Neuroscience of Looking

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A class in the course Introduction to Neuroscience: Systems Neuroscience

Dimensions of looking

- Behavior
  orienting … cognition-driven
- Sensor geometry
  uniform ….. Primate fovea
- Function
  image stabilization … discriminating image details

Theoretical approaches to looking

Orienting response

Attention

Mind-body

Theoretical approaches to looking

Large field

Small, high-res region

Primate fovea

Theoretical approaches to looking

Stabilize image

Seek next image

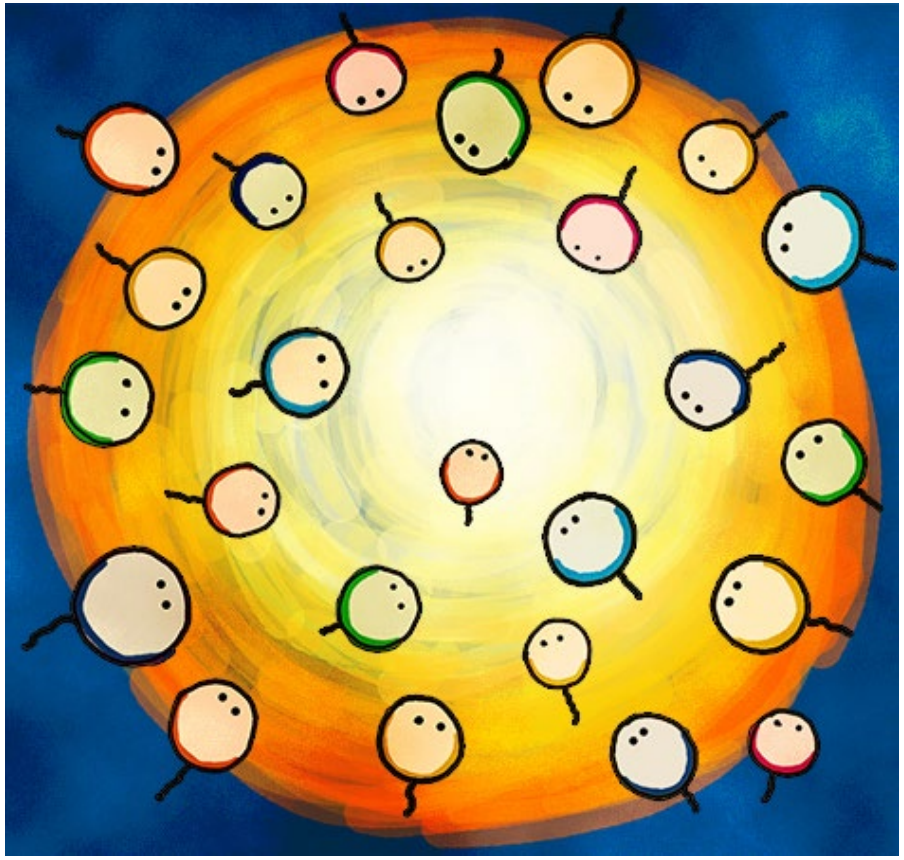
Saccadic eye movements

Evolution: orienting in the Cambrian

Orienting: phototaxis

‘Early’ evolution

Bacteria



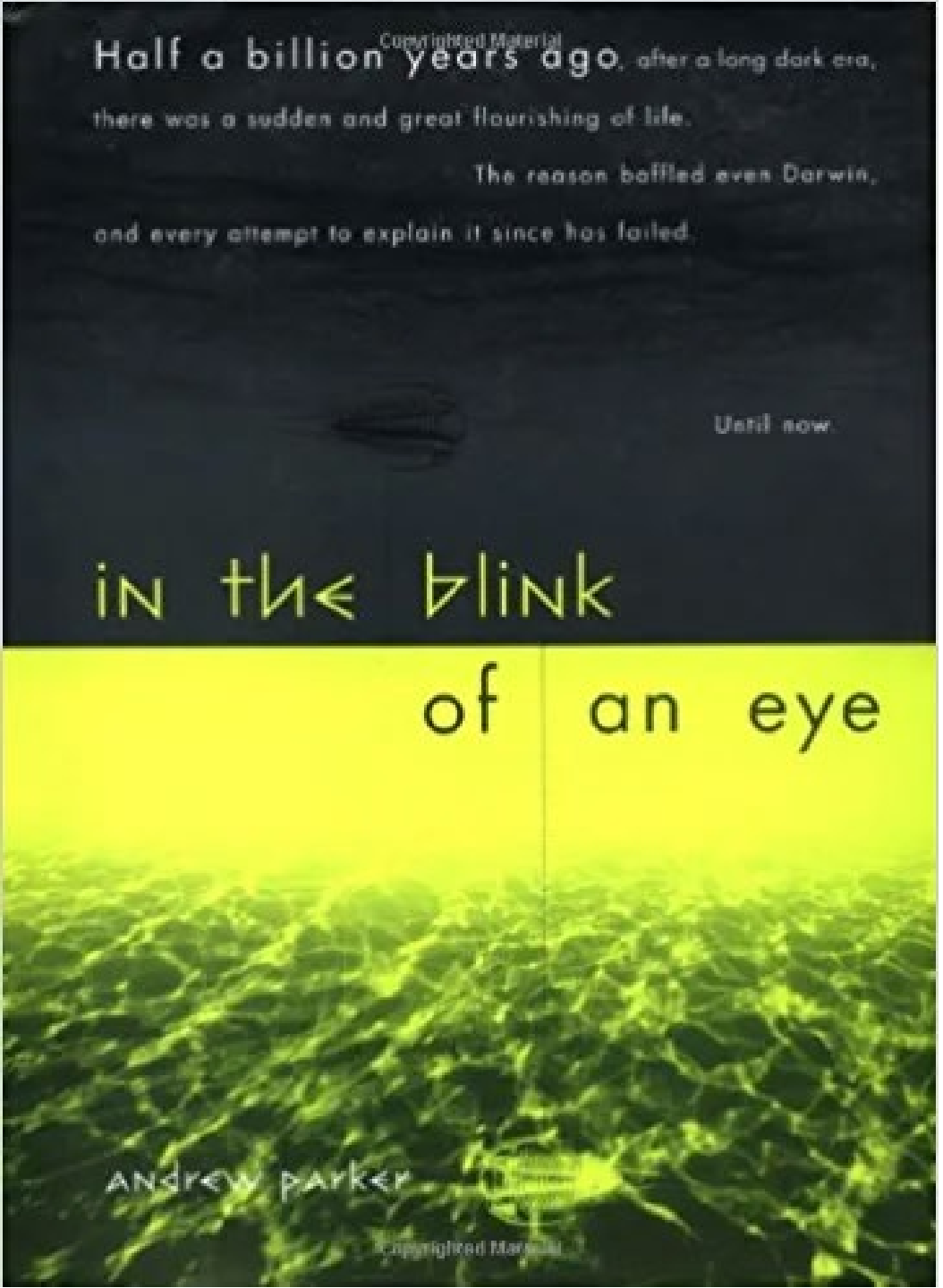
http://2012.igem.org/Team:Peking/Project/Phototaxis

Plants

https://www.fast-growing-trees.com/images/D/Cold-Hardy-Tea-Plant-3-450W.jpg

Moths

http://en.es-static.us/upl/2012/10/moths-light-e1503921825511.jpg

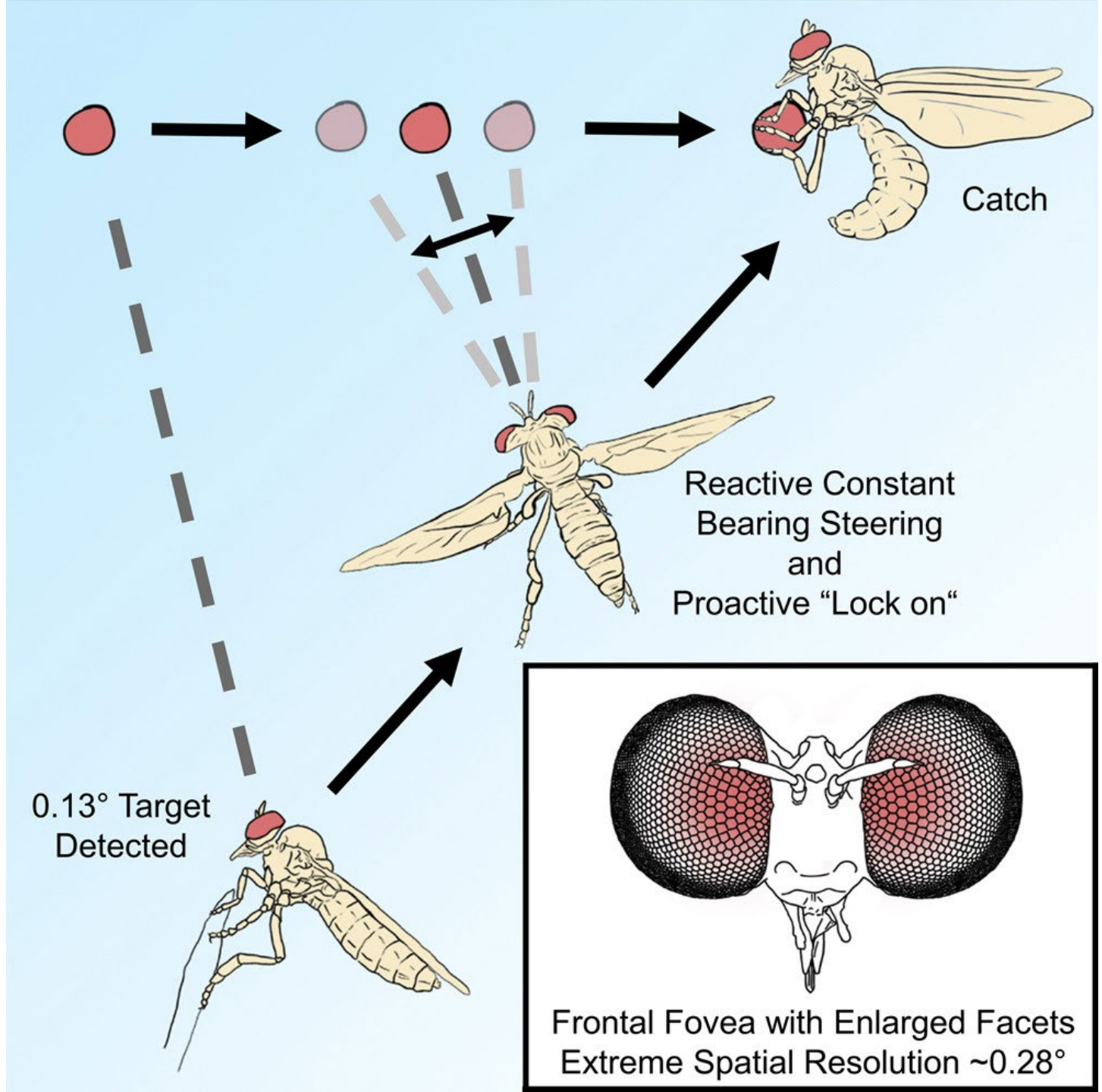


Andrew Parker's theory of the role of vision in the Cambrian explosion

Eyes evolve early in the Cambrian explosion

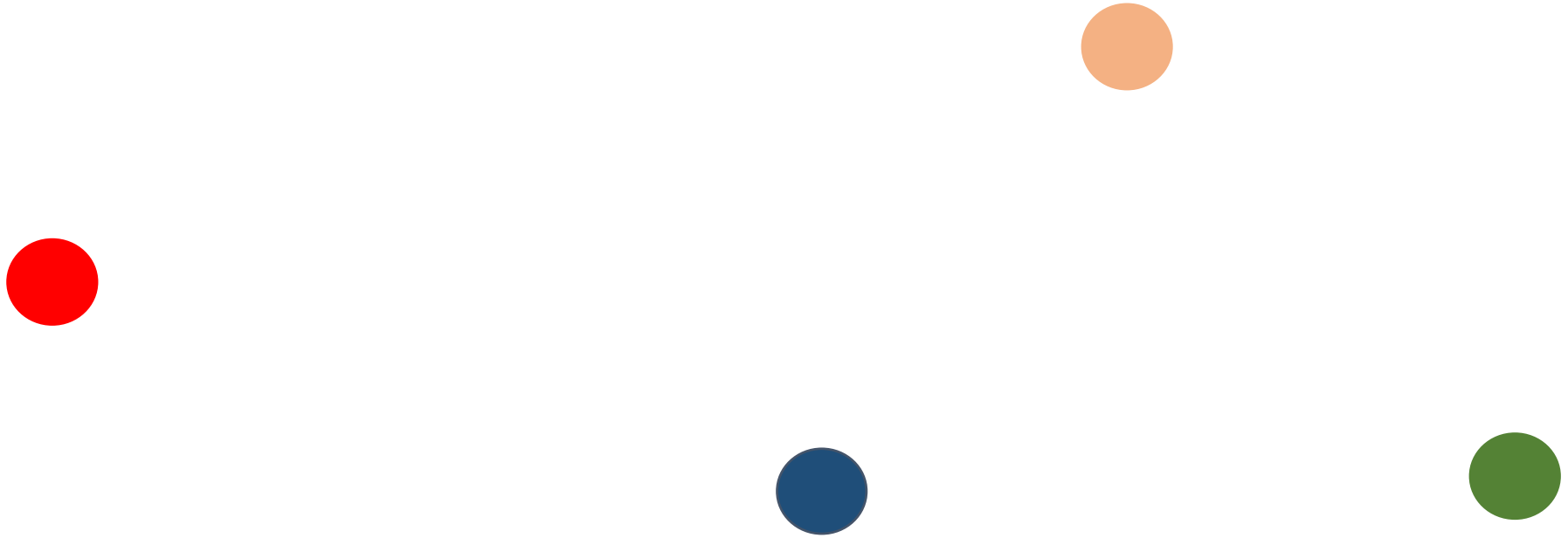
Compound eyes

Illustration – robber fly


Catch
Reactive Constant
Bearing Steering
and
Proactive “Lock on“
0.13° Target
Detected
Frontal Fovea with Enlarged Facets
Extreme Spatial Resolution ~0.28°

Gaze shifting appears later

Gaze reflex



Attention Human psychology & mind-body

Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem Several simultaneously possible objects or trains of thought… It implies withdrawal from some things in order to deal effectively with others….

James, 1980
The Principles of Psychology, pp. 403-404

The spotlight metaphor of attention

Mind-body: intention & attention

- Intention: plan
  - Subjective (accessible only to subject)
  - Exists in working memory
  - Ends in either:
    - Execution (becomes behavior, objective, accessible to all)
    - Cancellation (remains hidden forever in subjective existence)
- Intended action
- Attention: same, but acts on sensation
  - Observed only indirectly (because percepts are subjective)
  - (Concept can be extended)

Cone density map Fovea evolves in primates

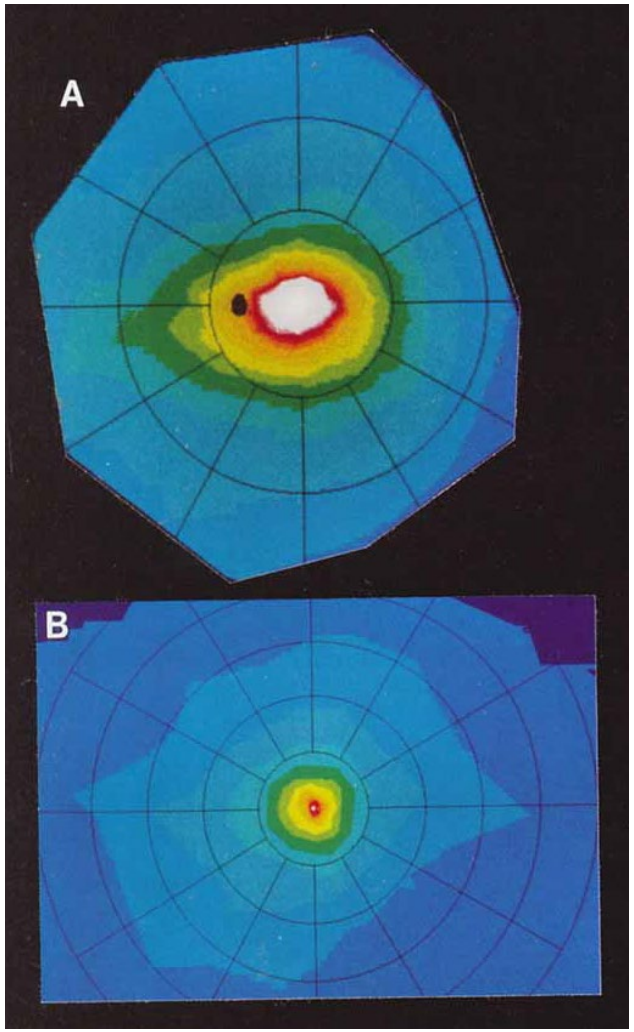
THE JOURNAL OF COMPARATIVE NEUROLOGY 288:165–183 (1989)

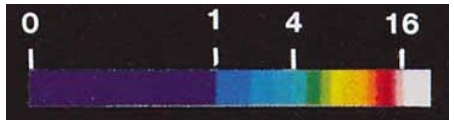
Photoreceptor Topography of the Retina in the Adult Pigtail Macaque (*Macaca nemestrina*)

ORIN PACKER, ANITA E. HENDRICKSON, AND CHRISTINE A. CURCIO

Entire retina

Center





Cones per unit area

Ilya Repin
1844-1930, Russian

<u>Unexpected Visitors</u>

1884 - 1888
Oil on canvas
167.5 x 160.5 cm

Tretyakov Gallery
Moscow, Russia

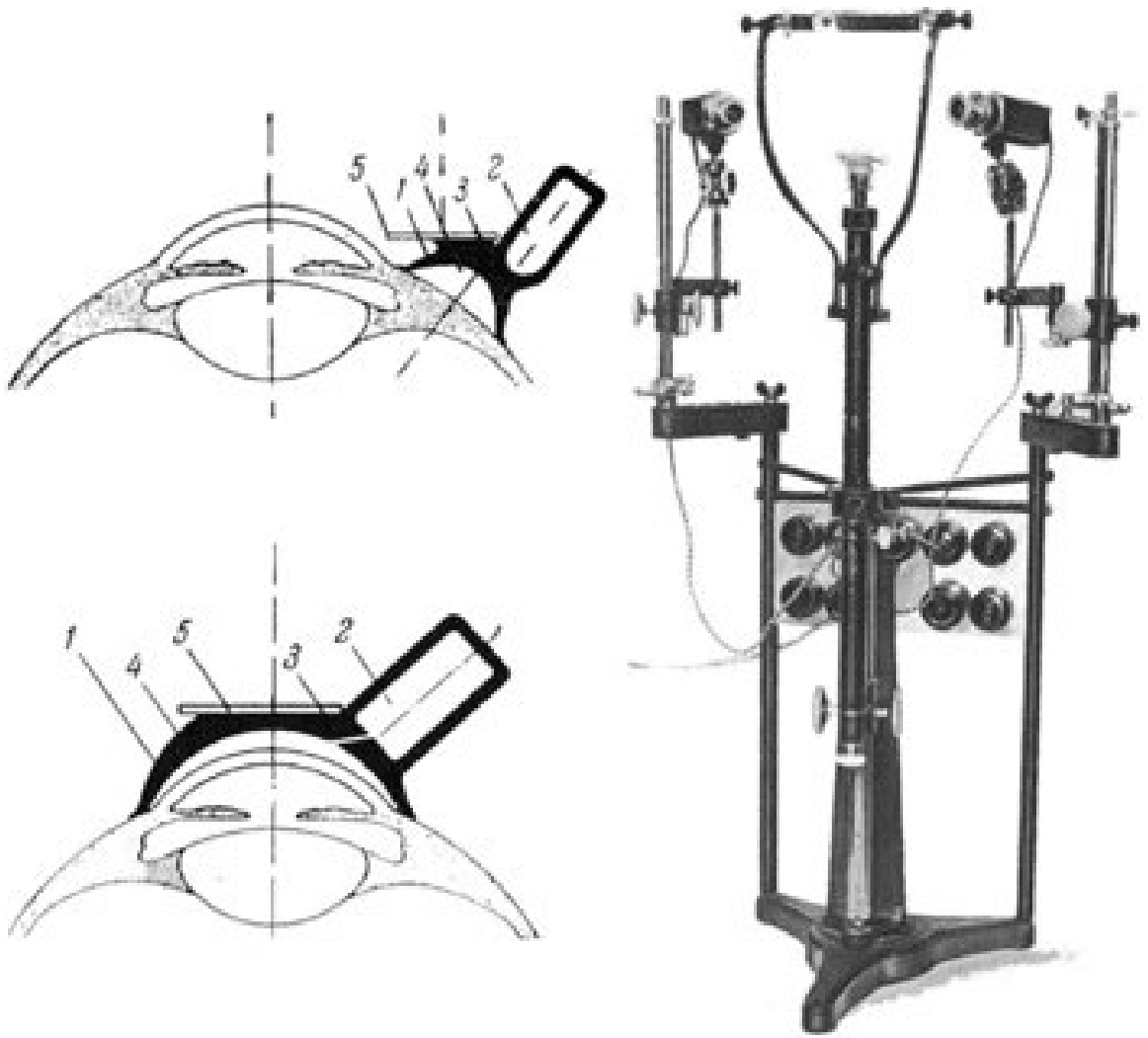
Alfred Lukyanovich Yarbus (Альфред Лукьянович Ярбус)

- Moscow, 1914 – 1986
- PhD on visual illusions
- From 1957 **USSR Academy of Sciences**
- Lab leaders Bongard (Soviet AI) Smirnov
- **Vadim Invanovich Chernishev**, technician, made the suction cups (together with Yarbus)
- PhD in Biology 1964
- Book 1965, English 1967
- Faced resentment due to credit
- 1975-1980 papers on vision inspired by analog electrical engineering

(a)

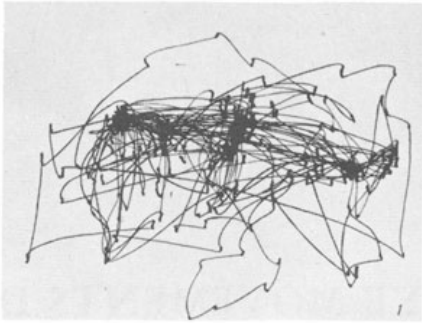
WWII (1944?)

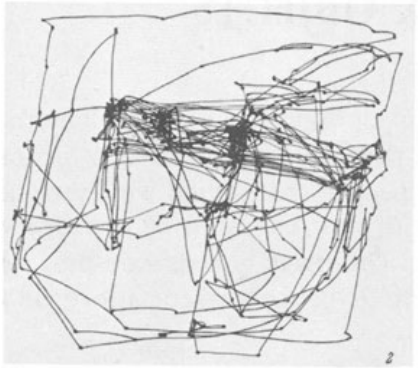
Iperception. 2010; 1(1): 7–27.
Published online 2010 Jul 12. doi: 10.1068/i0382
Yarbus, eye movements, and vision
Tatler, Wade, Kwan, Findlay, and Velichkovsky

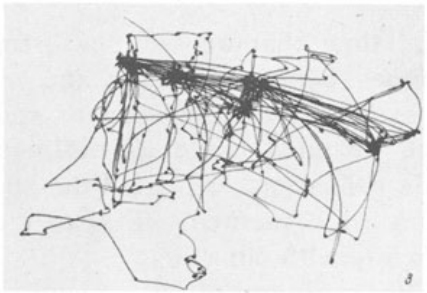


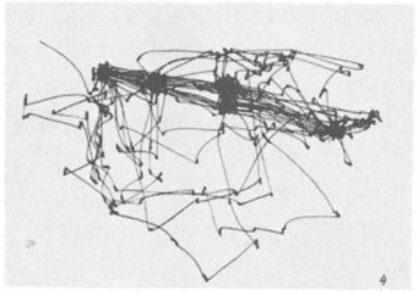
(b)

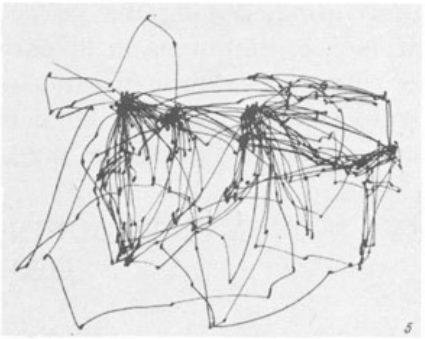
Yarbus
Records of
the eye movements
of
seven different subjects

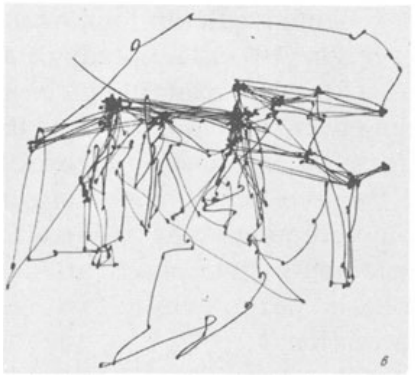


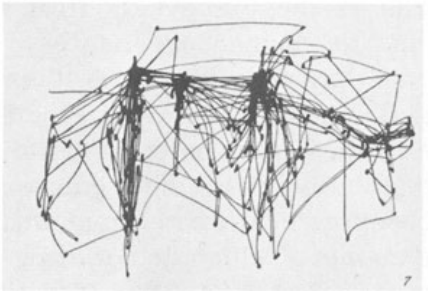


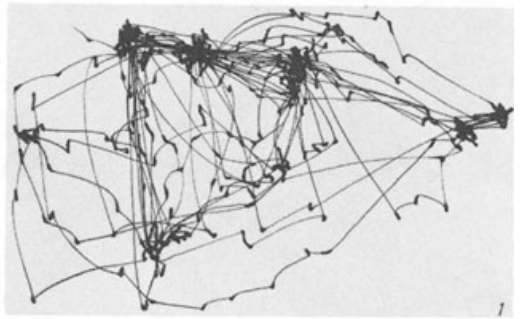




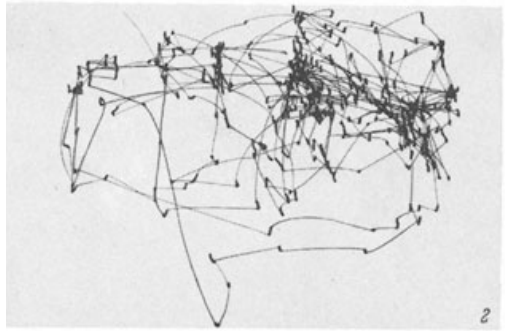


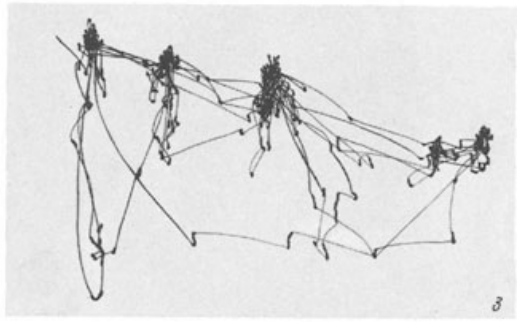






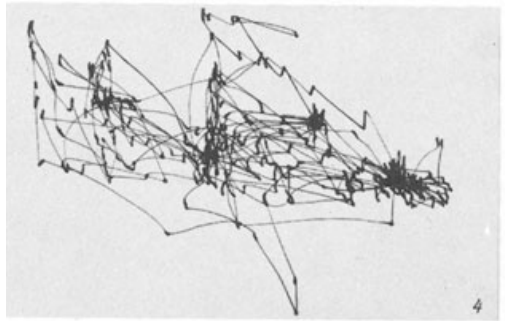
Estimate the material circumstances of the family in the picture

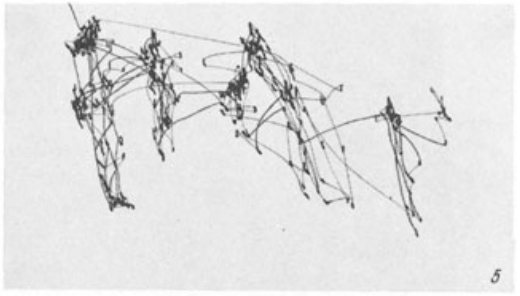




Give the ages of the people

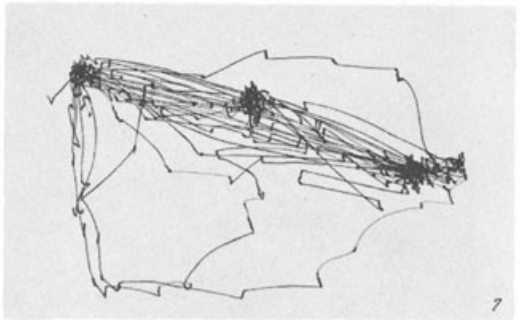
Surmise what the family had been doing before the arrival of the “unexpected visitor”



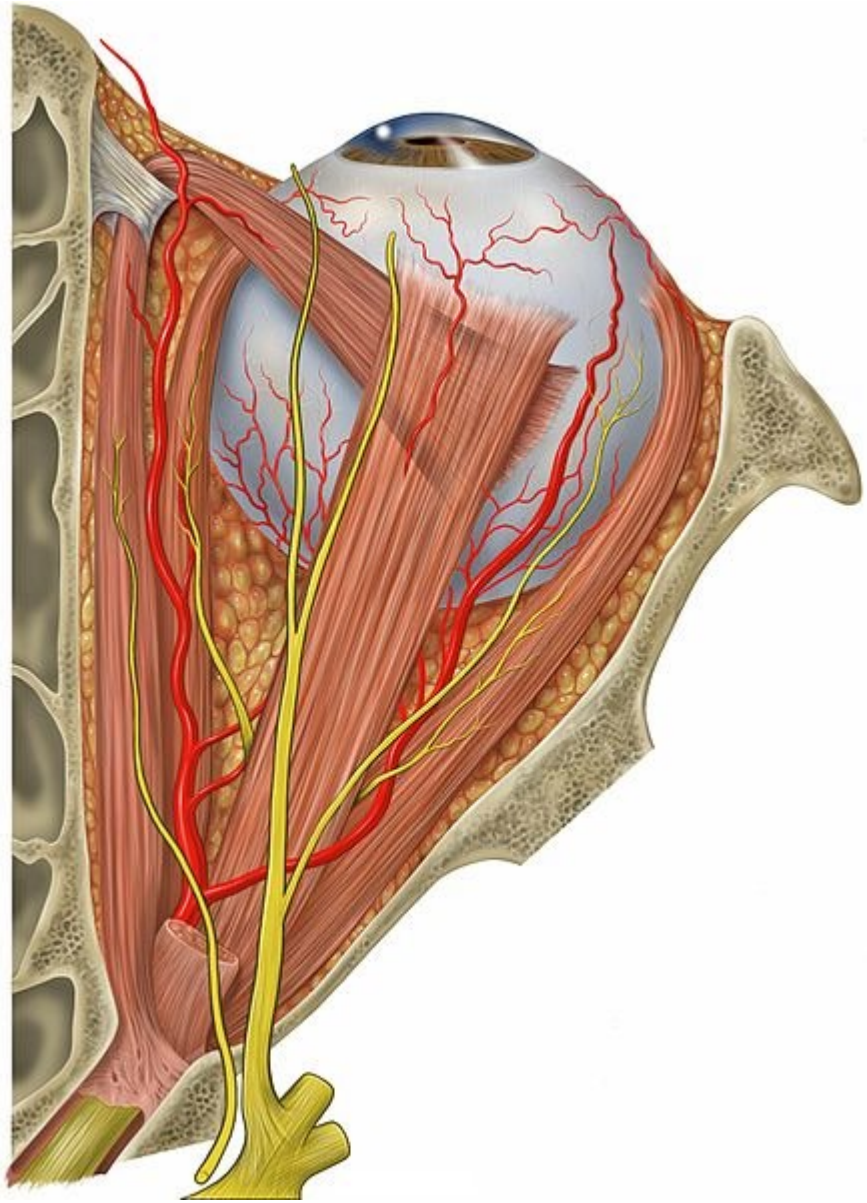


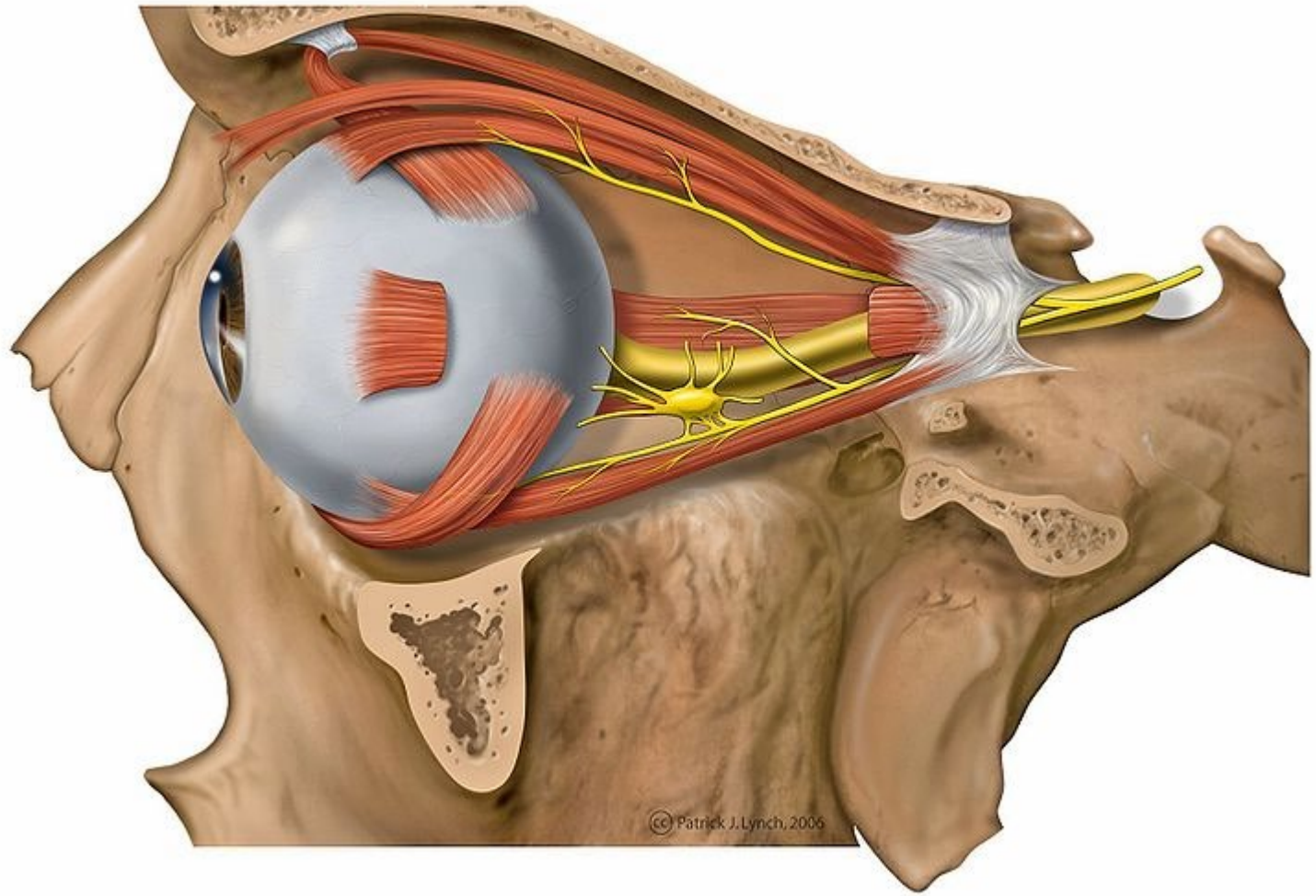
Remember the clothes worn by the people

Remember the position of the people and objects in the room

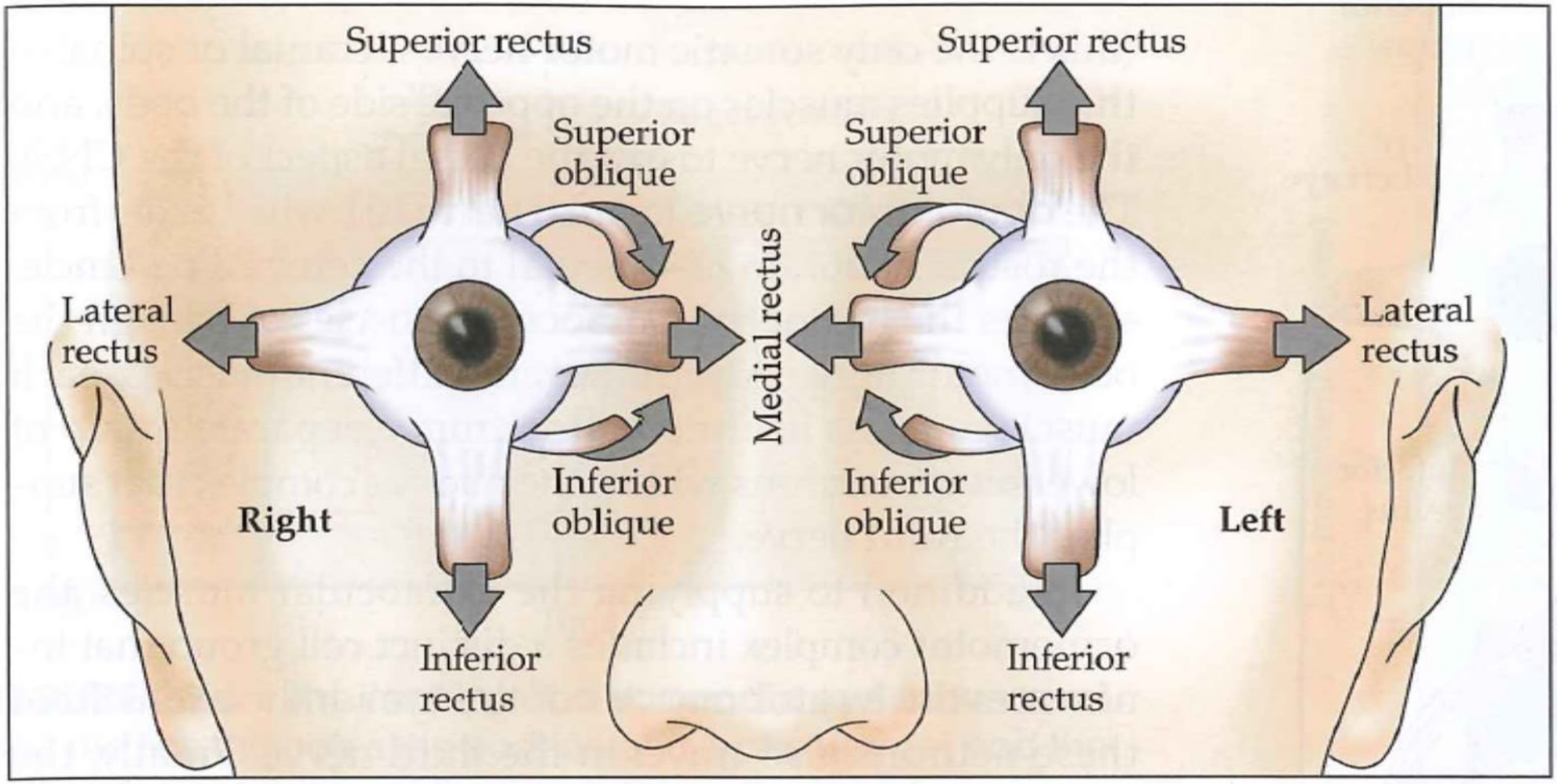


Estimate how long the “unexpected visitor” had been away from the family




© Patrick J. Lynch, 2006

The extraocular muscles



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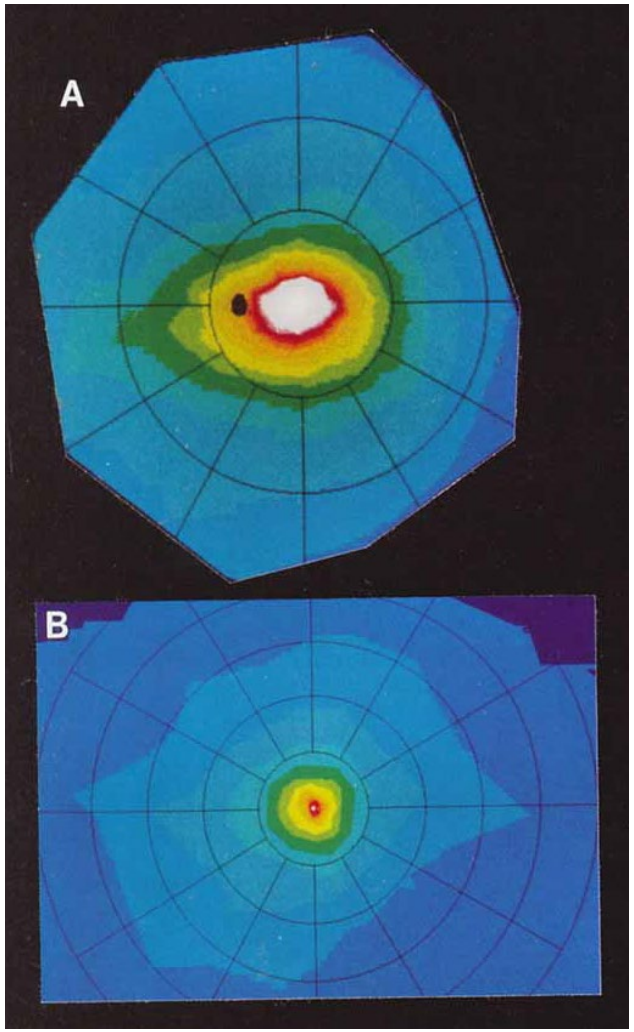

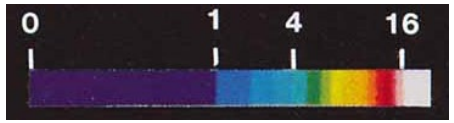

Cones per unit area

Eye movements with fovea

- Fixation
- Smooth pursuit
- Saccades

- Stay
- Stay*
- Change

מכבי ממבט ראשון

העיניים שלך זה לא משחק

פנה רק לאופטומטריסט מוסמך

לחנות הקרובה לחץ כאן >>

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פנה רק לאופטומטריסט מוסמך

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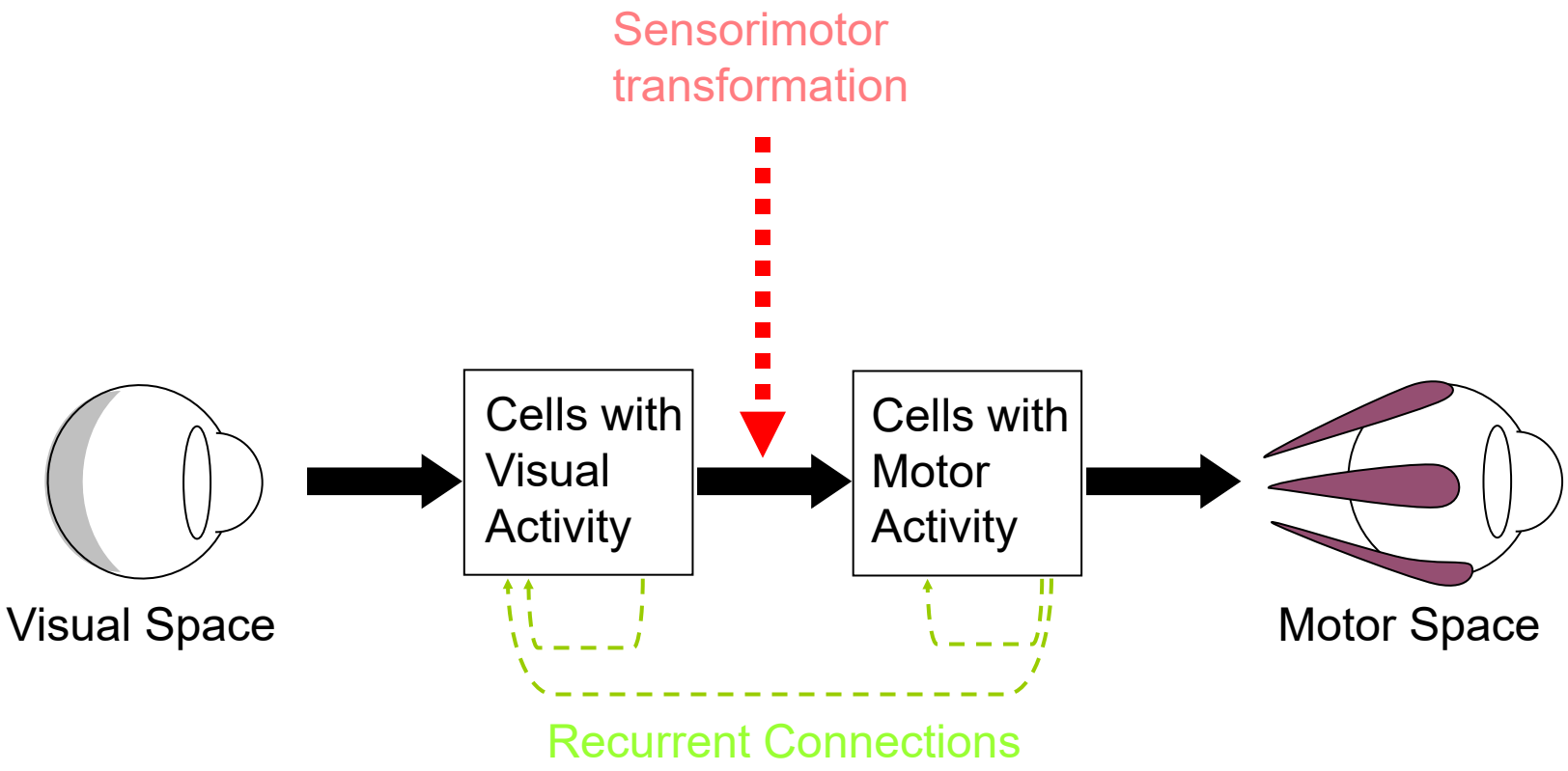
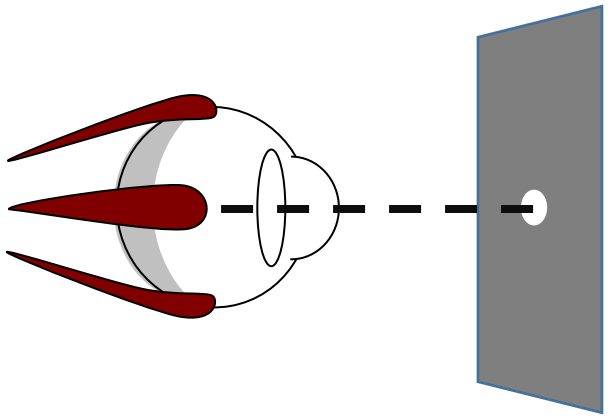
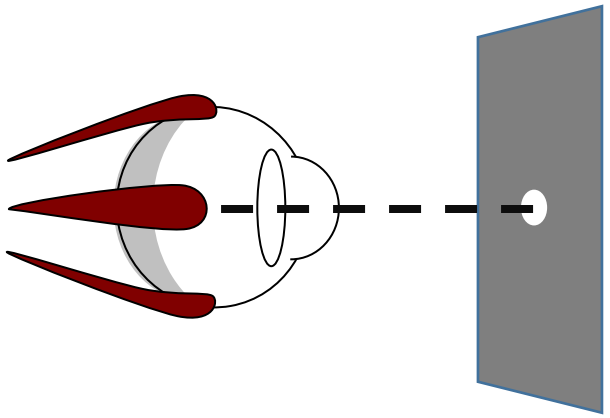
S→M transformations

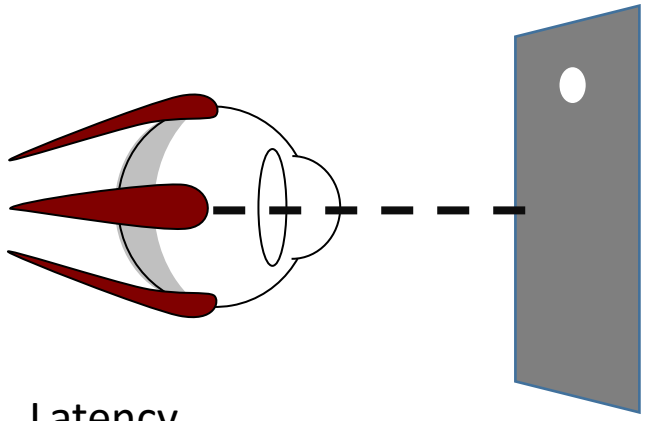




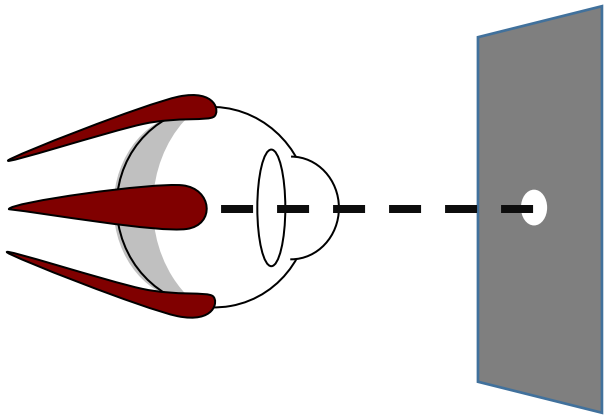
Pre-saccadic
Fixation



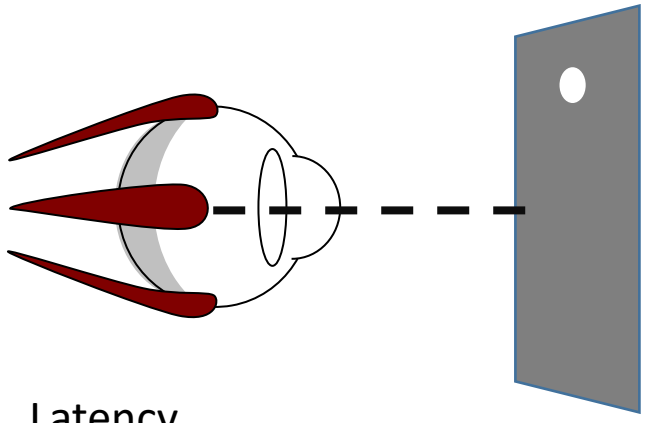
Pre-saccadic
Fixation



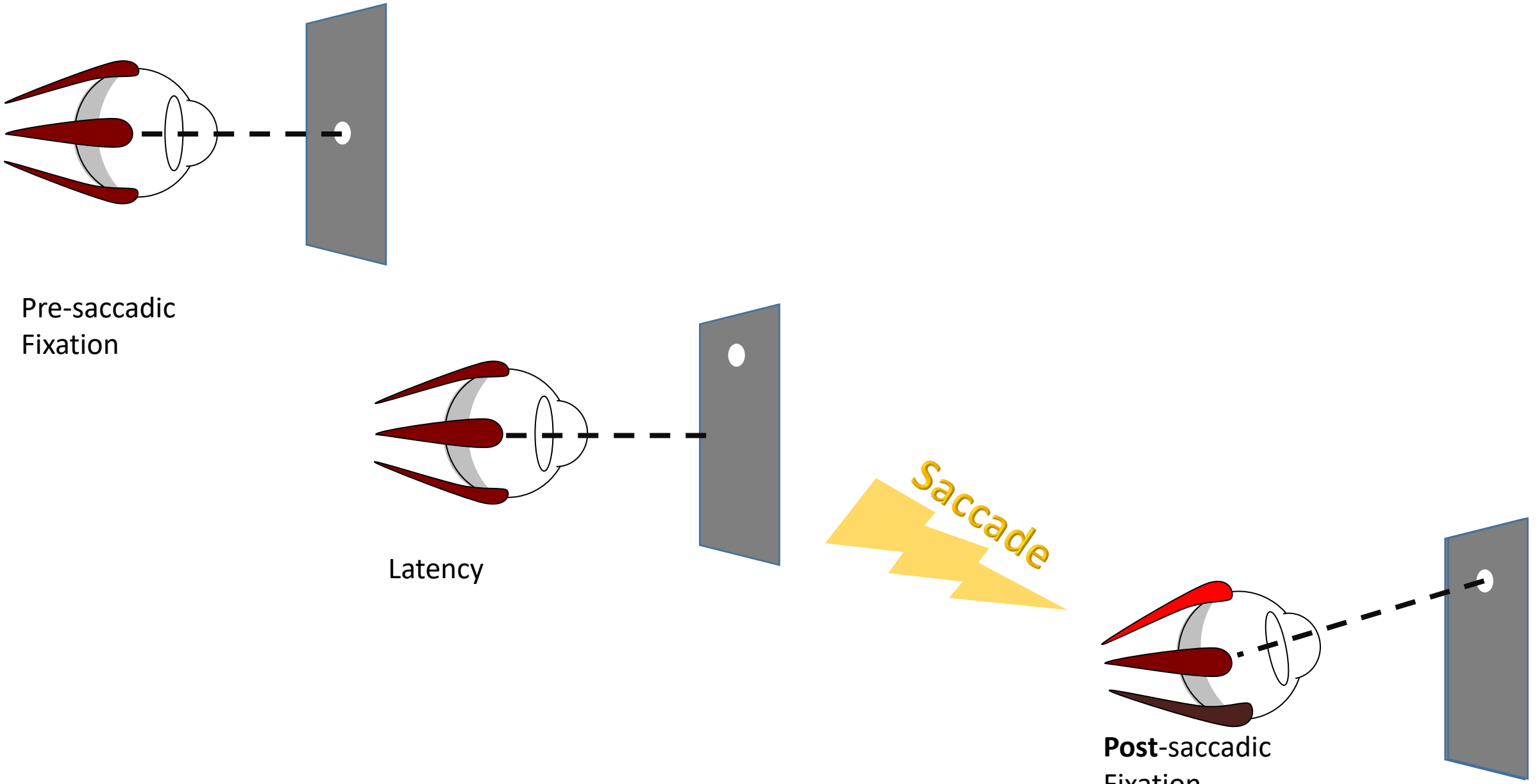
Latency



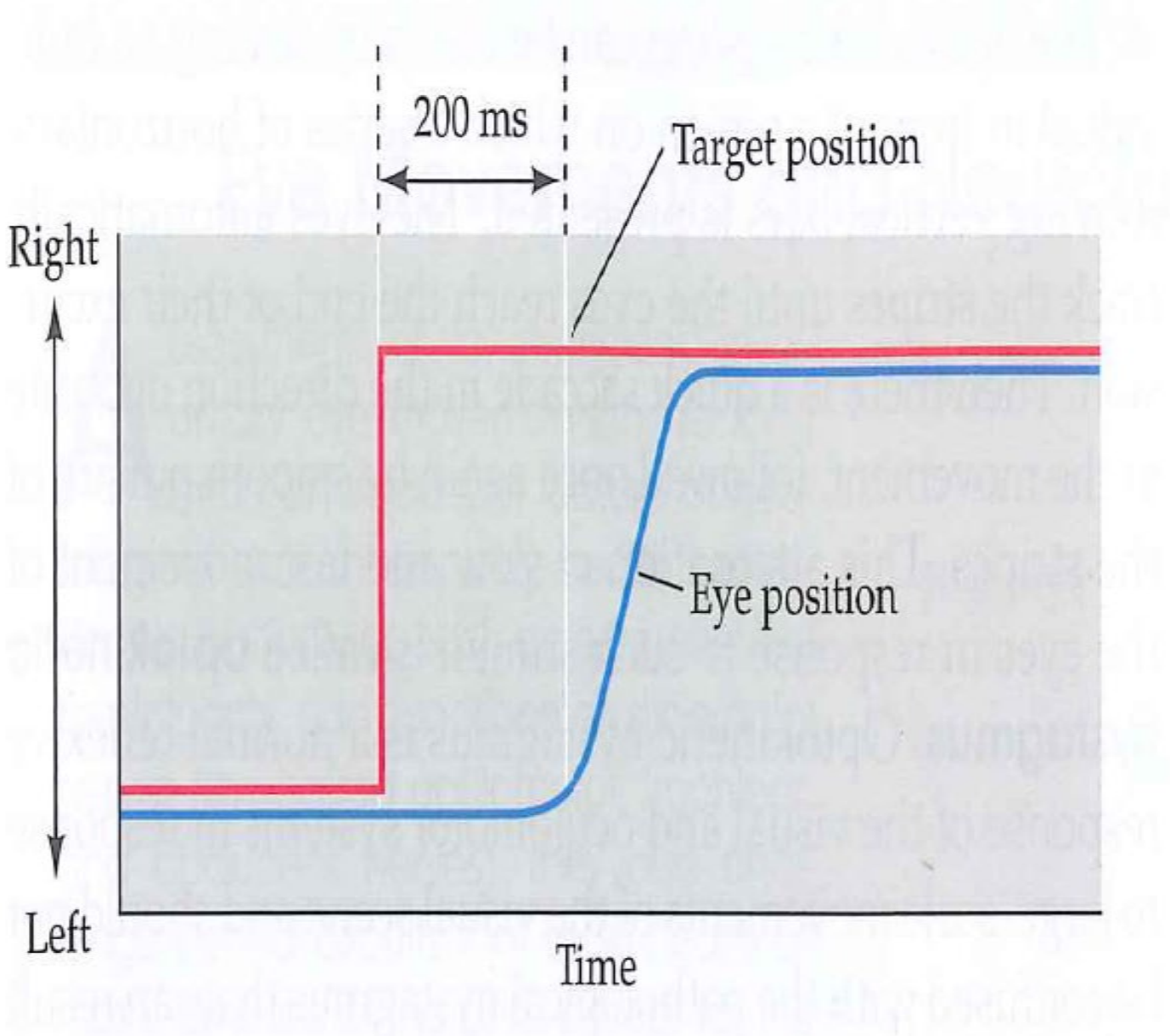
Pre-saccadic
Fixation



Latency


Pre-saccadic
Fixation
Latency
Saccade
Post-saccadic
Fixation

Saccade – timecourse



Saccades

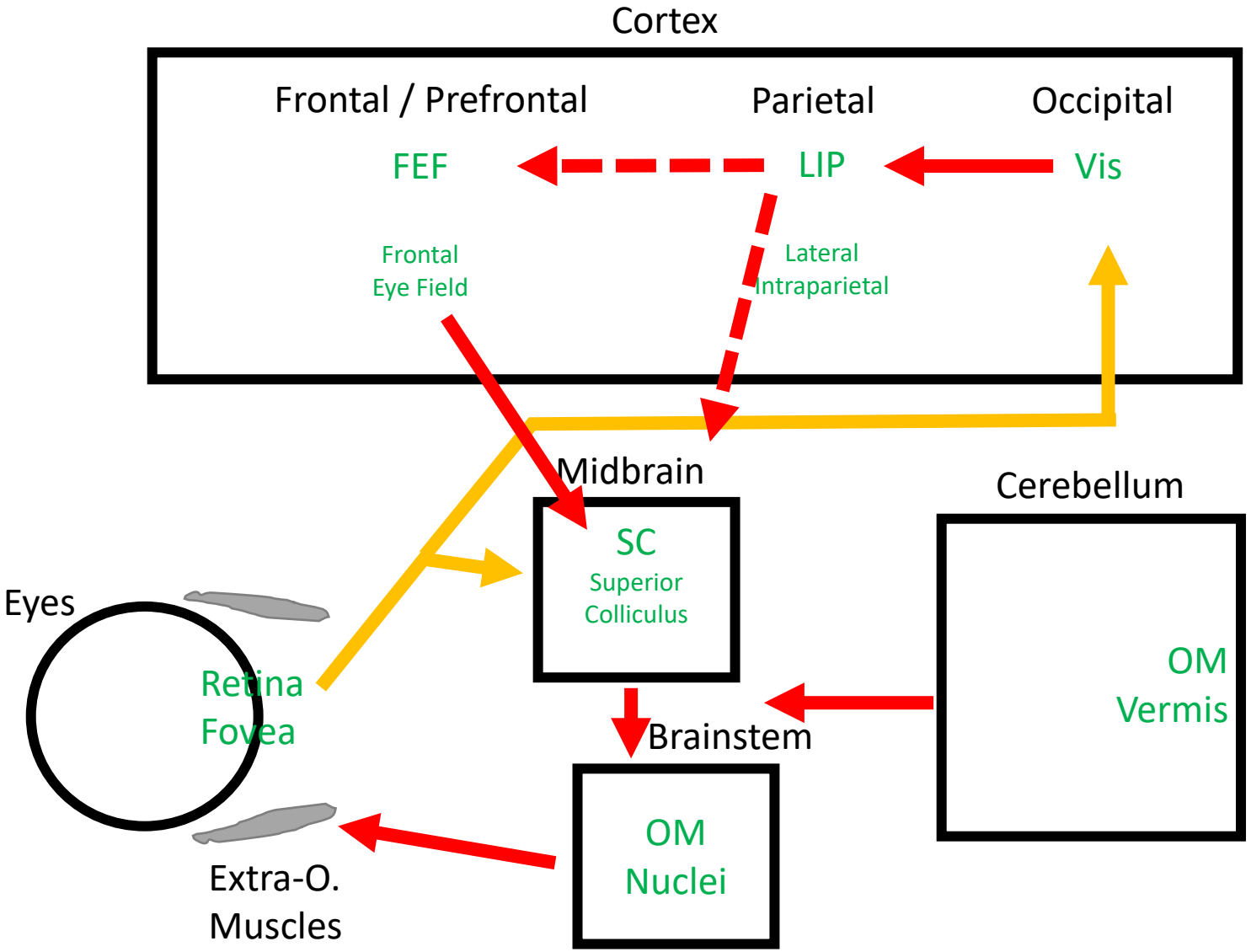
- Saccades occur all the time:
  - 2-5 per s during waking hours
  - Also during sleep
- Over life time, similar number of saccades to heartbeats
- Every saccade requires deliberation and choice
- Vision builds up trans-saccadically
  - Memory
  - Stability of perception
- Relationship to attention

Class 2

- Overall arrangement of the saccadic system
- Brainstem
- Superior colliculus
- Cerebellum

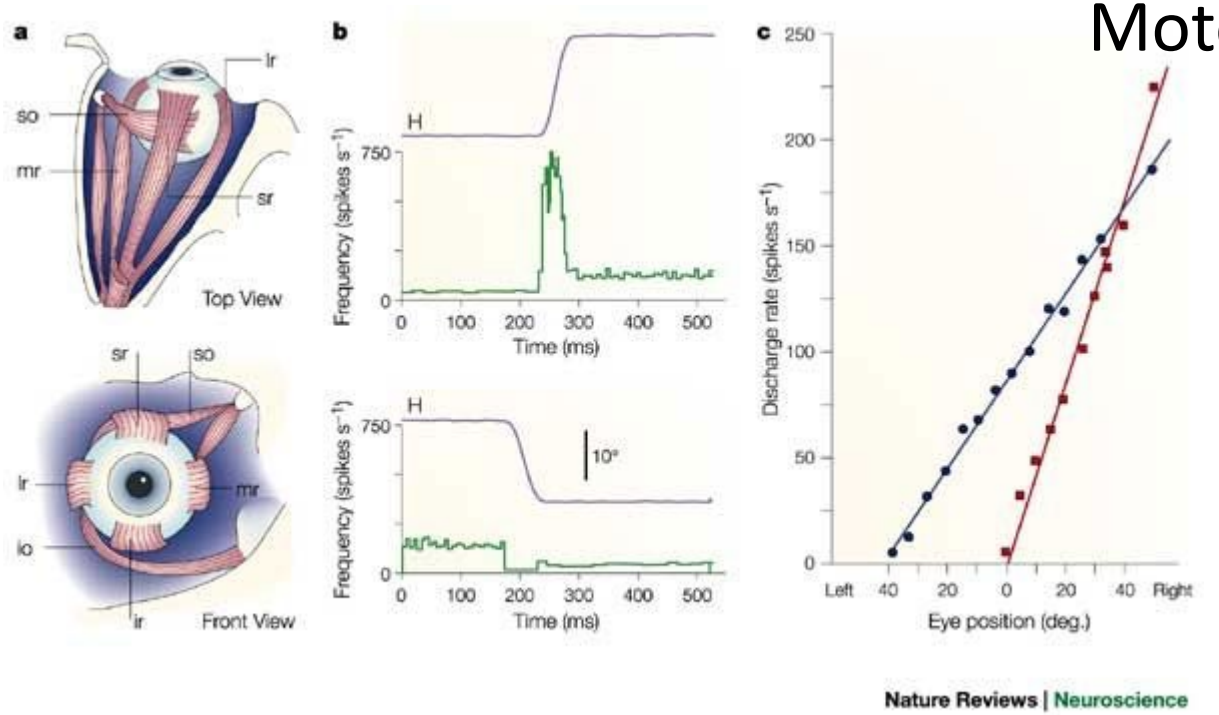
Simplified structure of the saccadic system

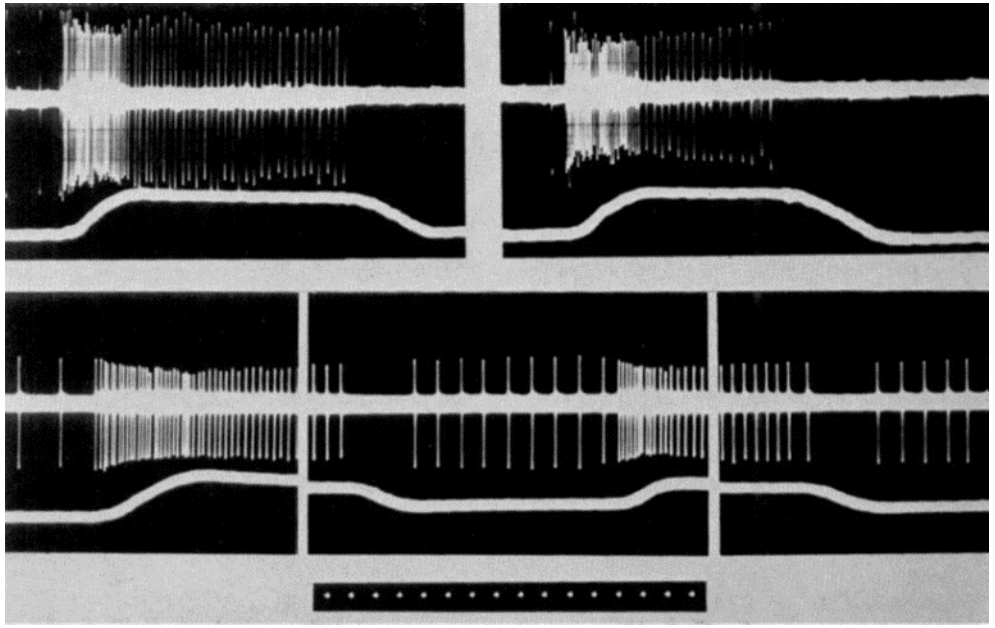
There are many additional regions



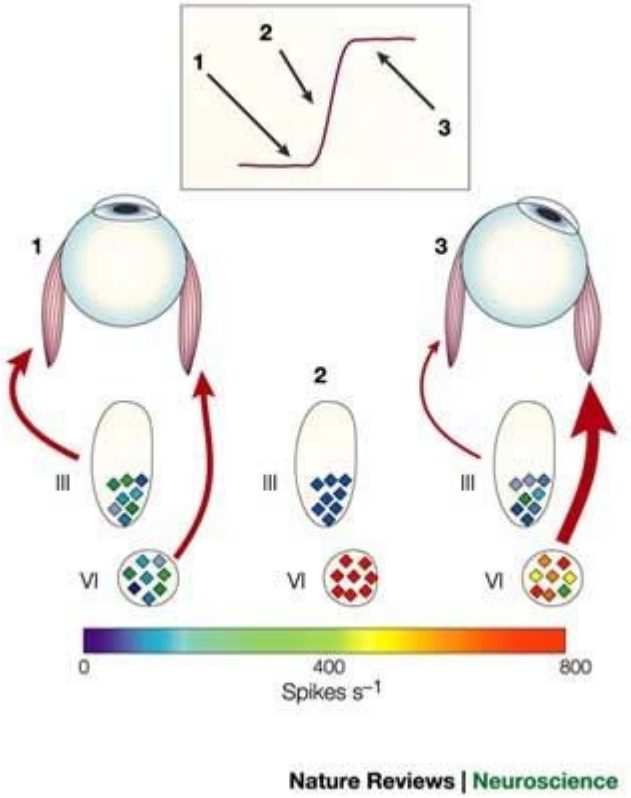
Oculomotor nuclei

Motor neurons pulse-step for saccade-fixation





Two abducens units. Up = lateral. Bar = 40 deg. Max rate, upper 740, lower 380. Time marks 20ms.
Fuchs and Luschei, JNP 1970?, Firing patterns of Abducens neurons of alert monkeys
in relationship to horizontal eye movement.



David L. Sparks: The brainstem control of Saccadic eye movements. NatNSRev 2002

Superior colliculus

SC - superior colliculus and FEF – frontal eye fields

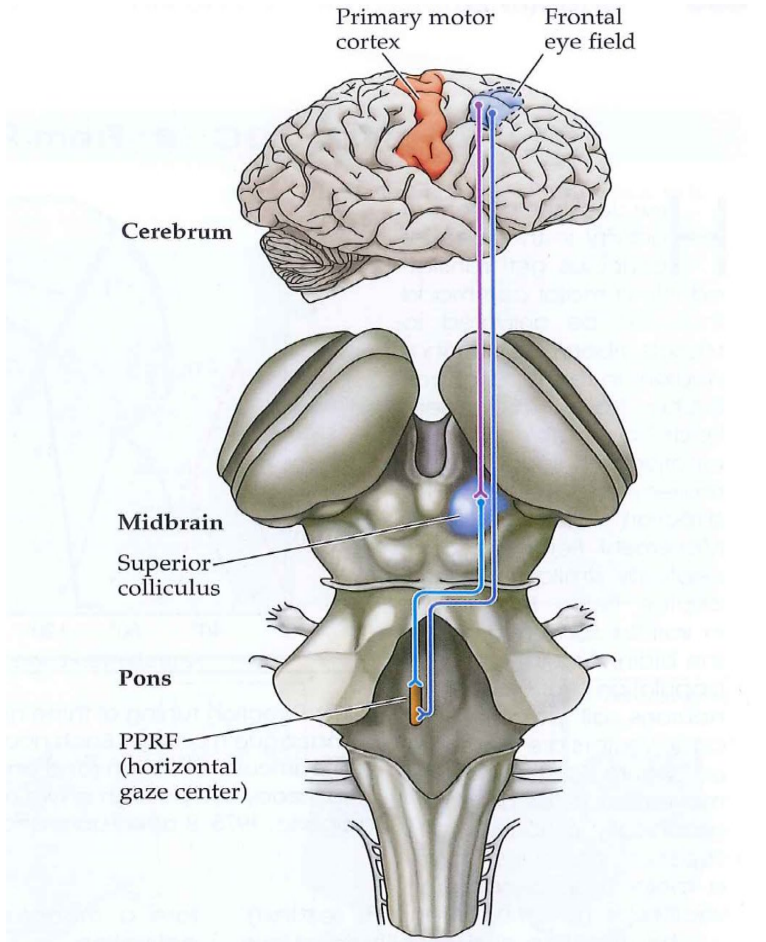
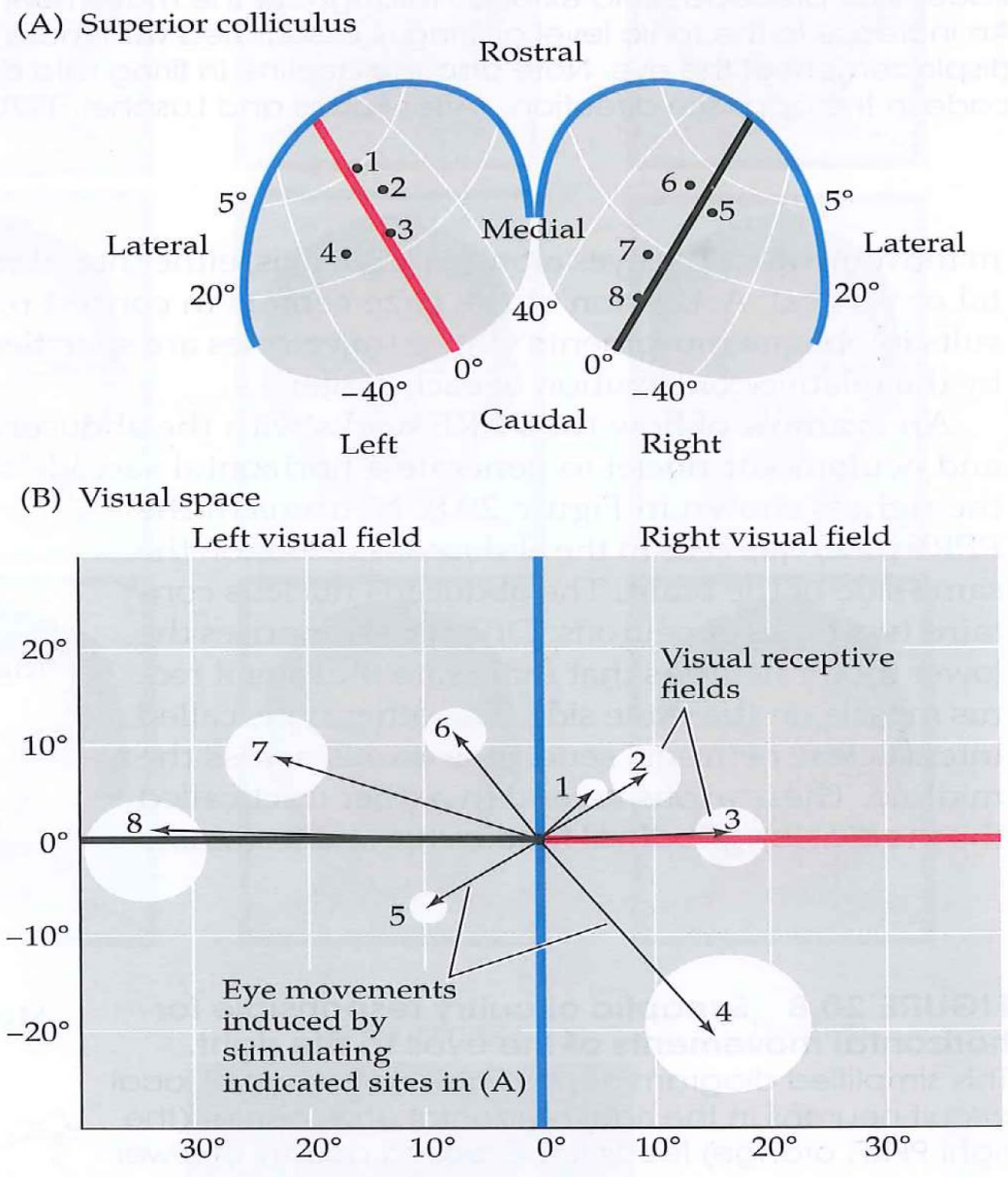
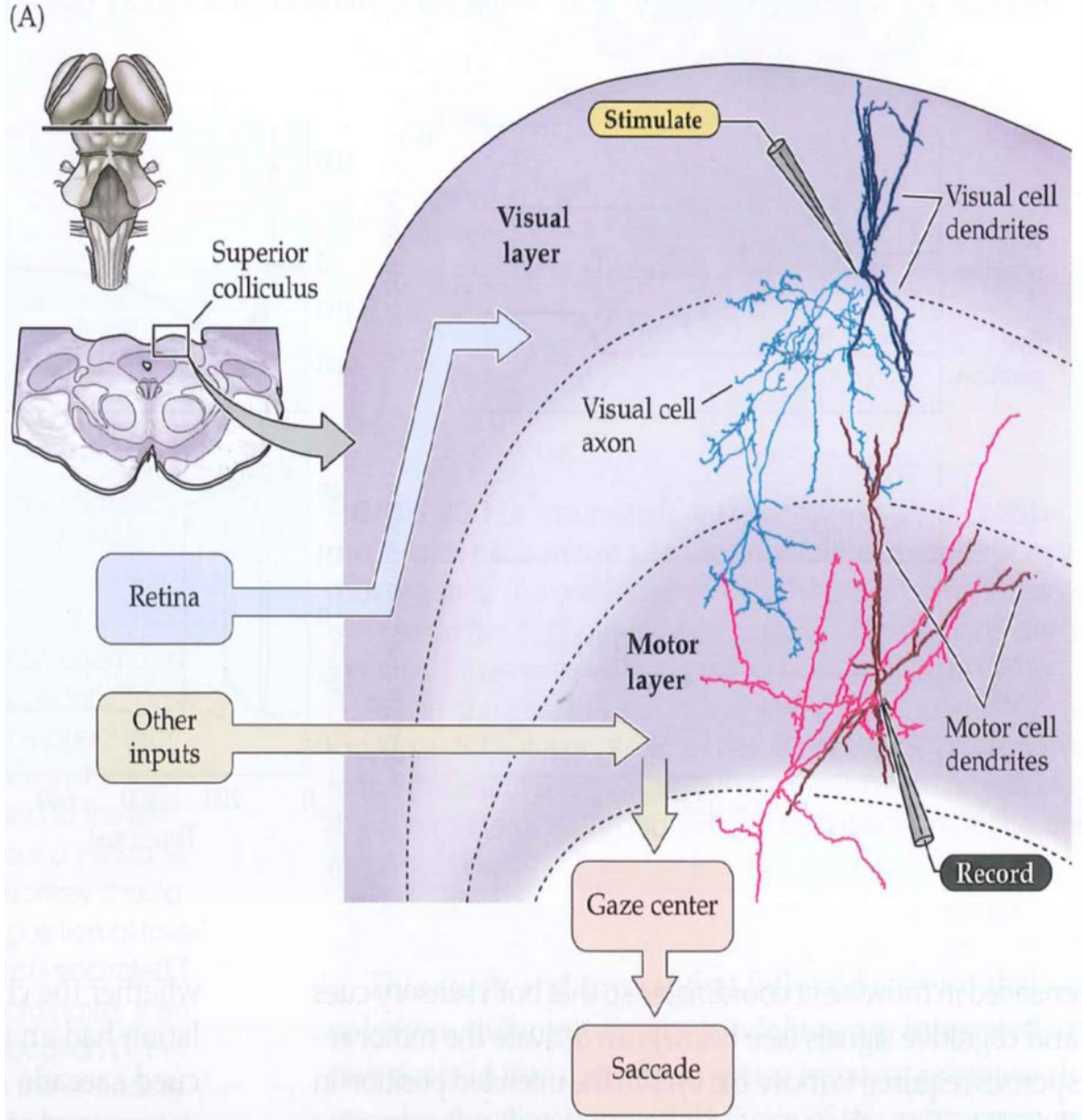


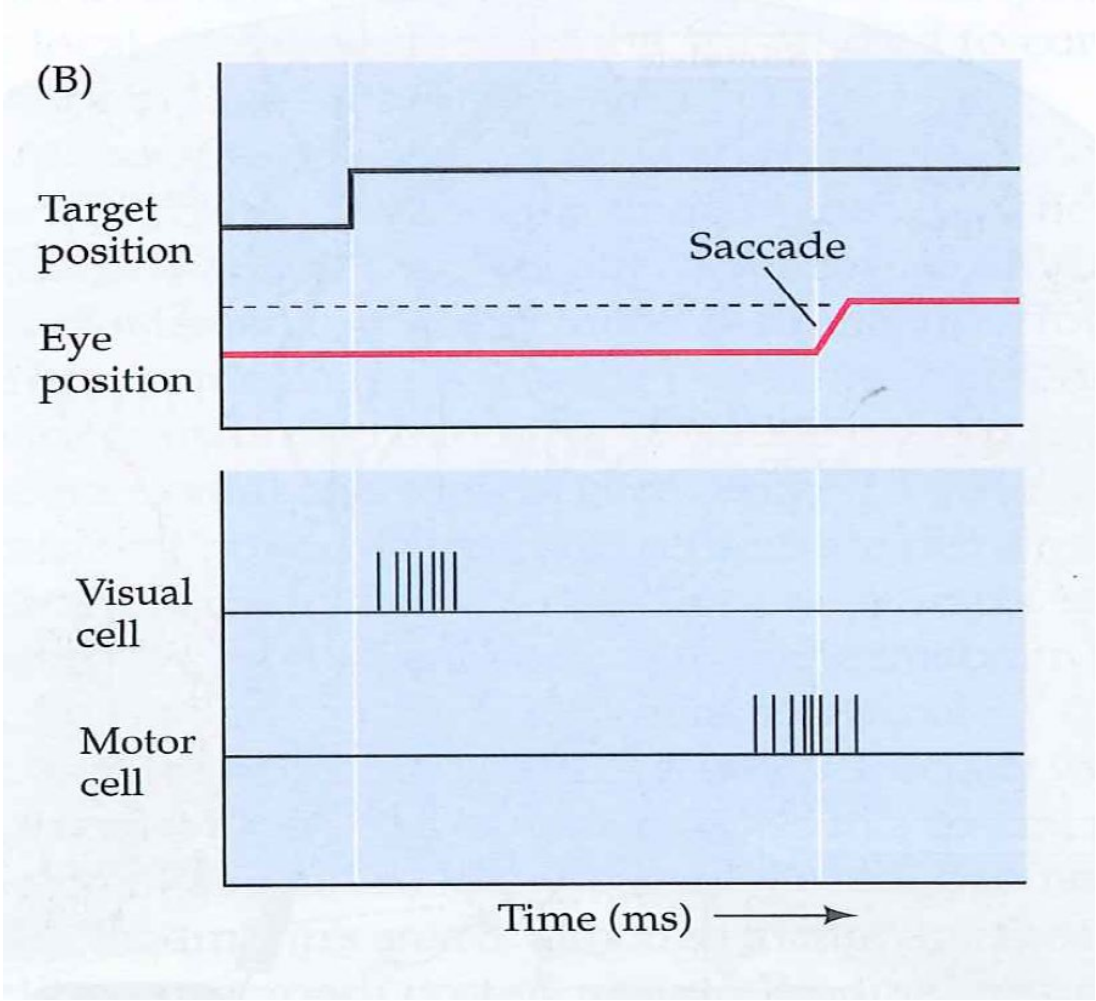
FIGURE 20.11 Neurons in the frontal eye field collaborate with cells in the superior colliculus to control eye movements. The projections shown here are from the frontal eye field in the right cerebral hemisphere (Brodmann's area 8) to the superior colliculus and the horizontal gaze center (PPRF). In humans, the frontal eye field can influence eye movements by either of two routes: indirectly, by projections to the ipsilateral superior colliculus, which in turn projects to the contralateral PPRF; and directly, by projections to the contralateral PPRF.

SC orients


(A) Superior colliculus
Rostral
Lateral
Medial
Lateral
Caudal
Left
Right
5°
20°
40°
0°
−40°
1
2
3
4
5
6
7
8
(B) Visual space
Left visual field
Right visual field
Visual receptive fields
Eye movements induced by stimulating indicated sites in (A)
20°
10°
0°
−10°
−20°
30°
20°
10°
0°
10°
20°
30°


(A)
Superior colliculus
Stimulate
Visual layer
Visual cell dendrites
Visual cell axon
Retina
Other inputs
Motor layer
Motor cell dendrites
Record
Gaze center
Saccade

Dissociating Visual from Motor in time



Visual and motor fields are large

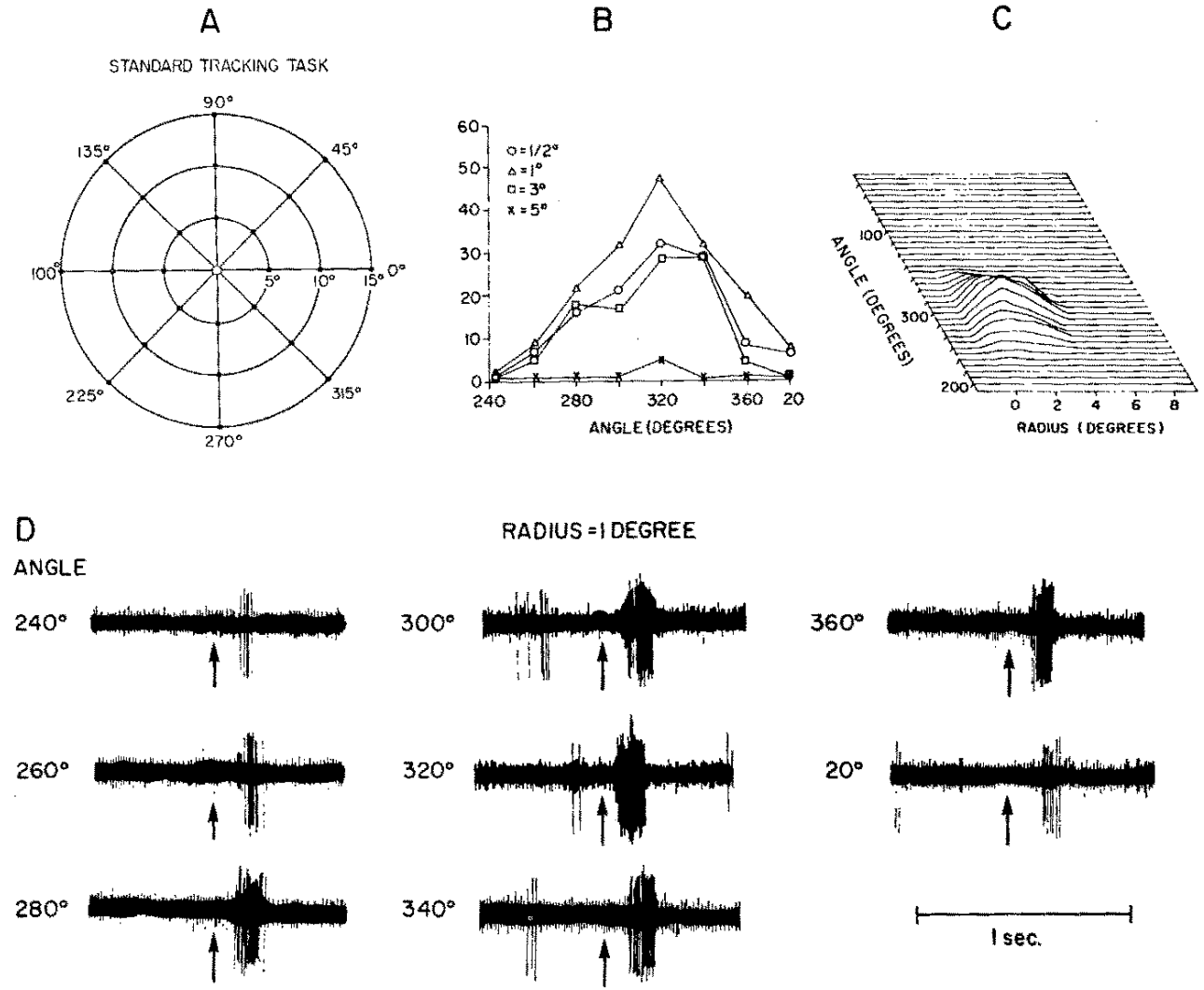
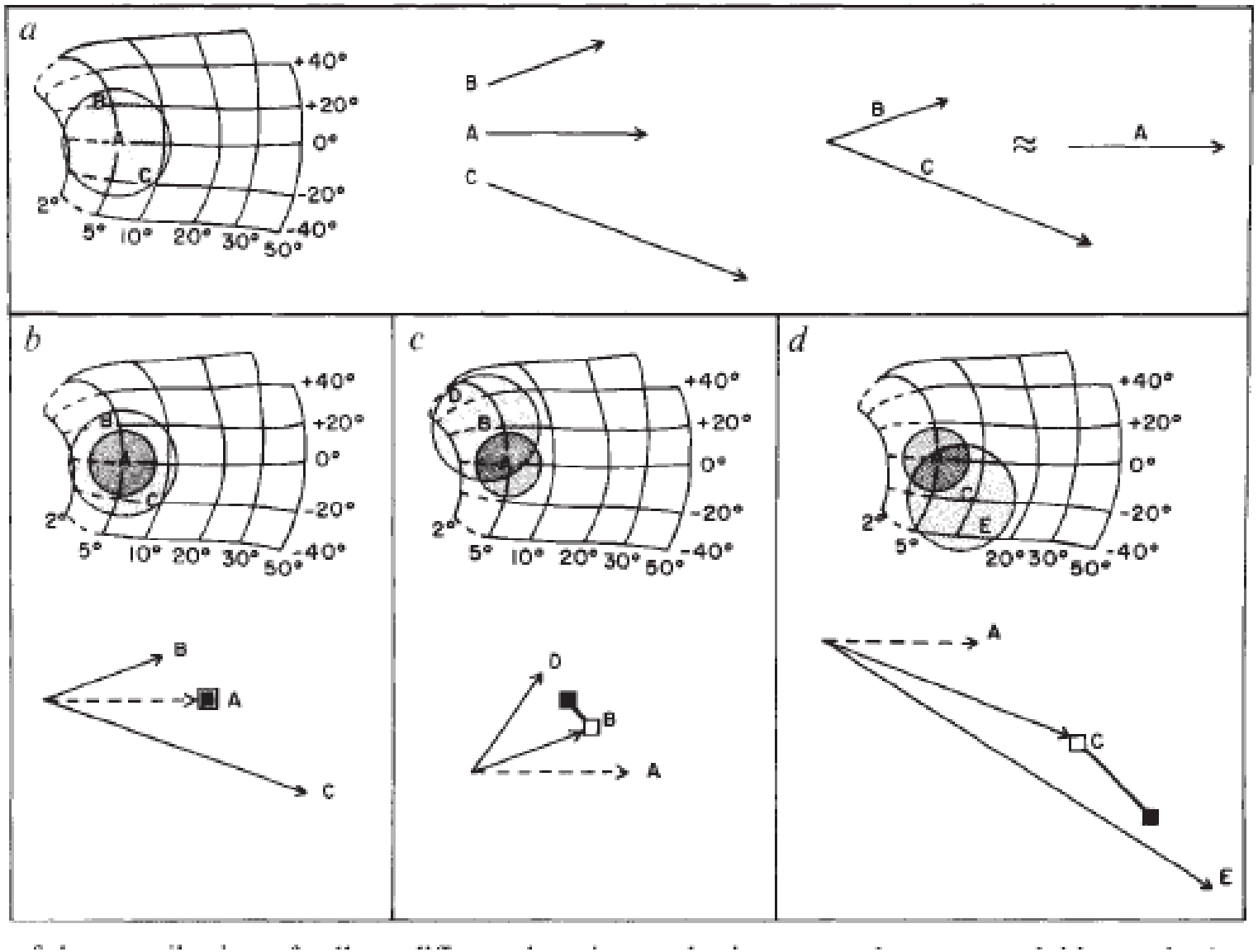
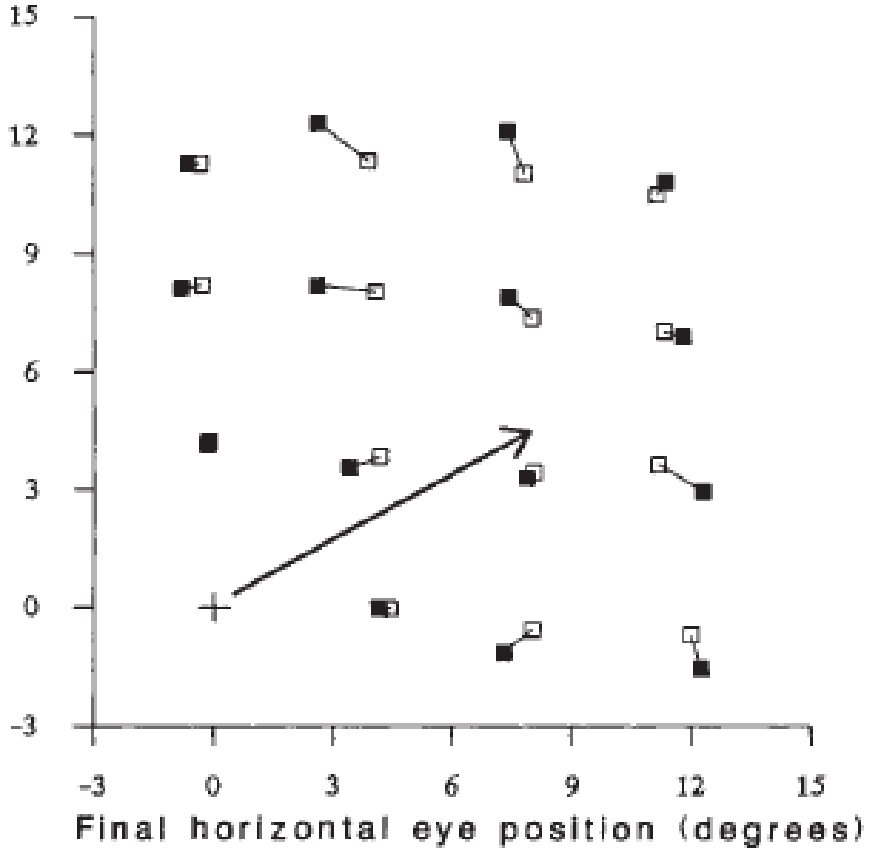


Fig. 1. A: the standard tracking task. If subject fixated the center dot for 2 sec, the target was moved to one of the 24 positions indicated by the filled circles. B: burst-index (see text) as a function of angle of movement. Each point represents the median value of three observations. C: burst-index as a function of angle and radius of eye movement. D: response of a superior colliculus unit to a series of saccades with a 1° radius but varying in direction. The onset of target movement is indicated by the arrow below each trace.

Sparks 1975

Sparks' demonstration of SC population coding

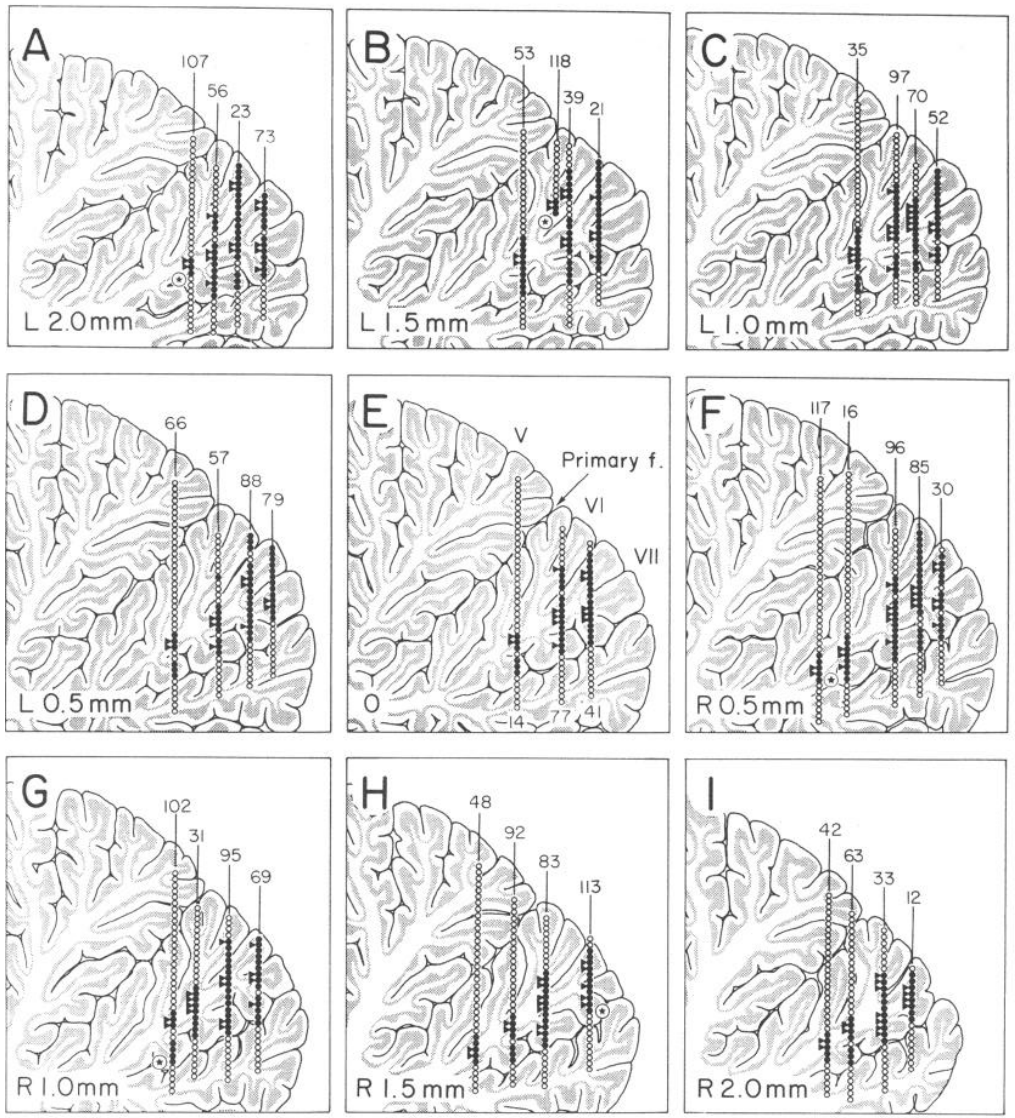




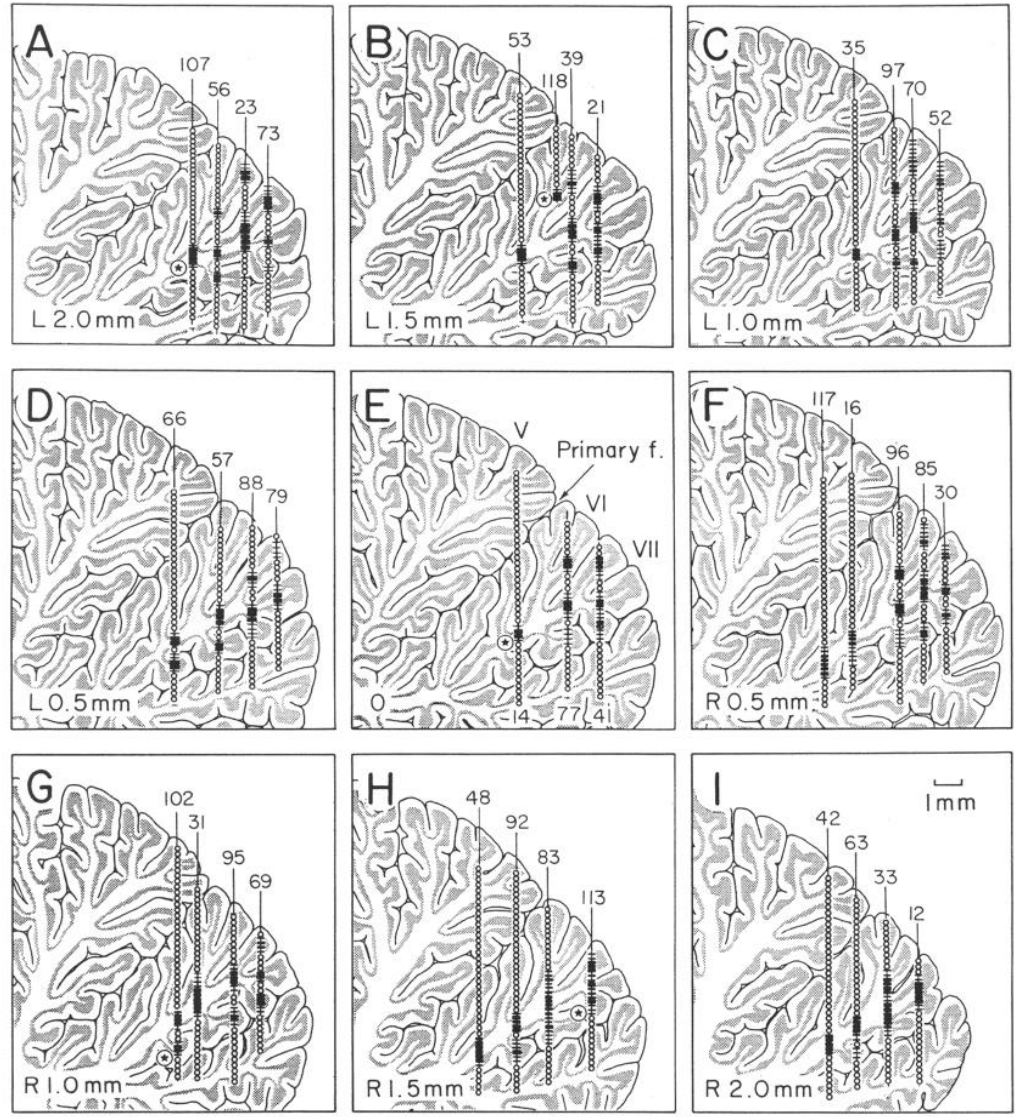
Lee Roher & Sparks Nature 1988

The SC fixation region of Munoz and Wurtz

The cerebellum:
OPV – oculomotor posterior vermis
also called OMV – oculomotor vermis

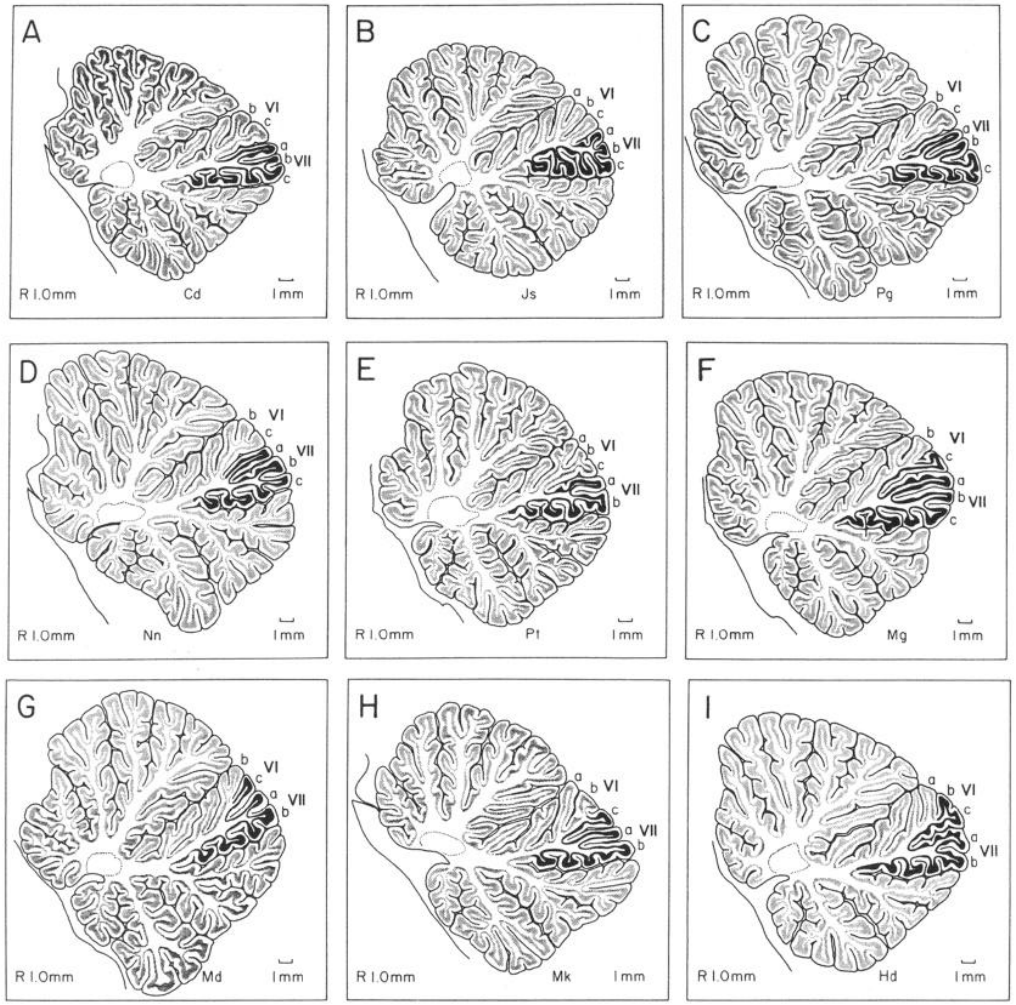


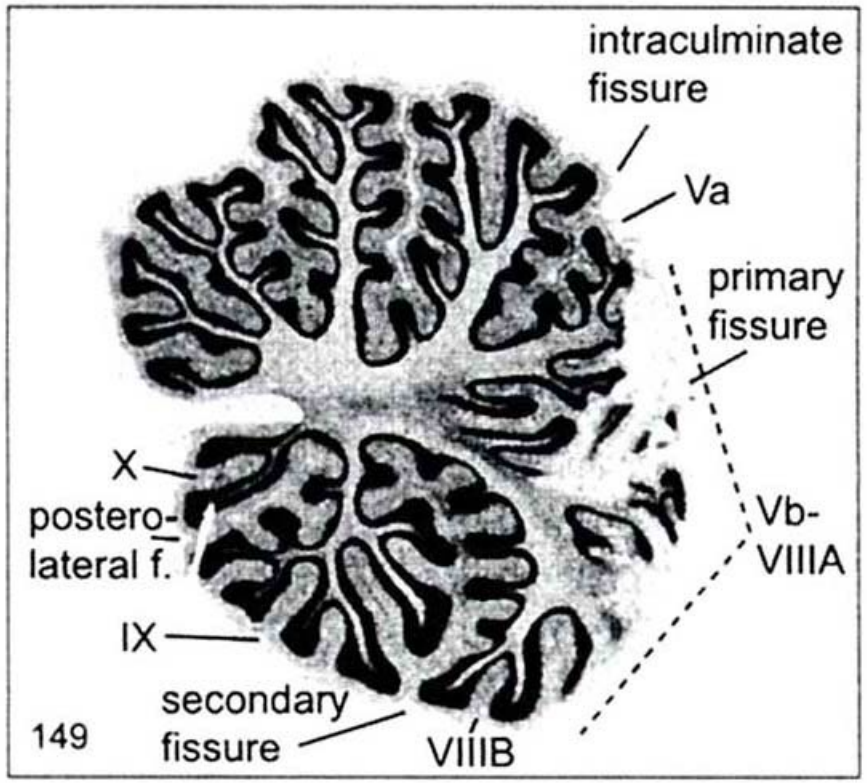
▶● Threshold ≦ 5 μA, ● 5 μA < Threshold ≦ 30 μA, ○ Threshold > 30 μA, Monkey Md

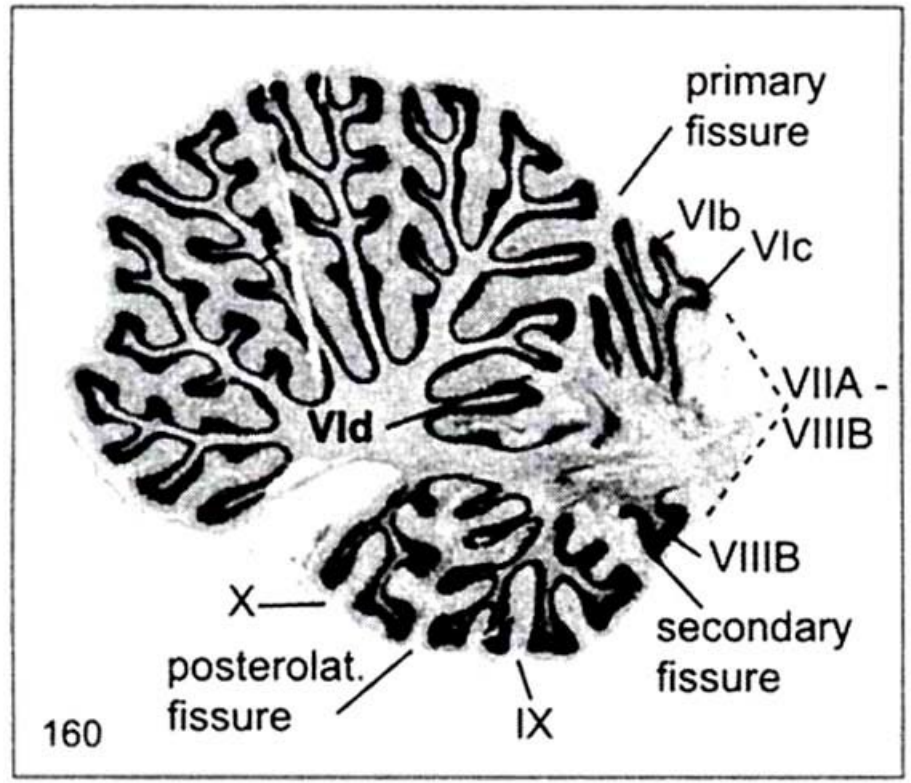


Saccade-related Background Neural Activity { ▬ strong, ━ weak, ○ none } Monkey Md

Noda's area – OPV – Saccadic cerebellar cortex




intraculminate
fissure
Va
primary
fissure
X
postero-
lateral f.
IX
Vb-
VIIIA
secondary
fissure
VIIIB
149


primary
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IX
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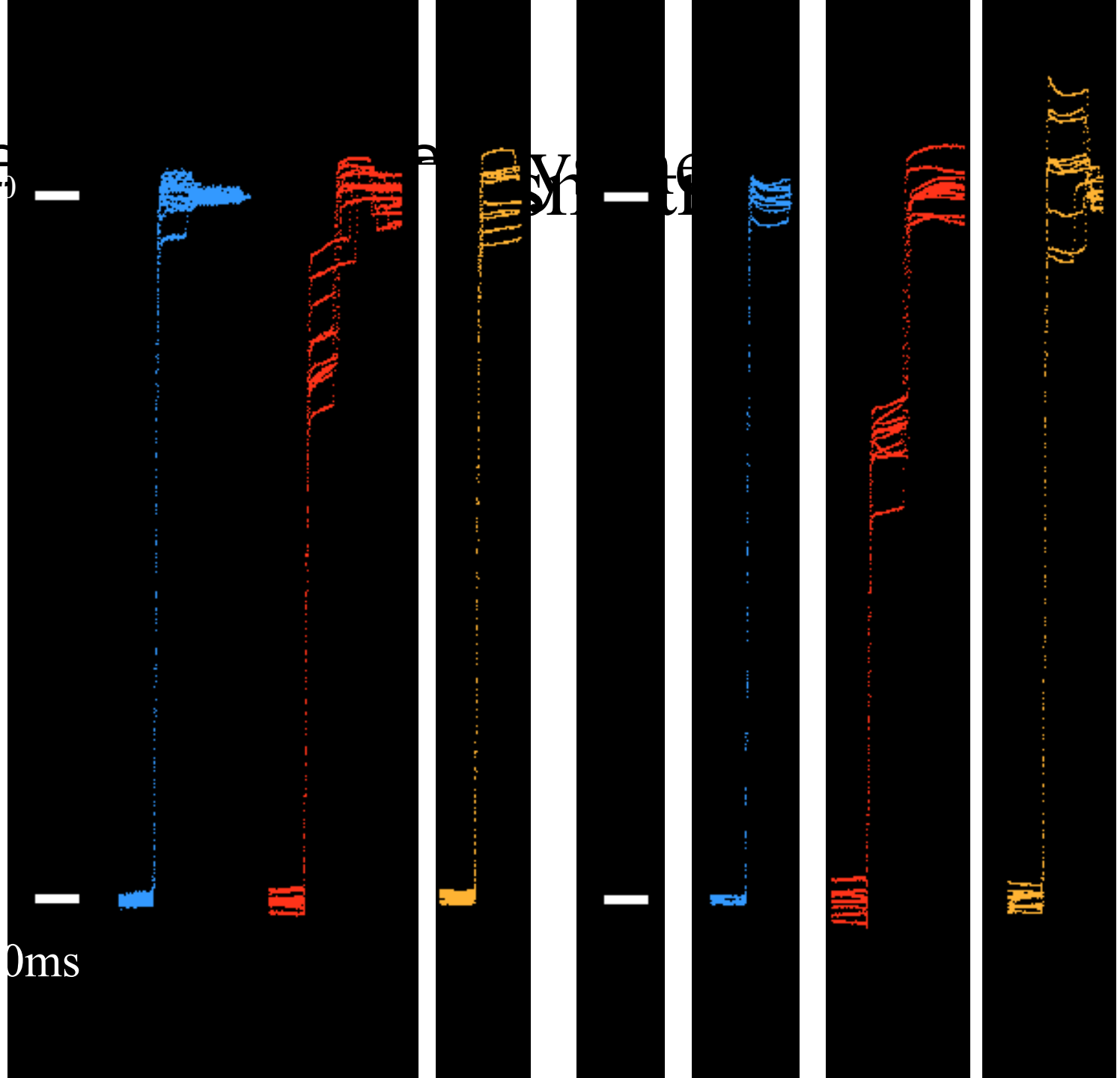
on

Animate

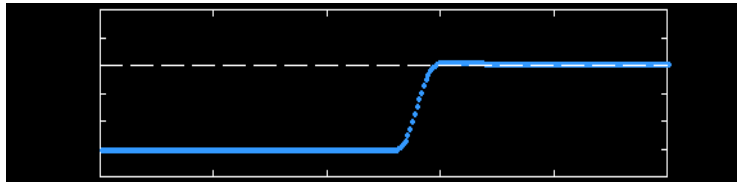


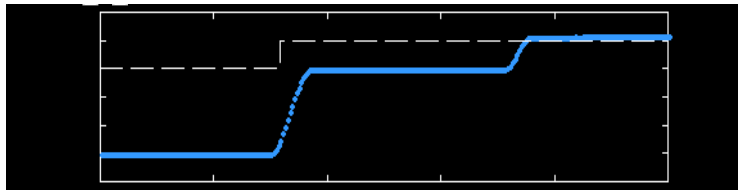
Summary 1

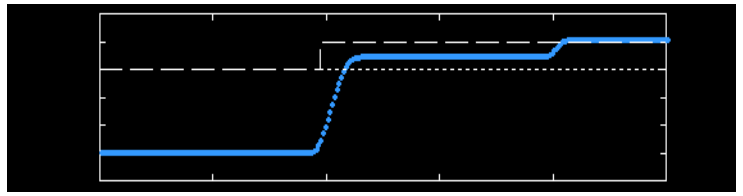
- Hypometria is an *acute* sign of OPV damage.
- The hypometria recovers completely.
- There remains increased variability in saccade size.

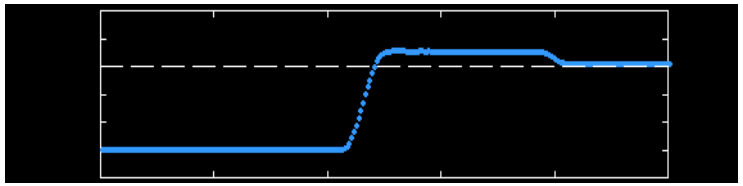
Saccadic Adaptation

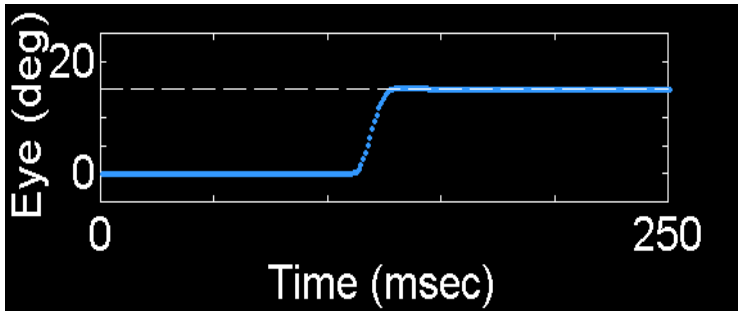
ind
str
ate
Ad
apt

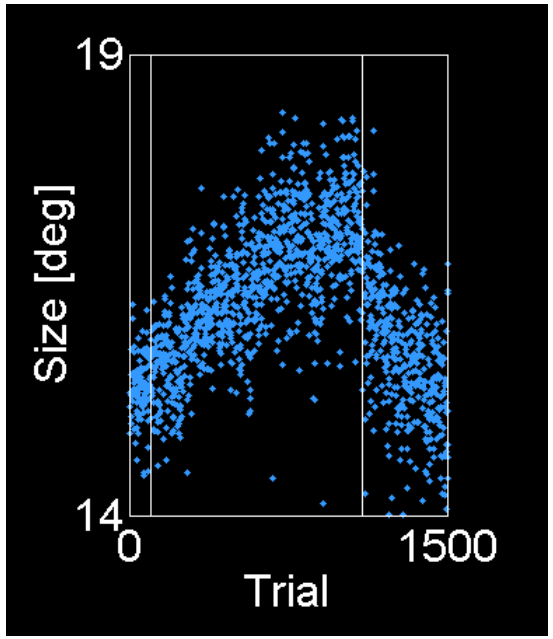


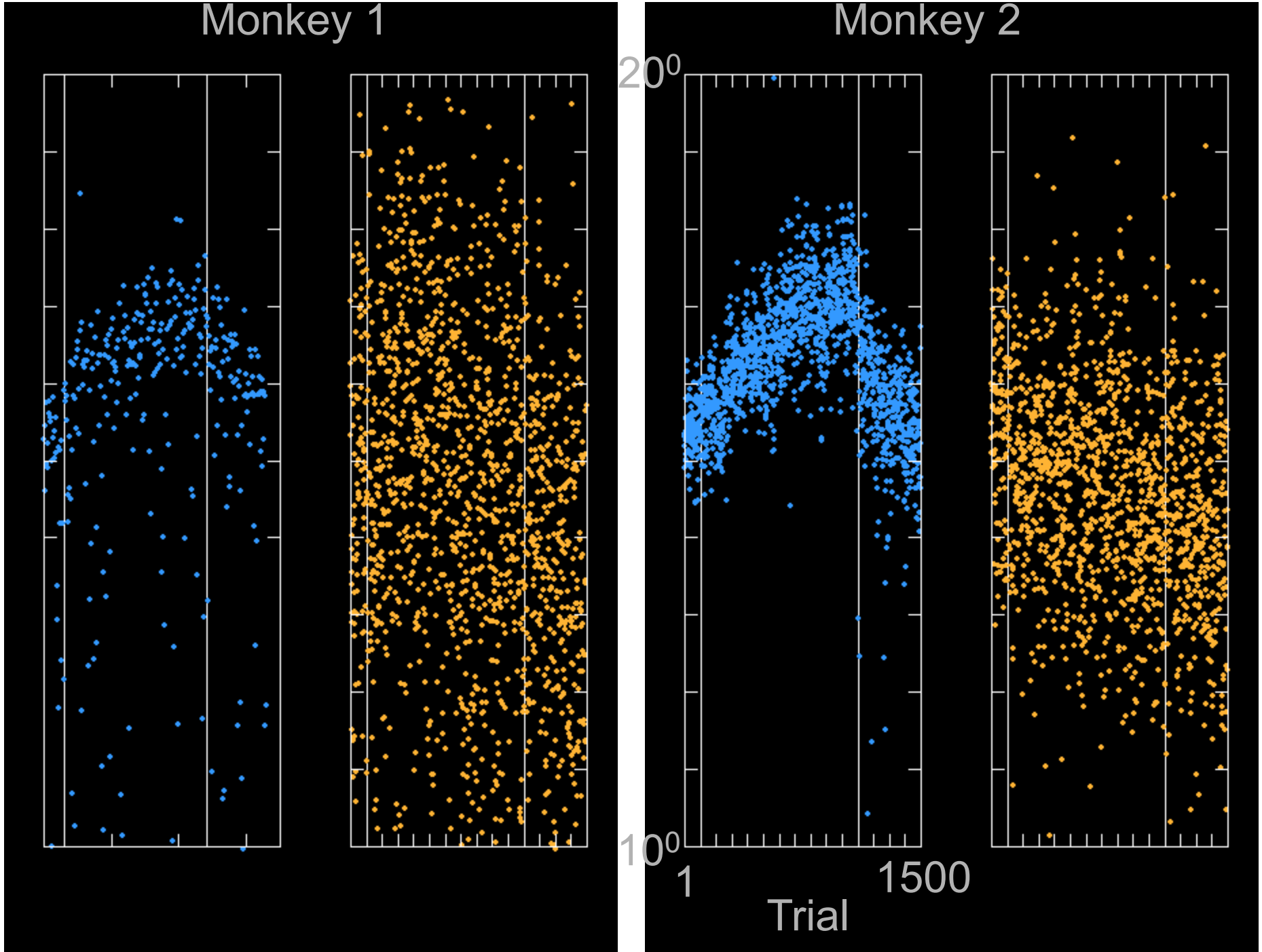


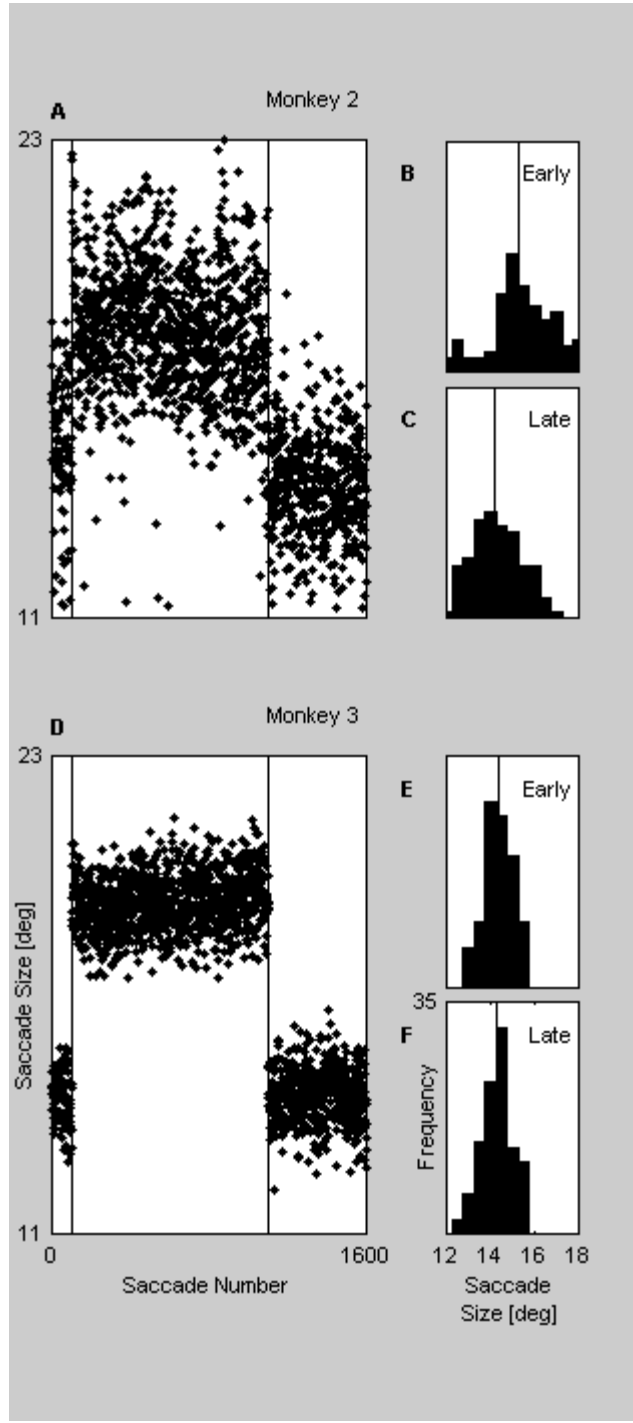









Monkey 1
Monkey 2
20°
10°
1
1500
Trial


Monkey 2
A
23
11
B
Early
C
Late
Monkey 3
D
23
11
Saccade Size [deg]
0
1600
Saccade Number
E
Early
35
F
Late
Frequency
12
14
16
18
Saccade
Size [deg]

Summary 2

Rapid saccadic adaptation is permanently abolished by the lesion - in contrast to the hypometria, which recovers.

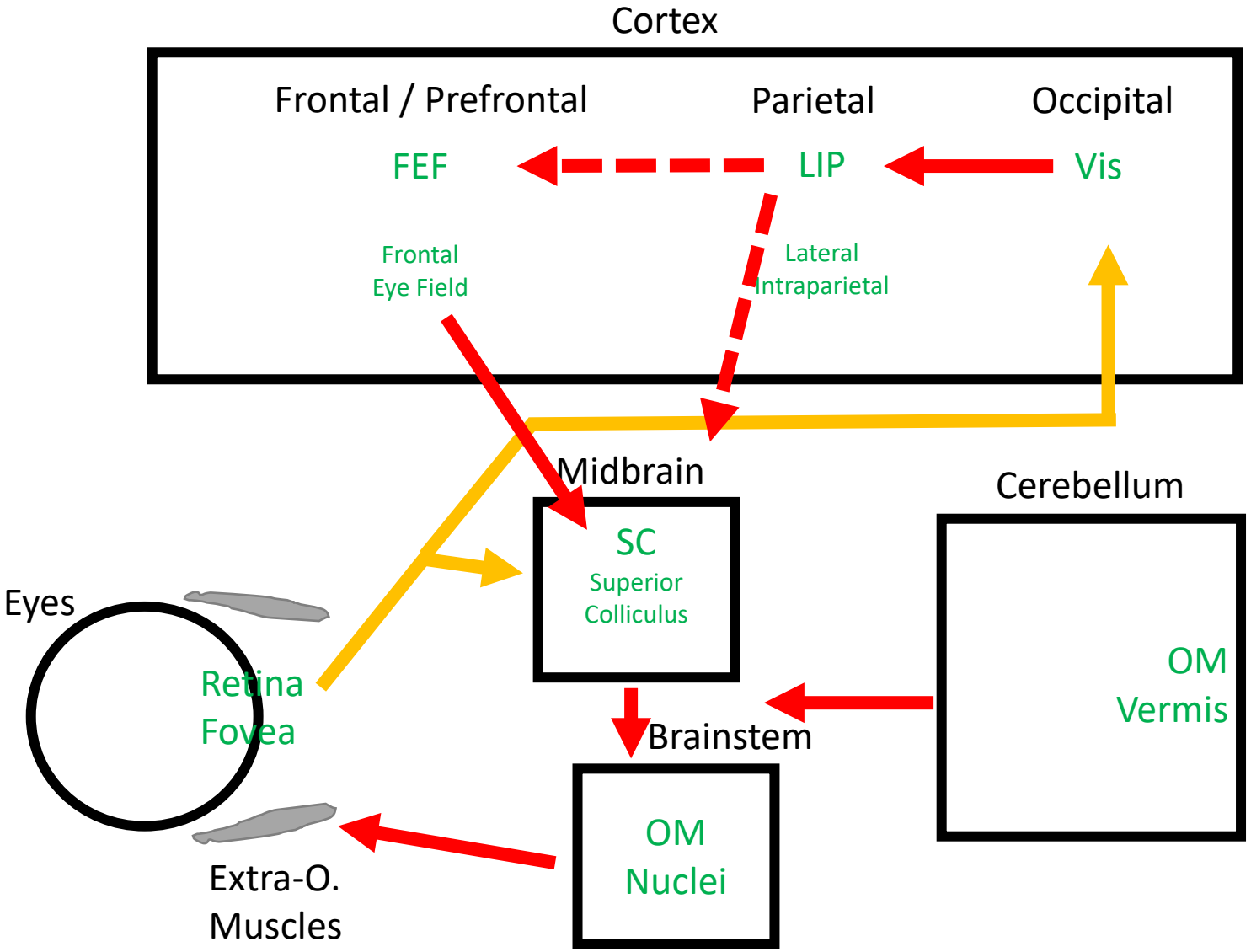
After adaptation is abolished, long repetitive series of saccades in the same direction may cause a gradual decrement in saccade size.

Class 3

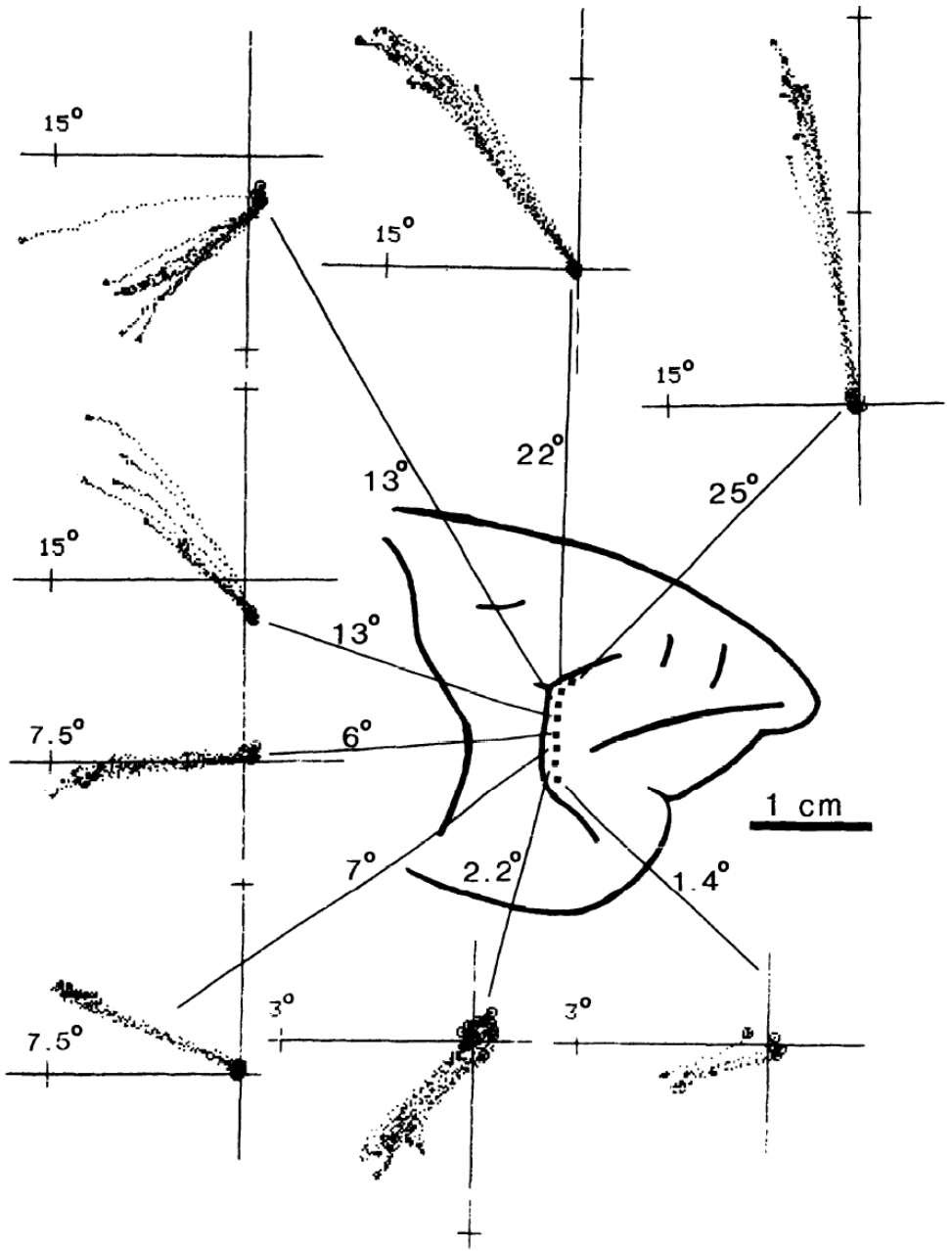
- Overall arrangement of the saccadic system
- Frontal eye fields
- LIP & Parietal cortex
- Split brain

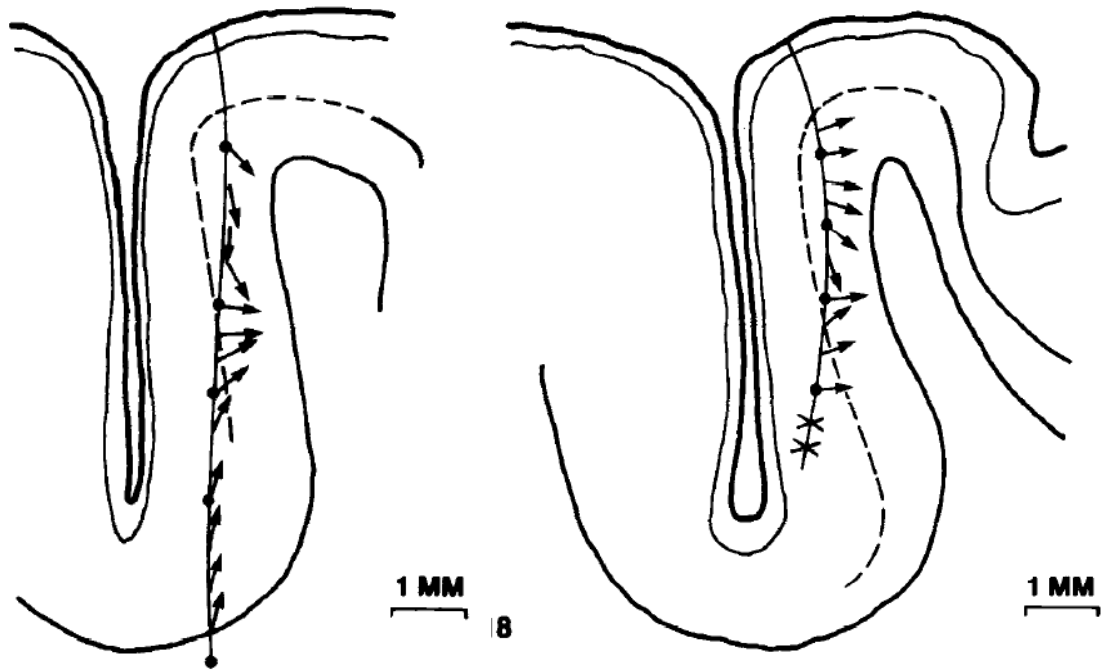
Simplified structure of the saccadic system

There are many additional regions



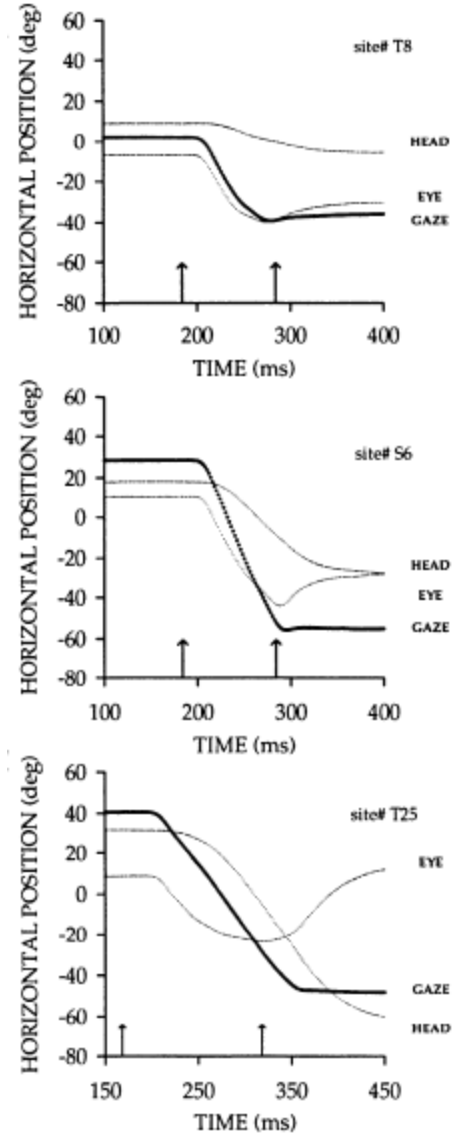
FEF stimulation map



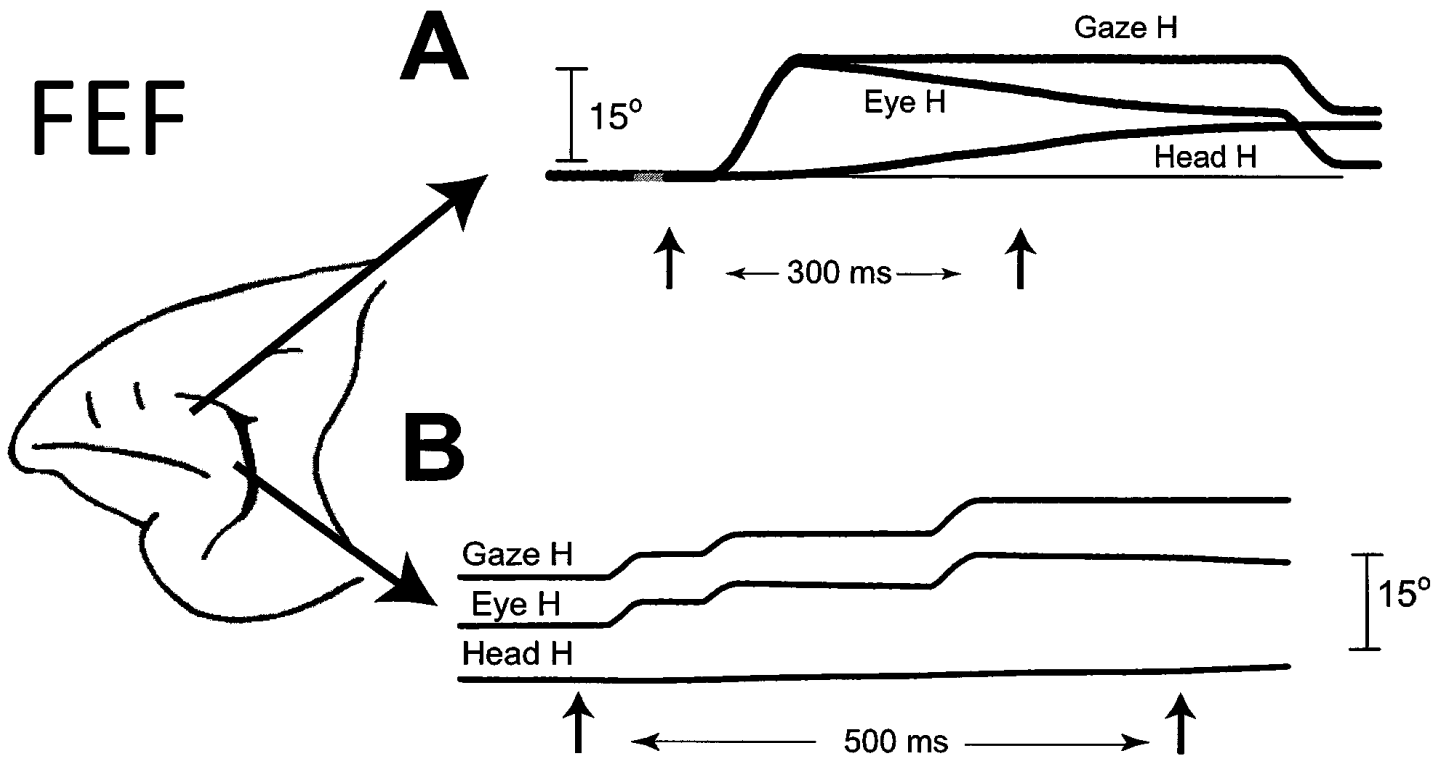


SC stim evokes head-moves, but FEF does not

SC

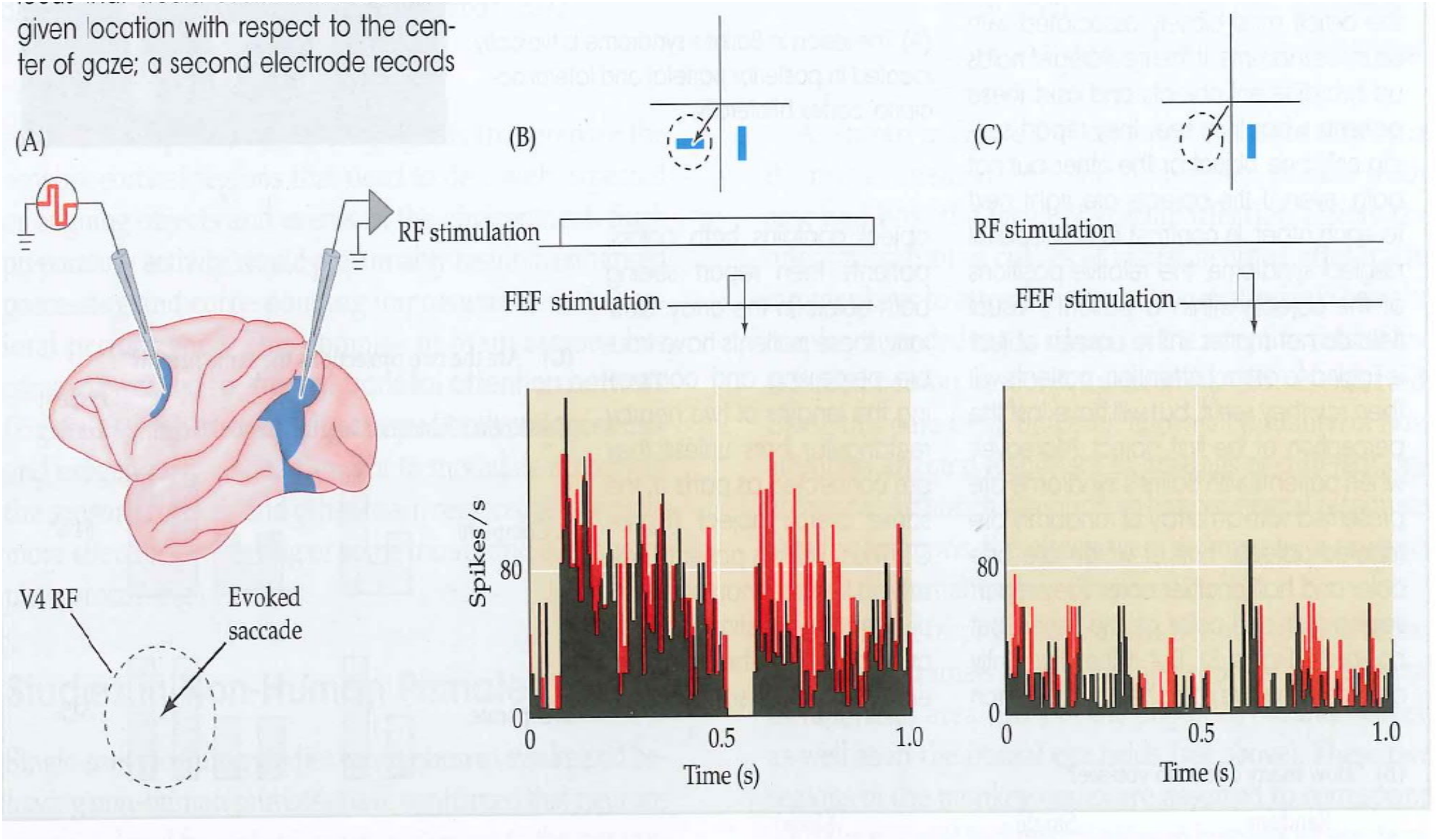


FEF

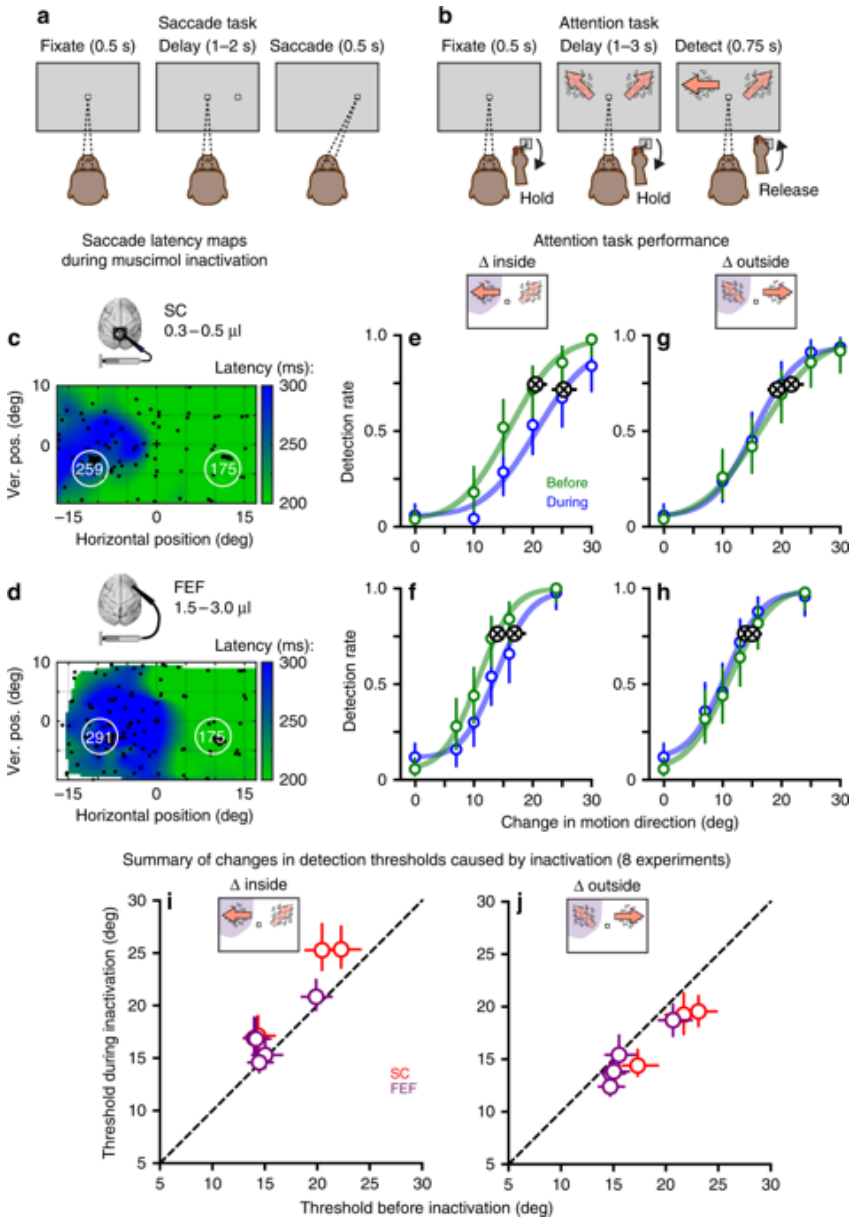


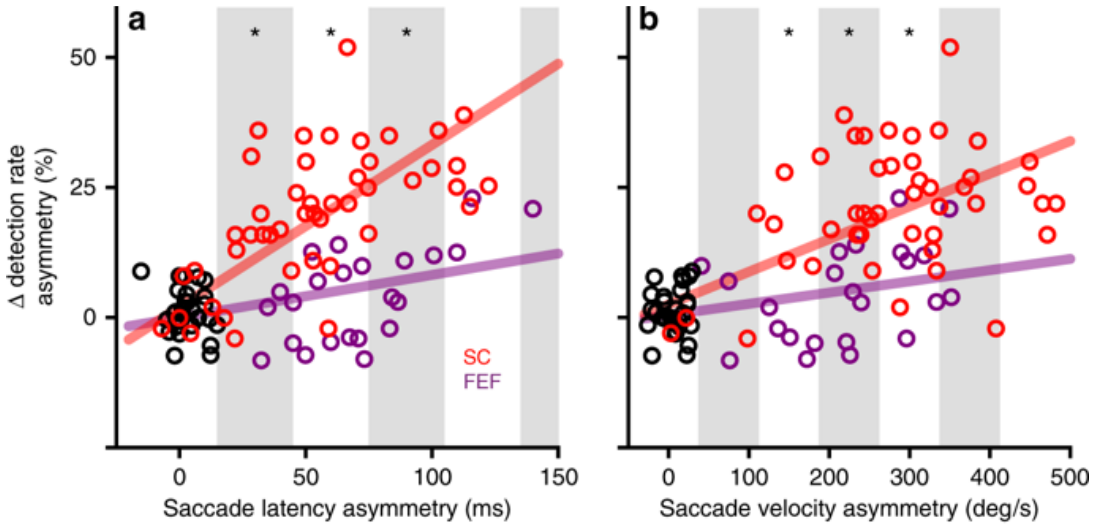
FEF activates covert attention

given location with respect to the center of gaze; a second electrode records



Suppression devastates covert attention: SC > FEF





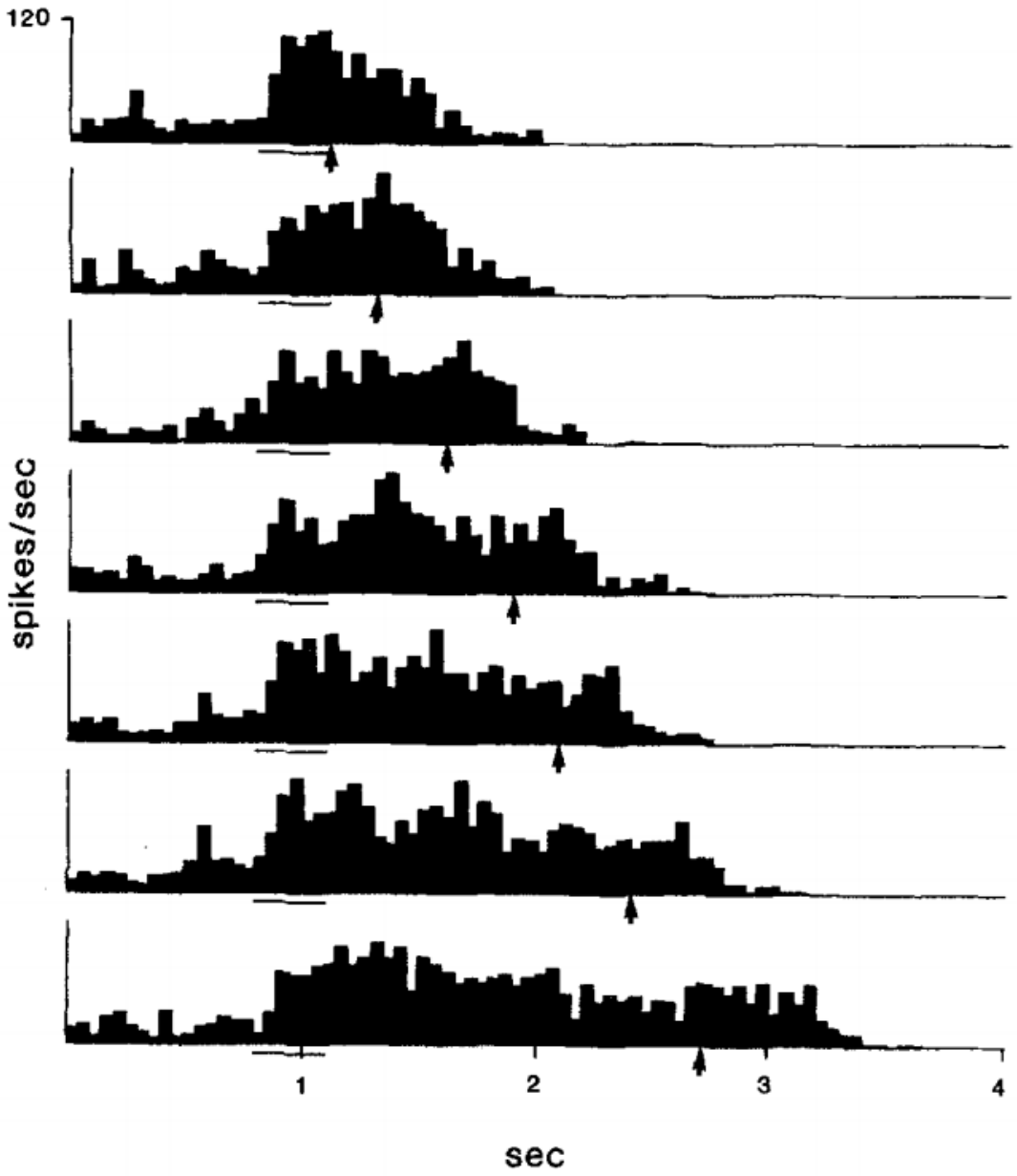
03 September 2018
Comparing frontal eye field and superior colliculus contributions to covert spatial attention
Bollimunta, Bogadhi & Krauzlis
Nature Communications 9:3553 (2018)

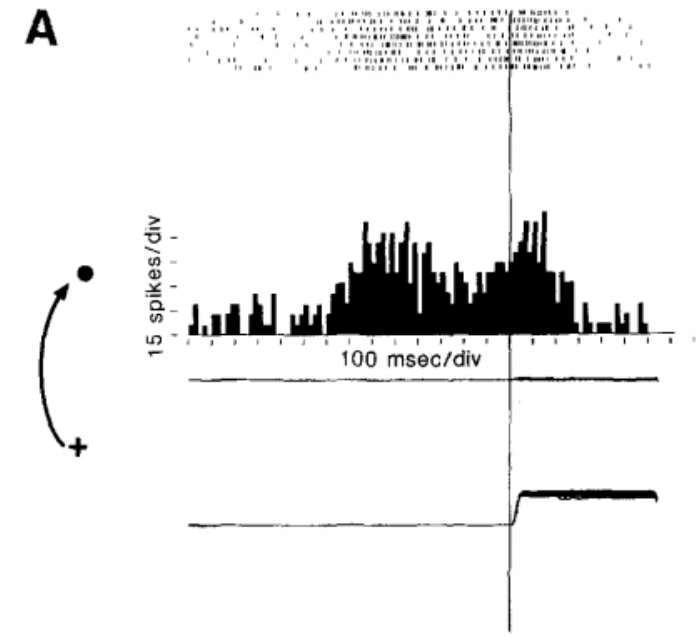
Area LIP (lateral intra-parietal)

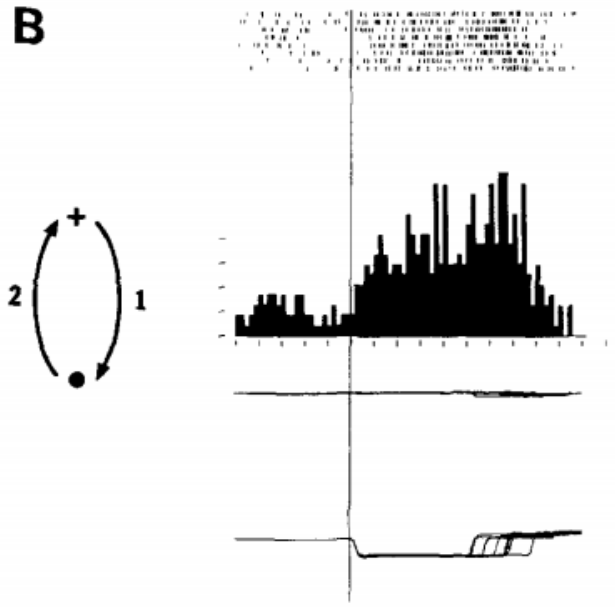
- Defined by connections to FEF, SC, and other saccadic areas
- Specific for saccades; borders PRR – Parietal reach region
- Neuronal activity: visual, motor, intentions to make saccades
- Sensorimotor transformations for saccades
- Perceptual decisions that lead to saccades
- Valuation decisions that lead to saccades
- More….

LIP – intention for next saccade?

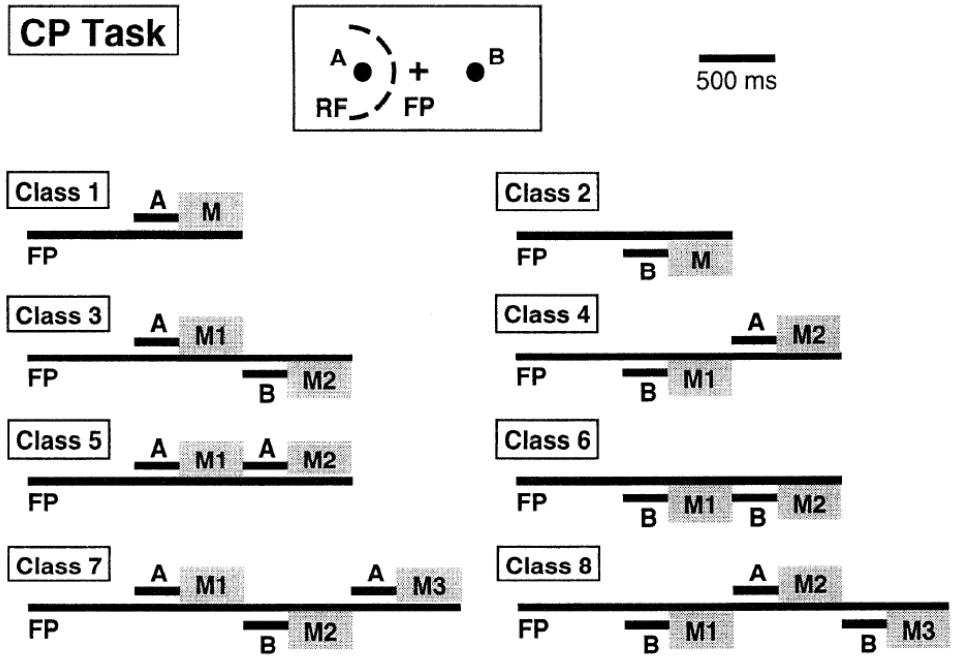
Gnadt et al. 1988



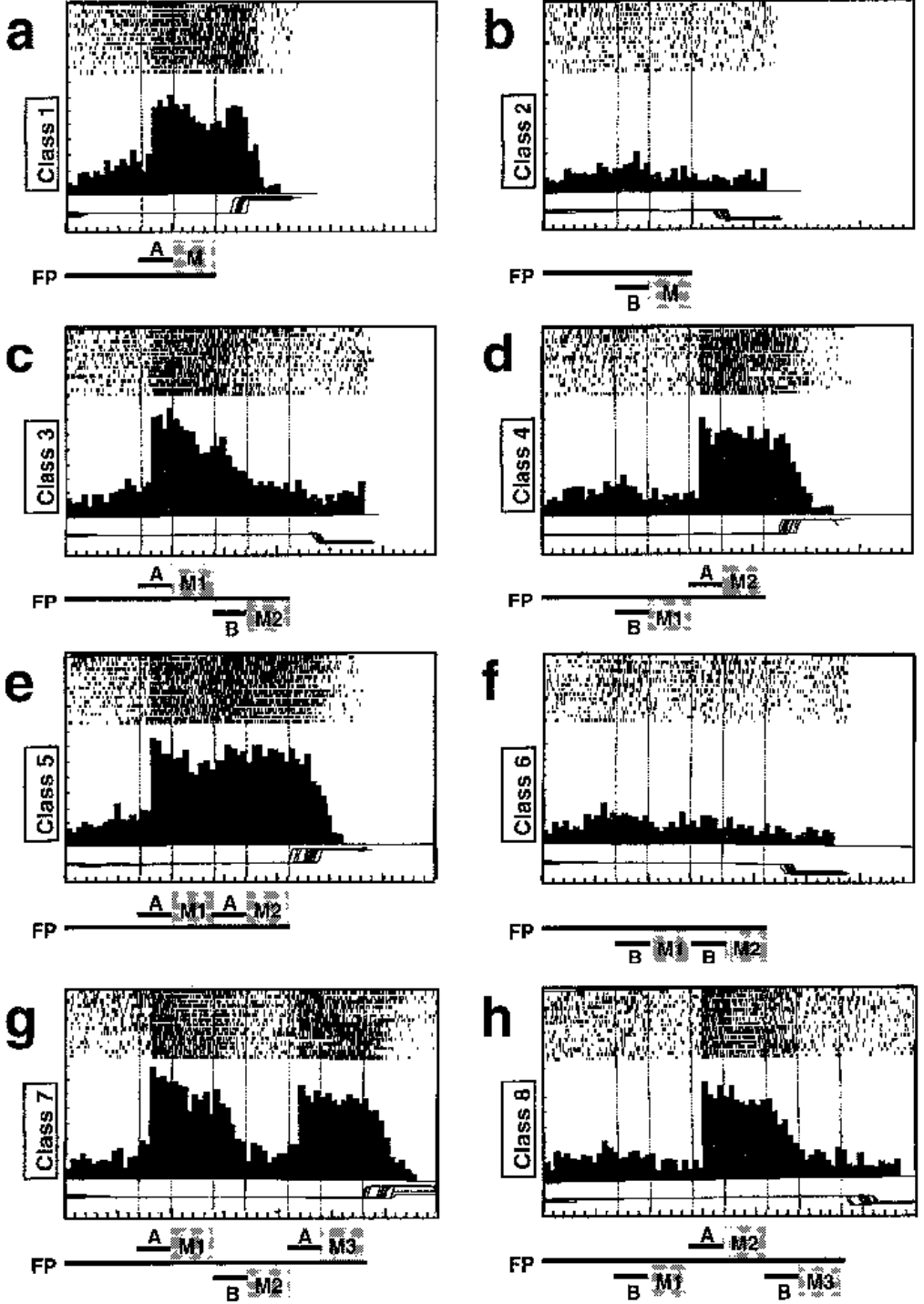




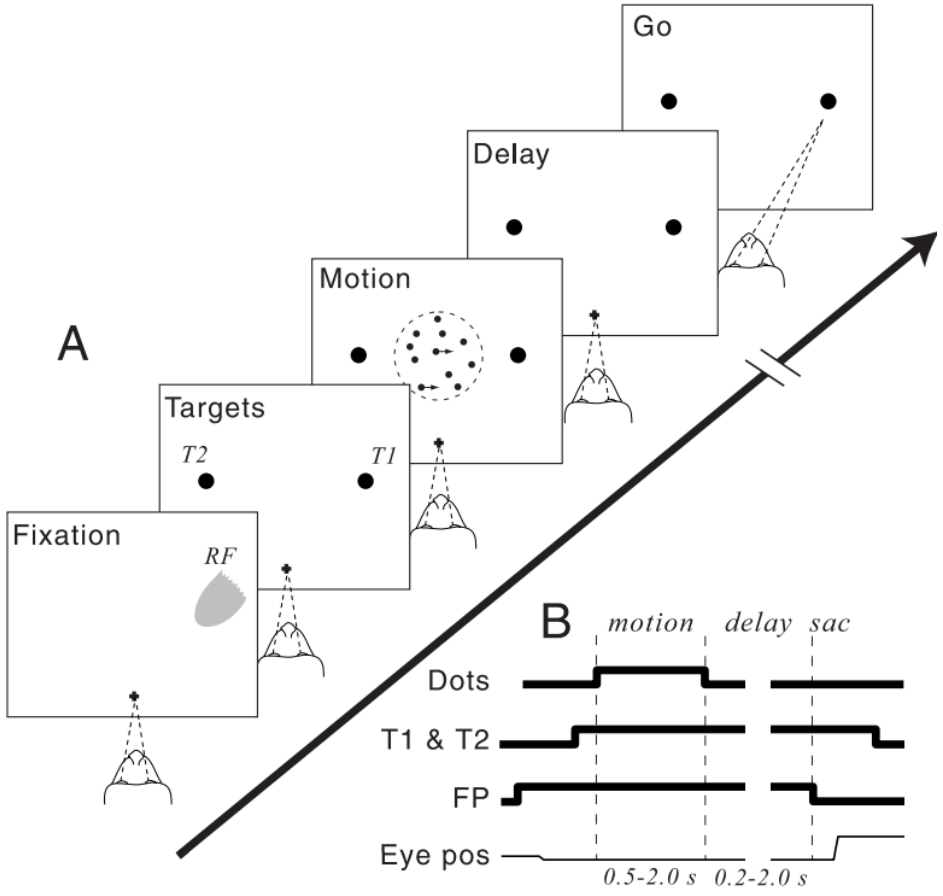
LIP – Intentions!

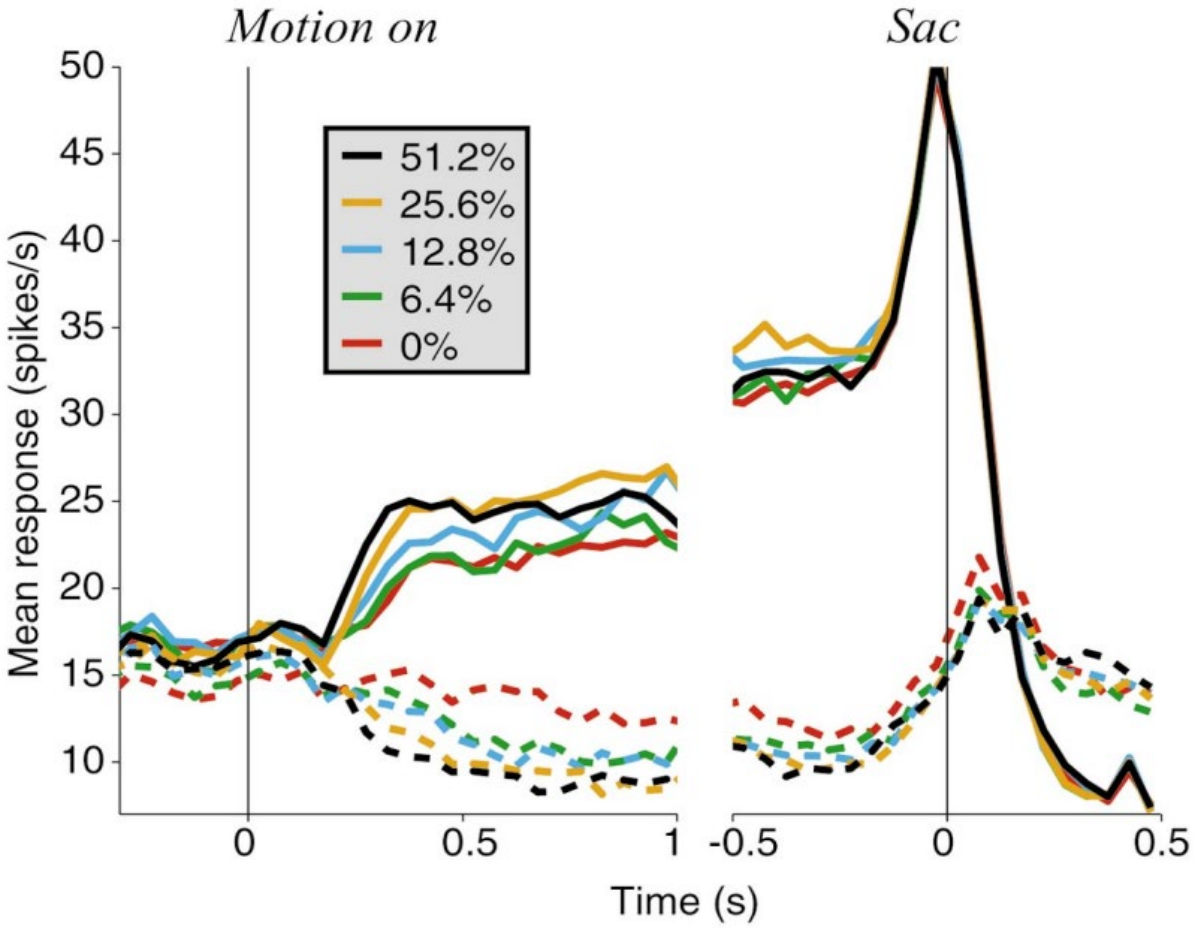


Bracewell et al 1996



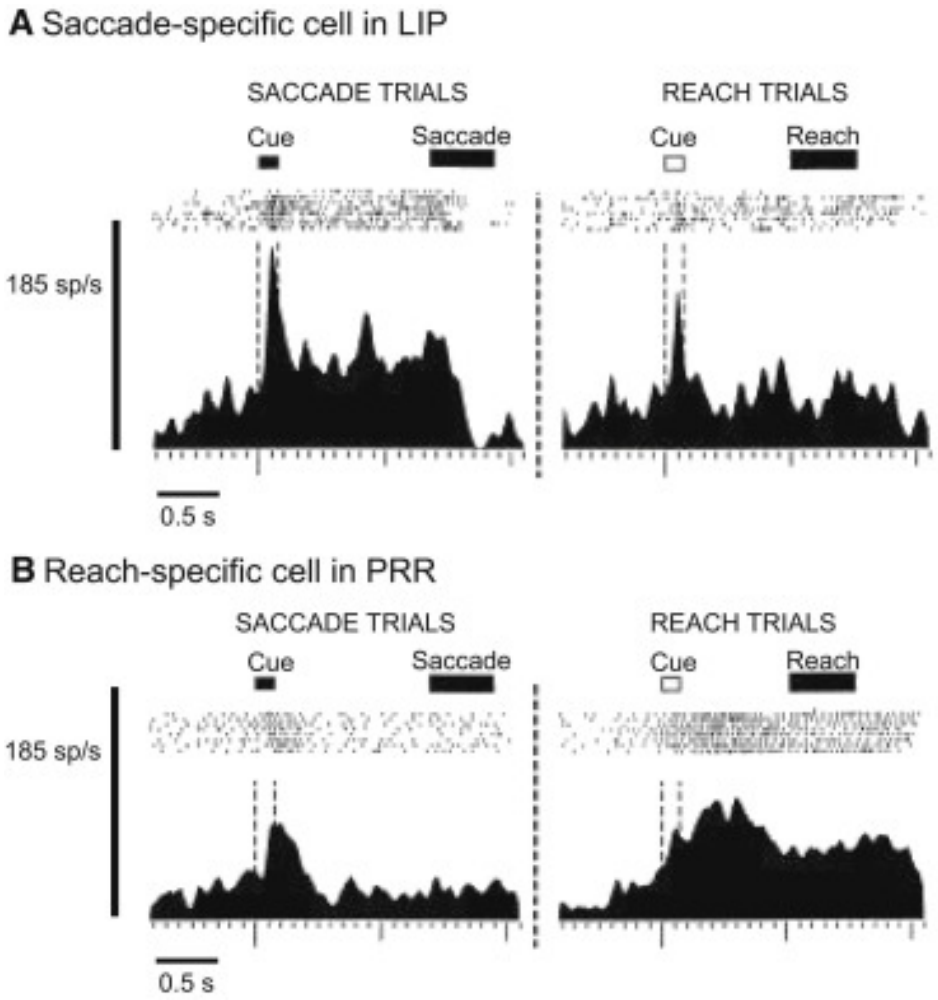
LIP reflects perceptual decisions

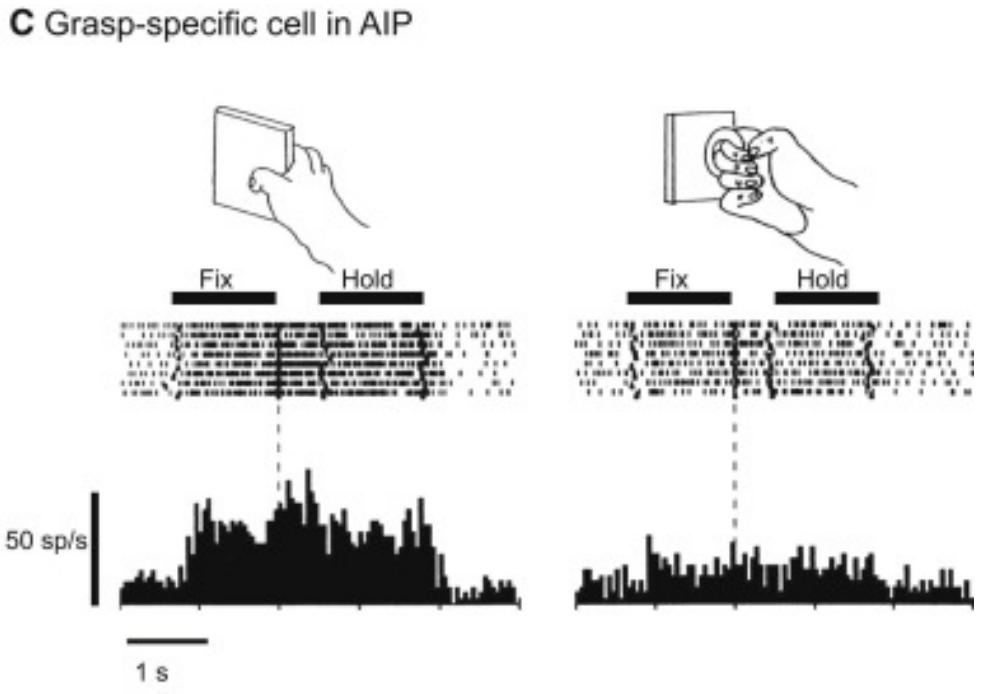




Shadlen and Newsome JNS 2001

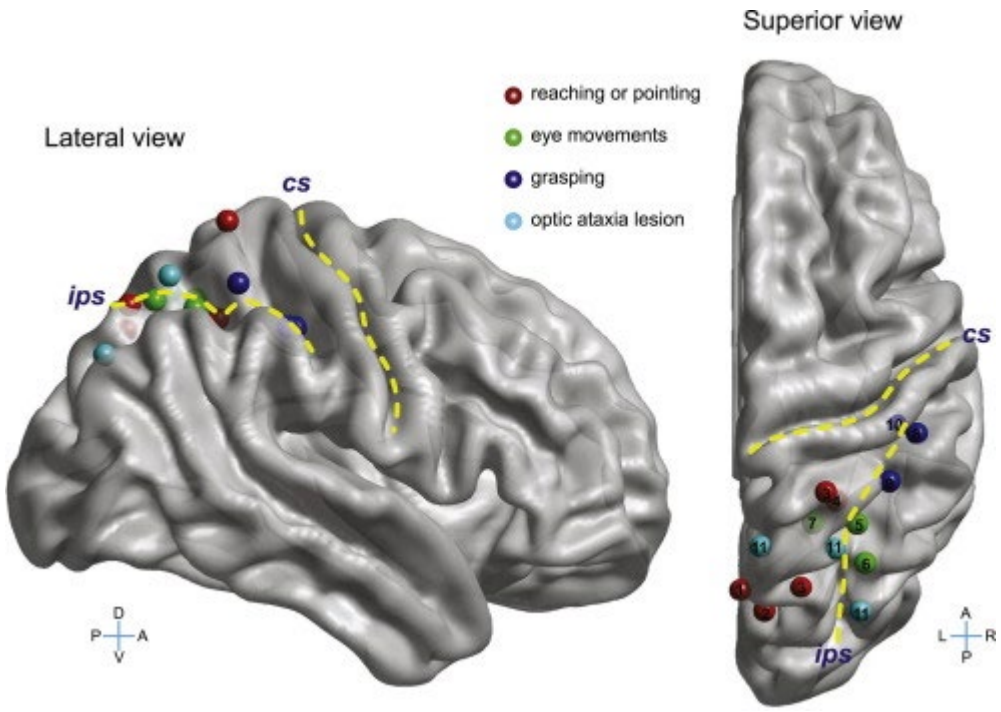
LIP – saccades PRR – reaching AIP - grasping





Snyder L.H. Batista A.P. Andersen R.A. Coding of intention in the posterior parietal cortex. *Nature.* 1997; **386**: 167-170

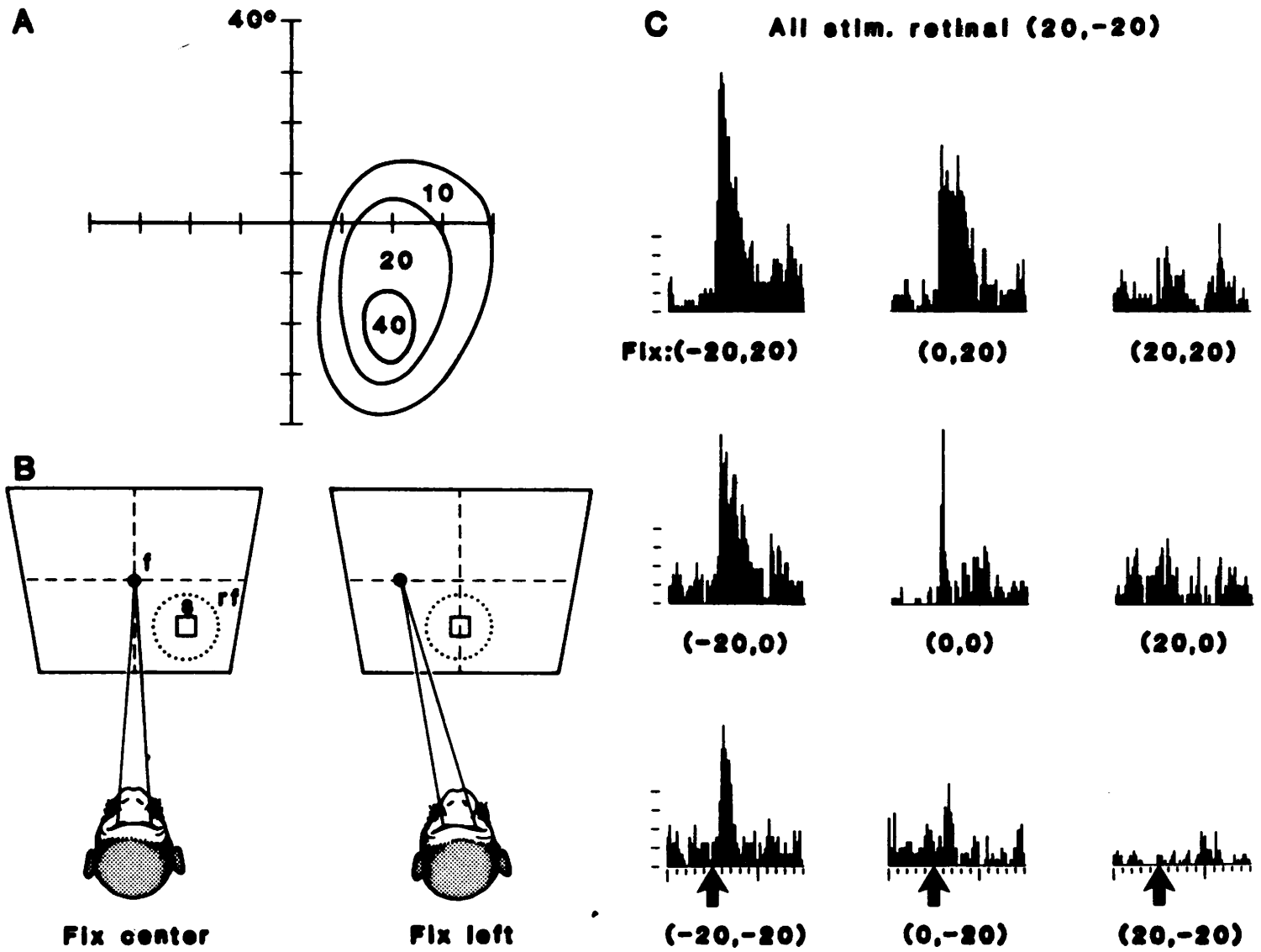
Posterior parietal cortex

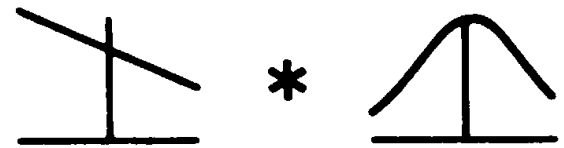


Andersen 2014

Cogan 1965

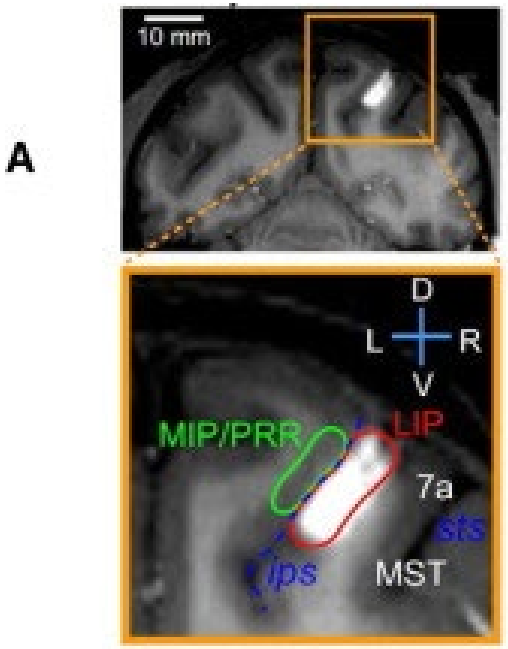
Area LIP Gain fields

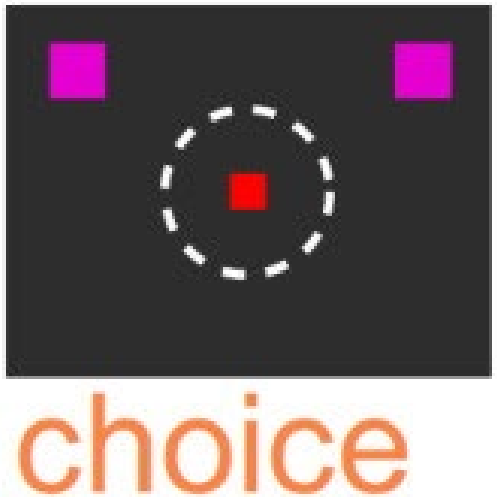


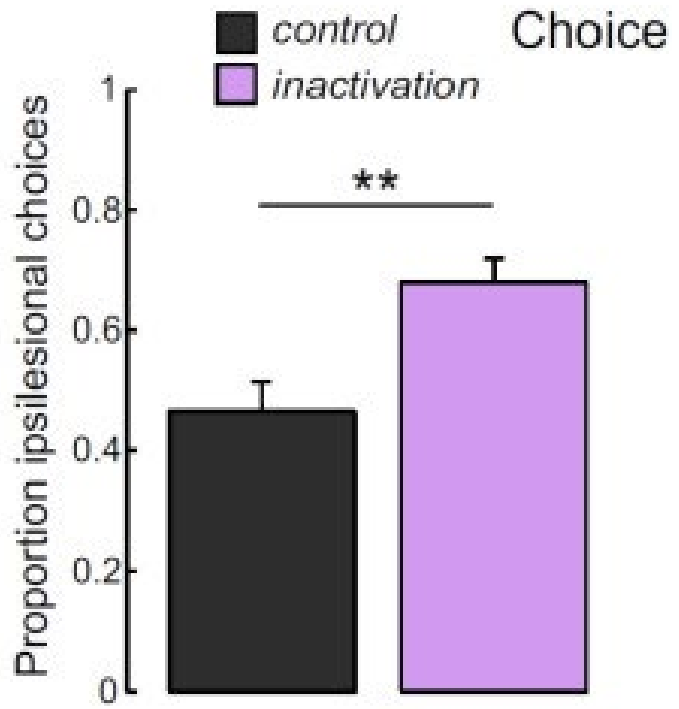


Andersen, Essick, Siegel
Science 1985

LIP inactivation leads to extinction, as in neglect







Wilke, Kagan, Andersen. PNAS 2012

Balint's syndrome – two-sided parietal lesions

Caused usually by multiple CVA's or sudden severe hypotension

Occasionally part of degenerative disorders

Oculomotor apraxia (psychic paralysis of gaze)

- Vision intact, saccades intact
- Sensorimotor transformations for saccades impaired
- Intentional saccades impaired
- Patients sometimes make head saccades

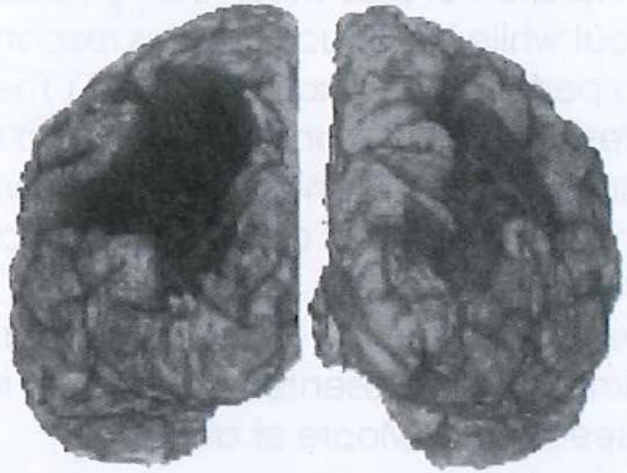
Simultagnosia (no simultaneous multiple objects)

Optic ataxia (impaired reaching and grasping)

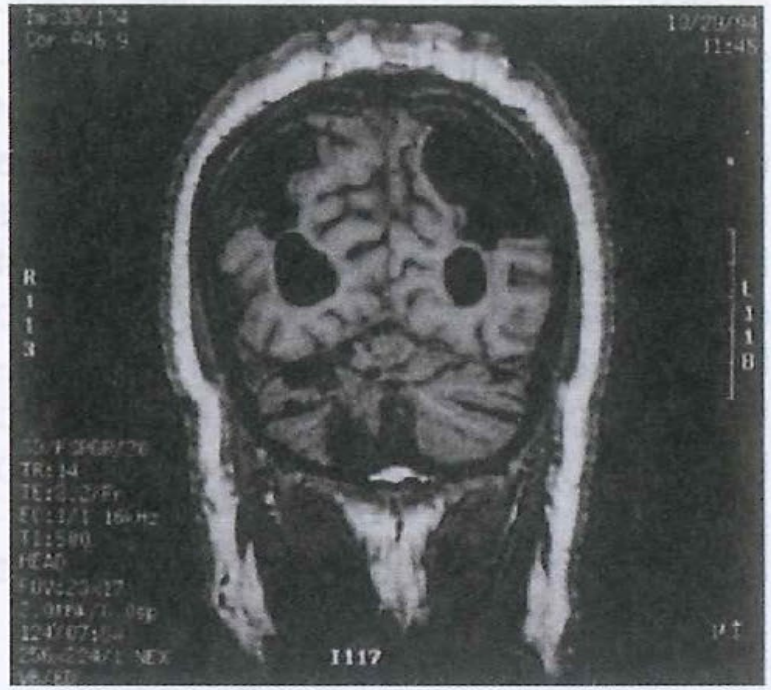
(A)

Lateral views

Occipital view



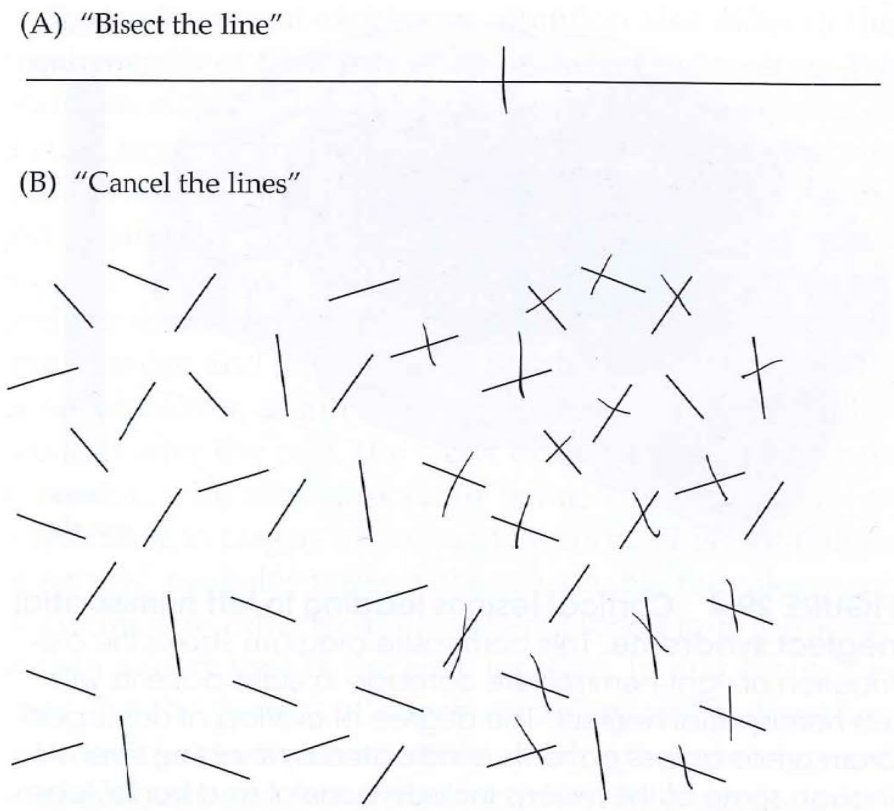
Coronal MRI



(A) The lesion in Balint's syndrome is typically located in posterior parietal and lateral occipital cortex bilaterally.

https://youtu.be/4odhSq46vtU

Cortical lesions leading to left hemispatial neglect



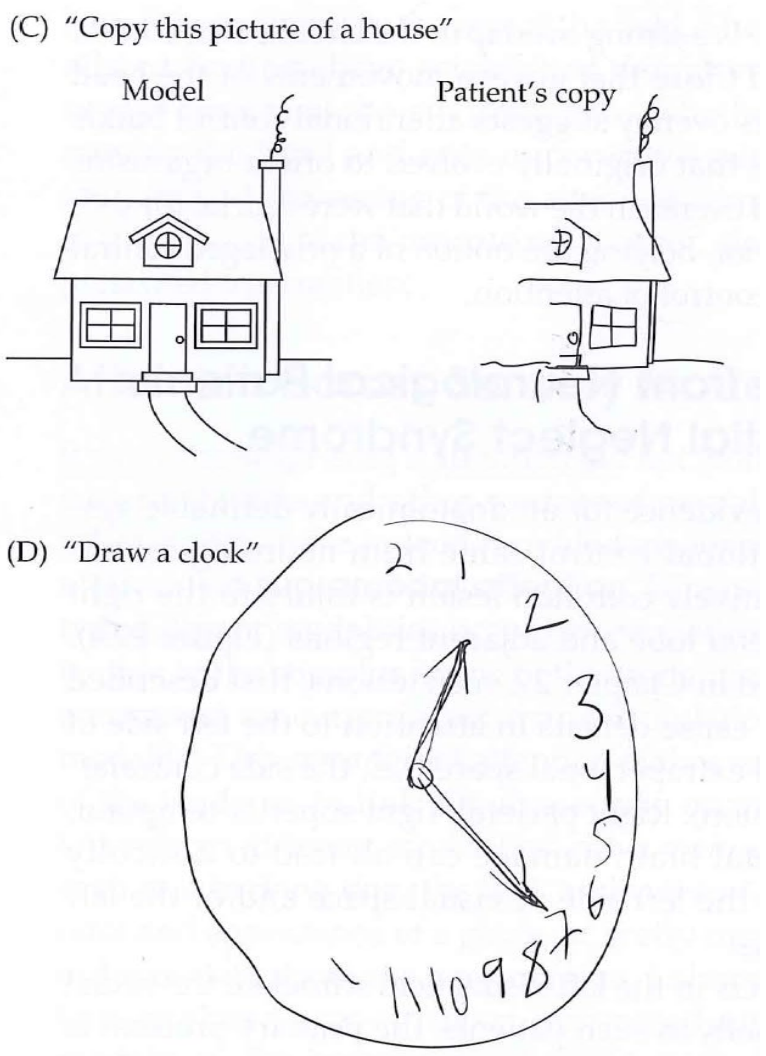
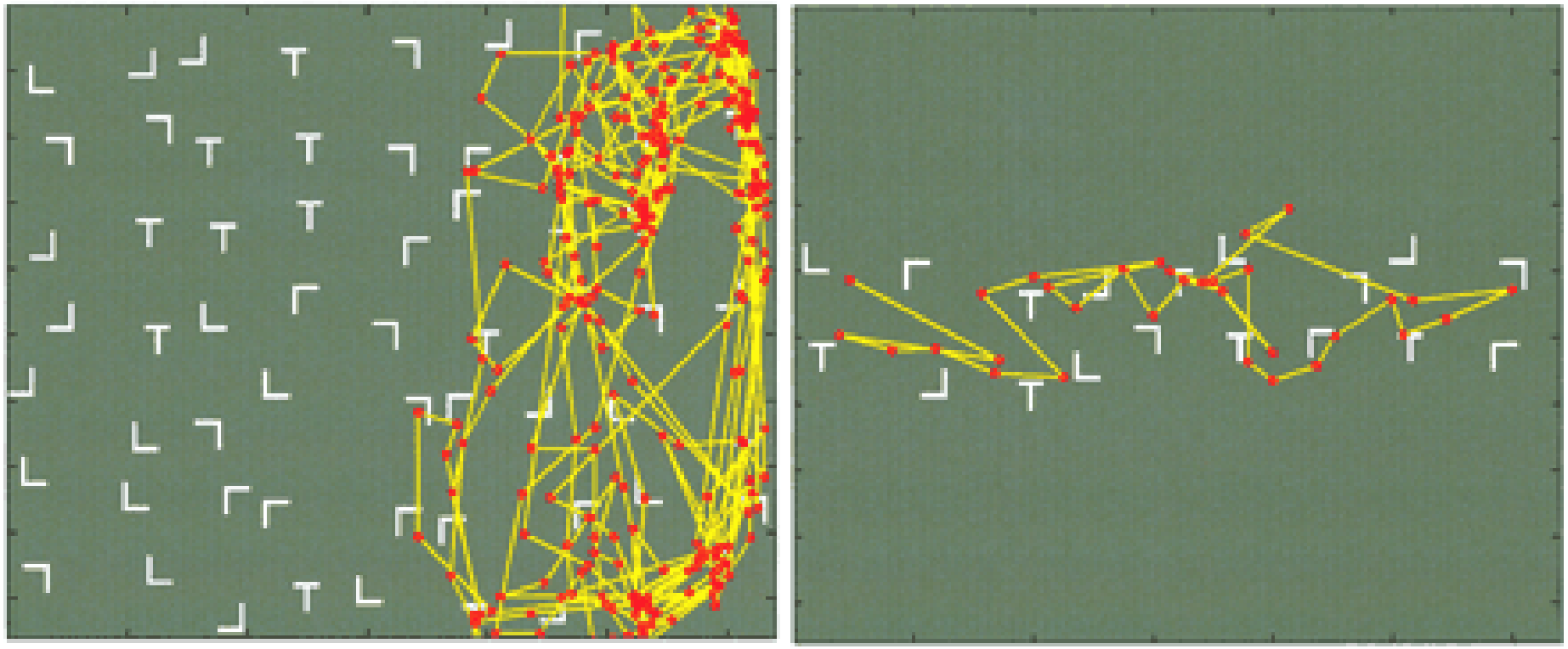


FIGURE 29.5 Clinical tests of left hemispatial neglect caused by damage to the right inferior parietal lobe. The performances in the single-line bisection test (A) and the line cancellation test (B) shown here are characteristic of hemispatial neglect patients. (C) An example of a visual copying task as performed by a hemispatial neglect patient. (D) A drawing of a clock face from memory by a hemispatial neglect patient. (A,C after Posner and Raichle, 1994; B after Blumenfeld, 2010; D after Grabowecky et al., 1993.)

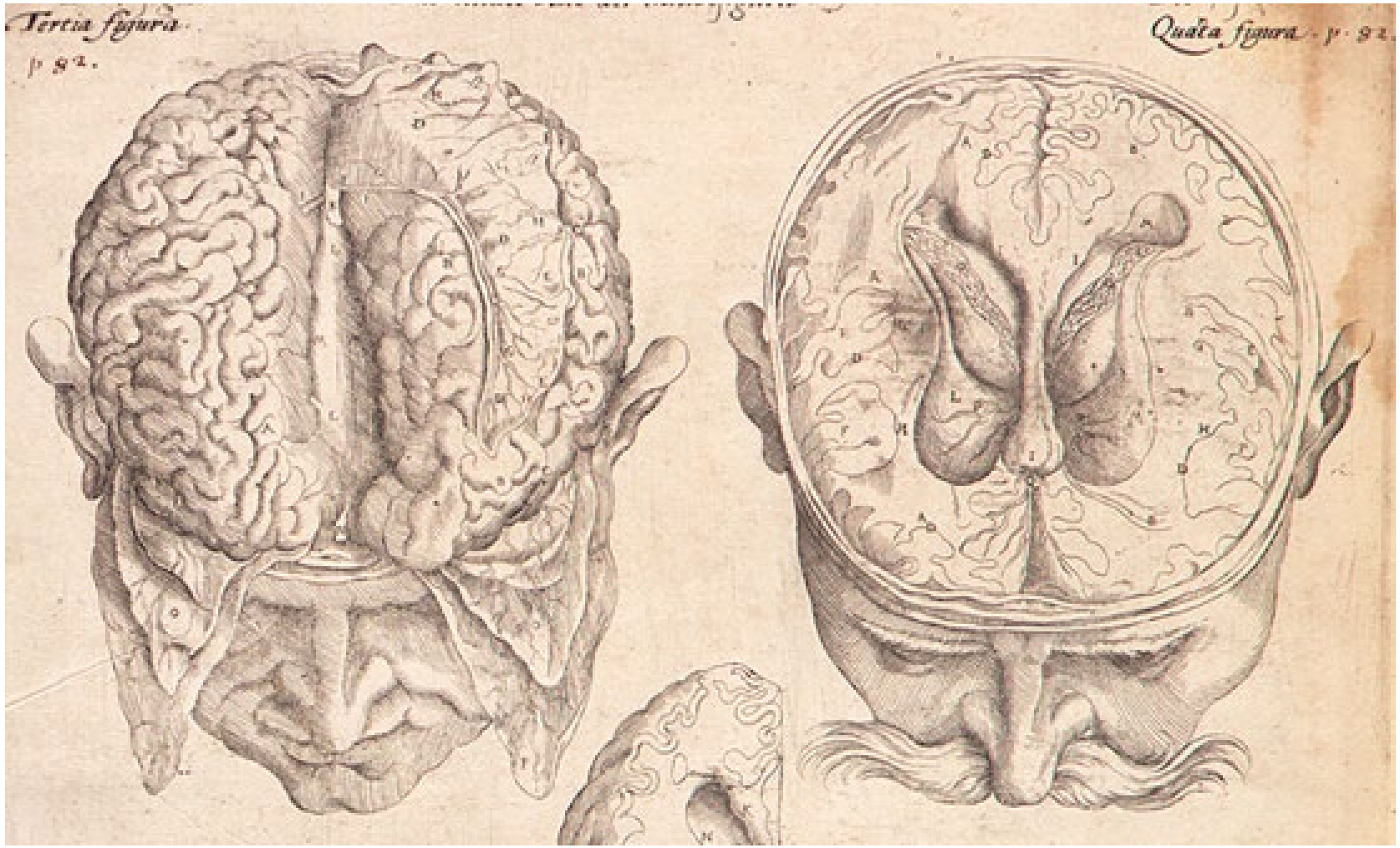
rule, unilateral frontal lesions tend to have a

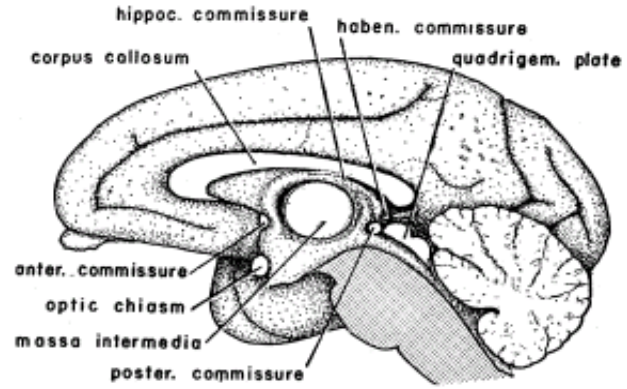
Memory saccades reveal a new deficit in neglect

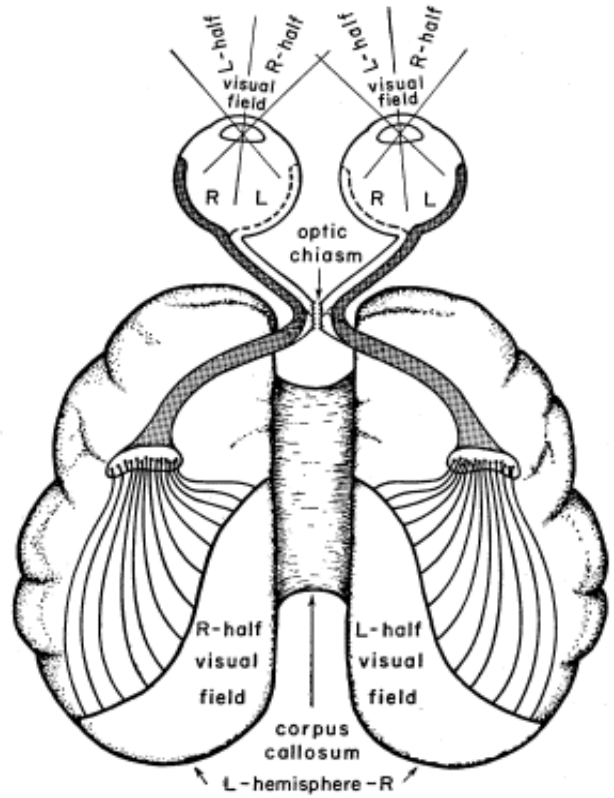


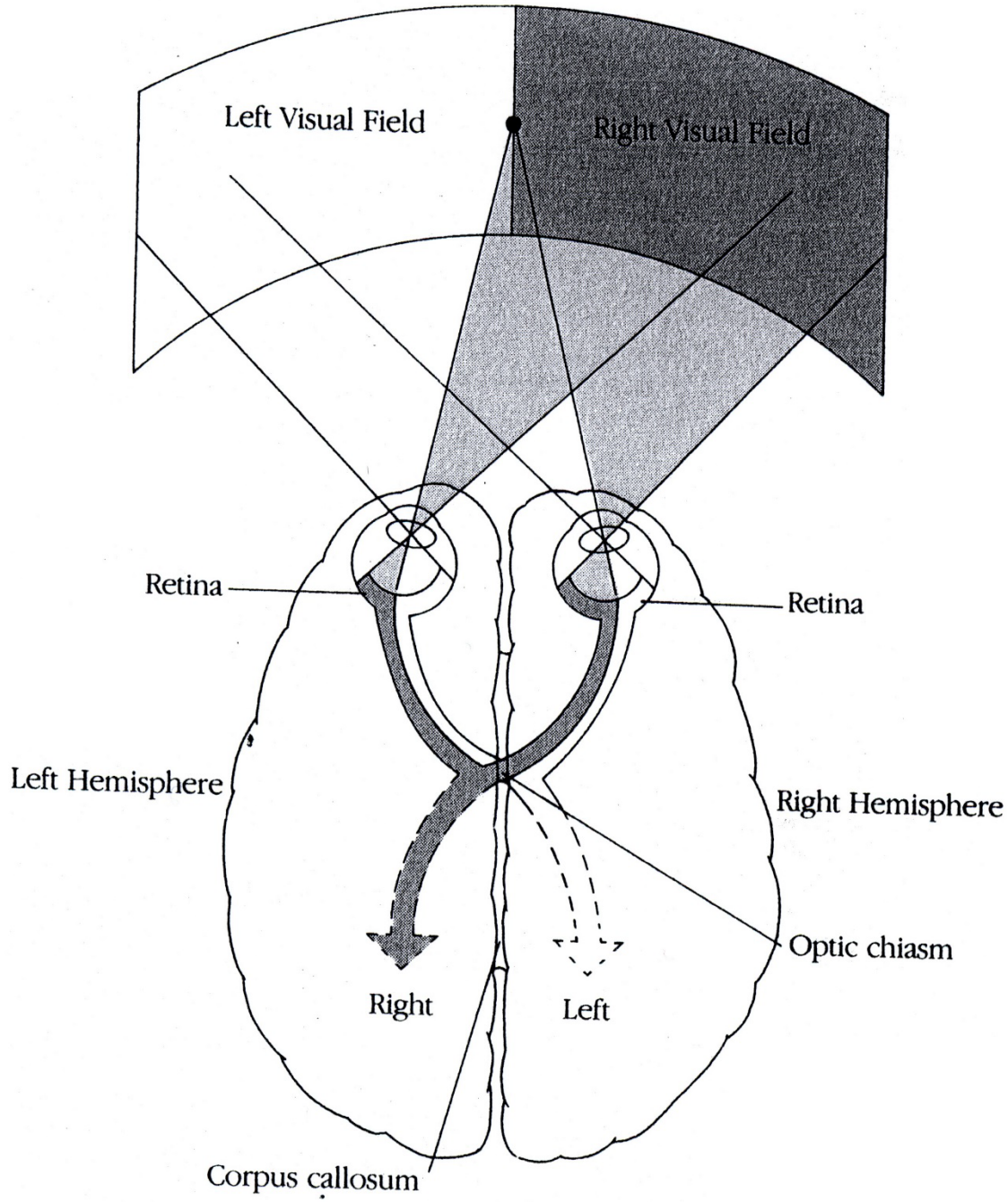
Split brain

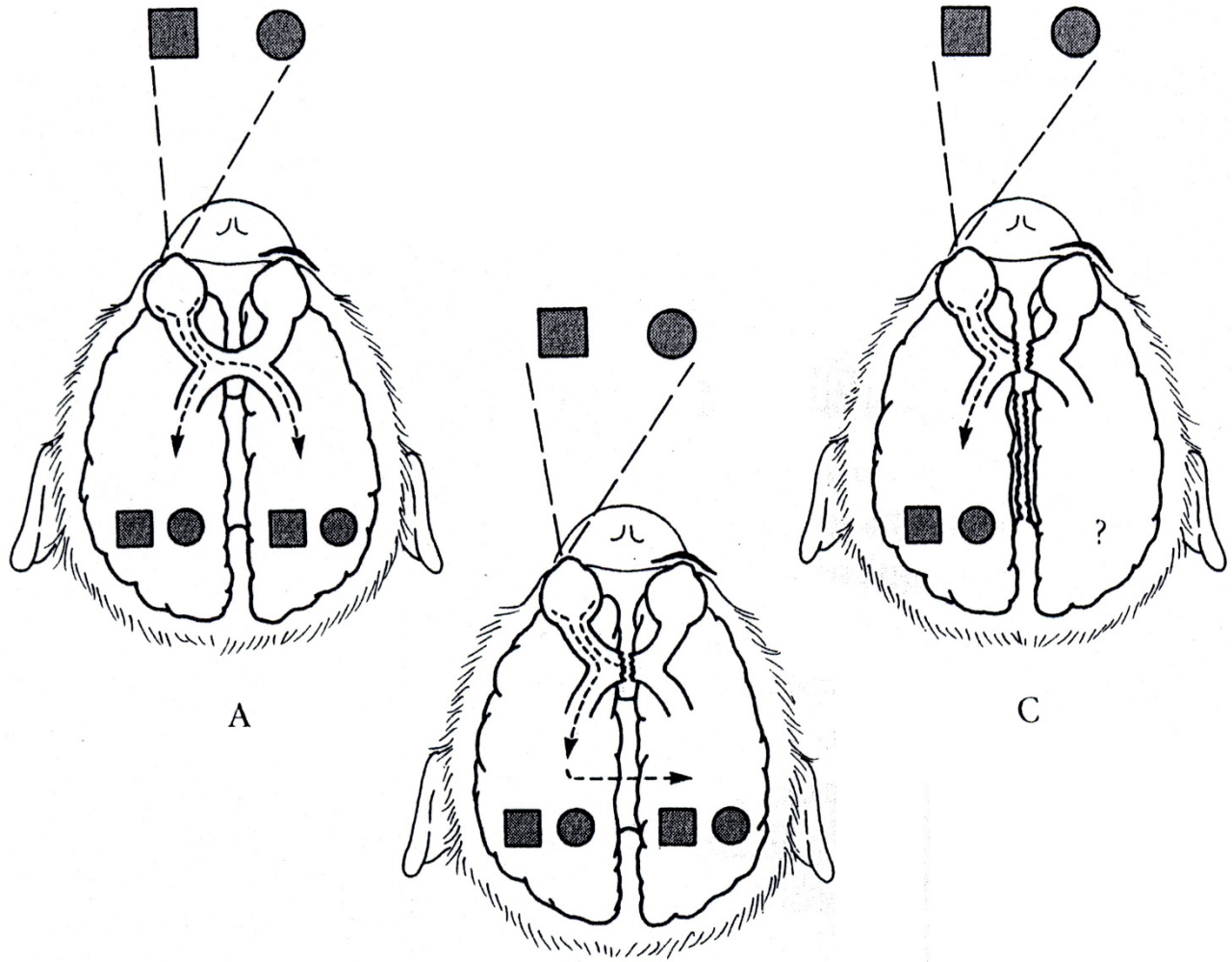
- Long history (Descartes's pineal gland hypothesis)
- Lashley → Sperry
- Akelaitis: no functional damage
- The critical discoveries made by Myers (PhD student) and Sperry
- Gazzaniga and Sperry: humans, language
- Recent work


Tertia figura
p. 92.
Quarta figura. p. 92.

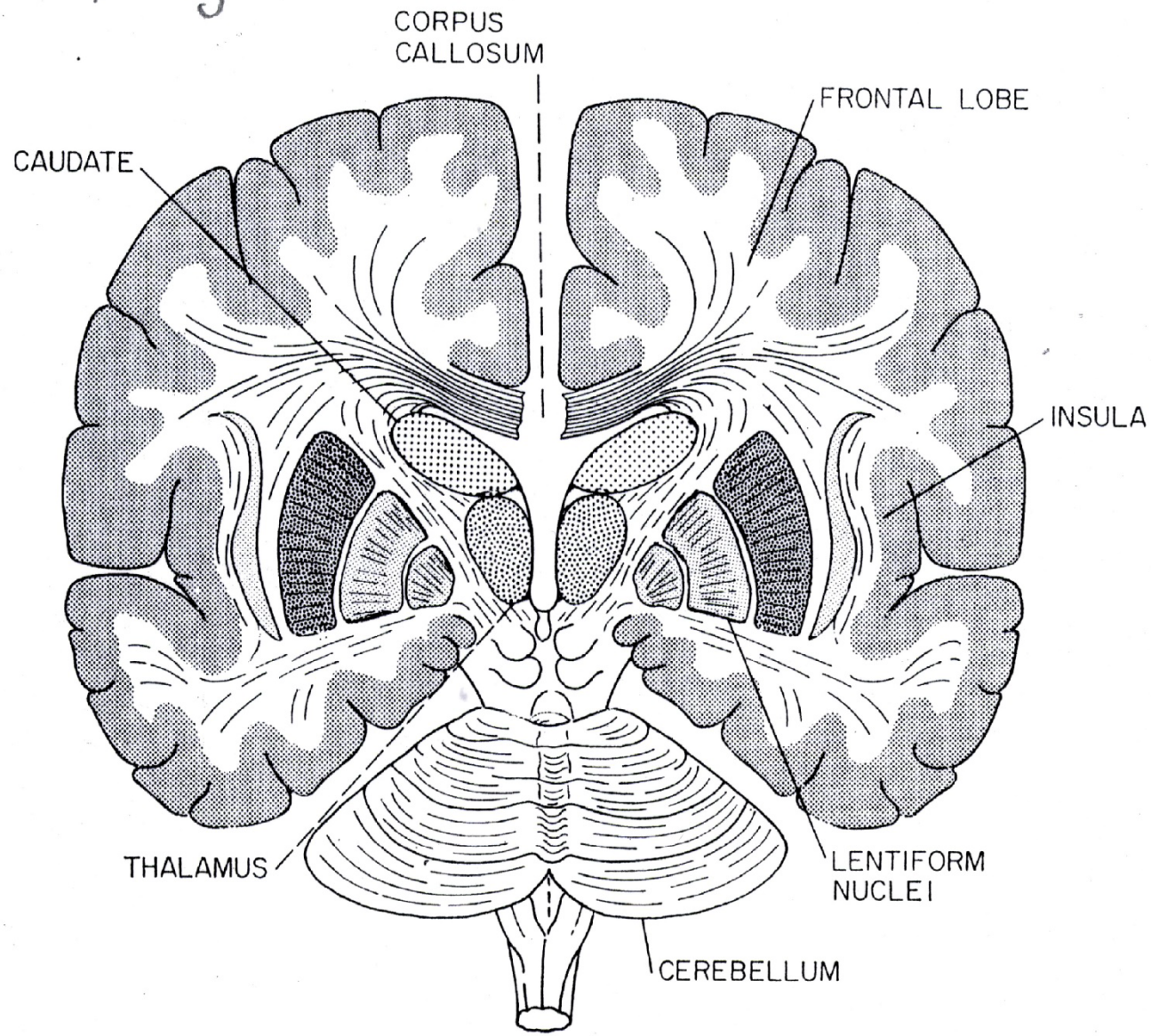

hippoc. commissure
haben. commissure
corpus callosum
quadrigem. plate
anter. commissure
optic chiasm
massa intermedia
poster. commissure


L-half visual field
R-half visual field
L-half visual field
R-half visual field
R
L
R
L
optic chiasm
R-half visual field
L-half visual field
corpus callosum
L-hemisphere-R


Left Visual Field
Right Visual Field
Retina
Retina
Left Hemisphere
Right Hemisphere
Optic chiasm
Right
Left
Corpus callosum


?
A
B
C

Sperry (1974)


CORPUS
CALLOSUM
FRONTAL LOBE
CAUDATE
INSULA
THALAMUS
LENTIFORM
NUCLEI
CEREBELLUM

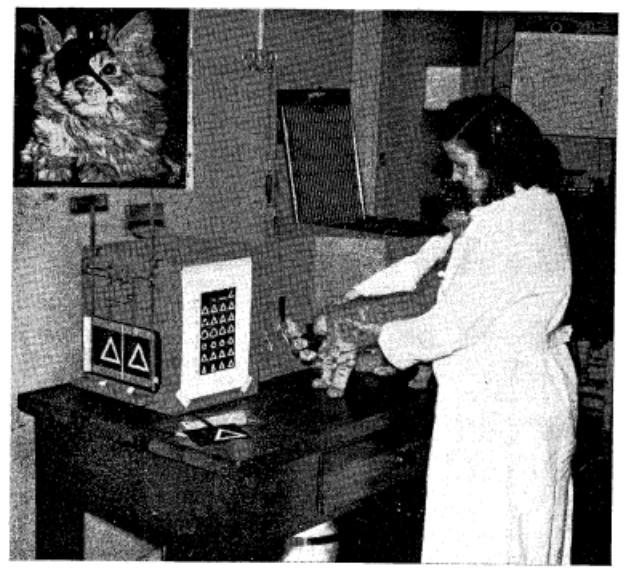
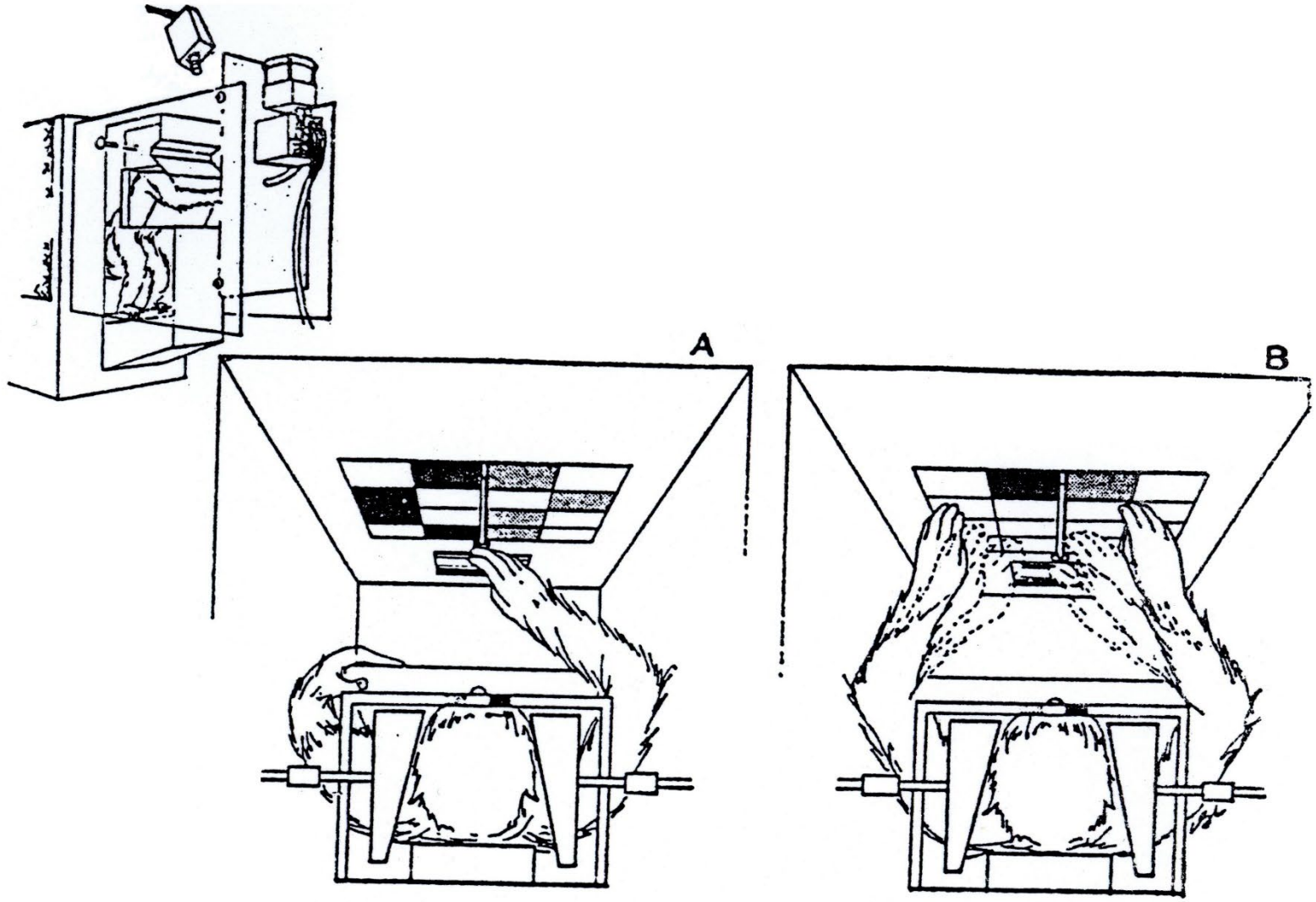
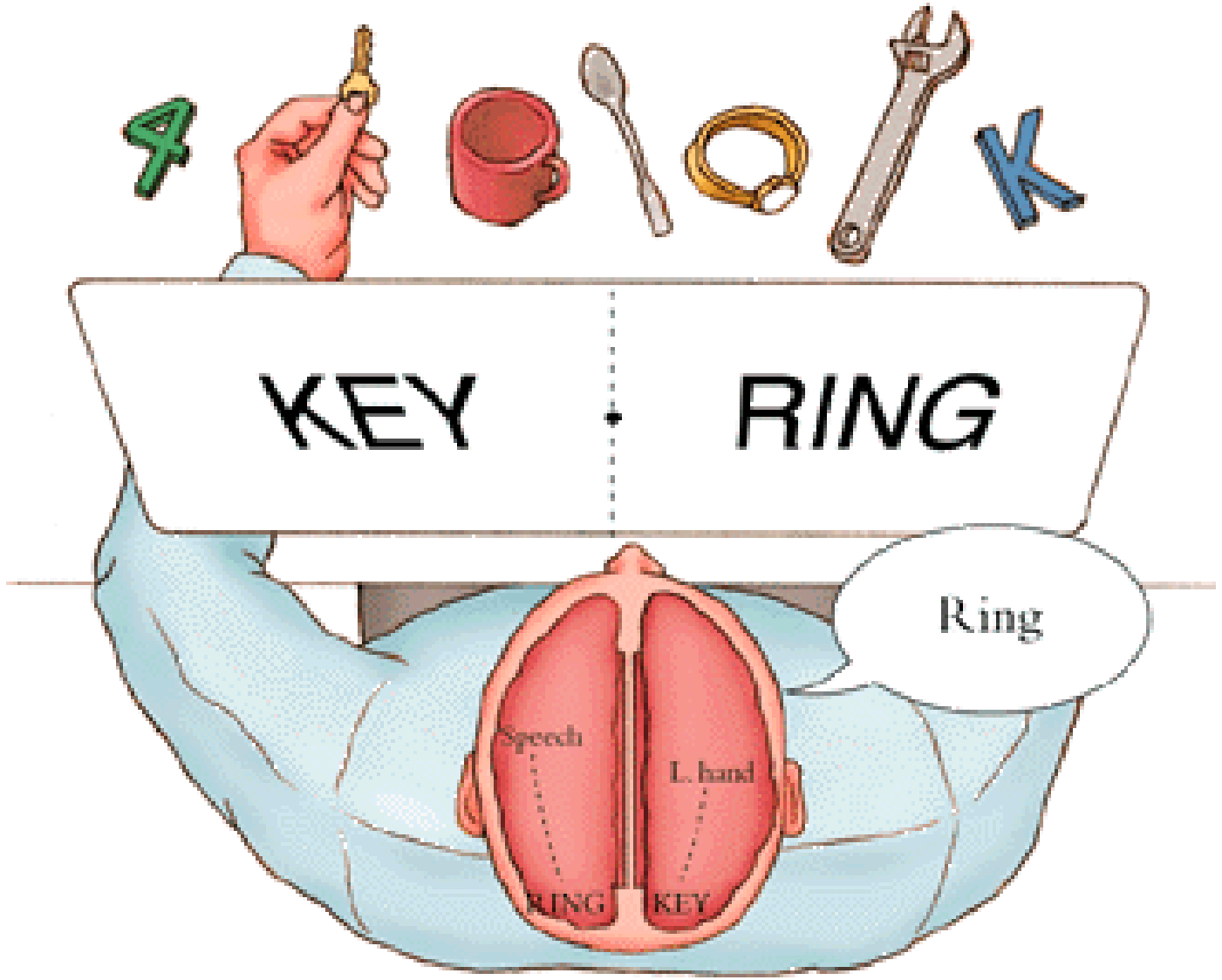
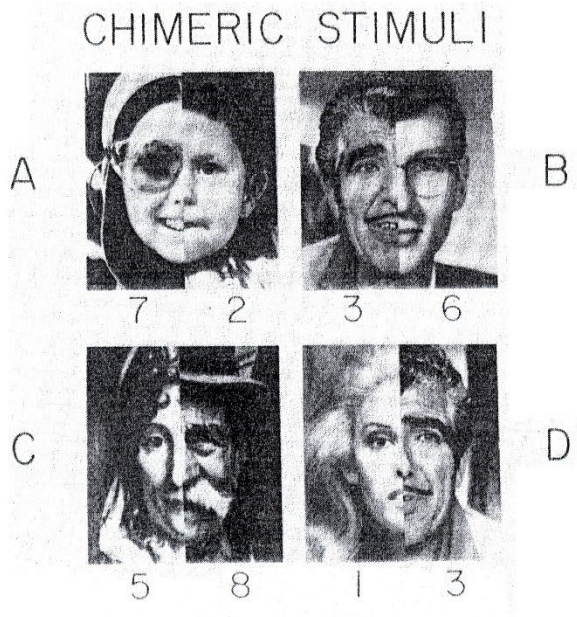


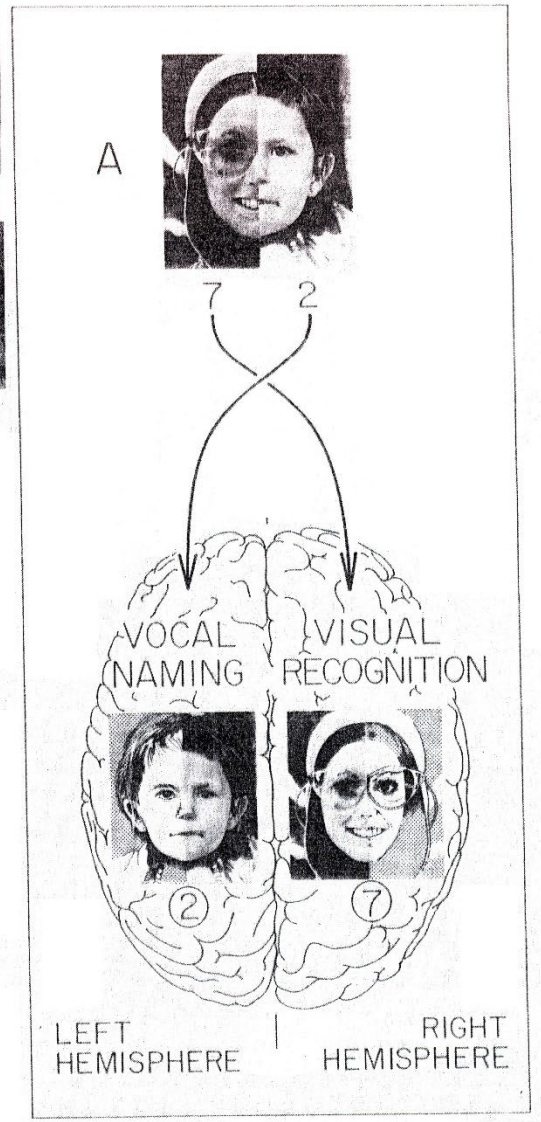
Fig. 3. Visual training apparatus. The cat, placed in the darkened box, obtains a food reward by pushing on the correct one of two translucent patterns interchanged in doors at the end of the box. Inset shows enlargement of the cat wearing the eye patch devised by Myers. Made of rubber, it is simply turned inside out to cover the other eye.


A
B

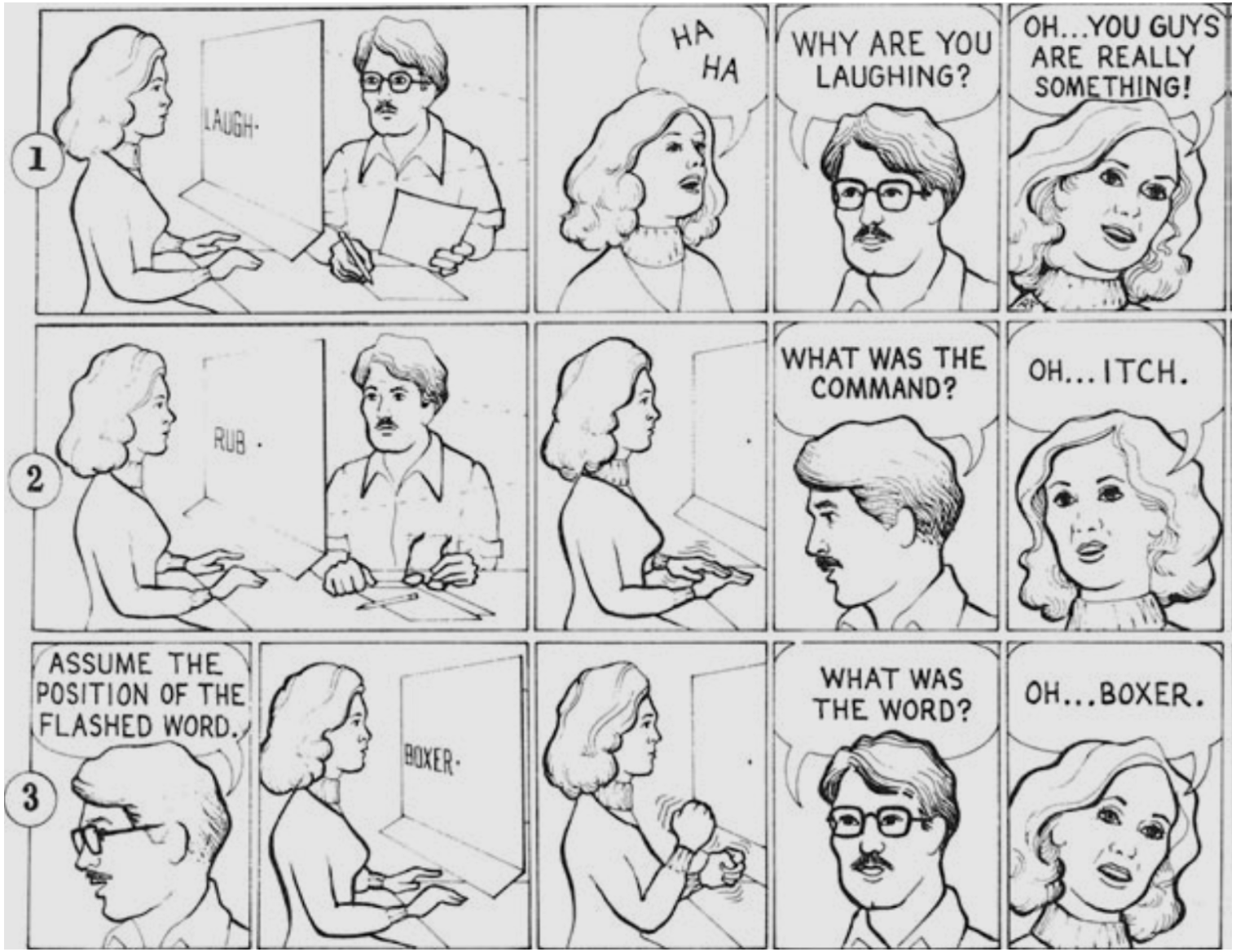

KEY
RING
Ring
Speech
L. hand
RING
KEY


1
2
3
4
5
6
7
8


CHIMERIC STIMULI
A
B
C
D
7 2
3 6
5 8
1 3


A
7 2
VOCAL NAMING
VISUAL RECOGNITION
②
⑦
LEFT HEMISPHERE
RIGHT HEMISPHERE

Split Brain: confabulation



Gazzaniga 1978: The integrated mind

FIGURE 41. When a series of commands were presented to the right hemisphere, each evoked a response. Although the left hemisphere did not know what the command was, it attempted to account for the response. When the command was *laugh* or *rub,* the left hemisphere instantly " filled in." When the response was less equivocal, the reason generated for the action was quite accurate, as with the word *boxer.*

Split Brain: Language in the right hemisphere

Gazzaniga 1978: The integrated mind

FIGURE 29. Using the methods developed by Pre mack for the chimpanzee, the global aphasic also learned to "write" simple sentences. Here, while the examiner carries out a simple act of stirring the water, the subject is about to arrange the appropriate symbols in a way that effectively says, "Mike stirs water."

Split Brain: Unity of the mind

Gazzaniga 1978: The integrated mind