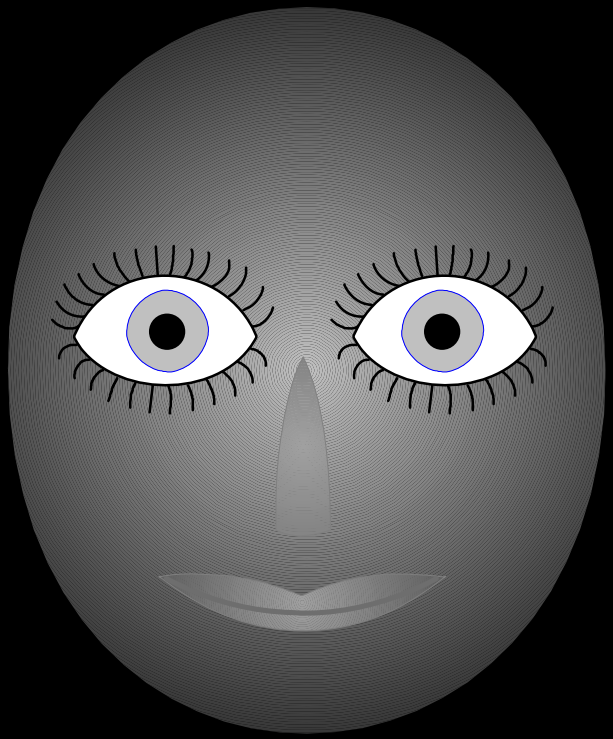
The neural control of eye movements



Peter H. Schiller

The problems we are trying to solve in a nutshell

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Please see lecture video or Jack Ziegler, "Cat Thinks of a Complex Equation to Get a Ball Off a Table," *New Yorker*, November 26, 2001.

New Yorker, 2001

Topics:

1. Basics of eye movements
2. The eye plant and the brainstem nuclei
3. The superior colliculus
4. Visual inputs for saccade generation
5. Cortical structures involved in saccadic eye-movement control
6. The effects of paired electrical and visual stimulation
7. The effects of lesions on eye movement
8. Pharmacological studies

1. Basics of eye movements

Why do we move our eyes?

A. To acquire objects for central viewing

Saccadic eye movements

B. To maintain objects in foveal view

Pursuit eye movements

C. To stabilize the world on the retina

Vestibulo-ocular reflex,
accessory optic system

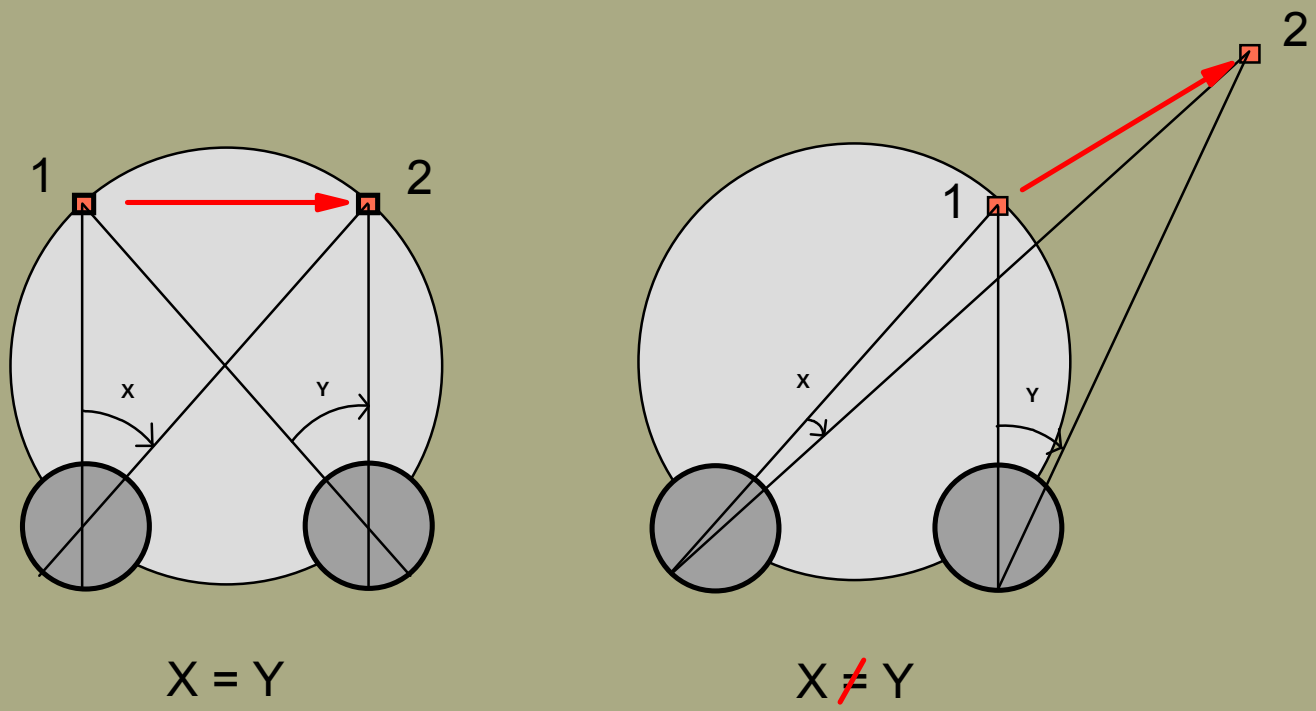
Classification of eye movements

Conjugate eye movements

saccadic (acquires objects for central viewing)

smooth pursuit (maintains object on fovea)

Vergence eye movements



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Please see lecture video or Rene Magritte's Le blanc-seing.

Rene Magritte
National Gallery of Art,
Washington, DC

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Saccadic eye movements made under free-viewing conditions by a subjet examining a picture of the bust of Nefertiti. By Yarbus

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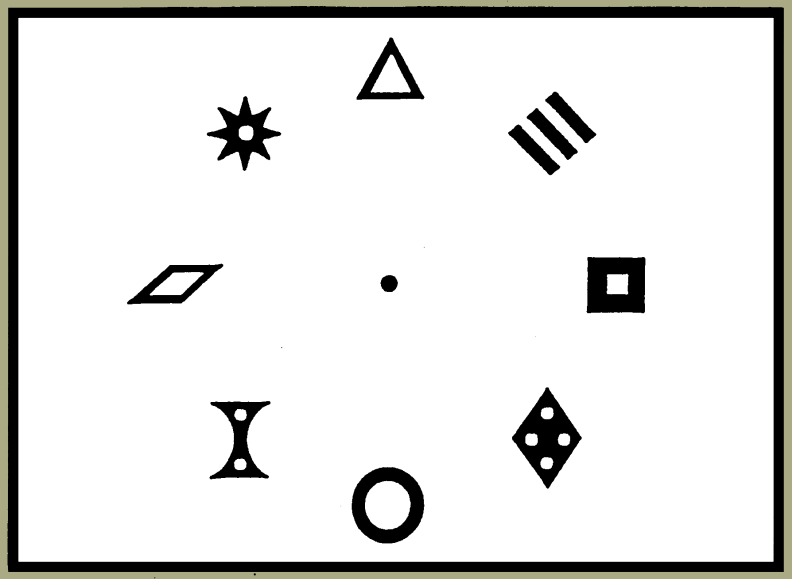
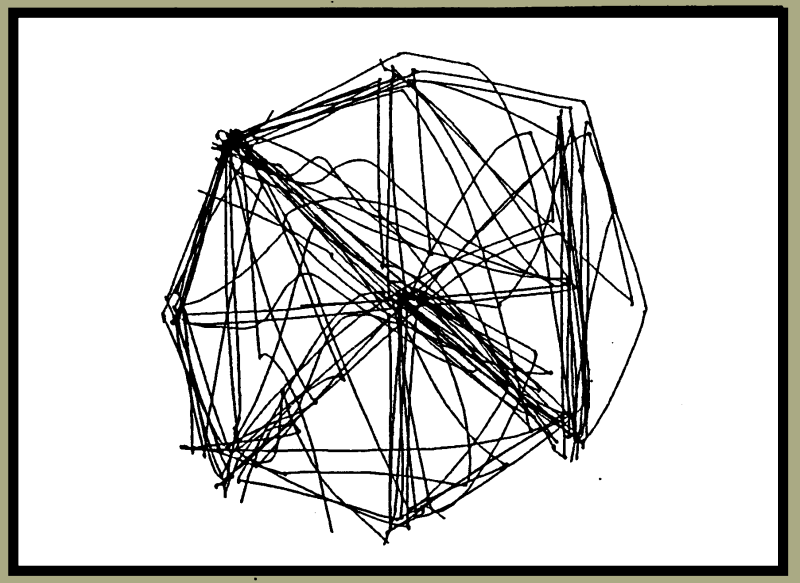
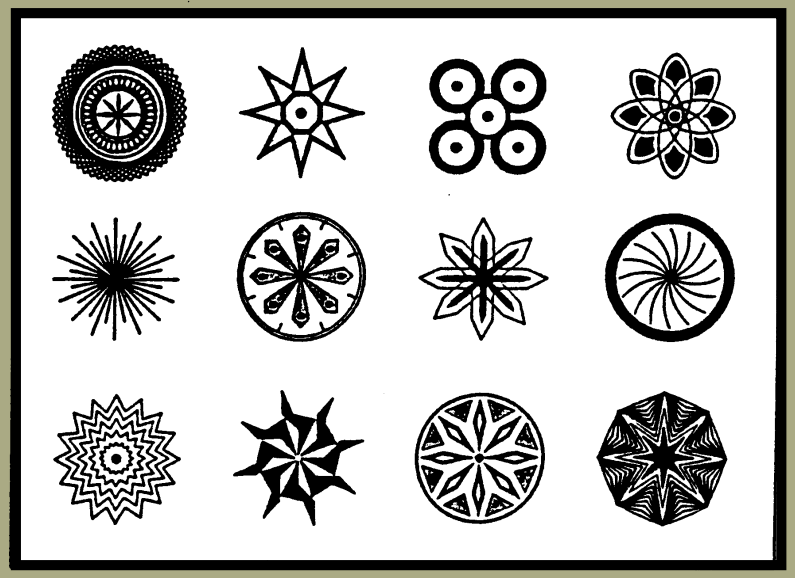
Please see lecture video.

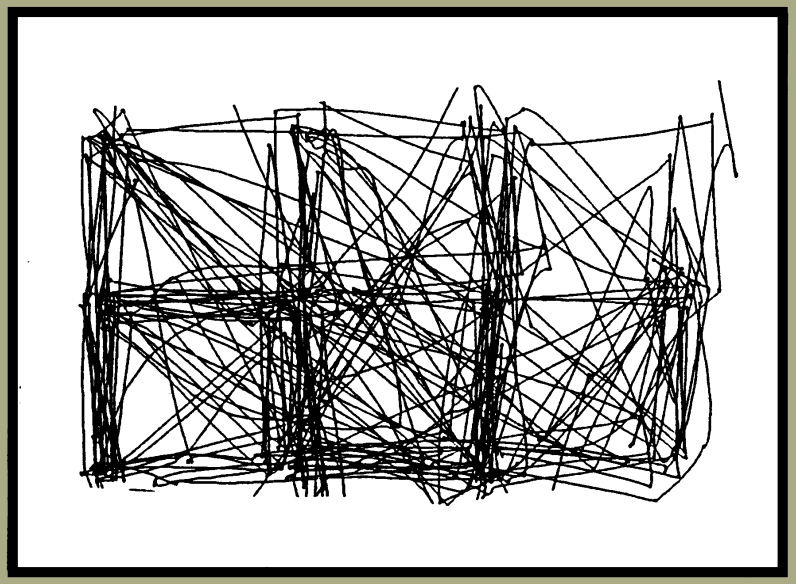
Ashley Bryan

Free viewing by intact monkey

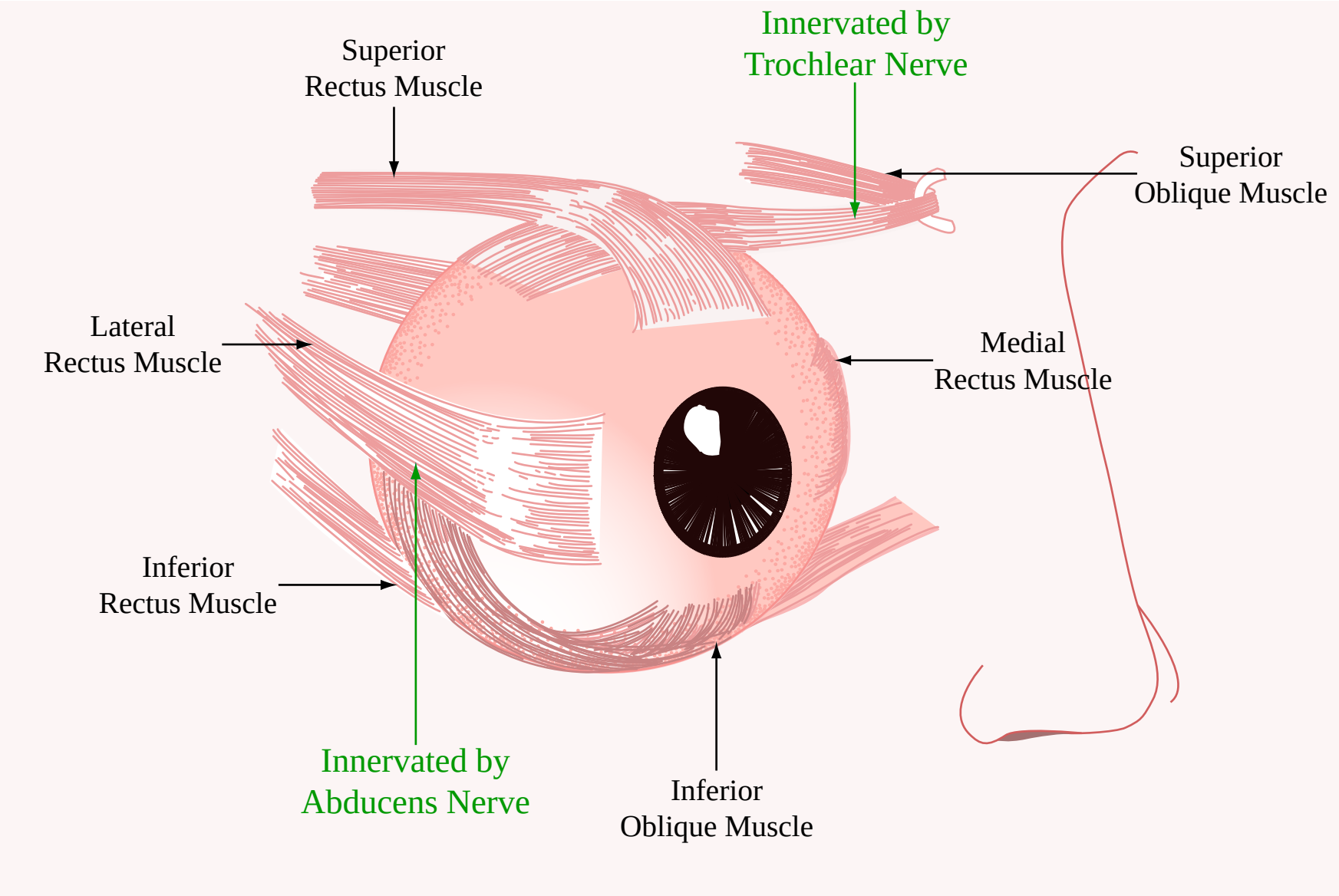








2. The eye plant and the brainstem nuclei



Other recti and inferior oblique innervated by oculomotor nerve

Cranial nerves

1 2 3 4 5 6 7 8 9 10 11 12

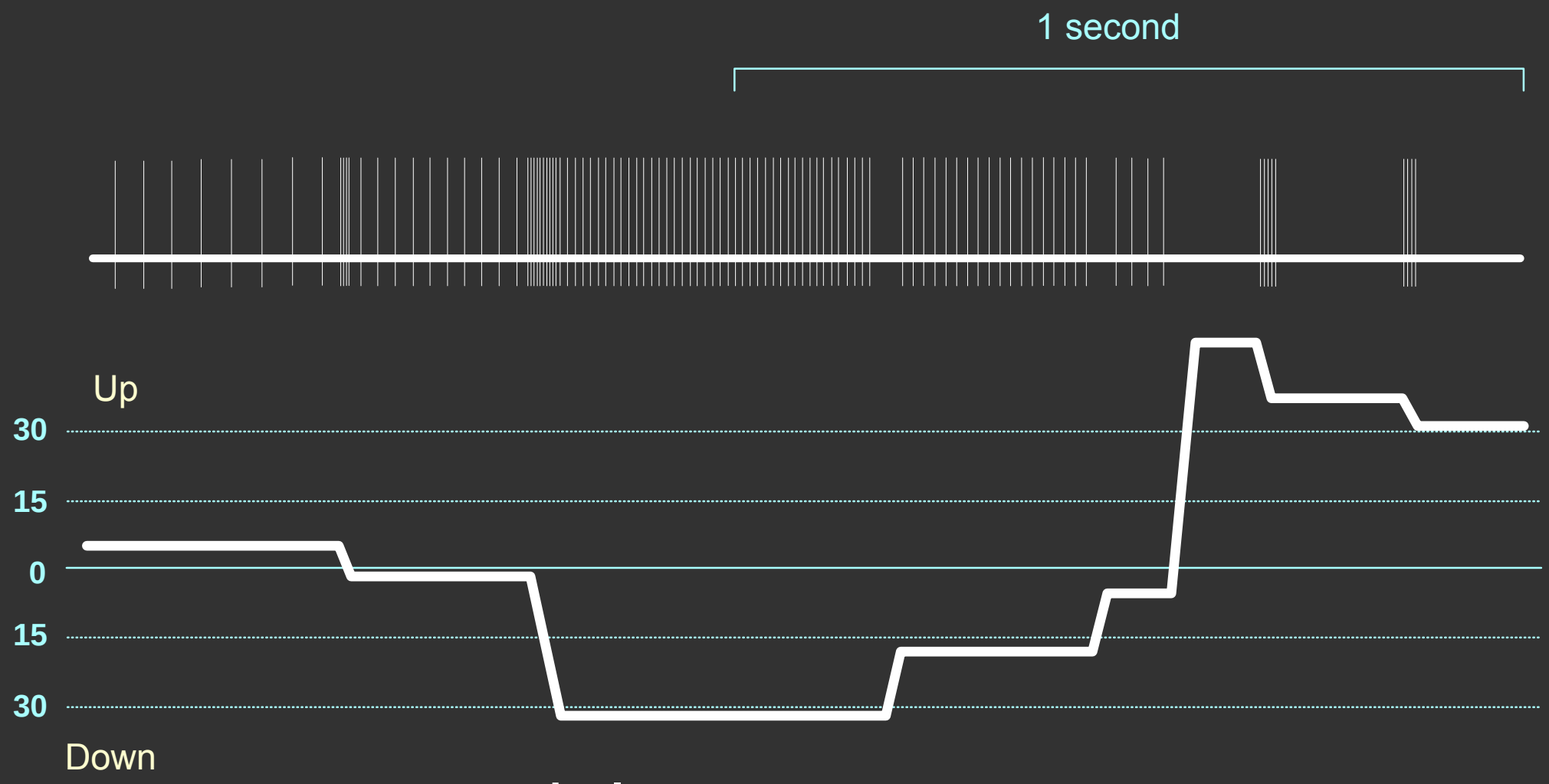
On old olympus' towering top a fat armed girl vends snowy hops

1.	**olfactory**	olfaction
2.	**optic**	vision
3.	**oculomotor**	eye movements, pupil, lens, tears
4.	**trochlear**	eye movements, superior rectus
5.	**trigeminal**	facial sensations, chewing
6.	**abducens**	eye movements, lateral rectus
7.	**facial**	facial muscles, salivary glands, taste
8.	**auditory**	audition
9.	**glossophayngeal**	throat muscles, salivary glands, taste
10.	**vagus**	parasympathetic, organ sensation, taste
11.	**spinal accessory**	head and neck muscles
12.	**hypoglossal**	tongue and neck muscles

Spinal nerves

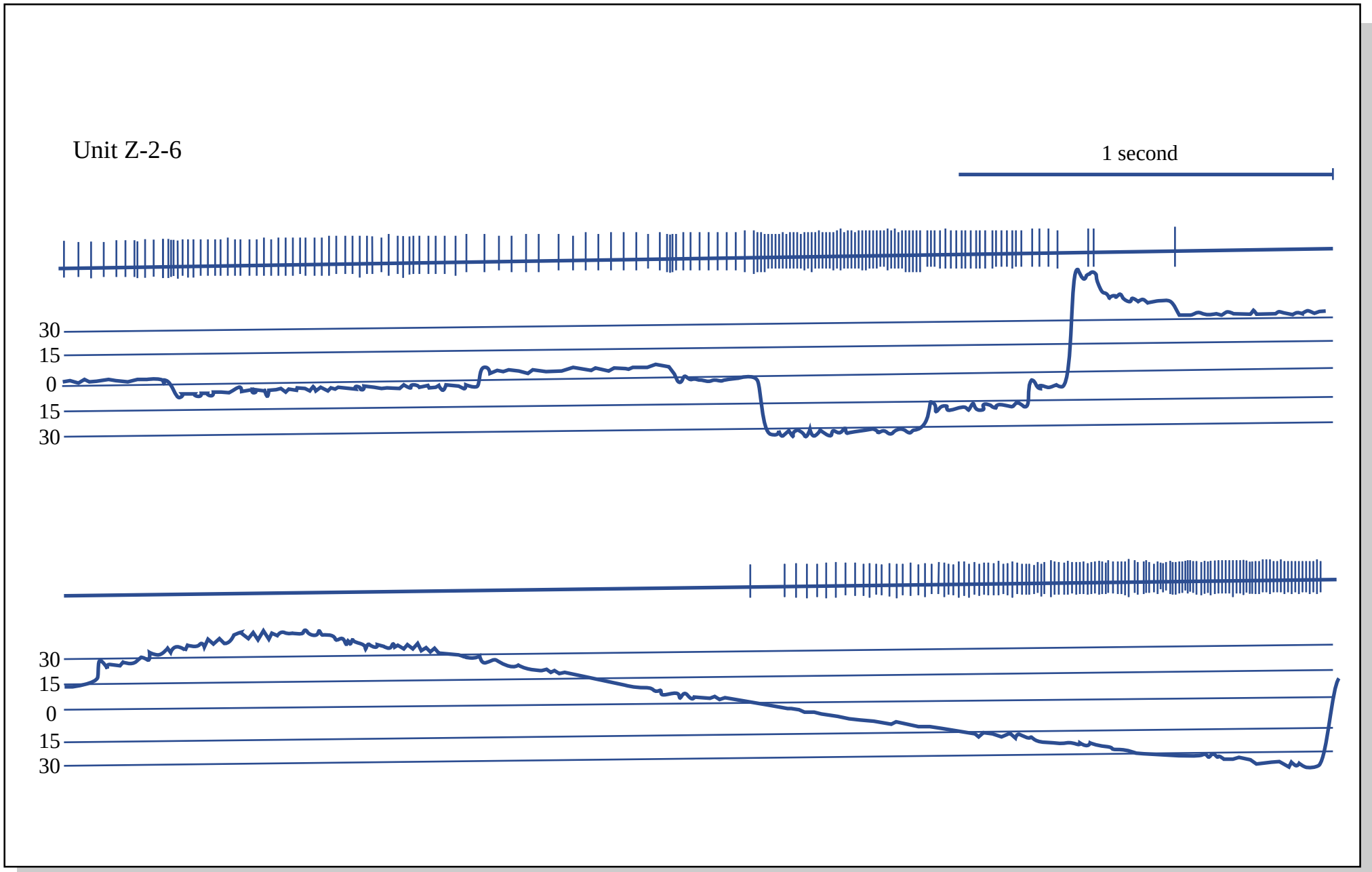
cervical	8
thoracic	12
lumbar	5
sacral	5
coccygeal	1

Neuronal discharge in oculomotor nucleus

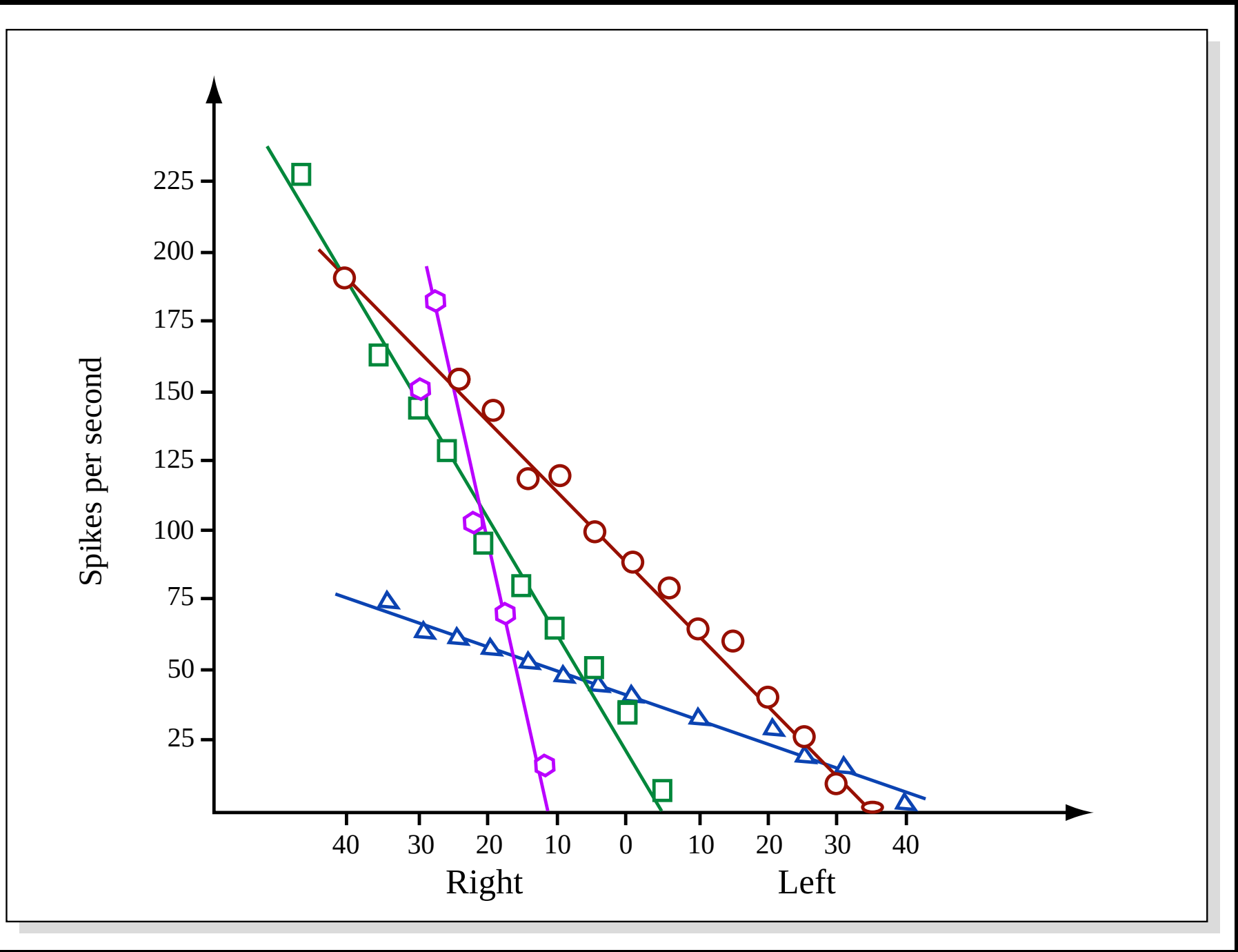


Vertical eye movements

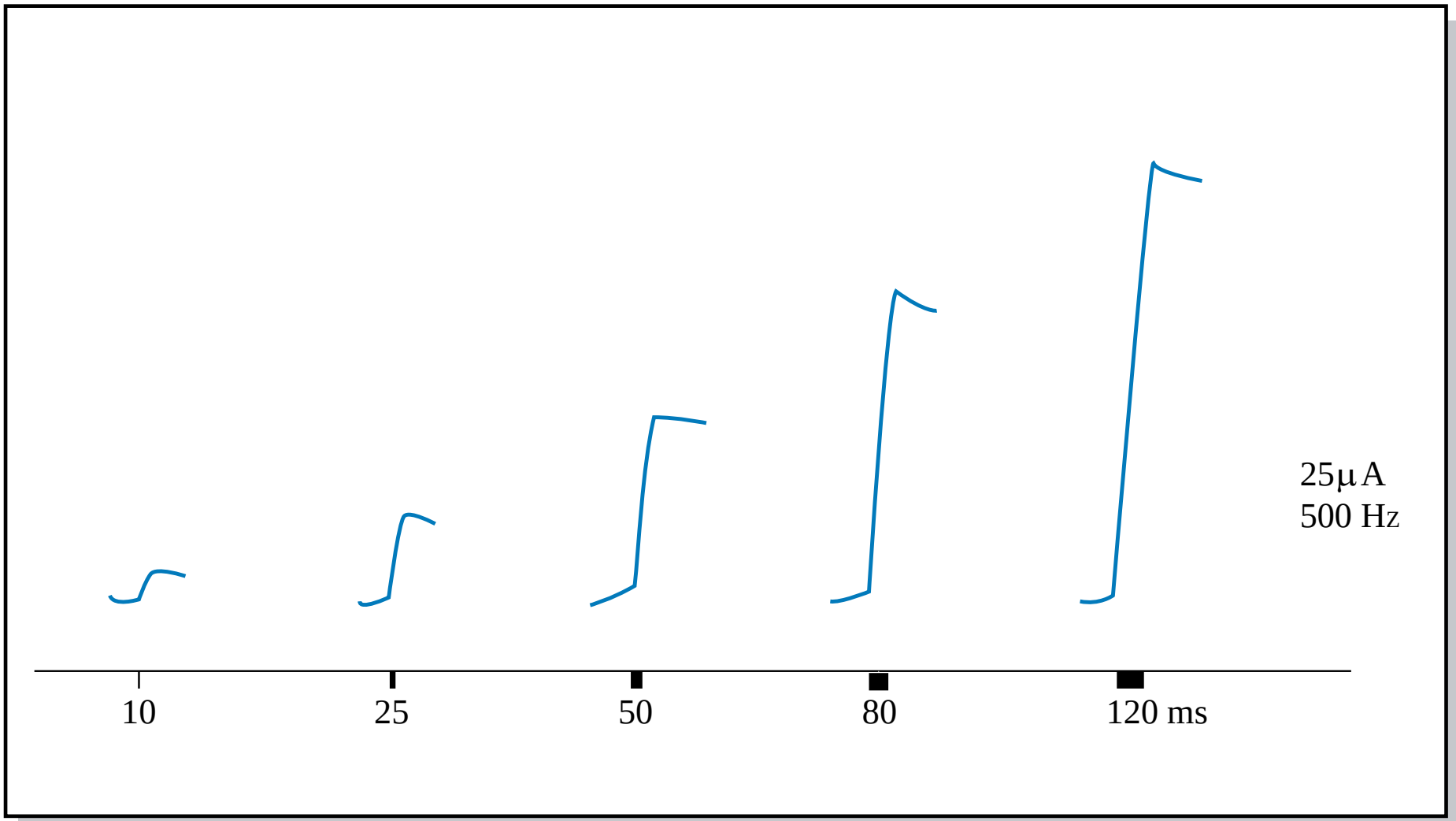
Responses of a neuron in the oculomotor nucleus that innervates the inferior rectus



The discharge of four oculomlotor neurons as a function of the angular deviation of the eye



Electrical stimulation of the abducens nucleus



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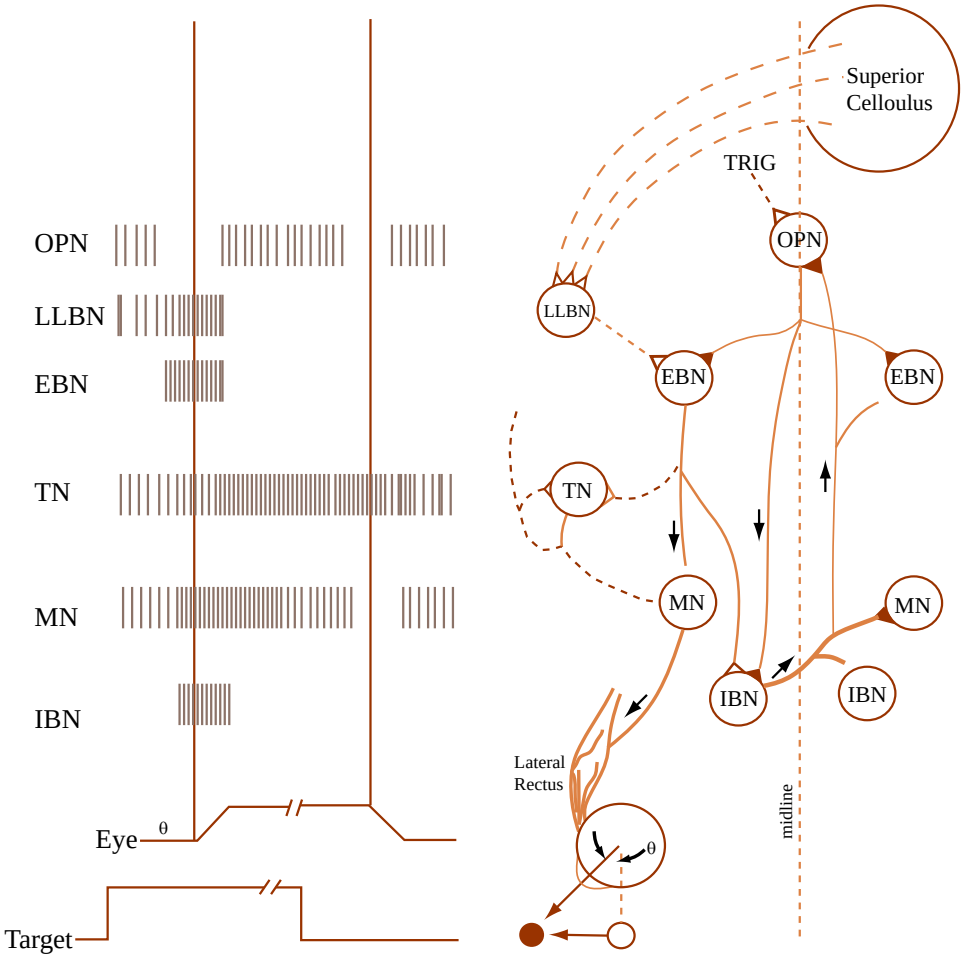
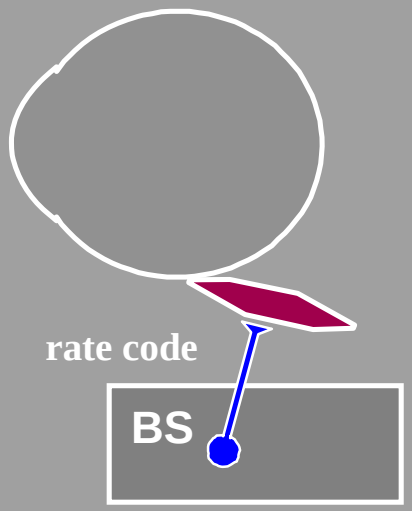
Brainstem inputs to oculomotor, trochlear and abducens nuclei



The discharge patterns and connections of neurons in the horizontal burst generator.Left: Firing patterns for an on-direction (first *vertical dashed line*) and off-direction (second dashed line) horizontal saccade of size θ to a target step (schematized in the eye and target traces below); Right: Excitatory connections are shown as *open endings* inhibitory connections are shown as filled triangles, and axon collaterals of unknown destination (revealed by intracellular HRP injections or postulated in models) are shown without terminals. Connections known with certainty are represented by *thick lines*.Uncertain connections by *thin lines*,and hypothesized connections by *dashed lines.* A complete description of the behavior of this neural circuit is found in the text.The abbreviations here and in figure 4 identify excitatory (EBN) and inhibitory (IBN) burst neurons, long-lead burst neurons (LLBN) , trigger input neurons (TRIG), omnipause neurons (OPN), tonic neurons (TN), and motoneurons (MN).


rate code
BS

3. The superior colliculus

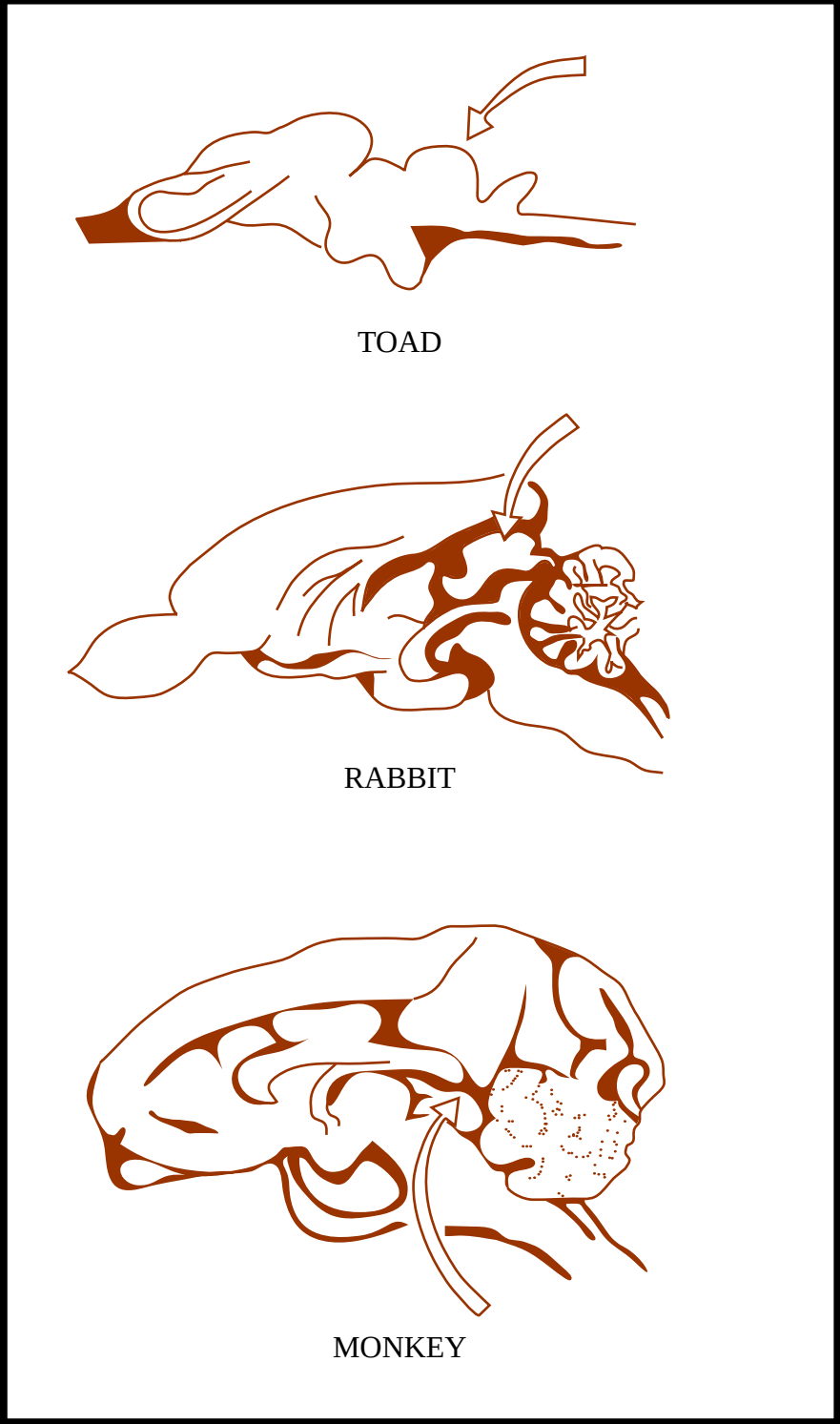
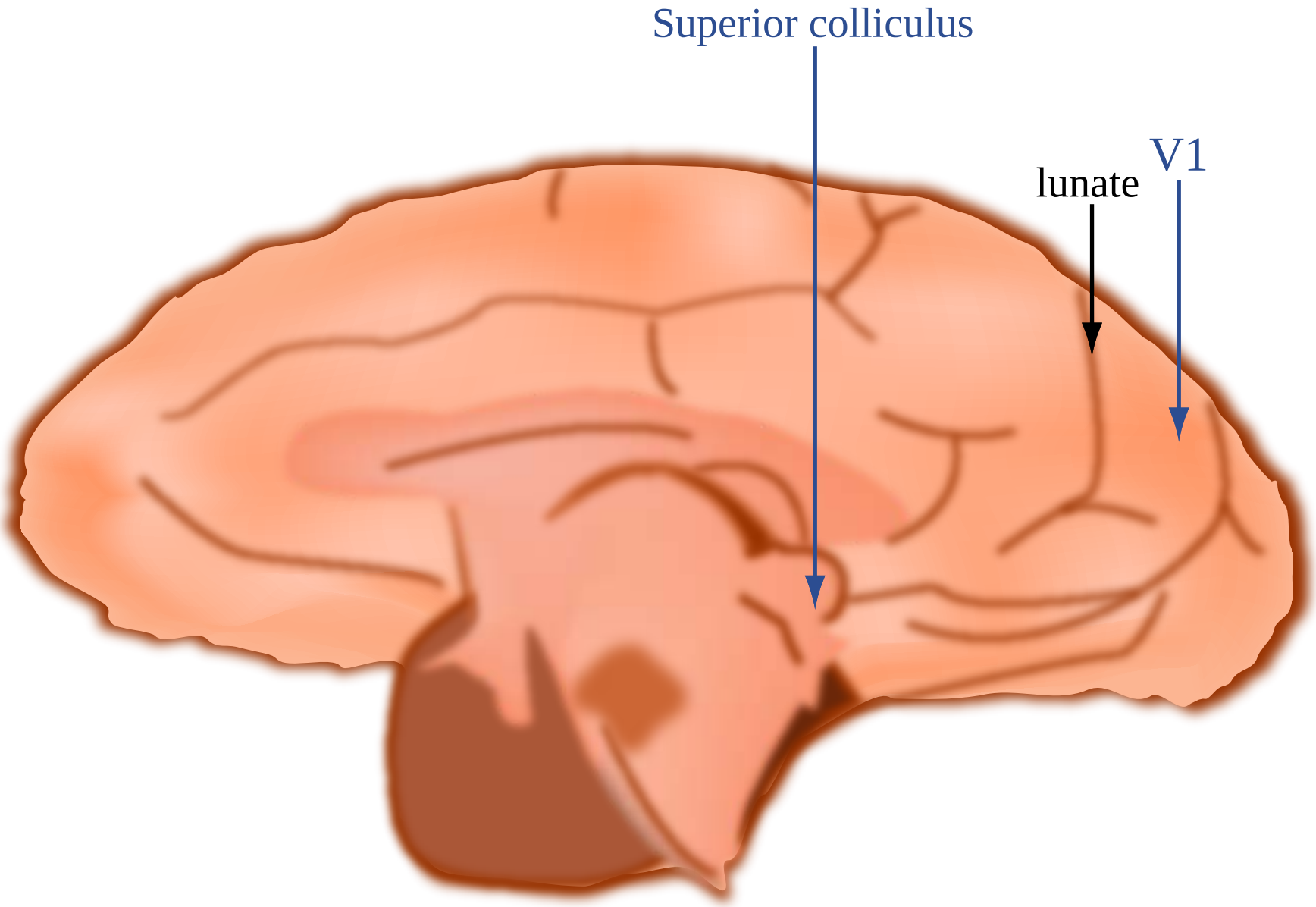


Image by MIT OpenCourseWare.

Arrows point to optic tectum in three species.

Optic tectum = superior colliculus

Midline sagittal section through monkey brain

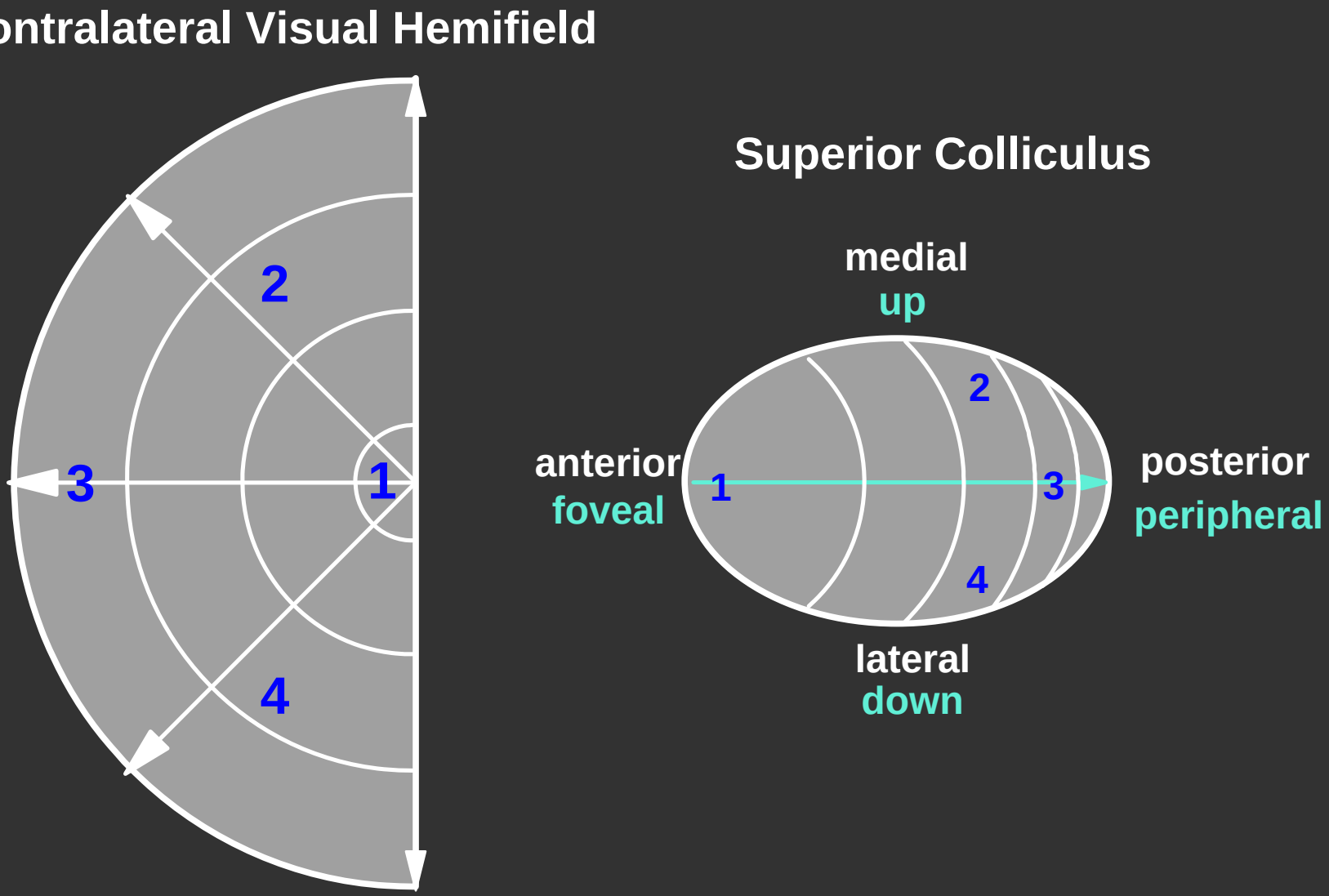


Coronal section through the cat superior colliculus

Figure removed due to copyright restrictions.

Please see lecture video or Figure 3 of Kanaseki, T., and J. M. Sprague. "Anatomical Organization of Pretectal Nuclei and Tectal Laminae in the Cat." *Journal of Comparative Neurology* 158, no. 3 (1974): 319-37.

Visual field representation in the superior colliculus



Visual response of superficial collicular cells

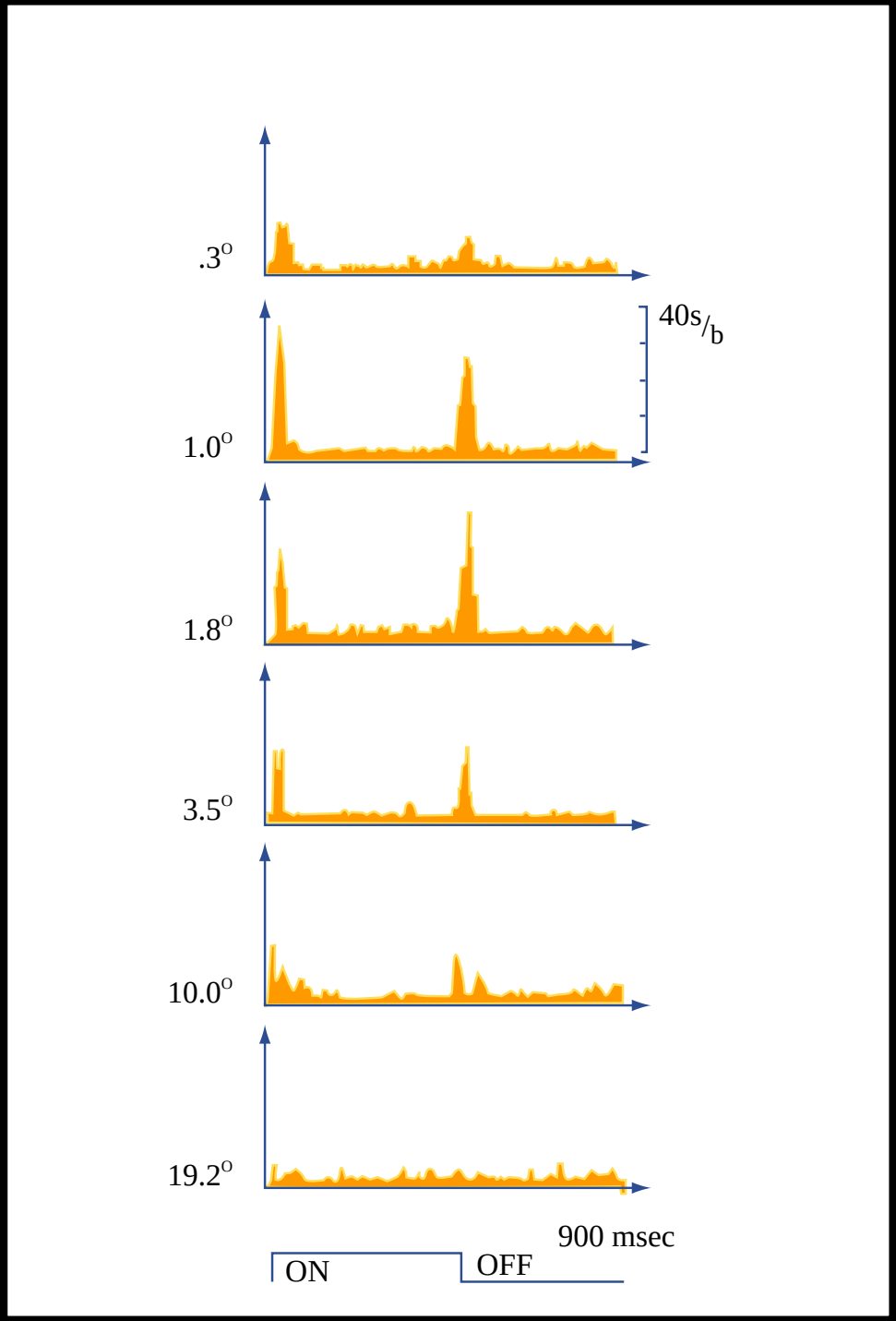


Image by MIT OpenCourseWare.

Responses of a neuron in the superior colliculus with eye movement

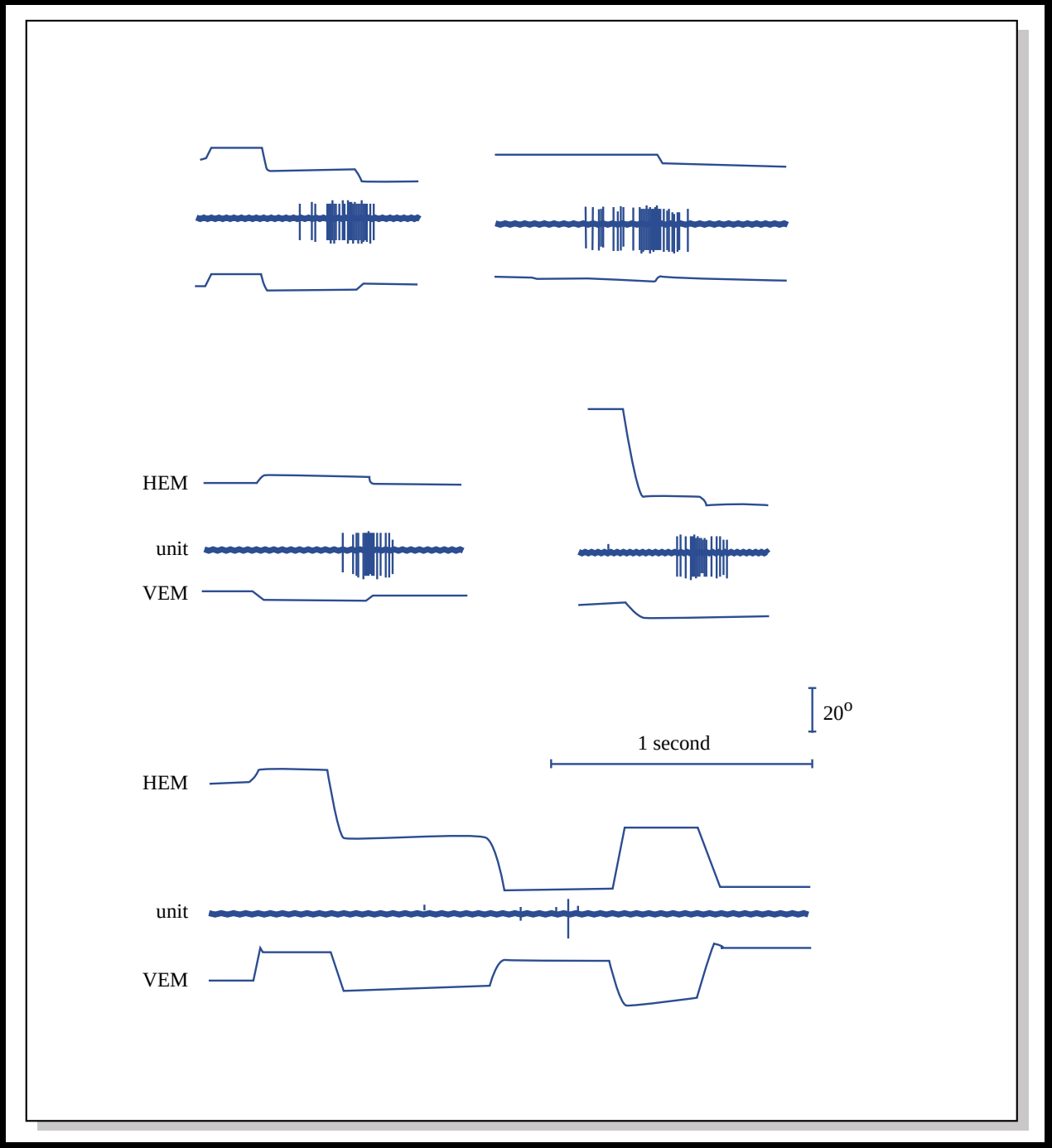
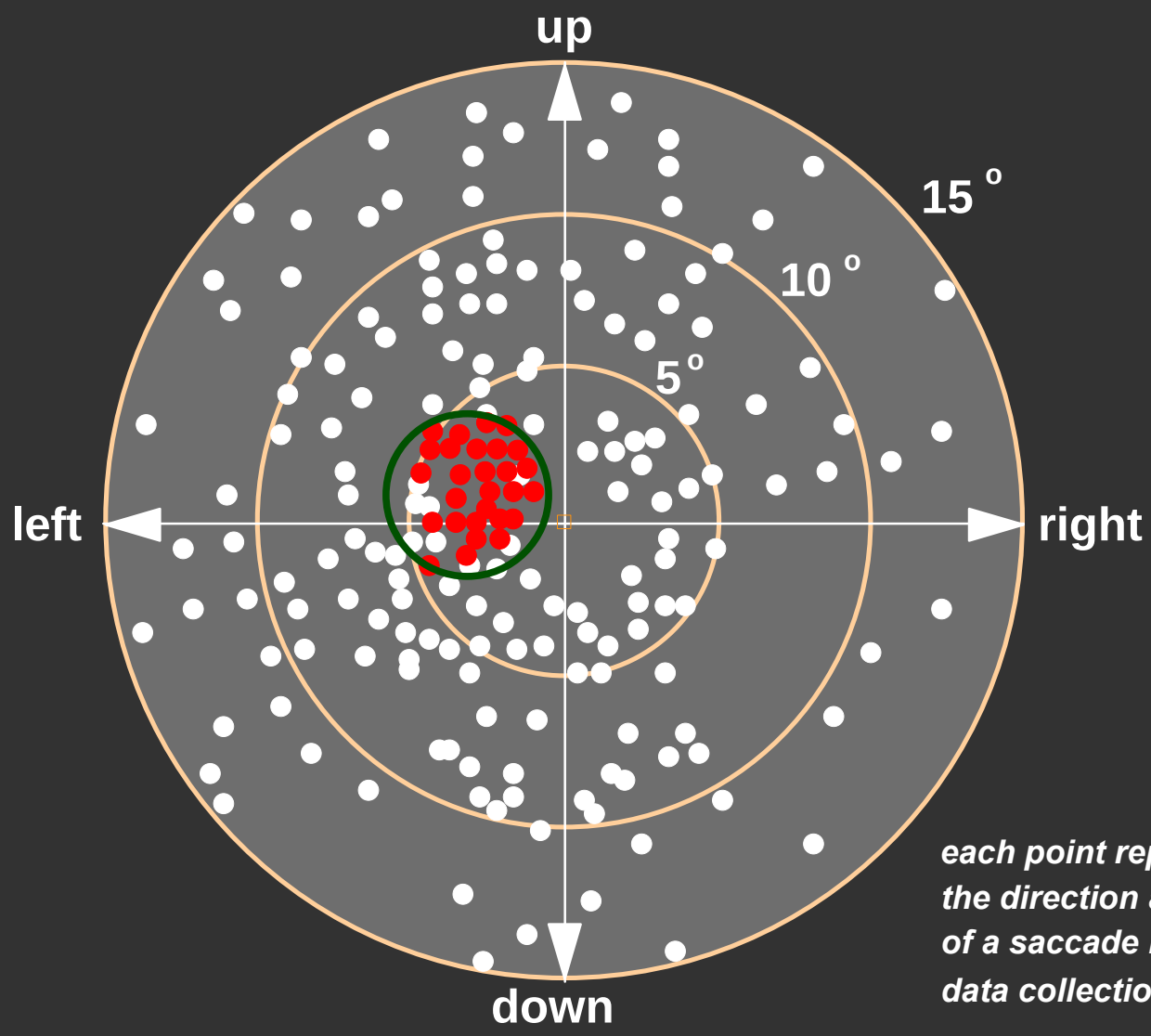


Image by MIT OpenCourseWare.

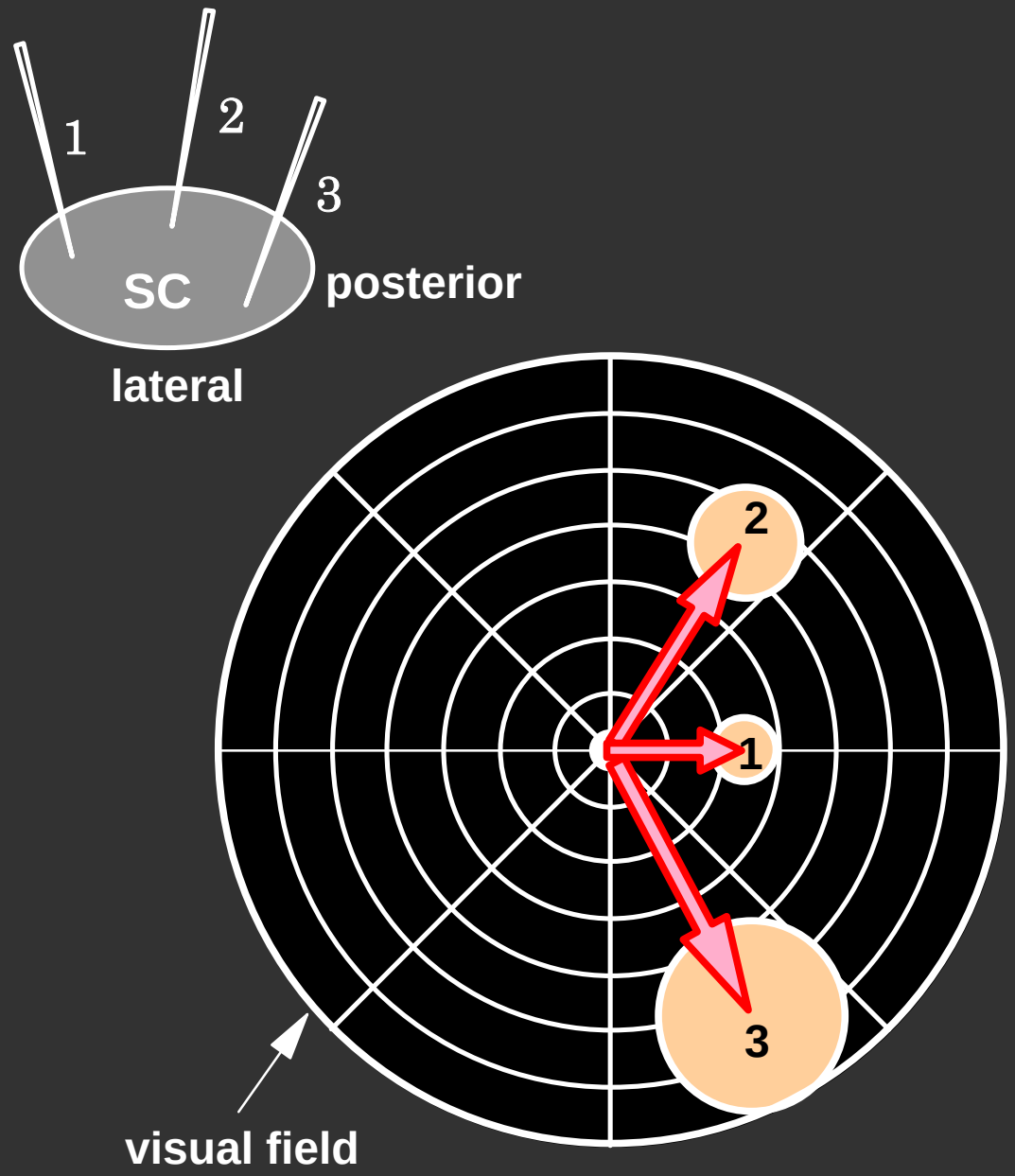
Saccade-associated discharge in a collicular cell



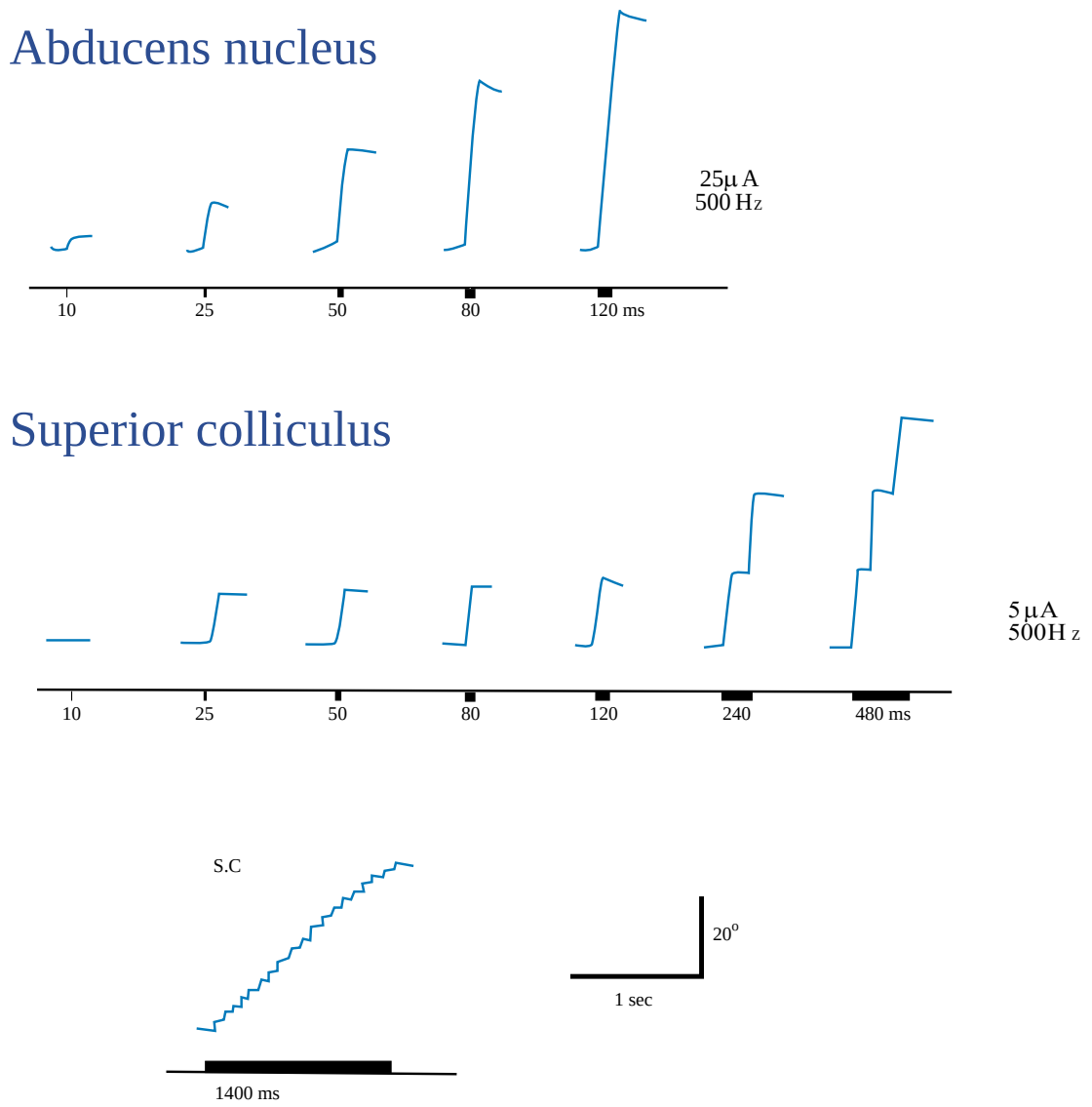
each point represents the direction and amplitude of a saccade made during data collection

Recording and stimulation in the superior colliculus

Recording and stimulation at three collicular sites

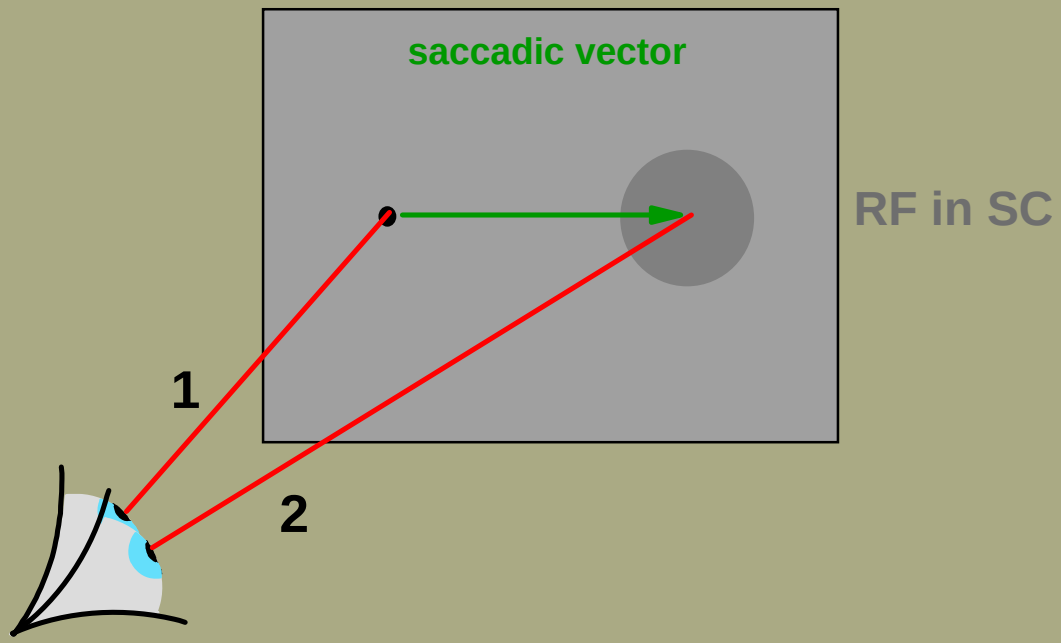


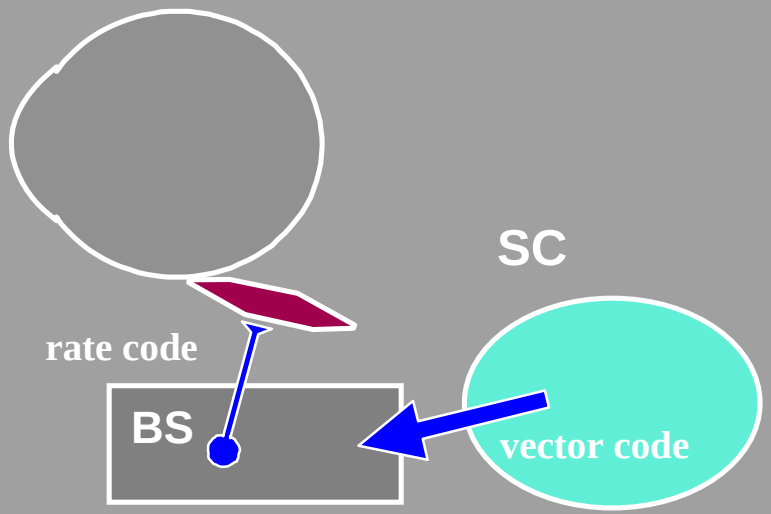
Electrical stimulation of the abducens and the superior colliculus



Basic principle of coding in the superior colliculus

A saccade is generated by computing the size and direction of the saccadic vector needed to null the retinal error between the present and intended eye position.

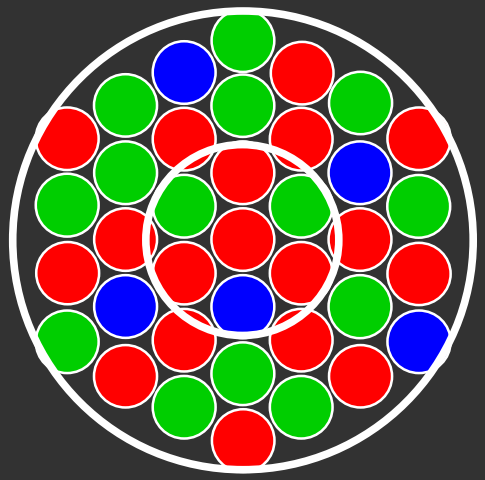



SC
rate code
BS
vector code

4. Visual inputs for saccade generation

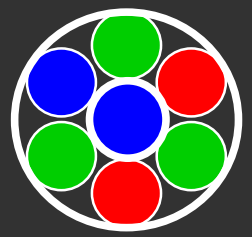
MIDGET SYSTEM

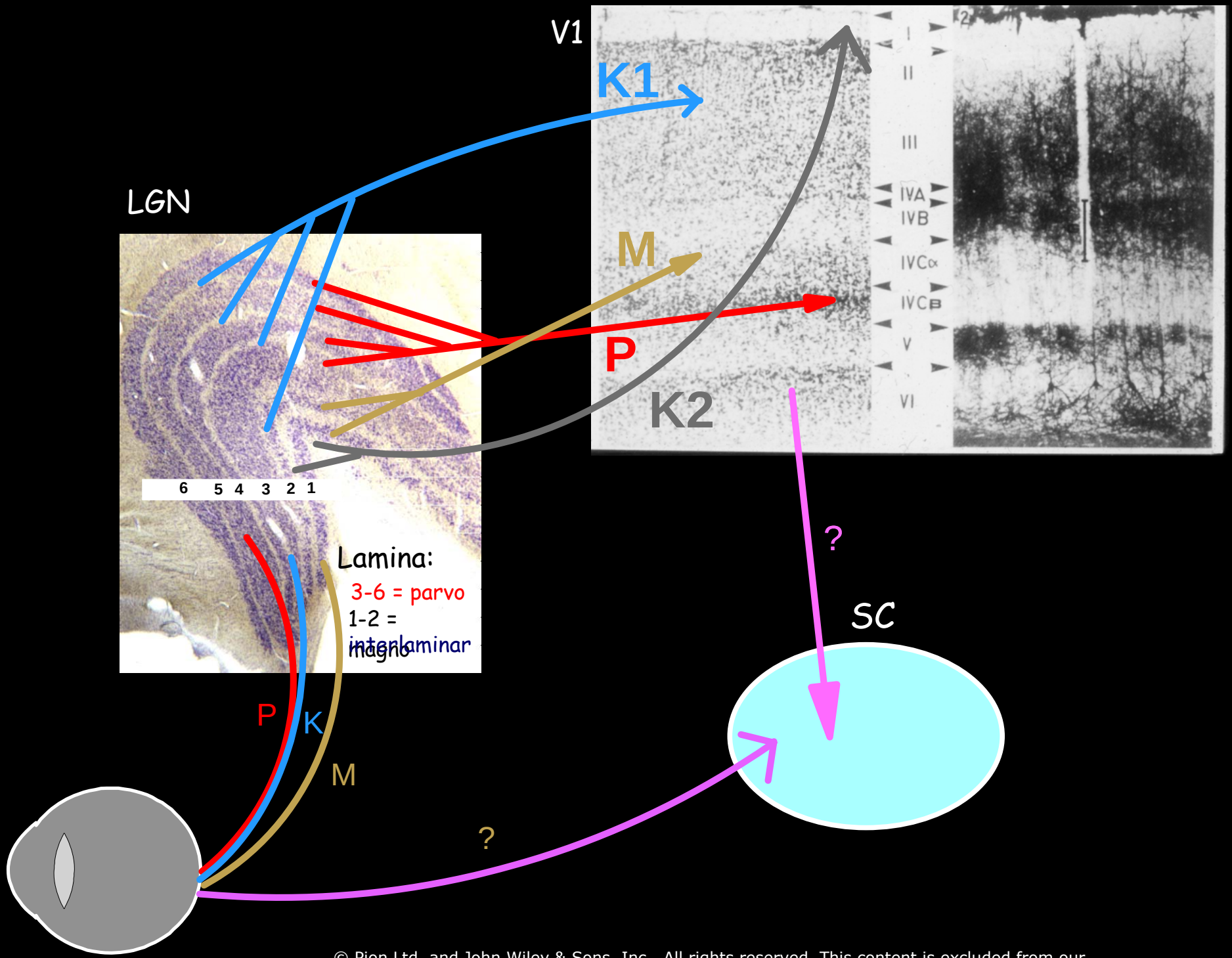
PARASOL SYSTEM



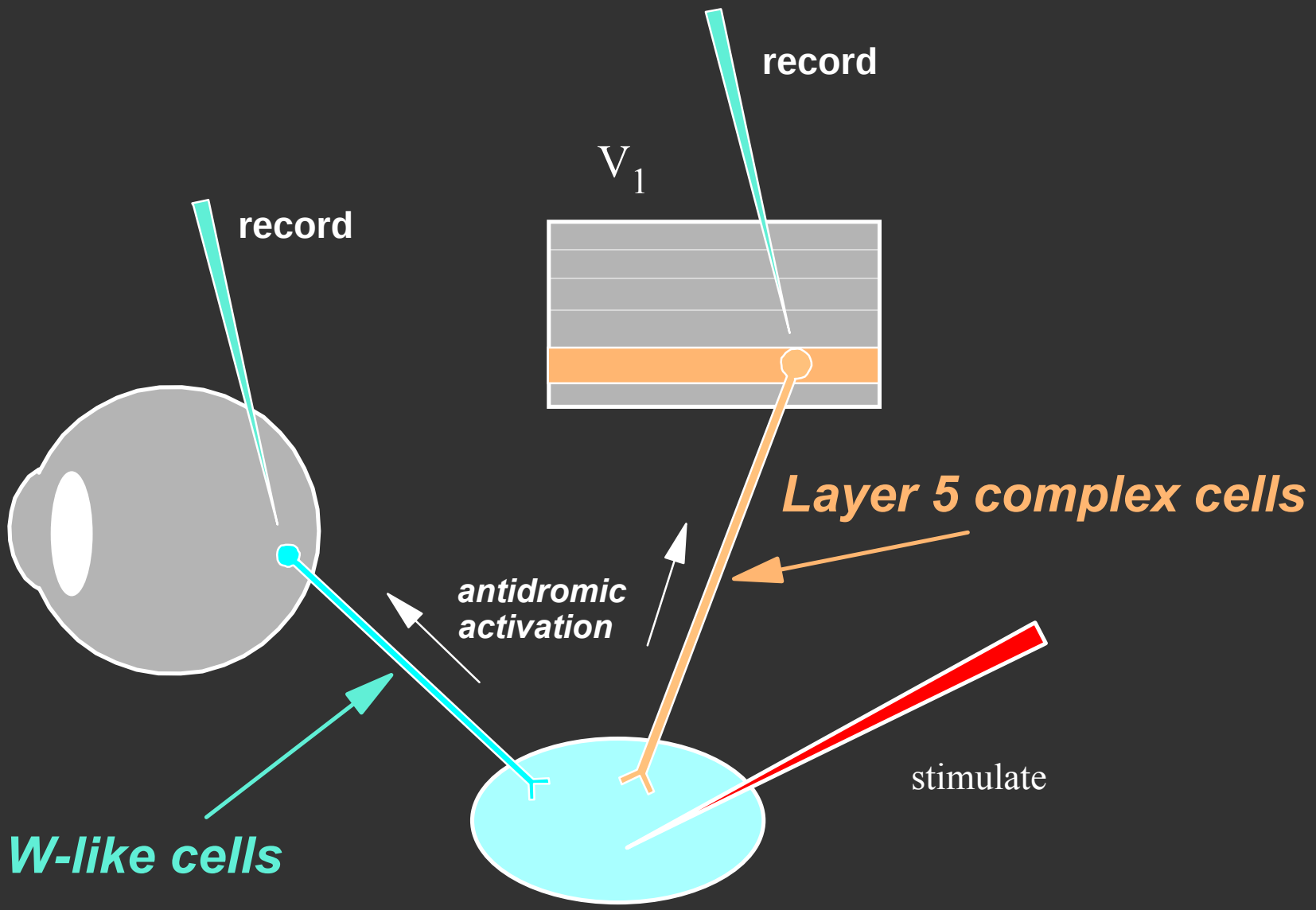
W SYSTEM

koniocellular cells

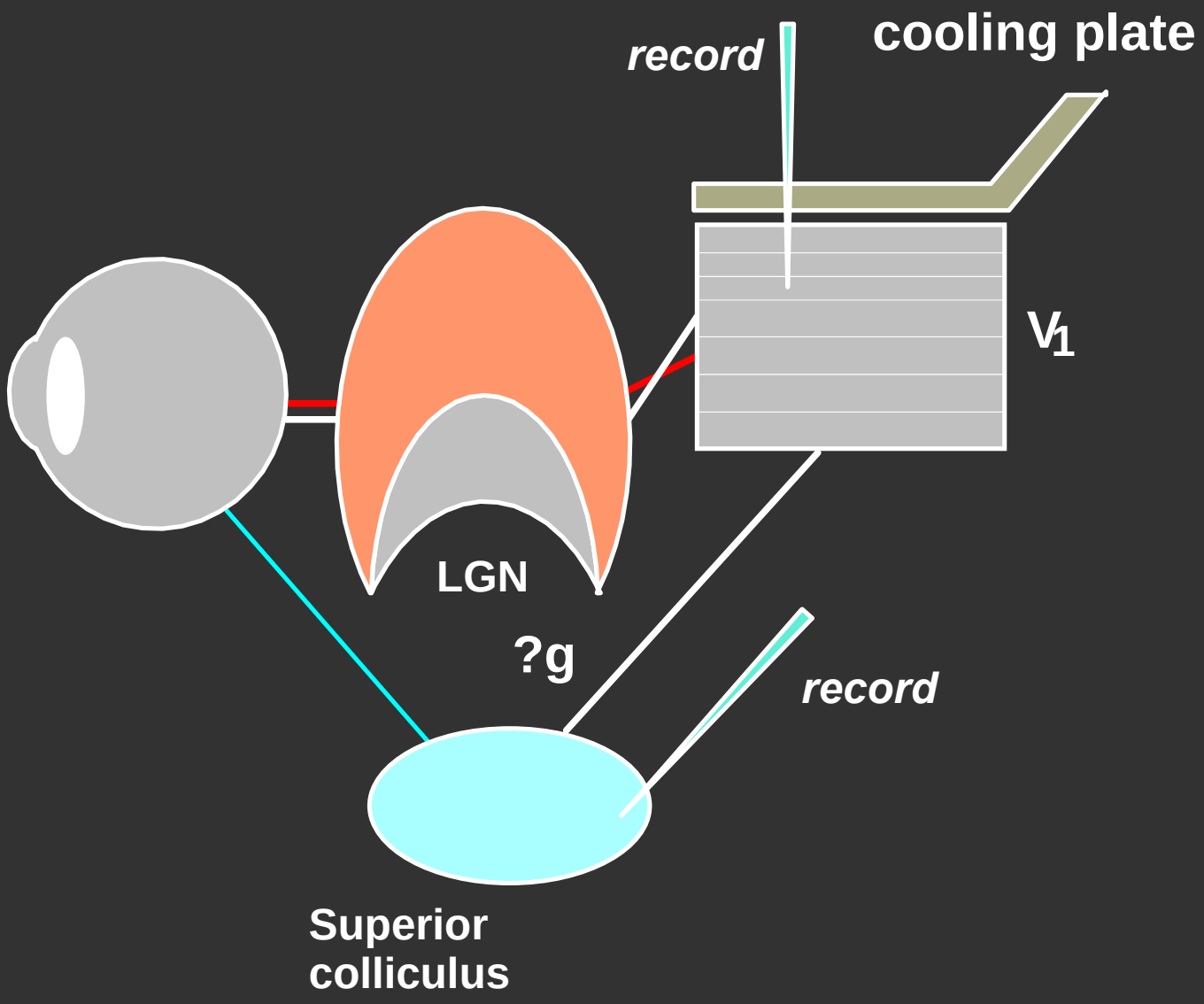




Antidromic activation method



Cooling method



Recording in the superior colliculus while cooling V1

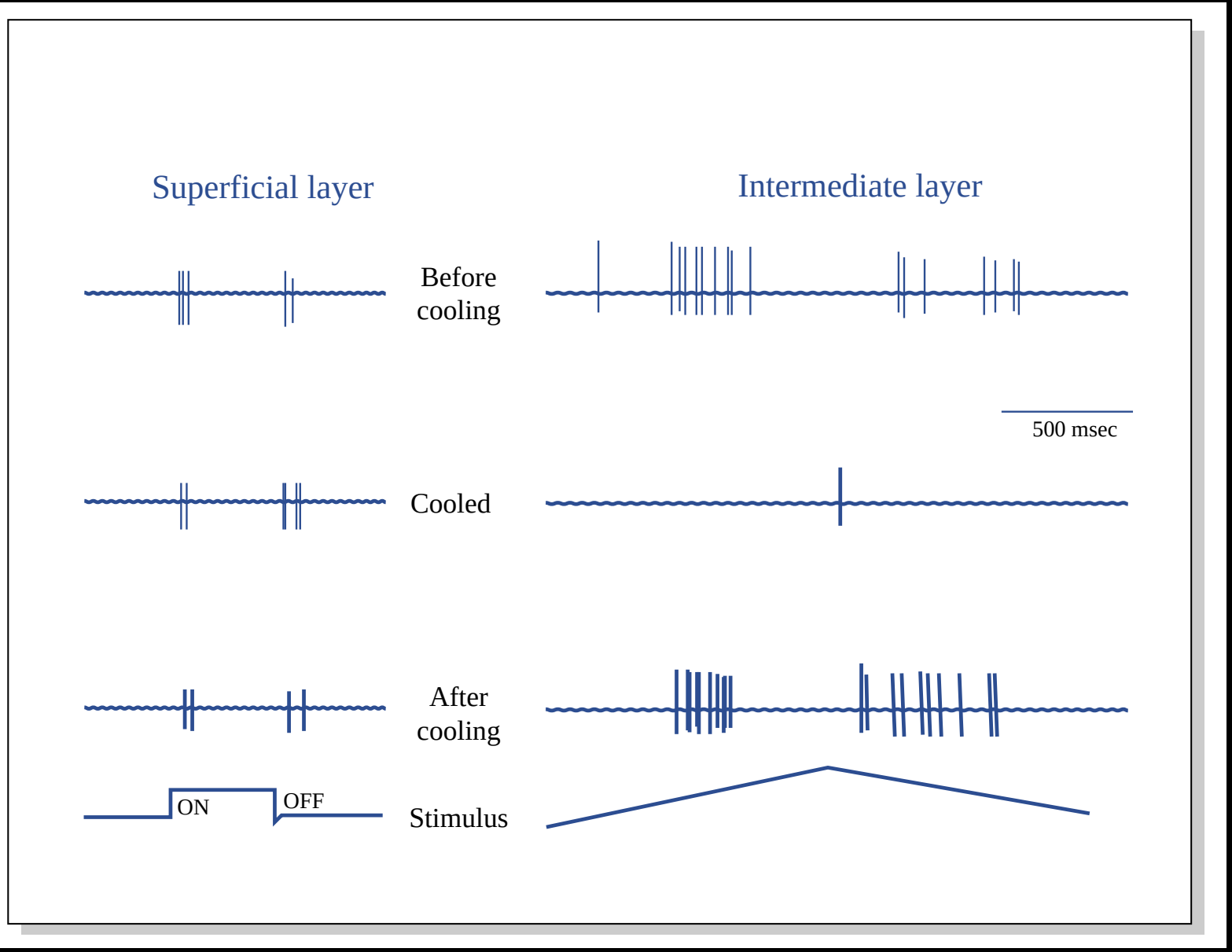


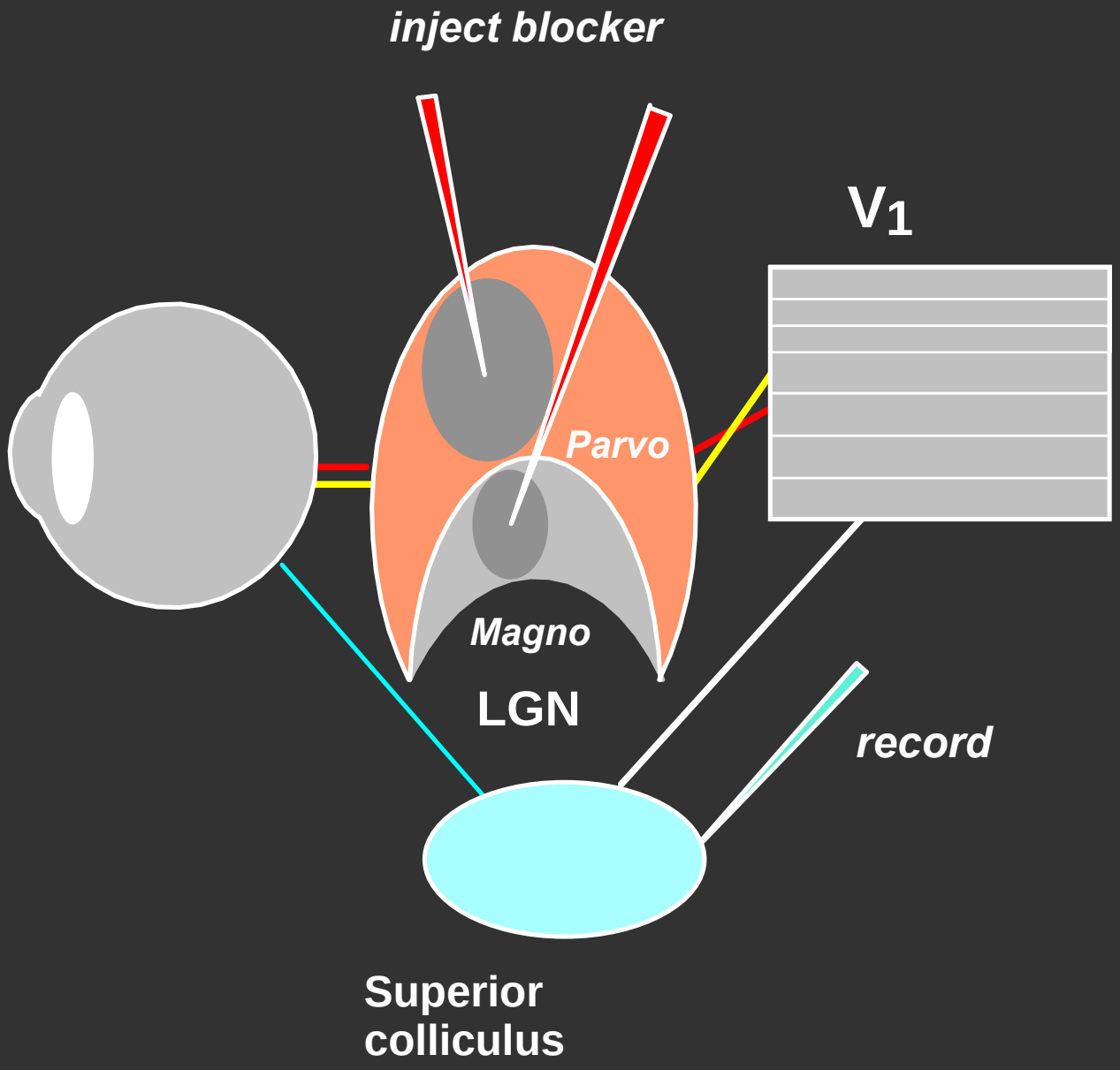
Image by MIT OpenCourseWare.

Coronal section through the superior colliculus of a monkey whose right visual cortex has been removed. Lesion marks location where cells can no longer be visually driven.

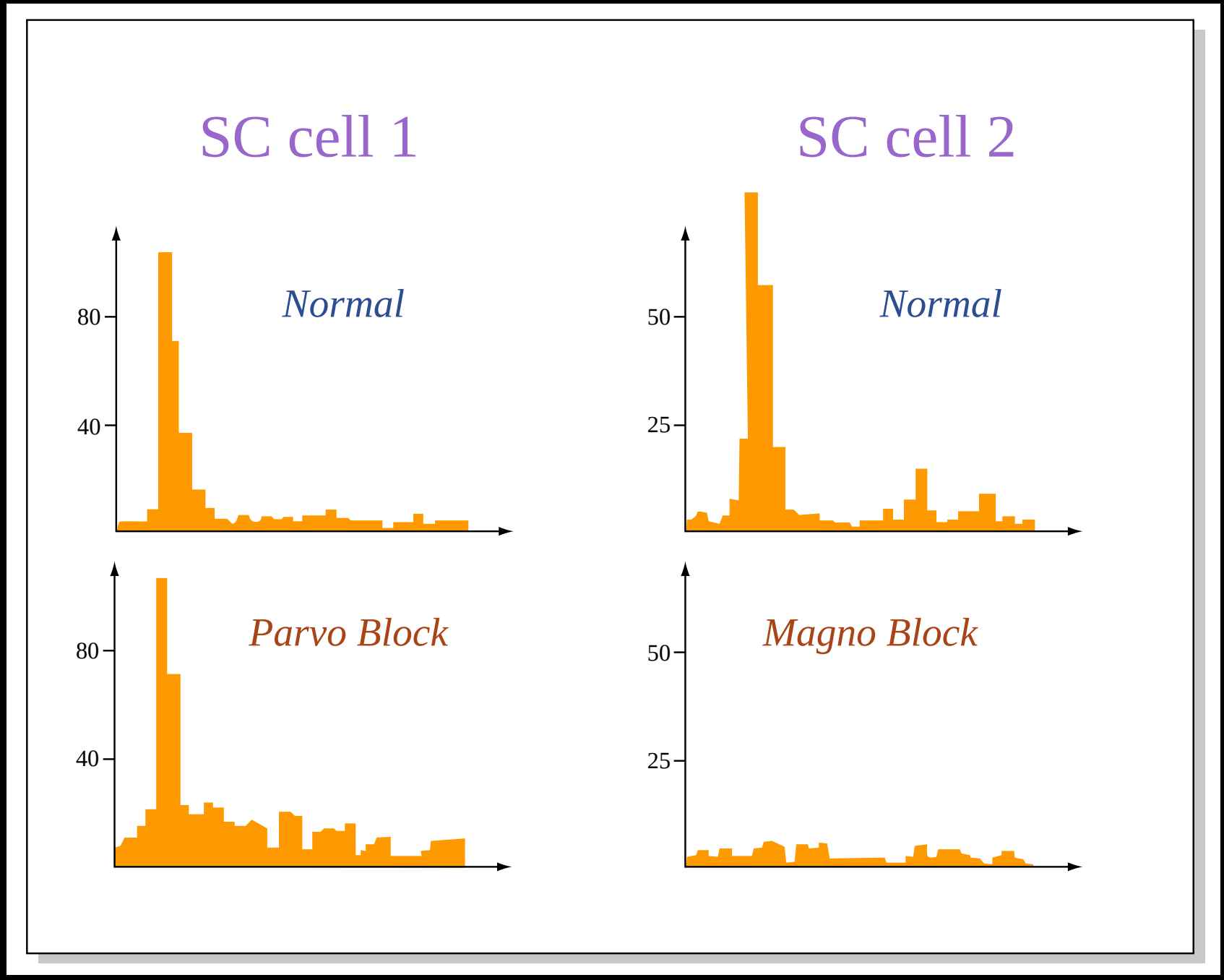
Image removed due to copyright restrictions.

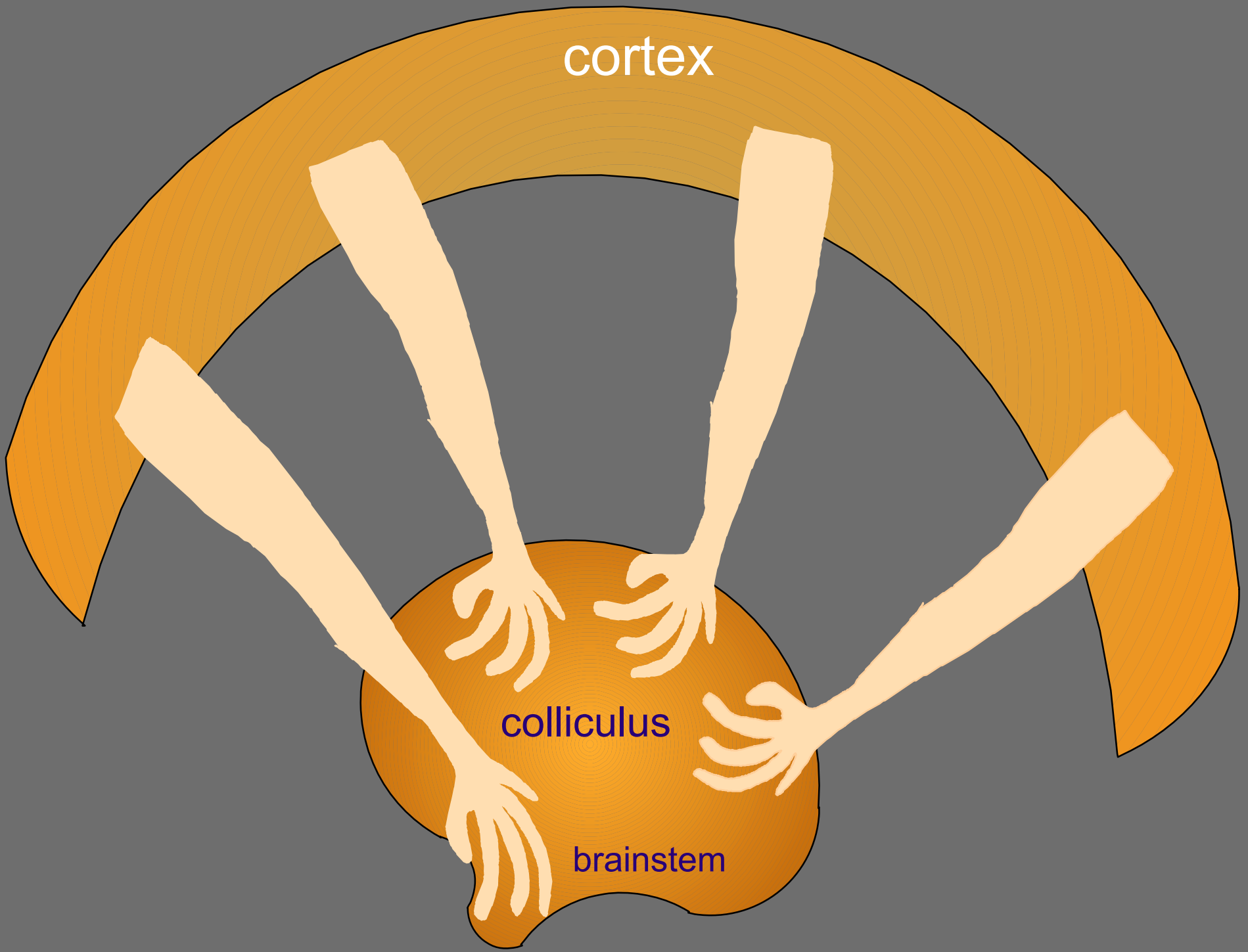
Please see lecture video.

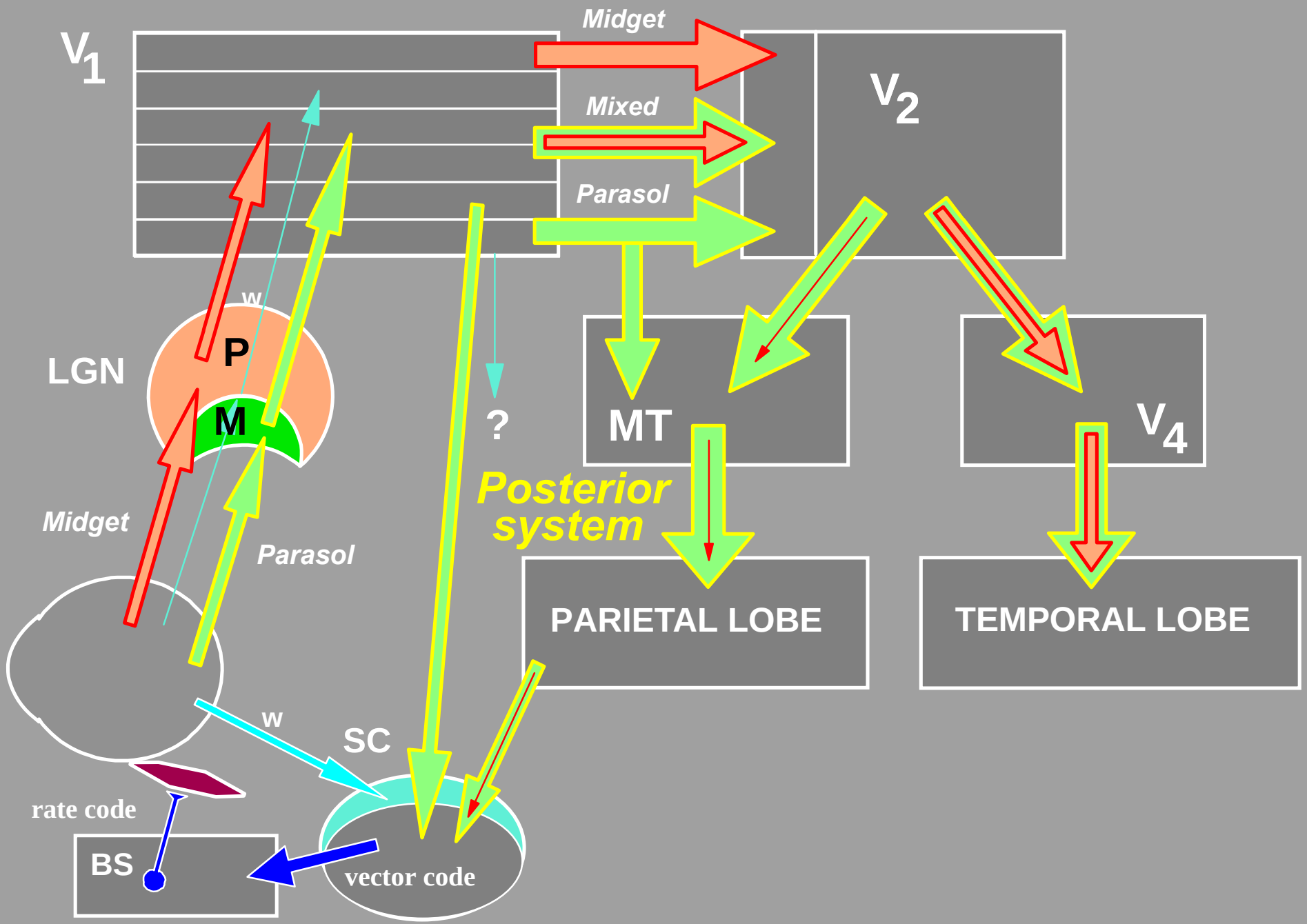
Tissue block with injections



Single-cell responses in SC while blocking parvo or magno LGN




cortex
colliculus
brainstem


V1
Midget
Mixed
Parasol
V2
w
LGN
P
M
?
MT
V4
Posterior system
Midget
Parasol
PARIETAL LOBE
TEMPORAL LOBE
w
SC
rate code
BS
vector code

Summary

1. Classes of eye movements are vergence and conjugate, with the latter comprised of two types, saccadic and smooth pursuit.

2. Eye movements are produced by 6 extraocular muscles that are innervated by axons of the 3rd, 4th and 6th cranial nerves.

3. The discharge rate in neurons of the final common path is proportional to the angular deviation of the eye. Saccade size is a function of the duration of the high-frequency burst in these neurons.

4. The superior colliculus codes saccadic vectors whose amplitude and direction is laid out in an orderly fashion and is in register with the visual receptive fields.

5. The retinal input to the SC comes predominantly from w-like cells. The cortical downflow from V1 is from layer 5 complex cells driven by the parasol system.

6. The superior colliculus is under cortical control.

9.04 Sensory Systems

Fall 2013