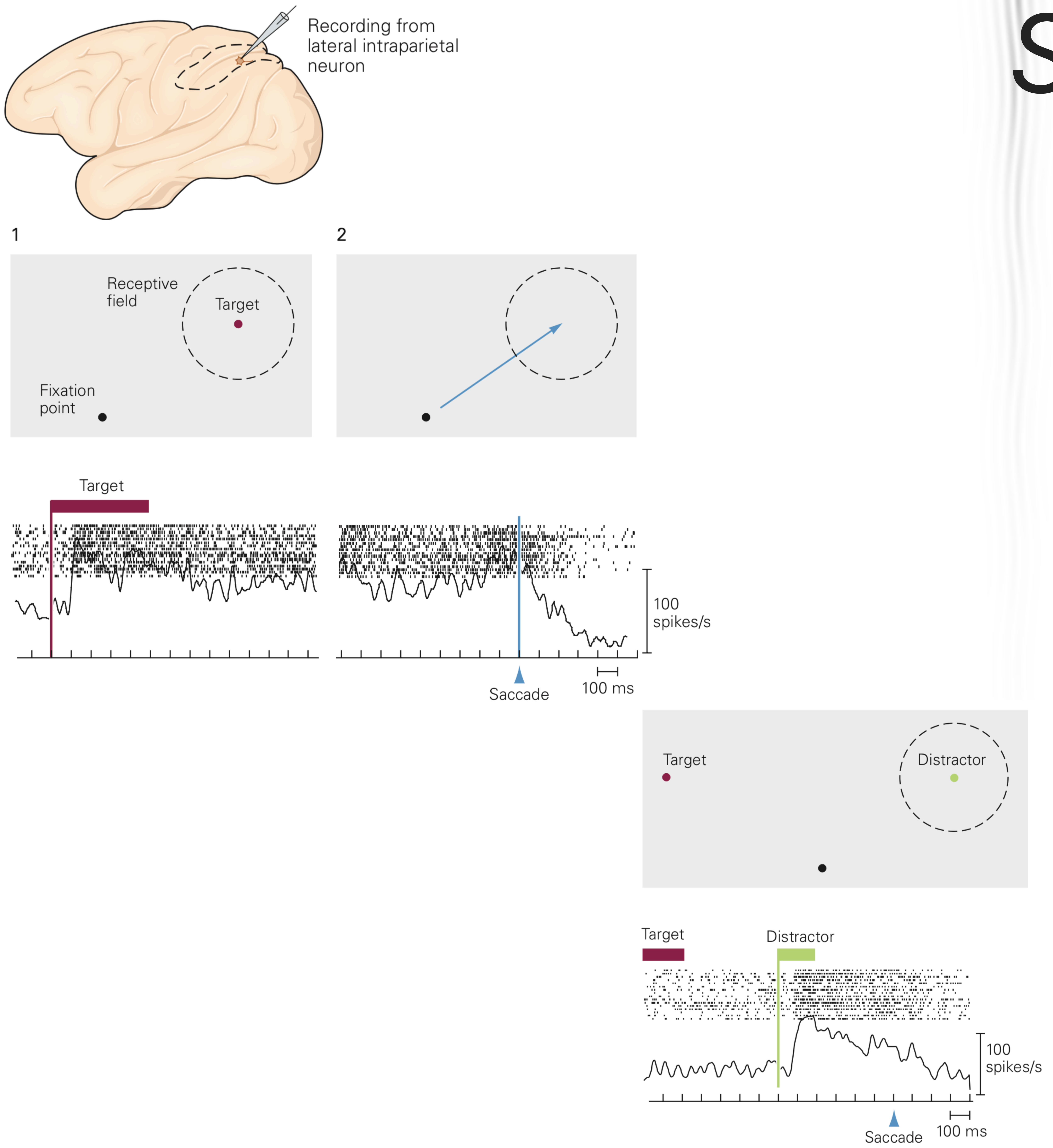
Cortical circuits on top of colliculus *(Monkey Nomenclature)*:

LIP *– Lateral IntraParietal region*
FEF *– Frontal Eye Field*
SEF *– Supplementary Eye Field*

Homologous Human Nomenclature:

IPS *– IntraParietal Sulcus*
iPCS *– superior PreCentral Sulcus*
sPCS *– inferior PreCentral Sulcus*
SEF *– Supplementary Eye Field (?)*

Saccade-generating circuit



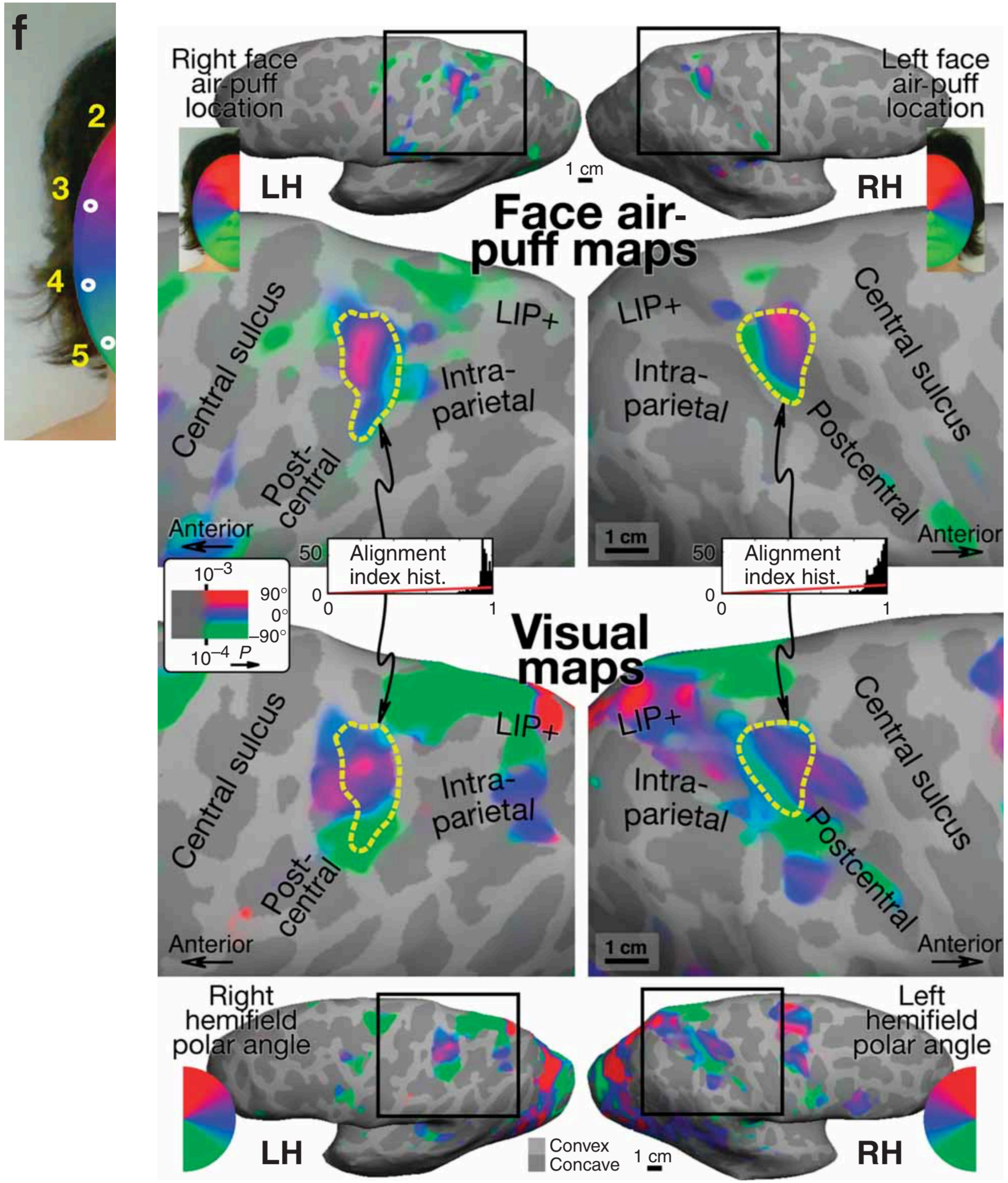
LIP

*Neurons keep firing during **memory-guided saccade planning***

Firing peaks at time of saccade

Distractors cause strong firing too

LIP encodes attention?

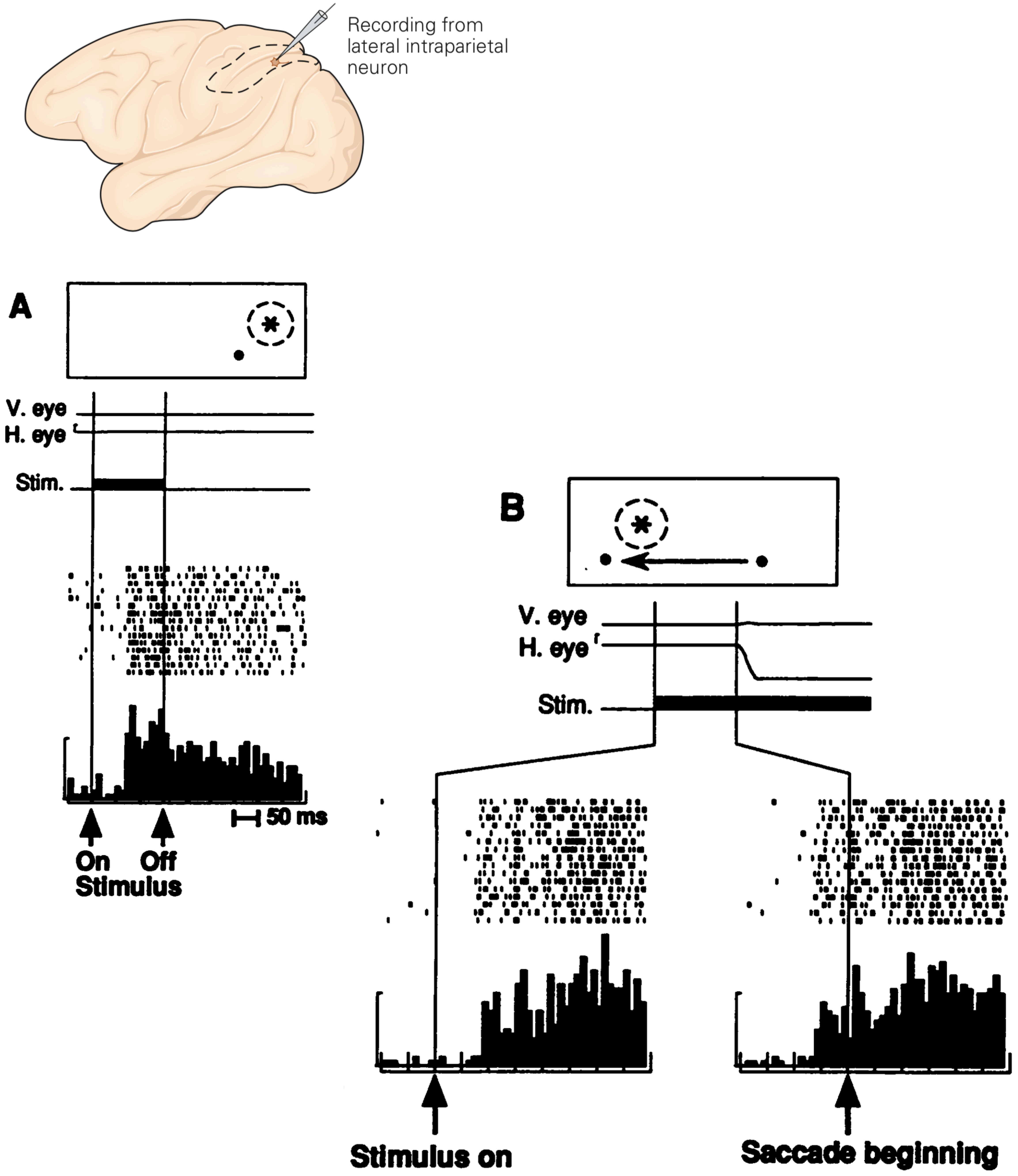


Saccade–generating circuit

LIP/VIP

In intra-parietal sulcus, variety of areas ***encode space in different formats:*** *somatosensory, visual, auditory, etc.*

IPS performs Multisensory integration.



Saccade–generating circuit

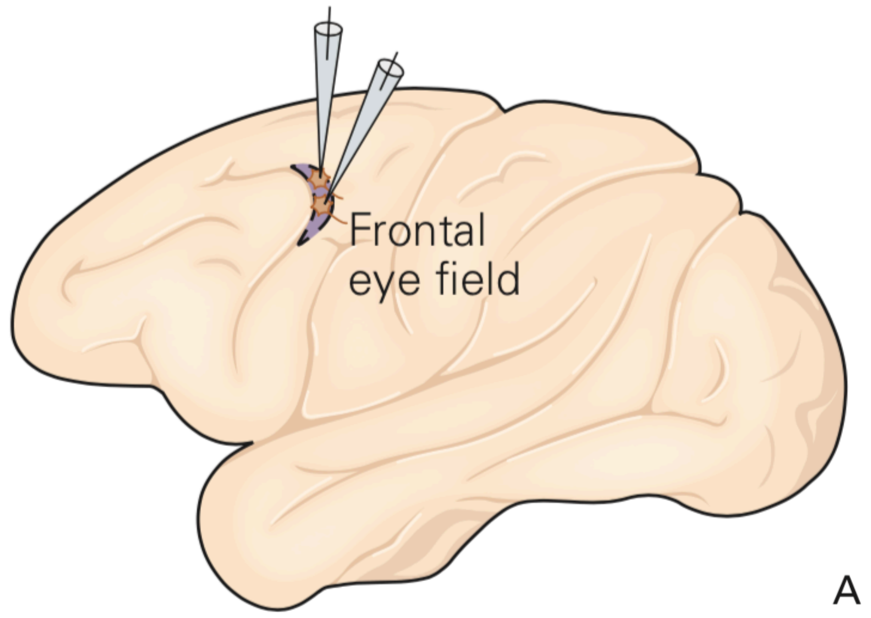
LIP

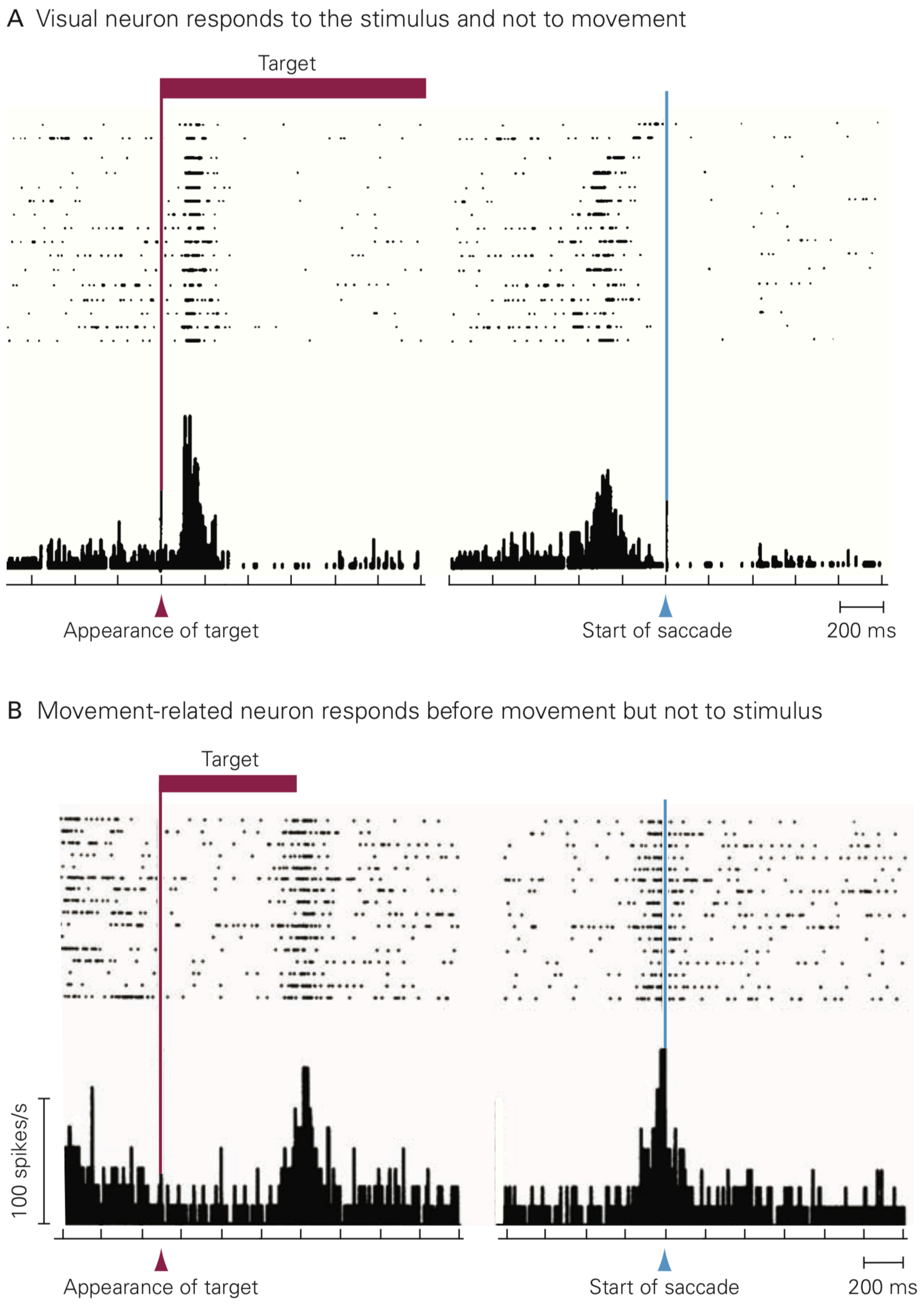
LIP cells have well–defined visual latency of around 50–70 ms

Remapping:
*LIP cells start firing before the stimulus enters the rf, **iff** a saccade will bring the stimulus into the rf.*

*Integration of "**efference copy" of motor command** into visual processing*

Saccade-generating circuit





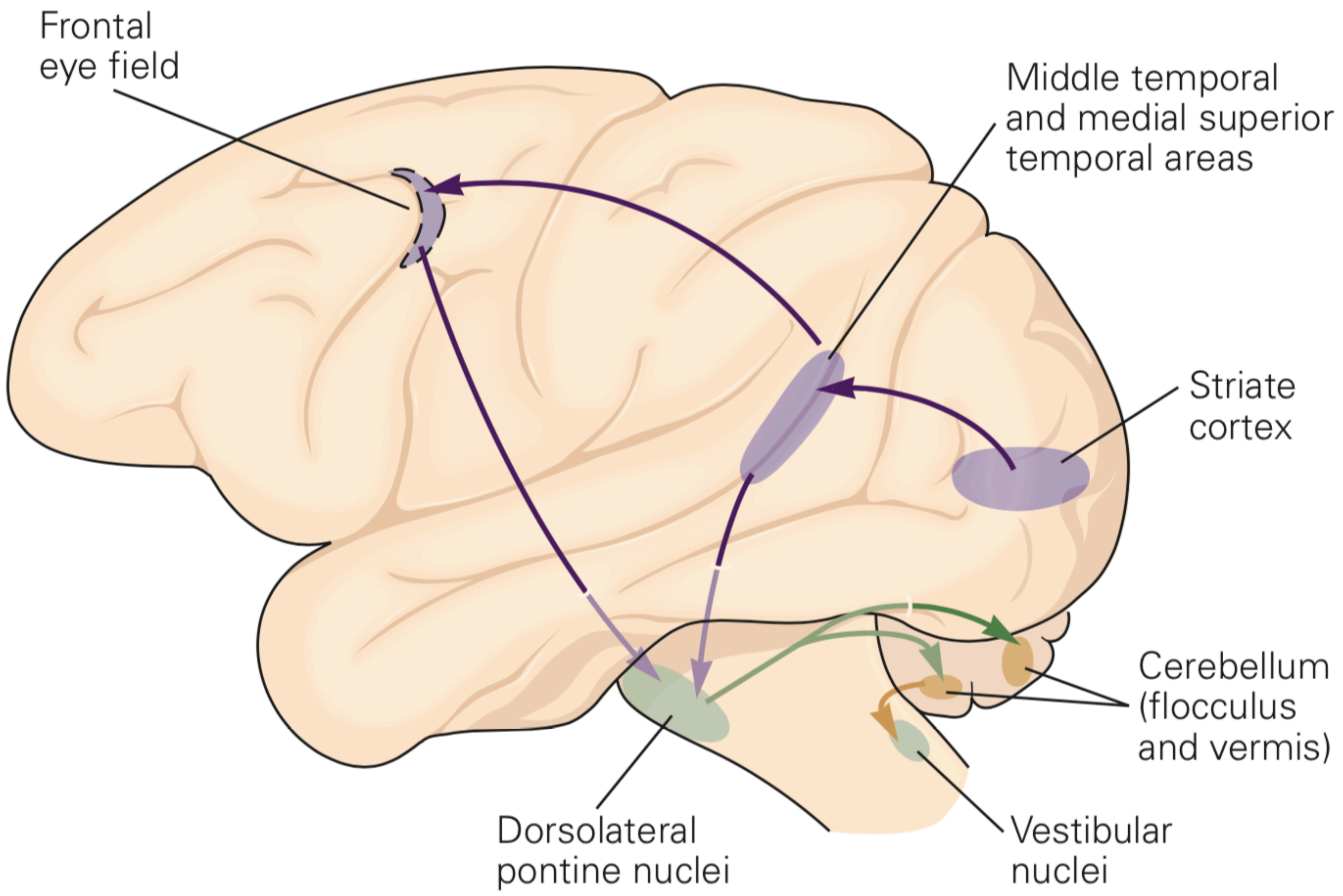
FEF

Different types of cells:

Visual neurons*, respond when a target enters rf*

Movement neurons*, respond when saccade is made to rf*

FEF is mixing motor and visual information, just like superior colliculus



Smooth Pursuit

FEF, *integrates motion and motor, orchestrates catch-up saccades when SP fails*

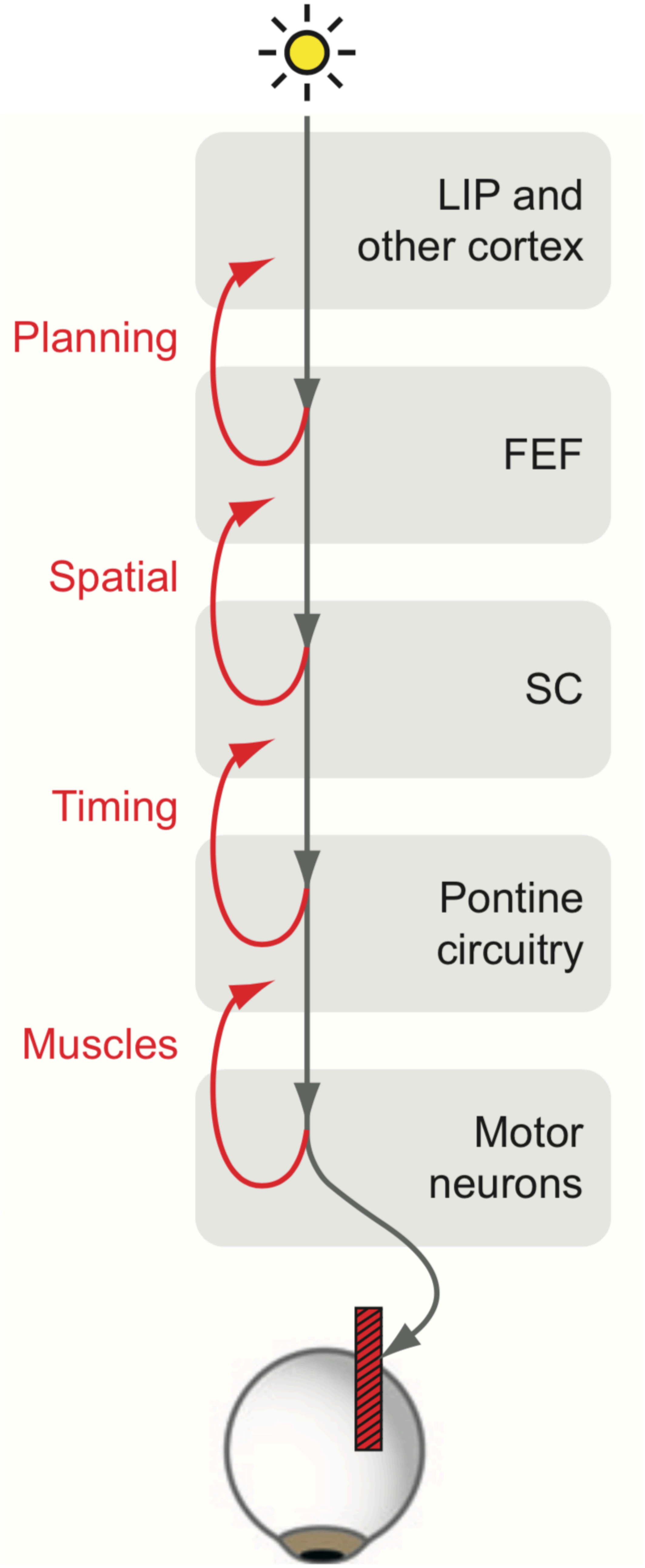
V1-MT/MST, *analyze visual motion and retinal slip*

Cerebellum, *computes exact eye velocity (fine-tuned)*

Brainstem, *generate smooth pursuit motor signals, integrate with smooth phase of Nystagmus*

Sensorimotor Interactions

Knowledge of eye movements: **Efference Copy**



Visual Processing, Direction of pre-saccadic attention

LIP – FEF – SC – Brainstem

The 'plan' for an eye movement is influenced by visual processing at all levels

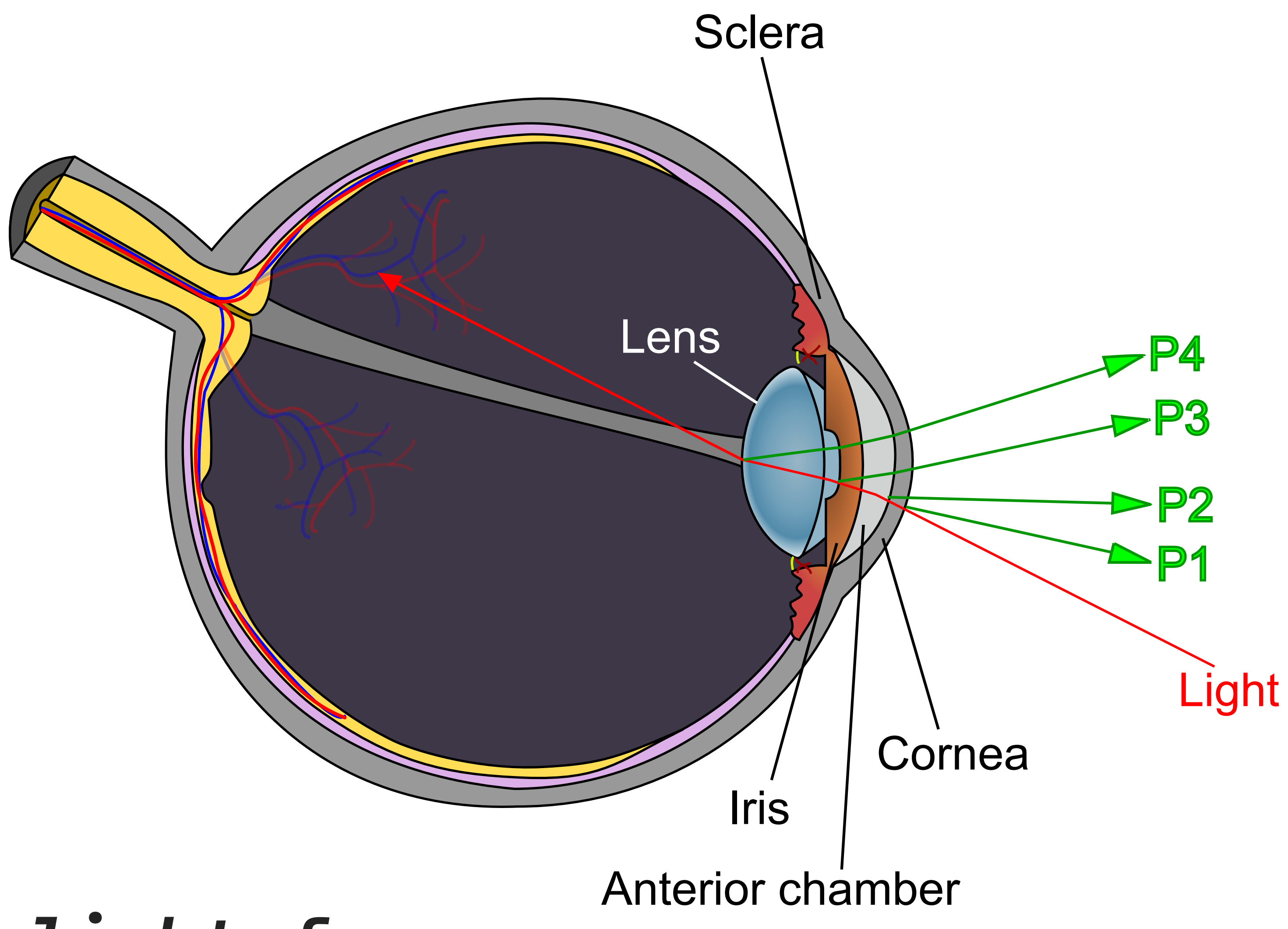
Visual processing *and* ***motor intentions*** *interact*

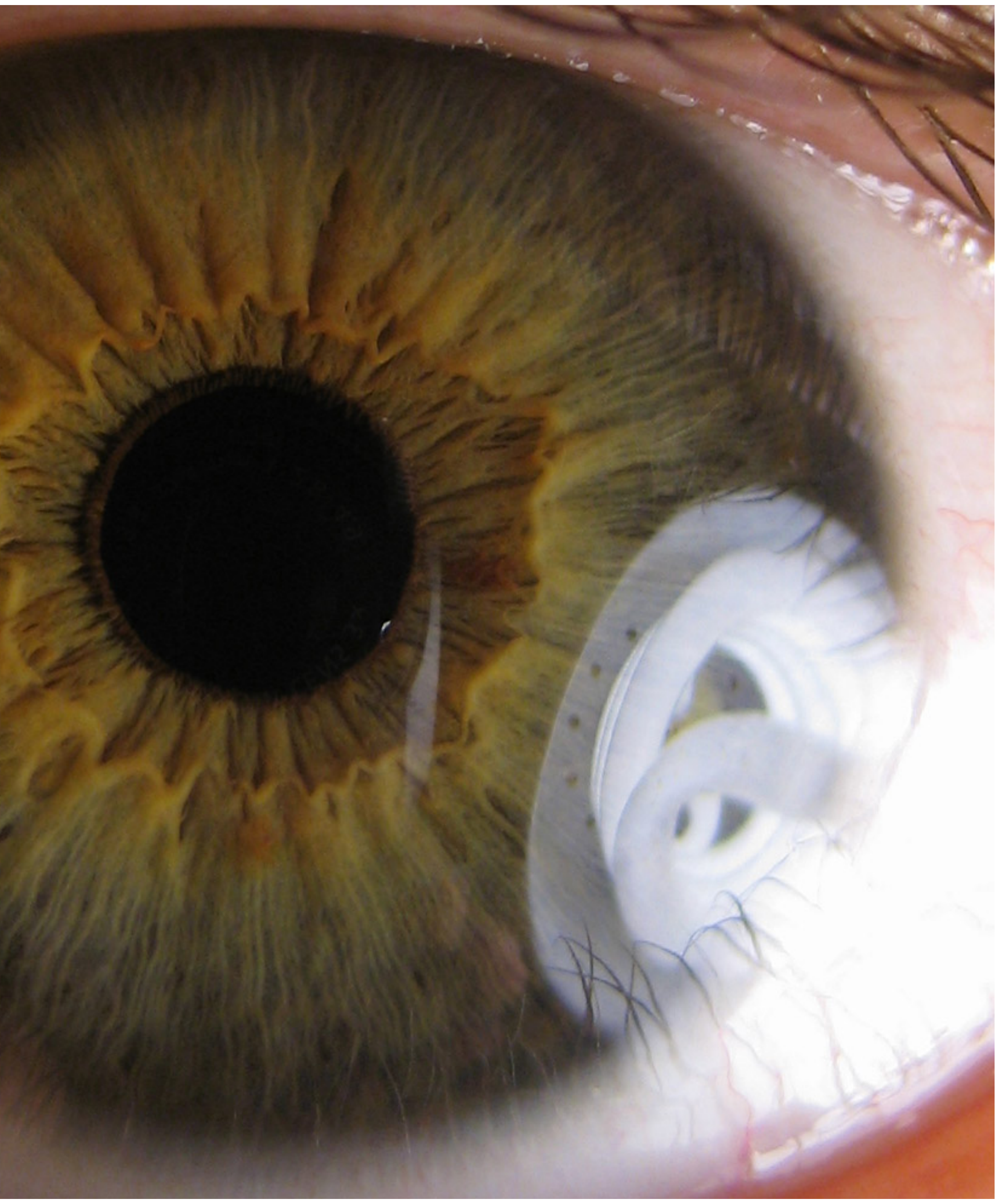
Predictions are compared to the actual sensory effects of movements: ***predictive coding?***

Eyetracking

start

Dual–Purkinje Eyetracker





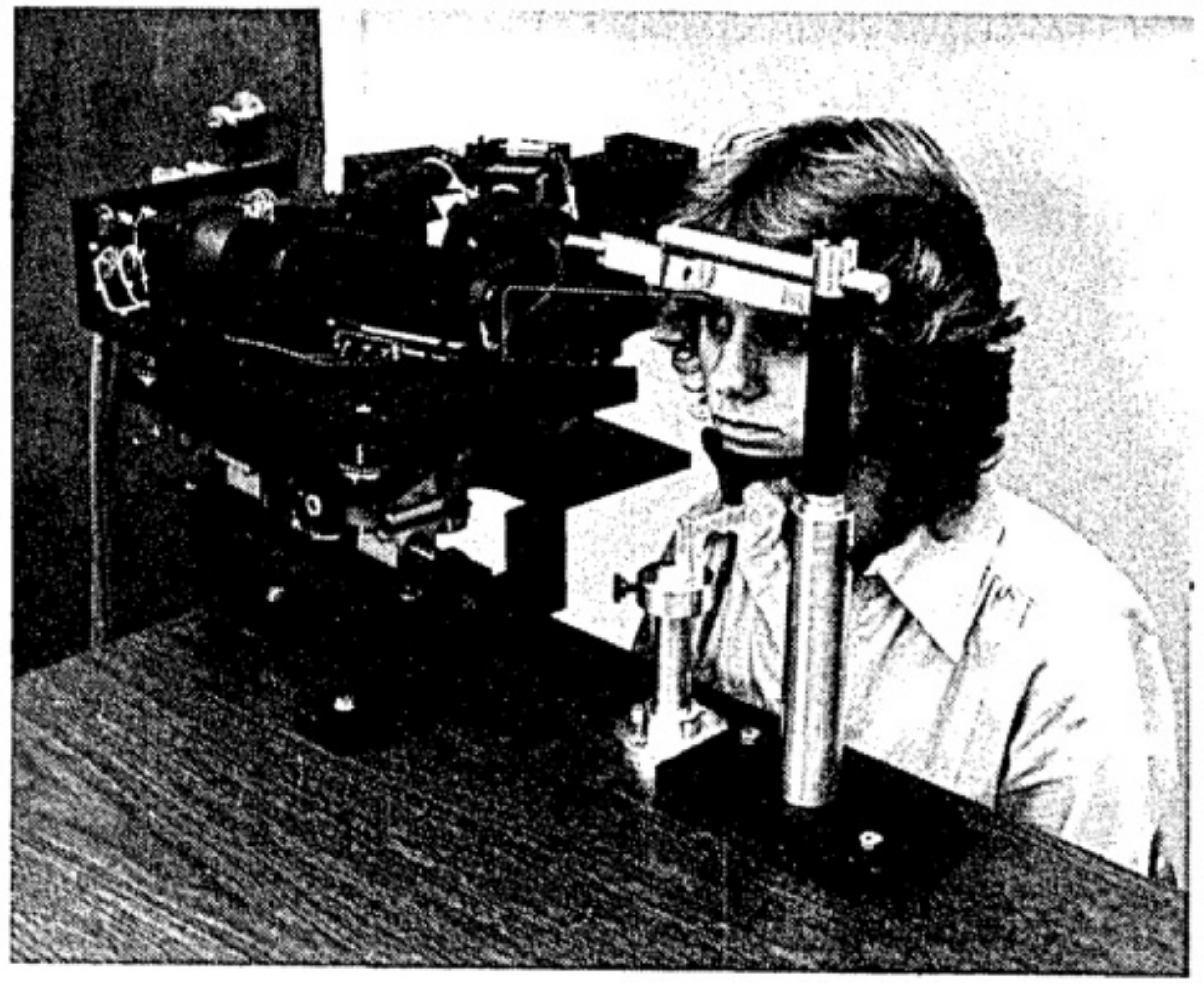
Purkinje images are reflections of a light from different surfaces in the eye

P1: *outer surface of the cornea*
P2: inner surface of the cornea
P3: outer surface of the lens
P4: *inner surface of the lens*

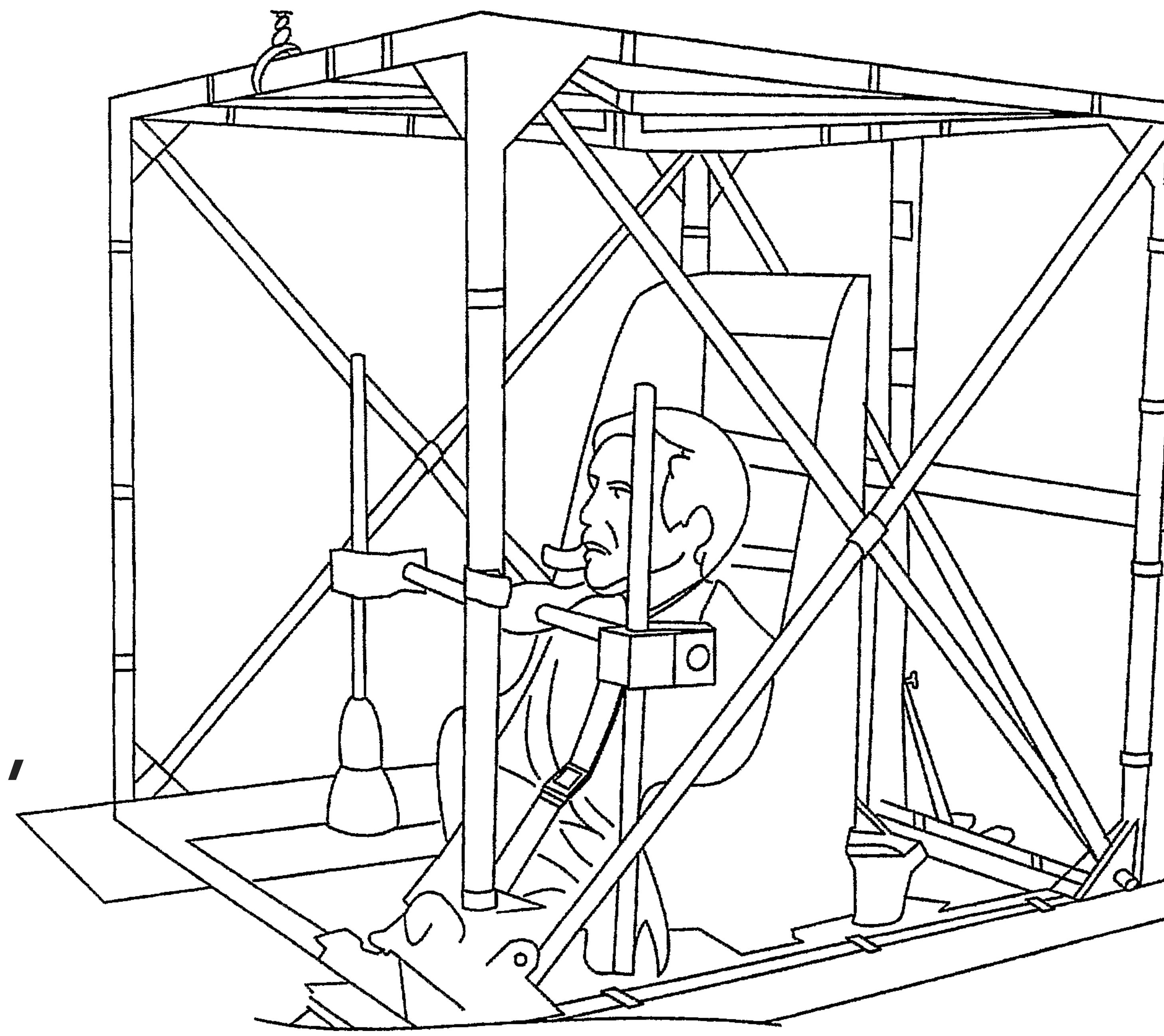
P1 & P4 are used in dual-purkinje eyetrackers

Advantages:
1. ***Really precise***
2. ***Benchmark in high-fidelity data***

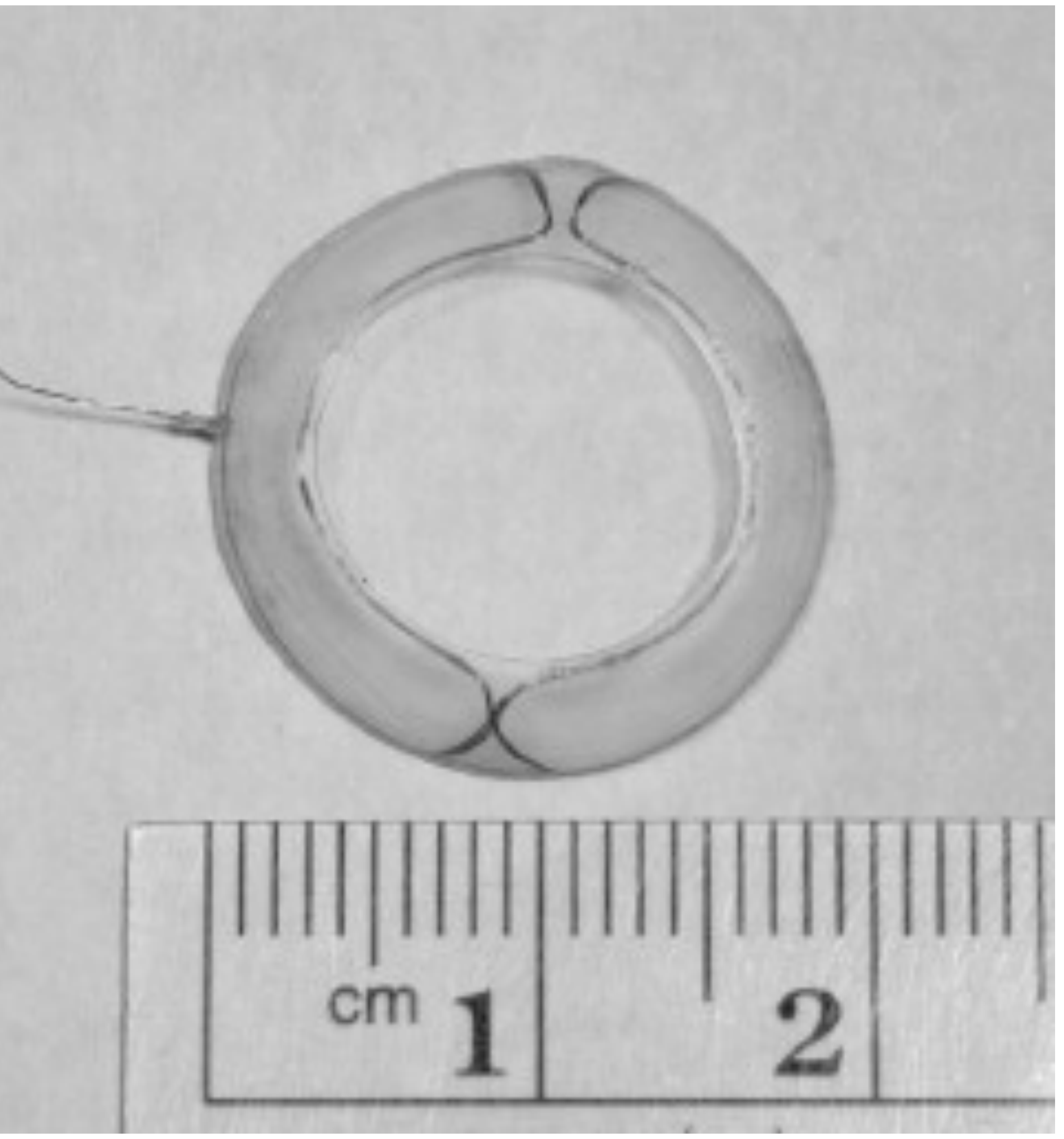
Disadvantages:
1. ***Large apparatus,***
2. ***Not robust: need bitebar***



Scleral Search Coil Eyetracker



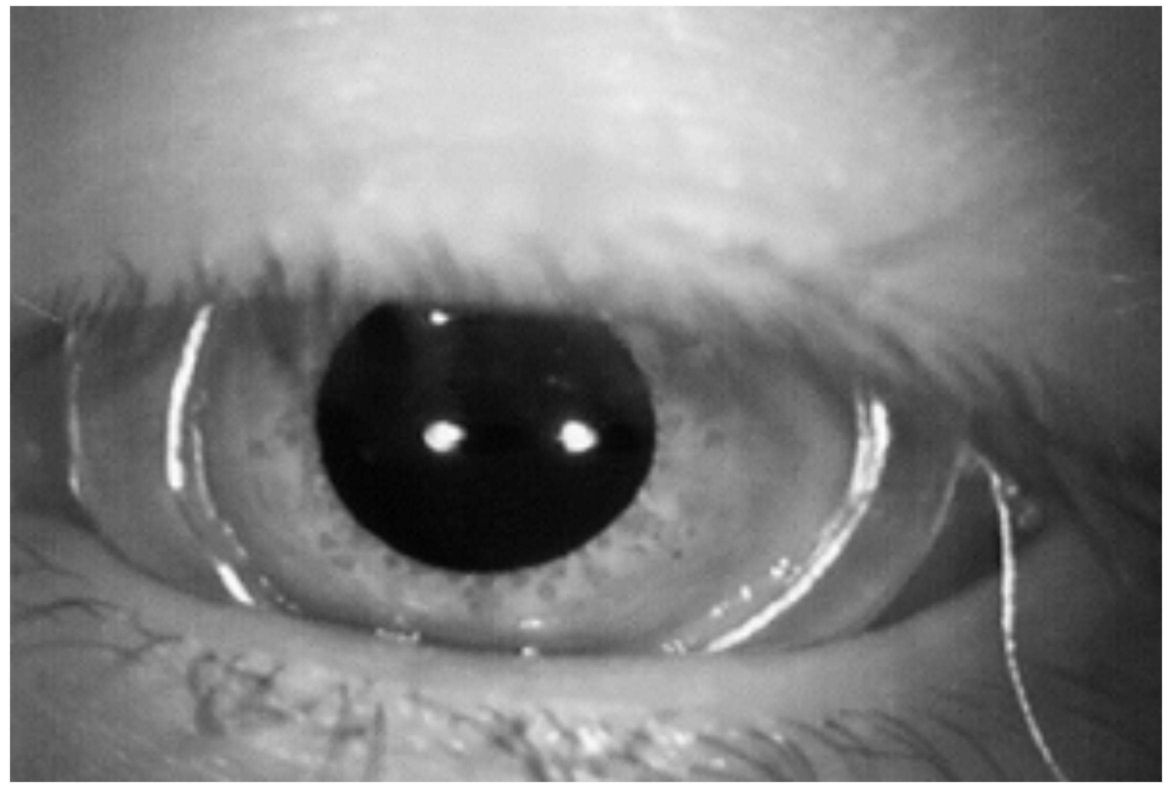
Copper wires coiled in a 'scleral search coil'



Participant is placed in a cage in which the magnetic field fluctuates rapidly, the coils pick this up and by analysing the currents in the coils one can determine eye position

Advantages:
1. *Really precise*
2. *Allows measurements of torsion*

Disadvantages:
1. *Large apparatus,*
2. *Not robust: need bitebar*
3. *Hurts, and possibly damages the eye needs local anaesthetic*



InfraRed Video Eyetracker

IR camera: Pupil is dark, 1st Purkinje reflection is light

Video-based eye tracker, converts image information to gaze direction.

Combination of IR reflection and pupil 'hole' allows for accurate and robust tracking.

Advantages:
1. ***Can be made very portable***
2. ***Relatively robust***
3. ***Slow tracking: Cheap Solution!***
4. ***Pupil size information for free!***

Disadvantages:
1. ***Expensive if you want >250 Hz tracking***
2. ***Mascara is deadly***