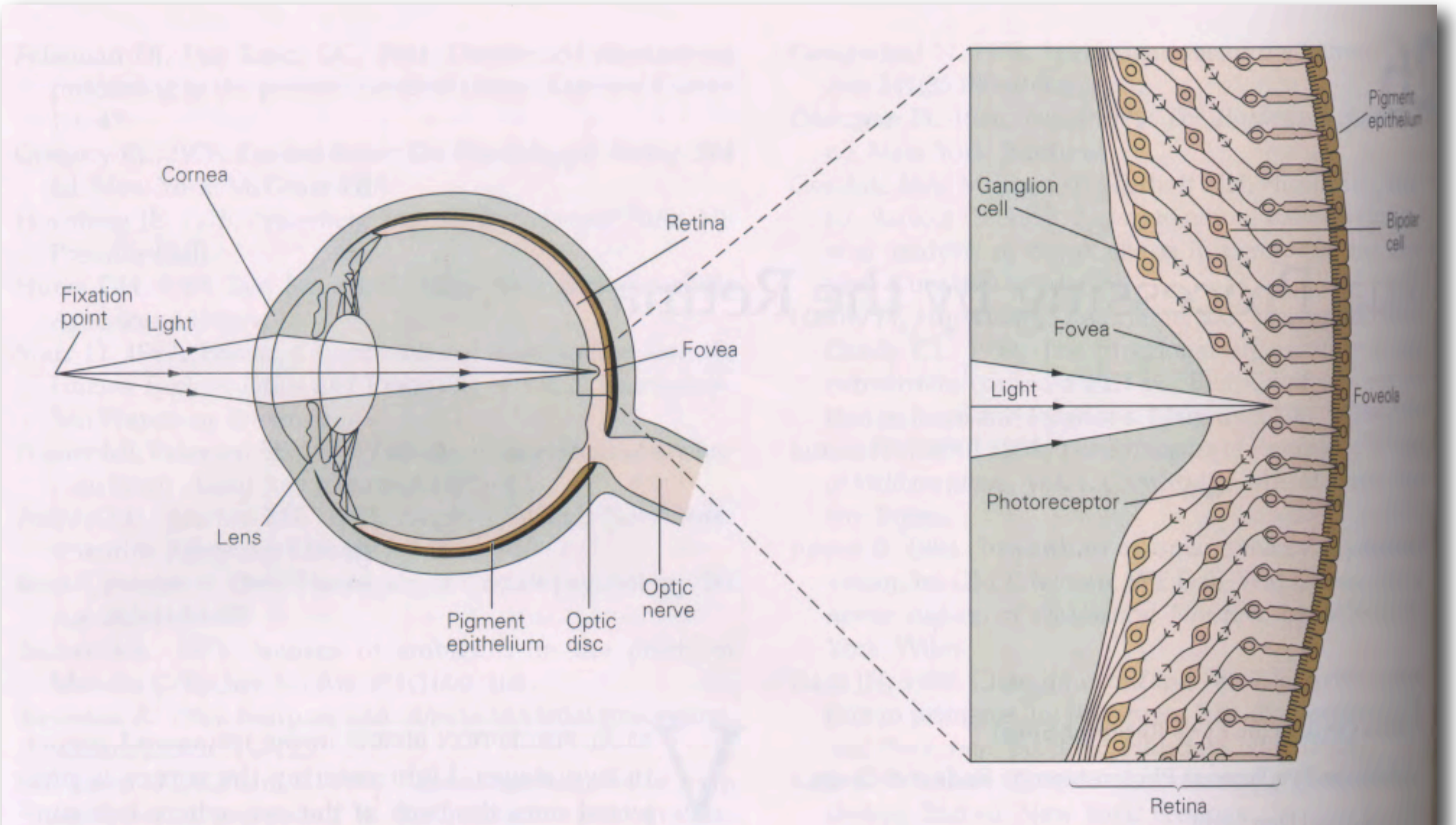
Neuro 500

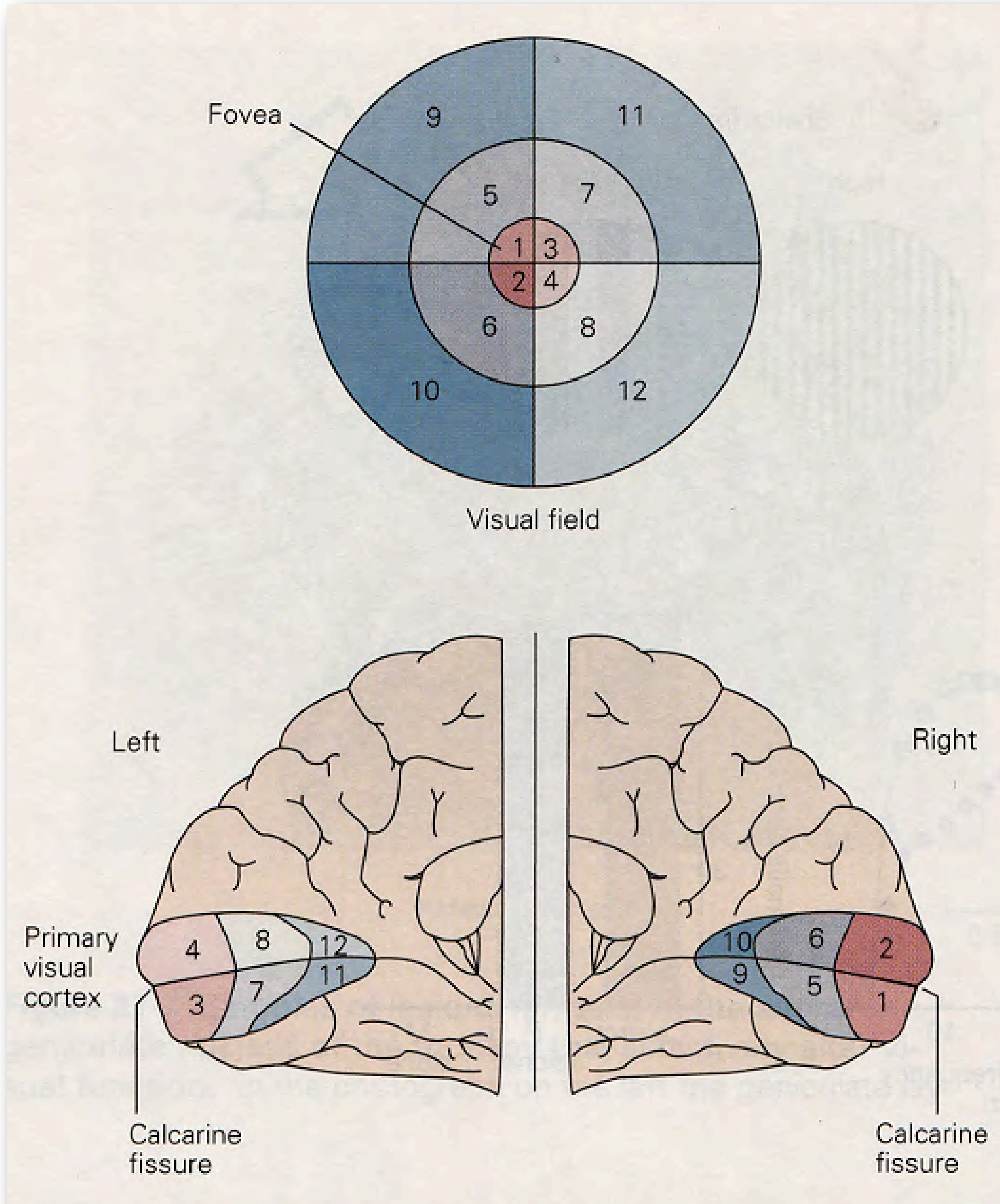
Eye Movements

What is the purpose of eye movements?

High visual acuity is restricted to the fovea. The fovea has a high density of cones and each cone projects to one retinal ganglion cell in the fovea.

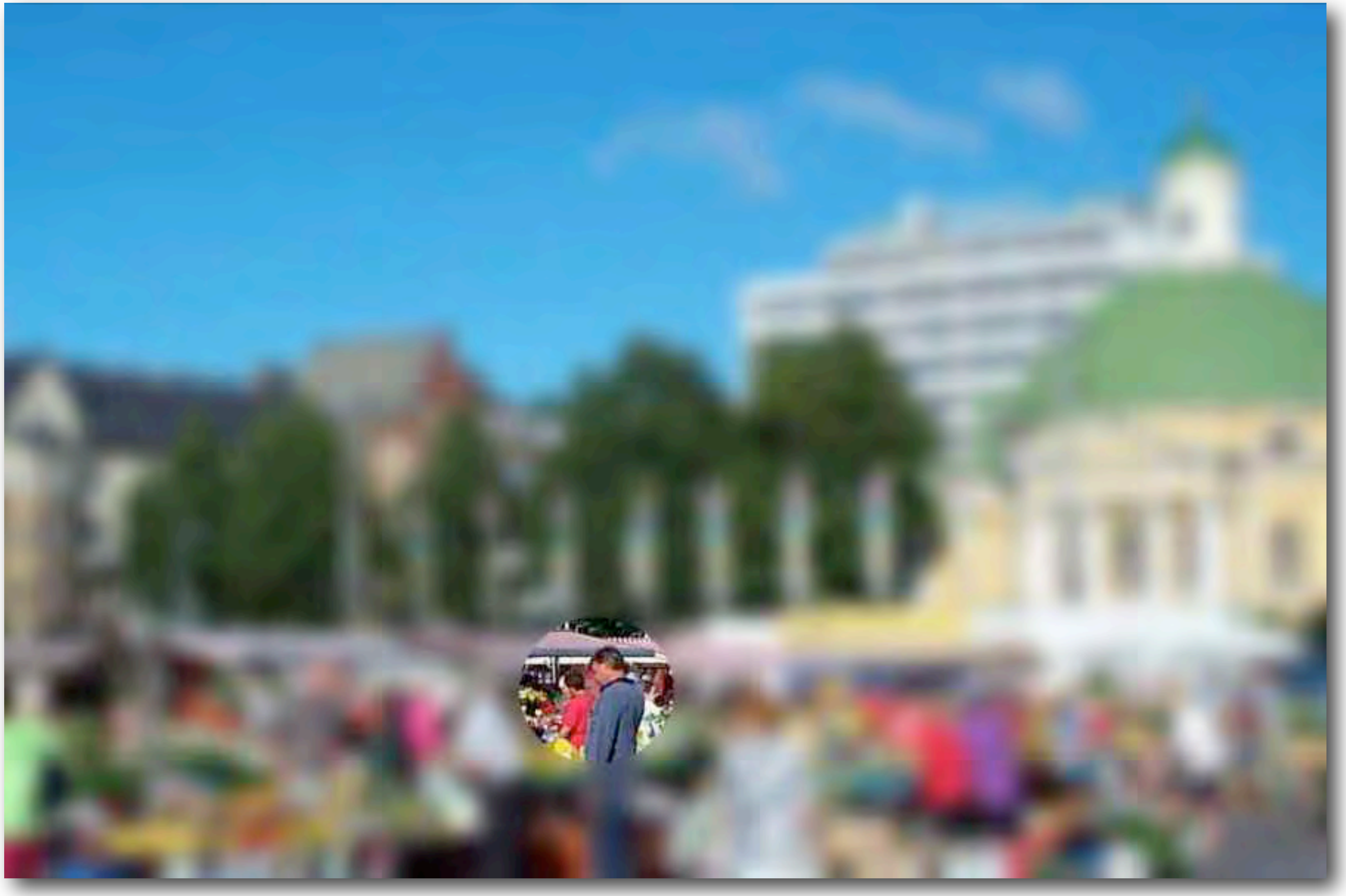


Cortical Representation of the Fovea



What is the purpose of eye movements?

The fovea has to be moved onto objects of interest to analyze them in detail.



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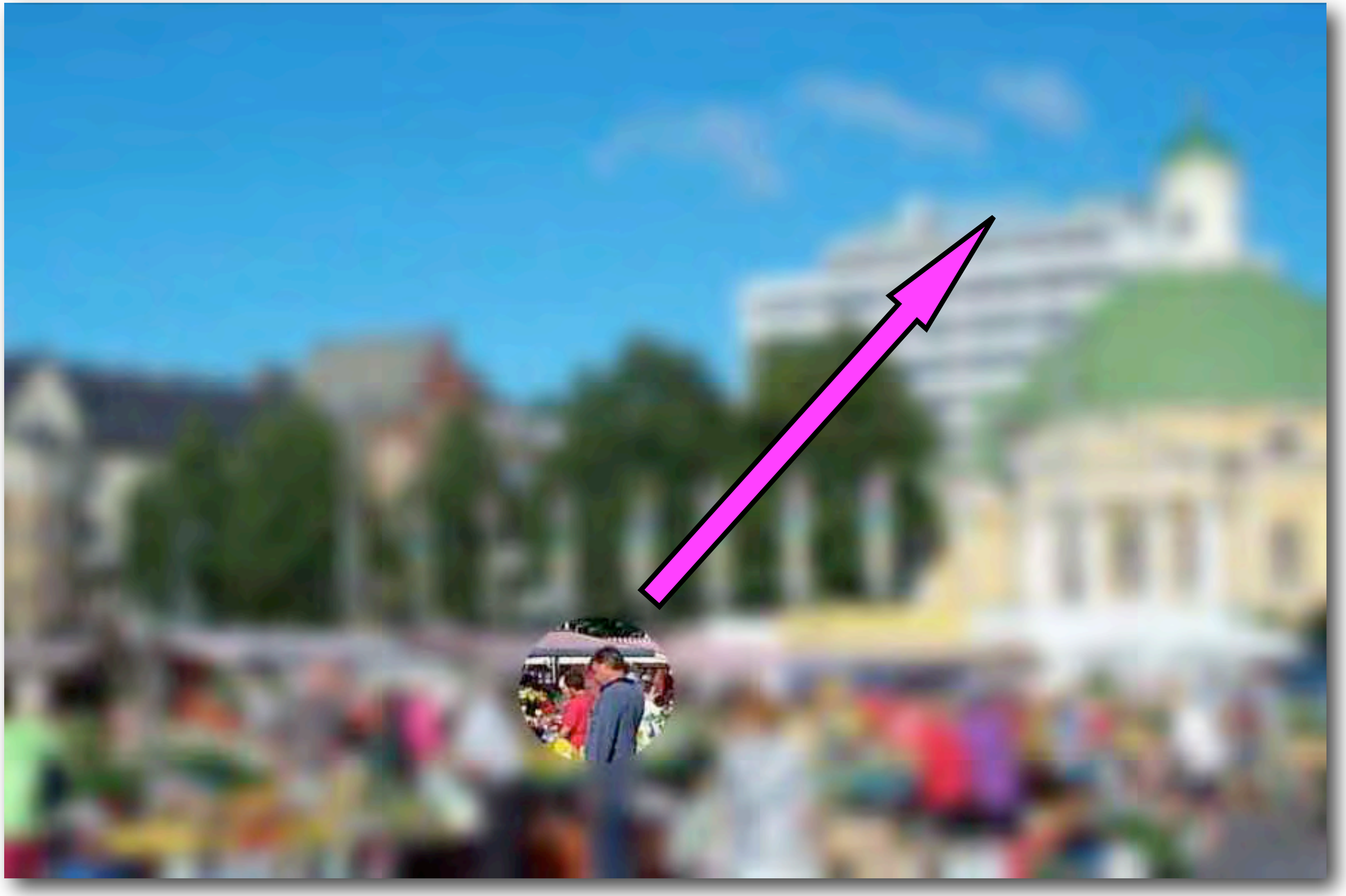

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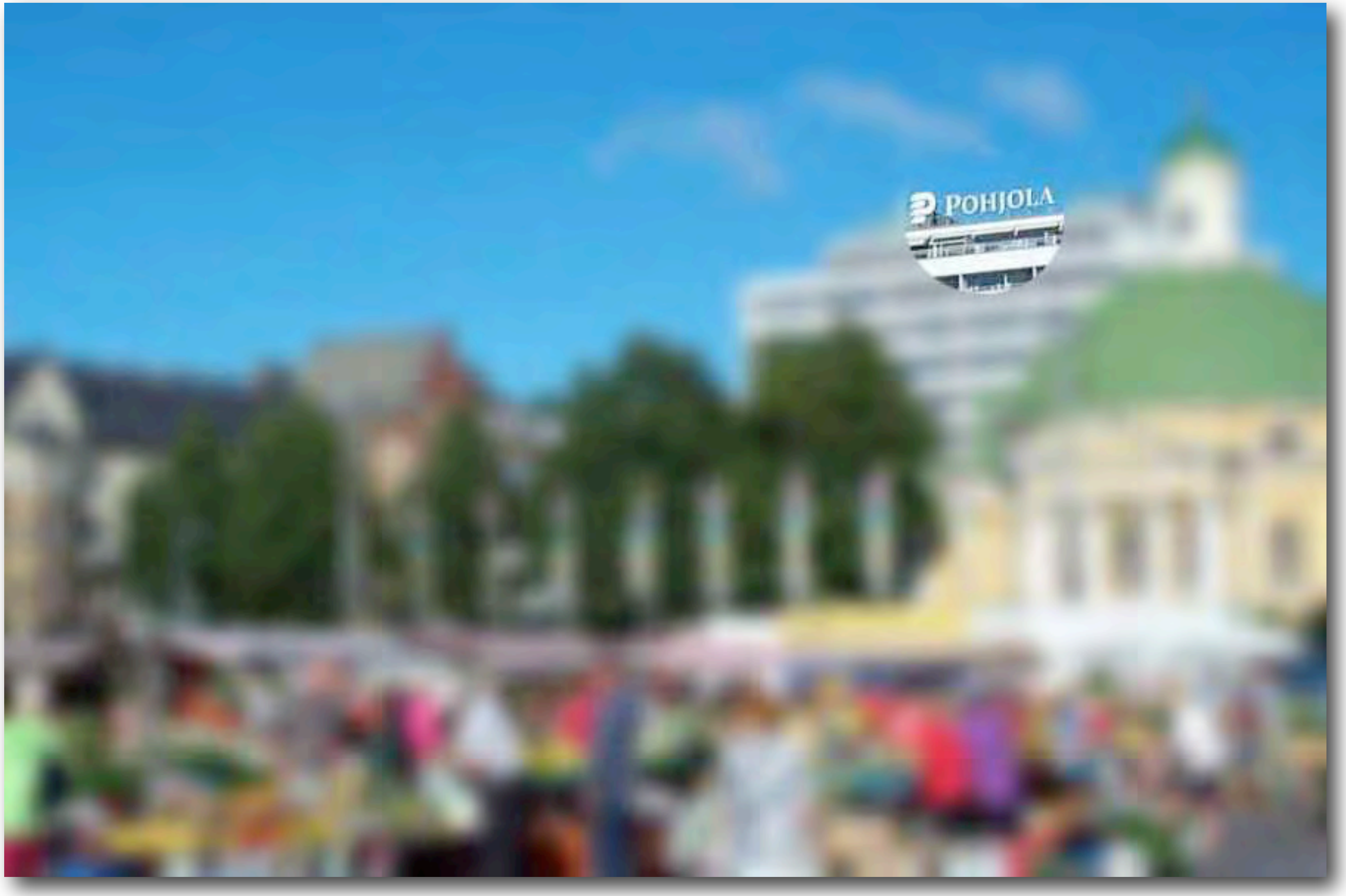
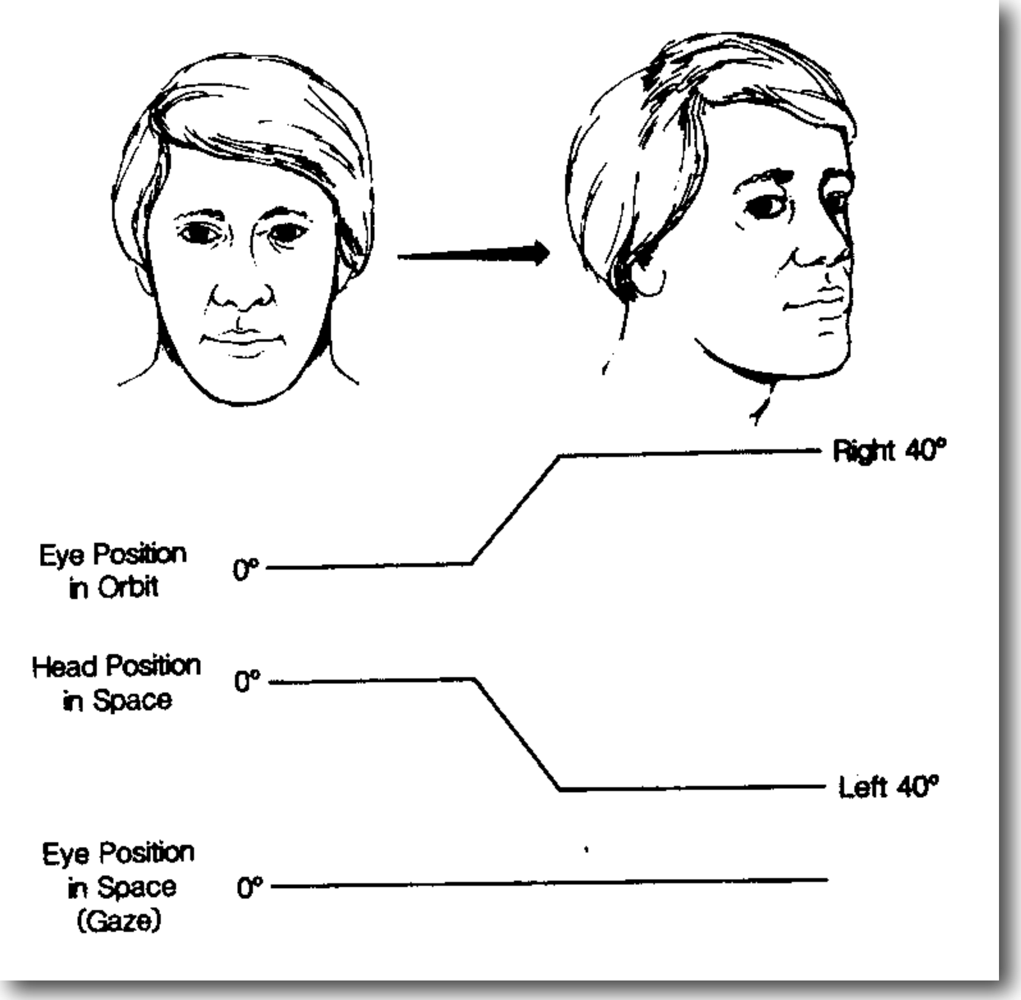


Types of Eye Movements

Movements that stabilize the retinal image

I. Vestibulo-ocular Refex

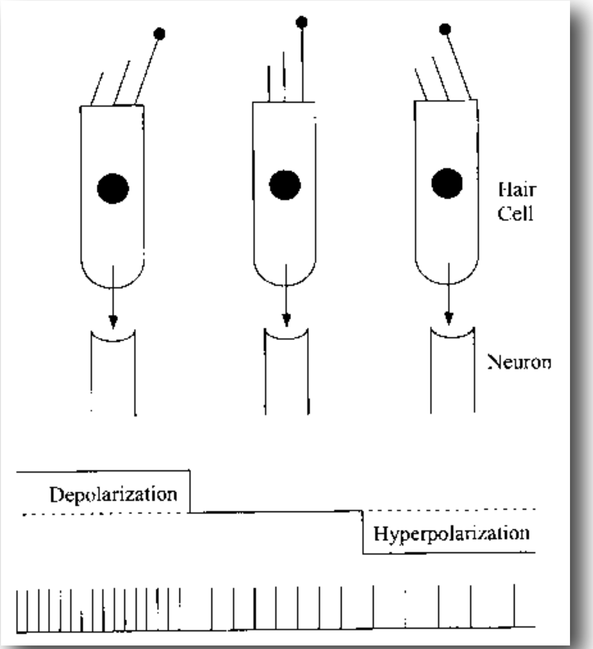
Vestibulo-ocular movements stablize the eyes relative to the external world, compensating for head movements. This reflex prevents visual images from "slipping" on the surface of the retina as head position changes.

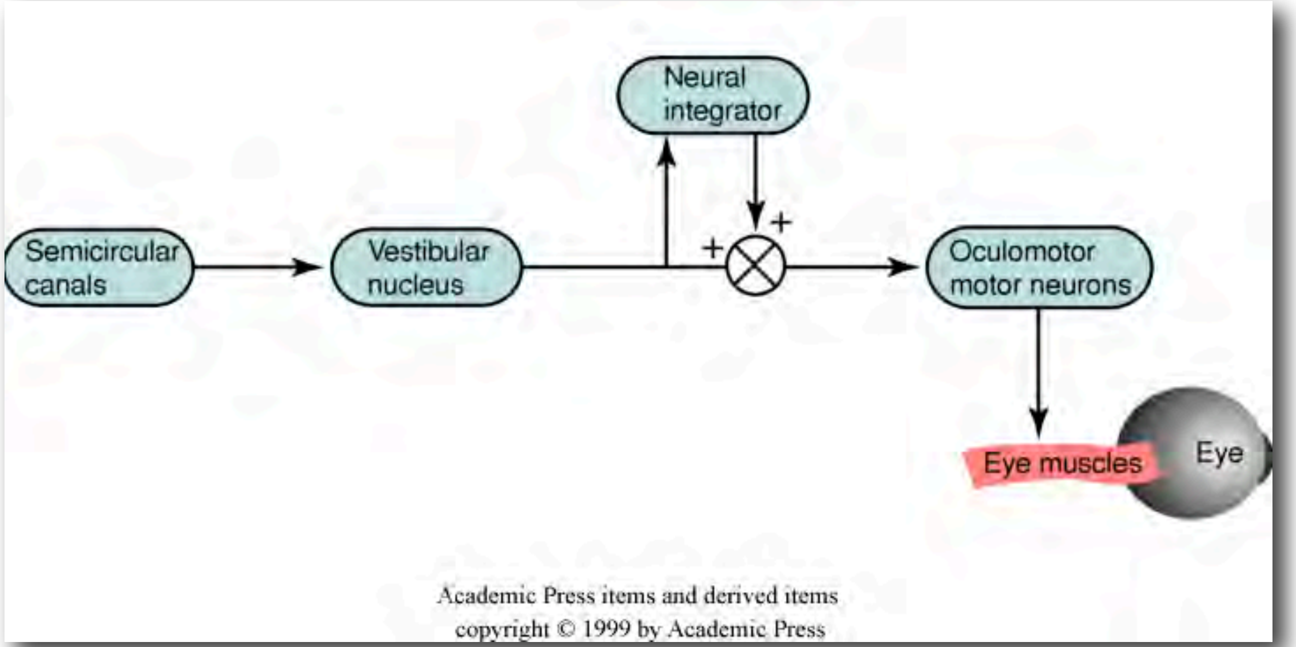


Types of Eye Movements

Movements that stabilize the retinal image
1. Vestibulo-ocular Reflex

The vestibular system detects brief, transient changes in head position and quickly produces corrective eye movements in a direction opposite to the head movement.





Types of Eye Movements

Movements that stabilize the retinal image
II. Optokinetic Nystagmus

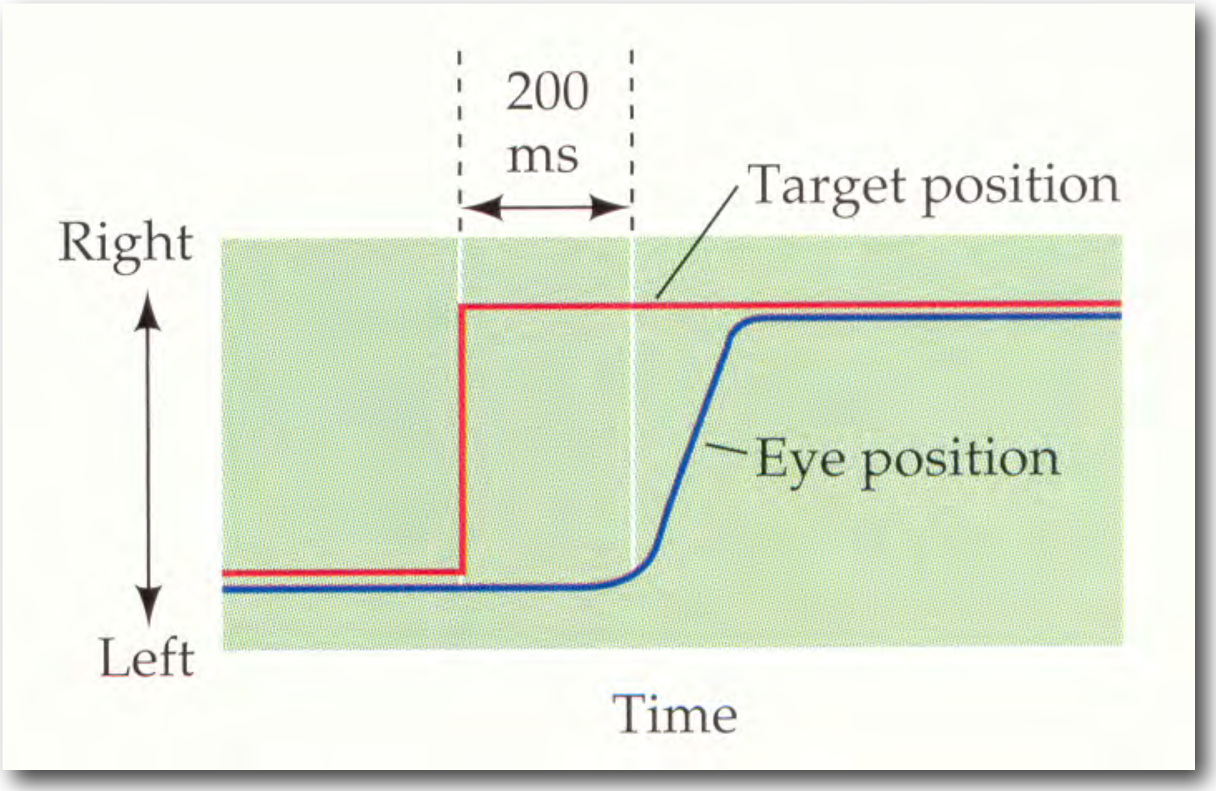
The optokinetic nystagmus stabilizes the eyes relative to the external world, compensating for ***movements of the visual image***. This reflex prevents visual images from "slipping" on the surface of the retina as the visual world moves.

Types of Eye Movements

Movements that align the fovea with a visual target

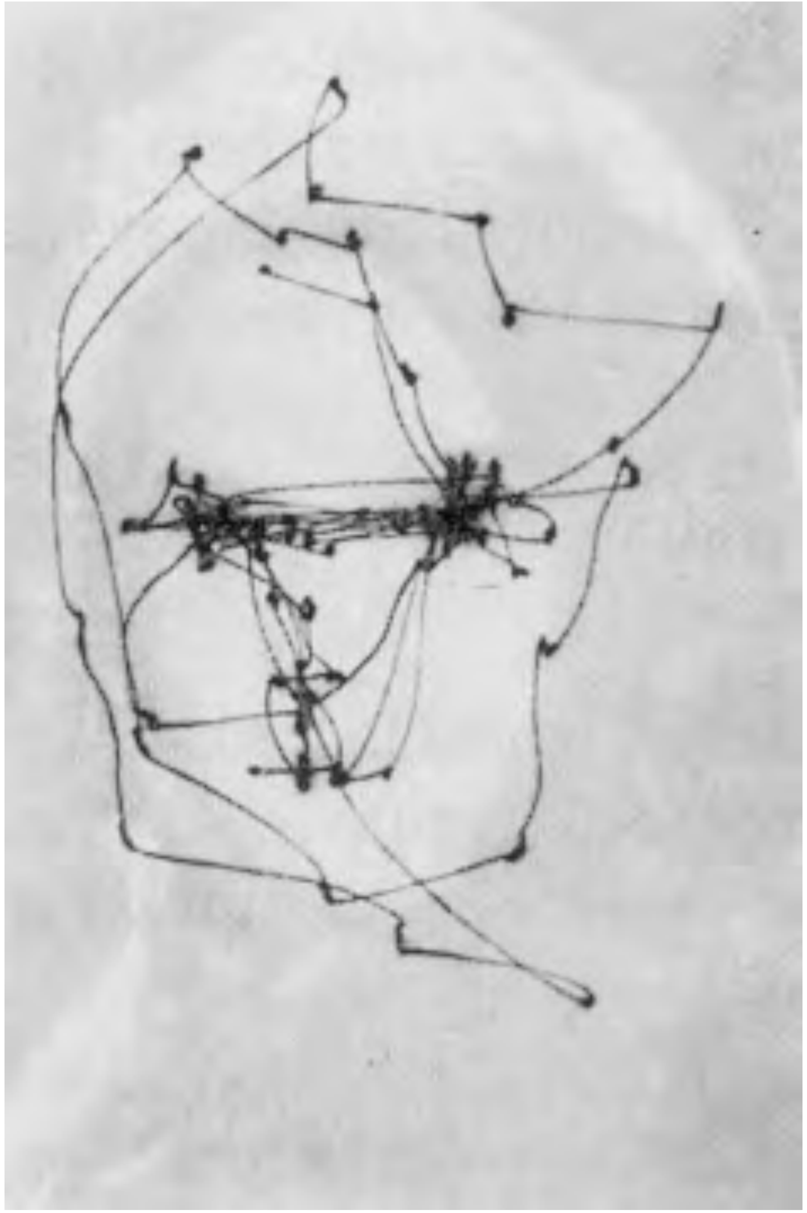
I. Saccadic Eye Movements

Saccades are made spontaneously in response to a suddenly appearing (or jumping) object. They are also the movements produced while we scan a visual scene or read. Thus saccades can either be *reflexive* or *voluntary*.



Saccade-Fixation Behavior

Saccade-Fixation Behavior

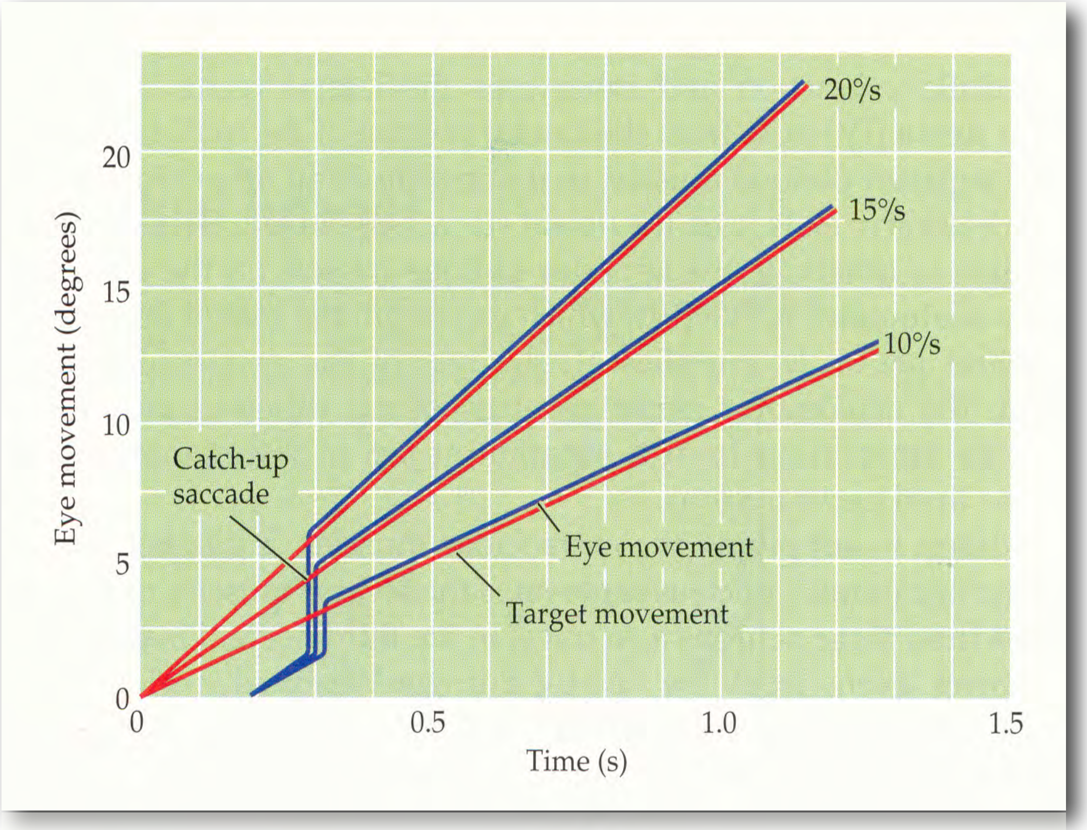


Types of Eye Movements

Movements that align the fovea with a visual target

II. Smooth Pursuit Eye Movements

Smooth pursuit movements are ***slow tracking movements*** of the two eyes designed to keep the image of a moving stimulus on the fovea. Fast moving stimuli cannot be tracked with precision, and they usually elicit saccadic eye movements.

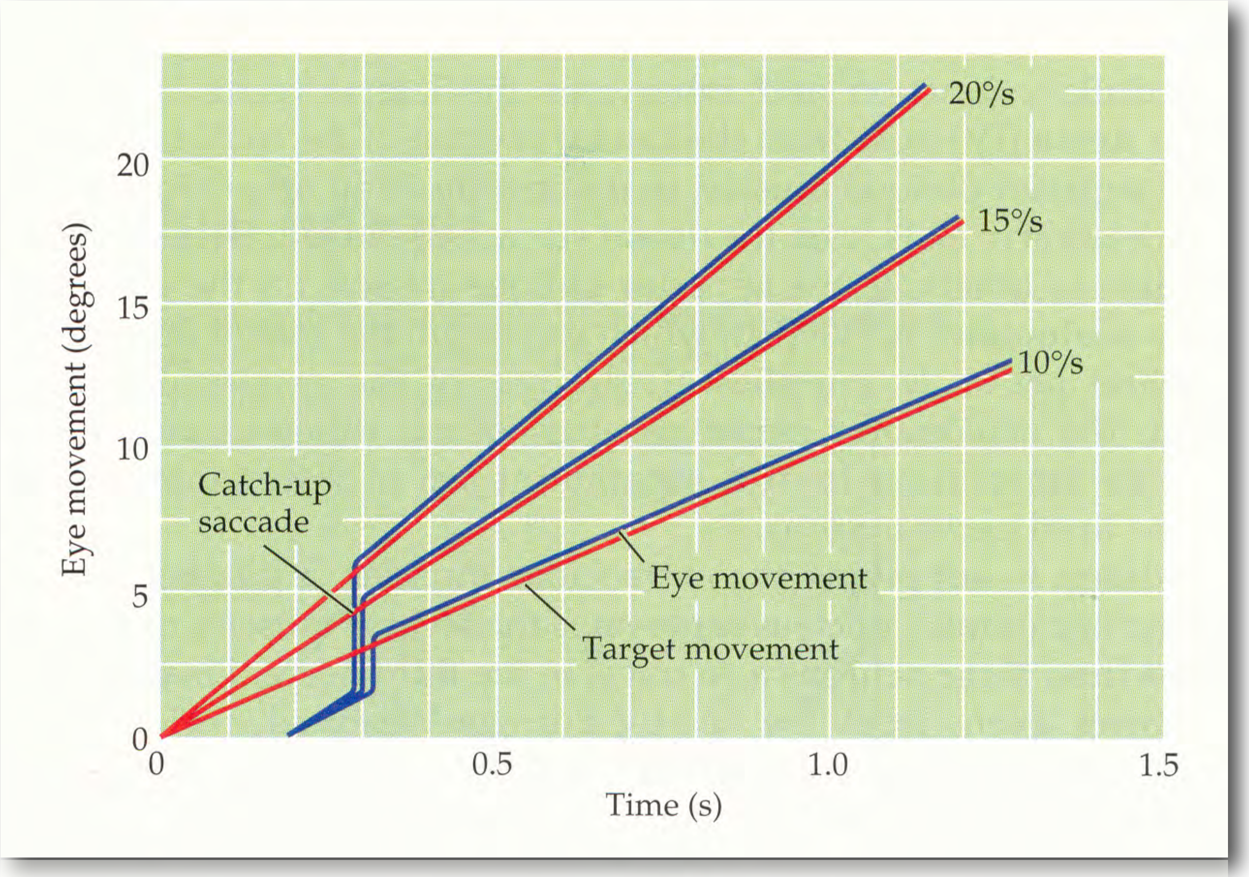


Types of Eye Movements

Movements that align the fovea with a visual target

II. Smooth Pursuit Eye Movements

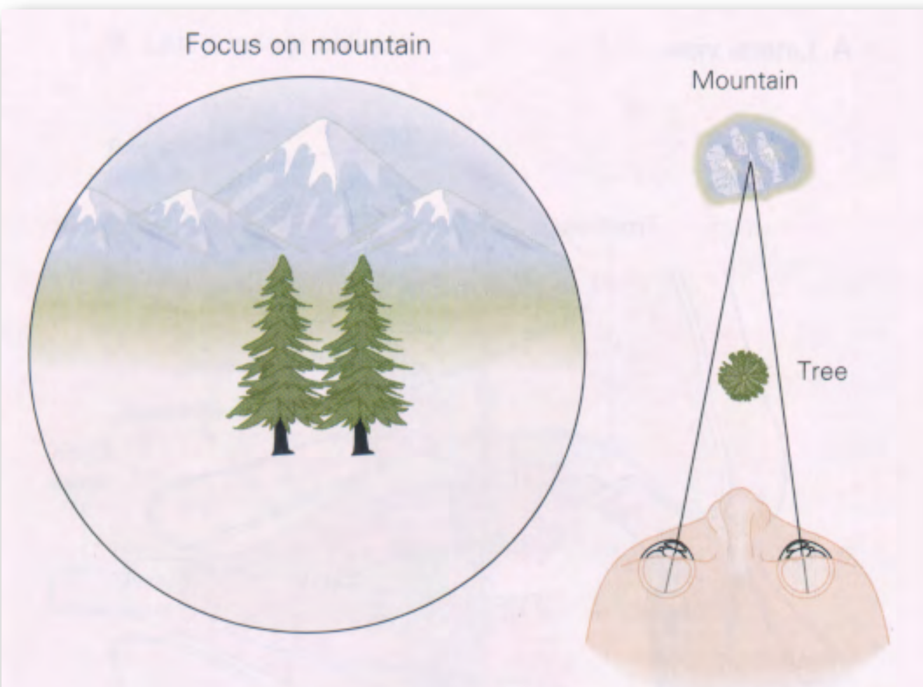
The pursuit system needs to compute the speed of the moving stimulus to produce the proper eye velocity. Moving your eyes in this fashion without a moving object is impossible.

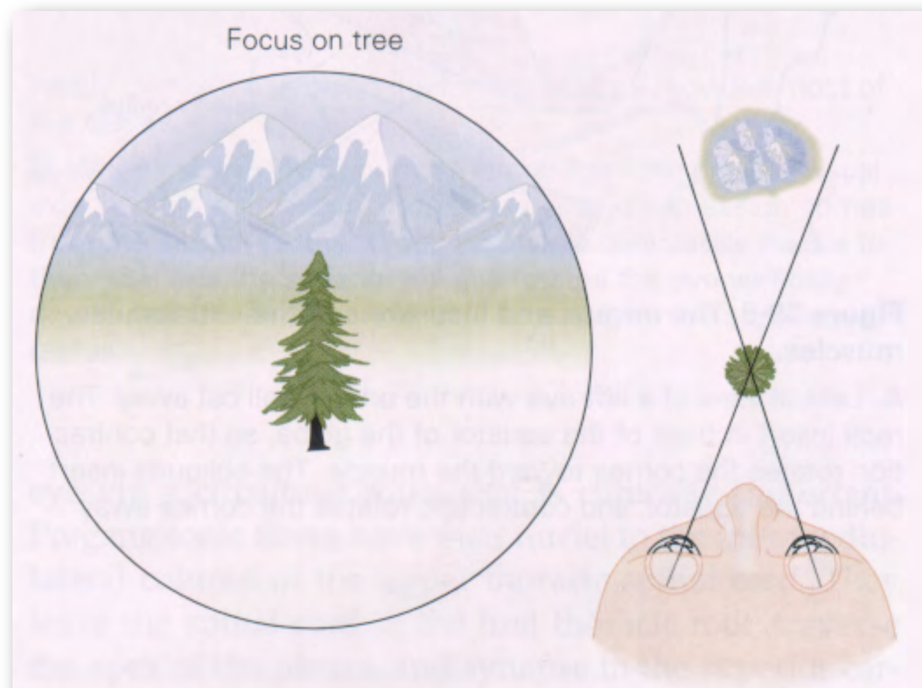


Types of Eye Movements

Movements that align the fovea with a visual target
III. Vergence Eye Movements

Vergence eye movements align the fovea of each eye with targets at different *distances* from an observer. They are *disconjugate* movements, i.e. they move the eyes in opposite directions.





Types of Eye Movements

Movements that stabilize the retinal image

Vestibulo-ocular Reflex

Optokinetic Nystagmus

Movements that align the fovea with a visual target

Saccadic Eye Movements

Smooth Pursuit Eye Movements

Vergence Eye Movements

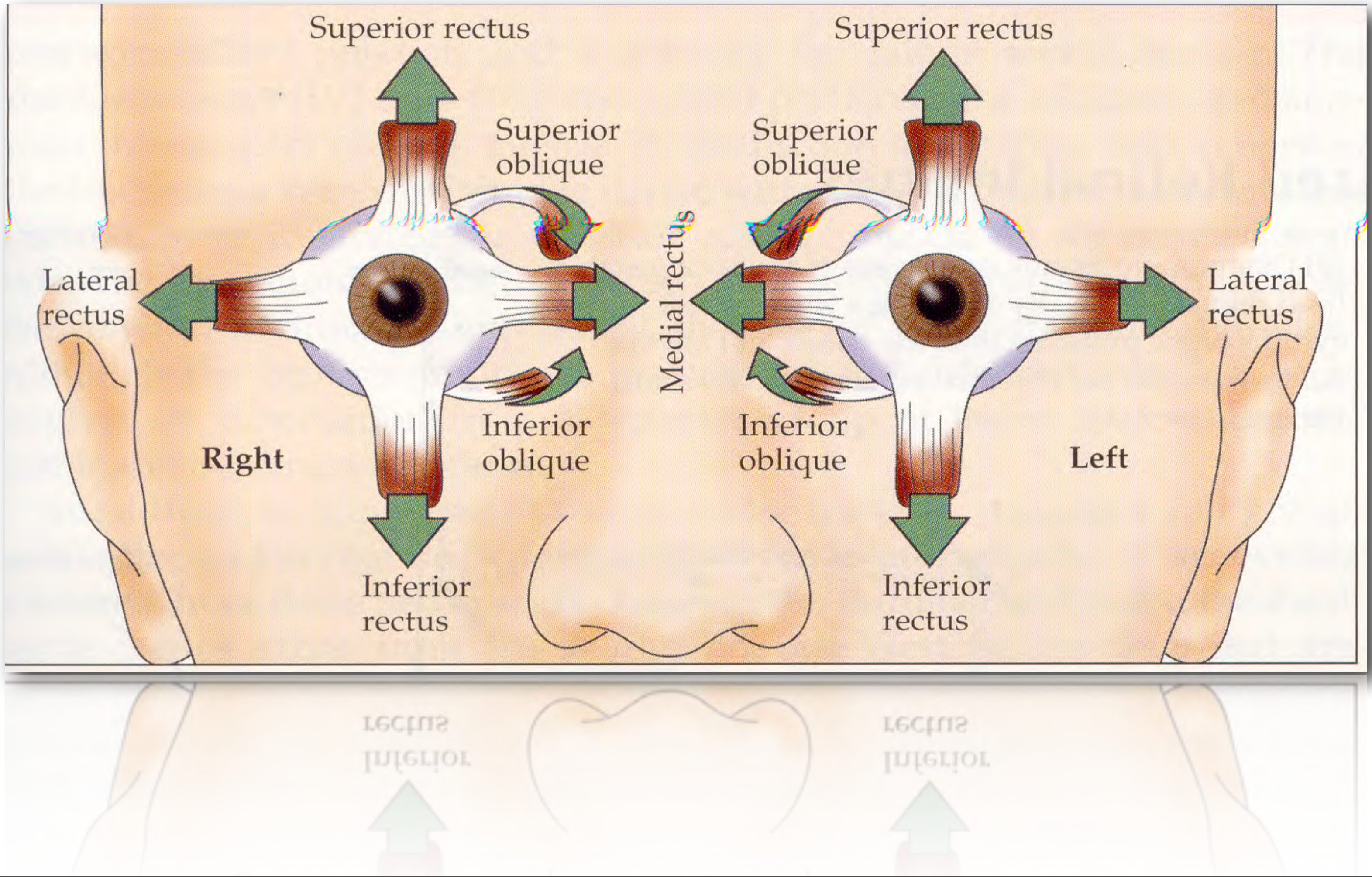
Types of Eye Movements

Movements that stabilize the retinal image
Vestibulo-ocular Reflex
Optokinetic Nystagmus

Movements that align the fovea with a visual target
Saccadic Eye Movements
Smooth Pursuit Eye Movements
Vergence Eye Movements

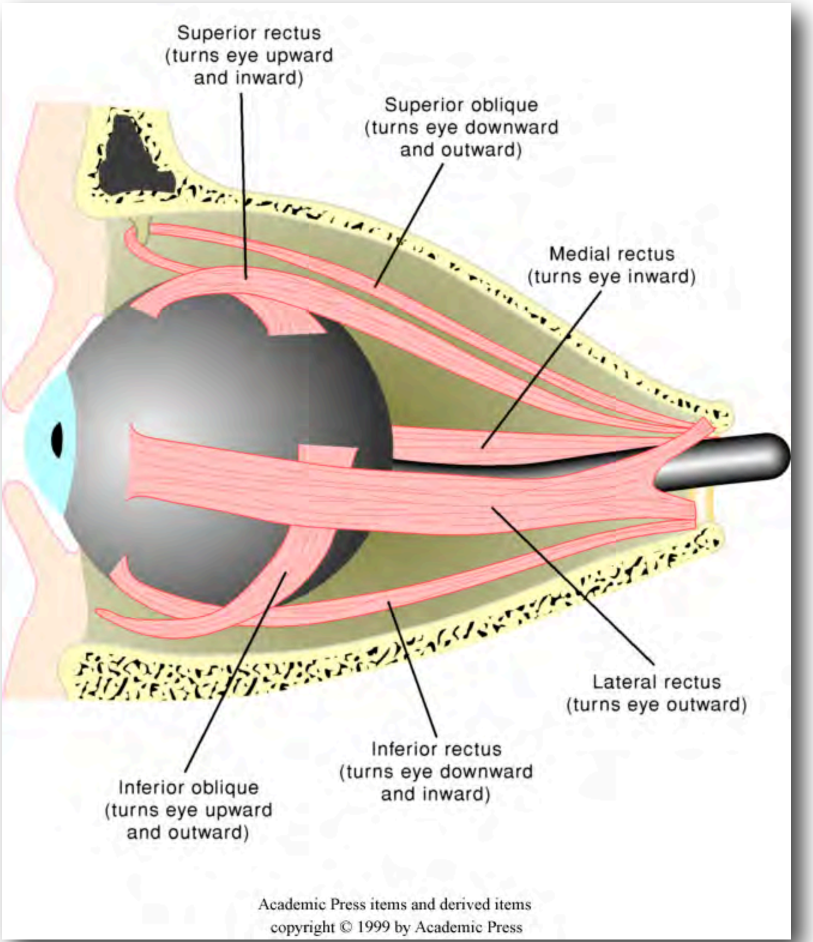
Extraocular Muscles

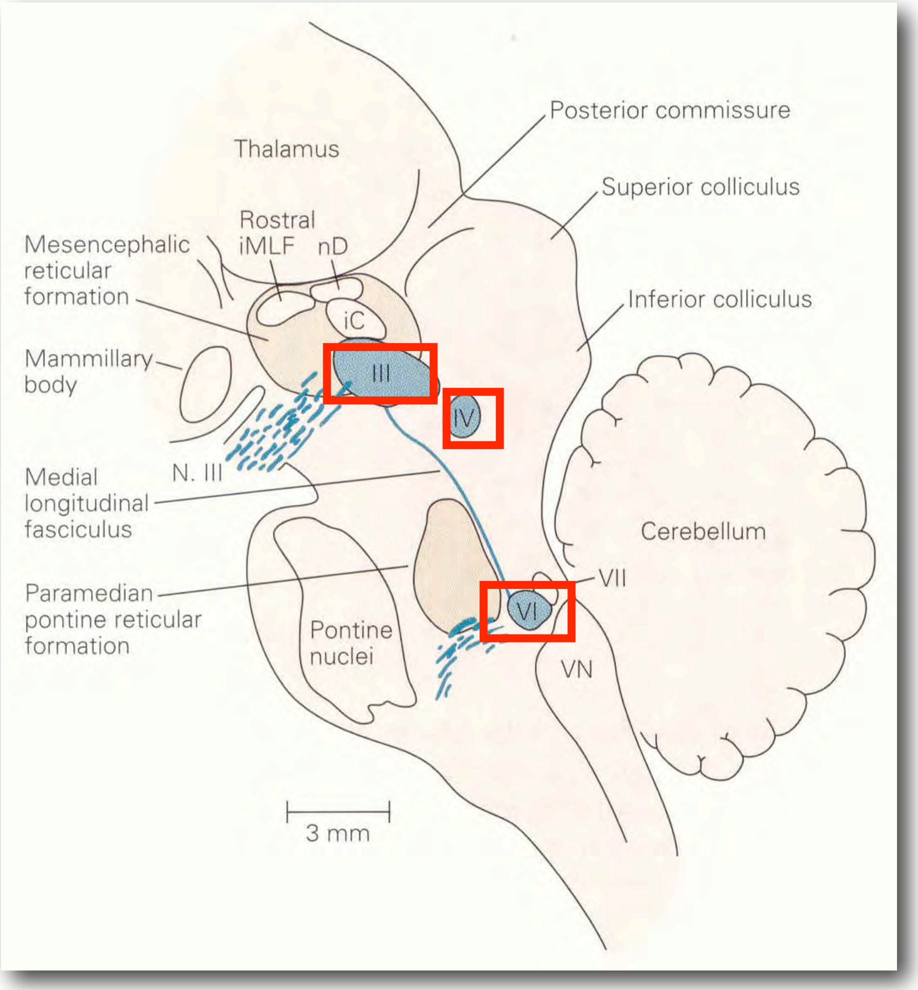
The eyes are rotated by the action of *six* extraocular muscles, which act as *three agonists/antagonists* allowing rotations in horizontal, vertical and torsional directions.



Extraocular Muscle Innervation

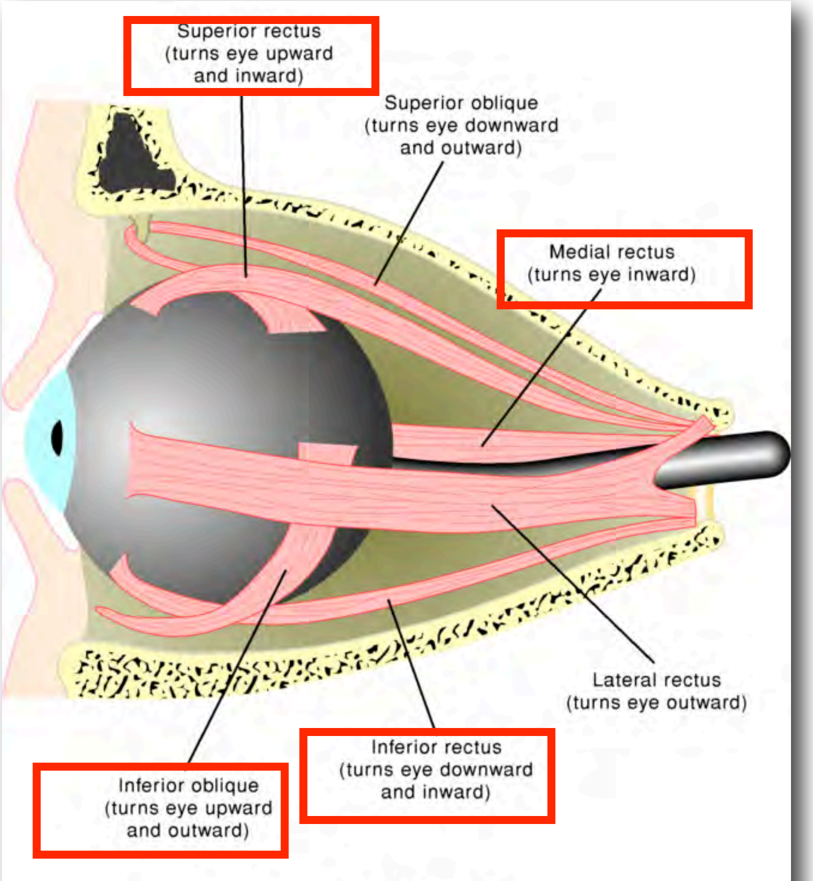
The six extraocular muscles are innervated by three cranial nerves: the ***Oculomotor*** nerve (III), the ***Trochlear*** nerve (IV) and the ***Abducens*** nerve (VI).

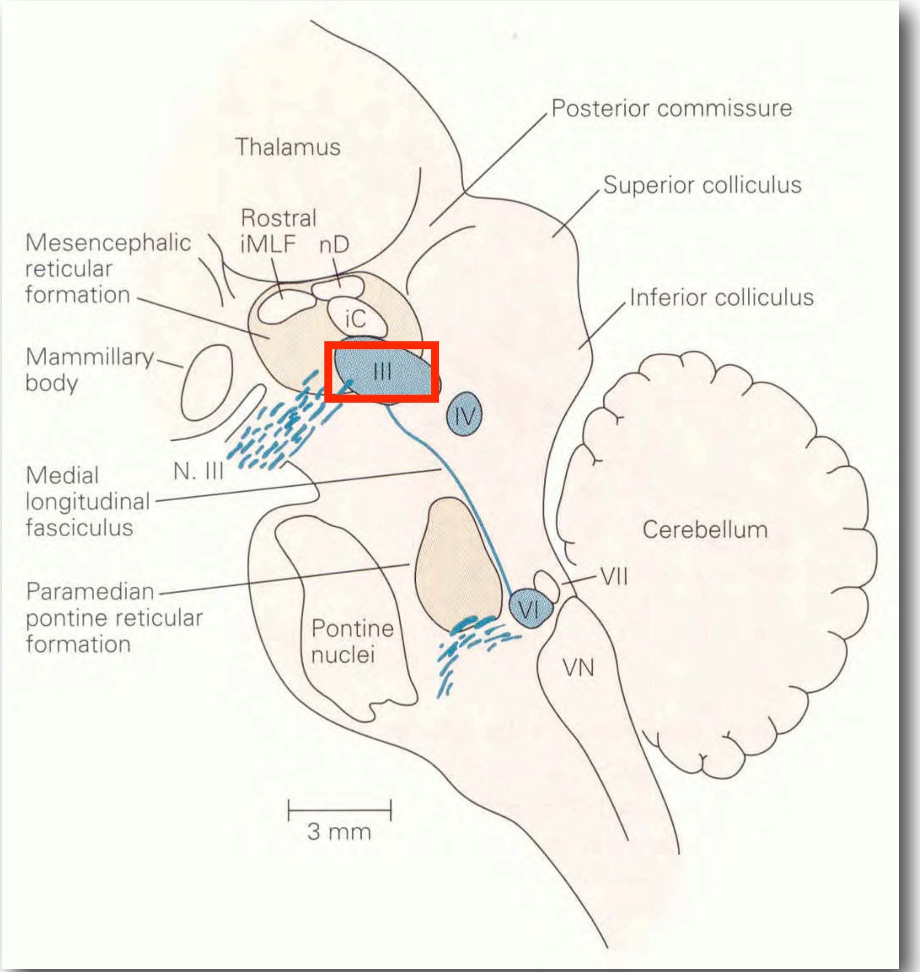




Extraocular Muscle Innervation

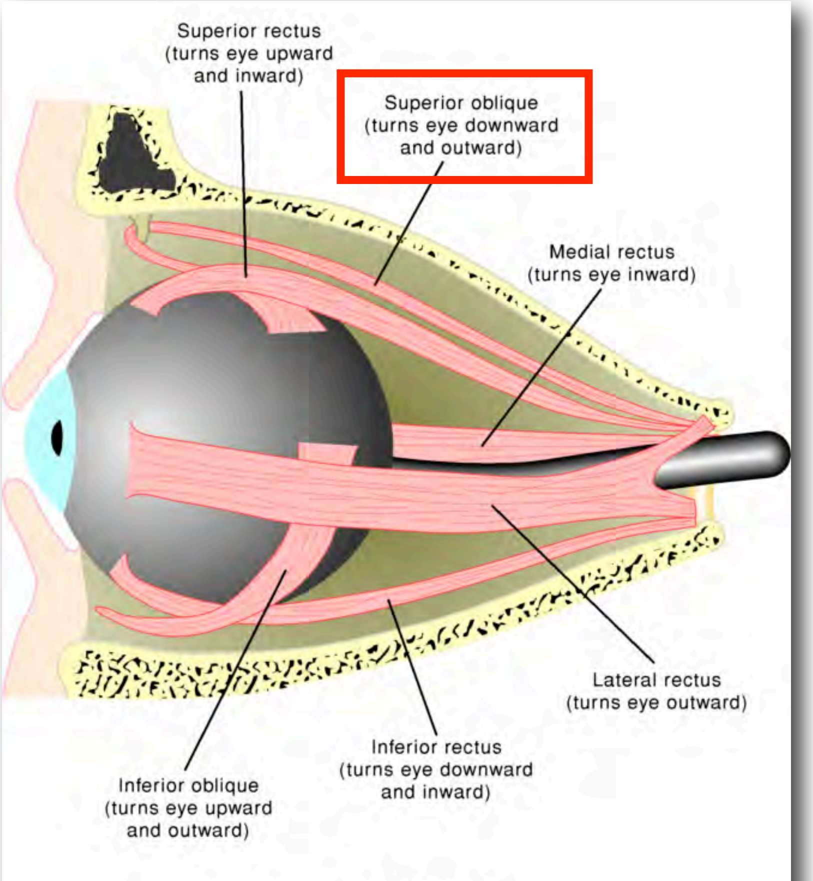
The ***Oculomotor nerve*** (III) originates in the midbrain. It innervates the ***superior*** and ***inferior recti***, the ***inferior oblique***, and the ***medial rectus***.

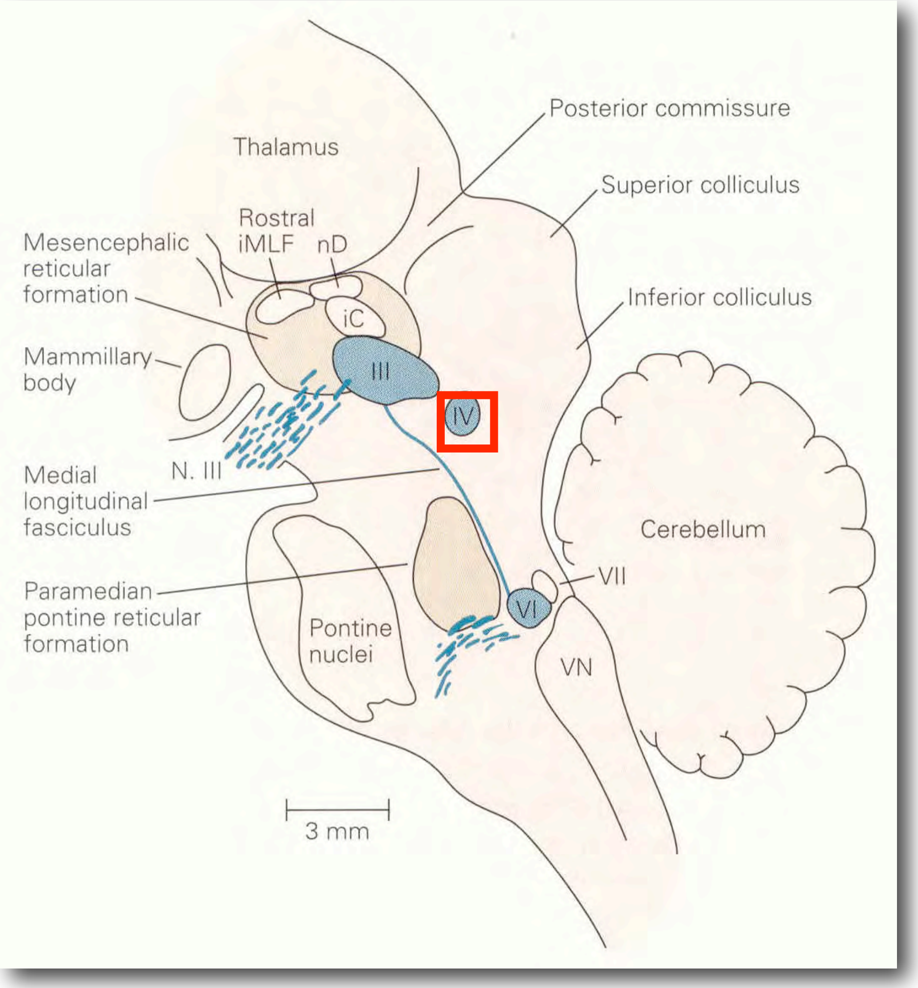




Extraocular Muscle Innervation

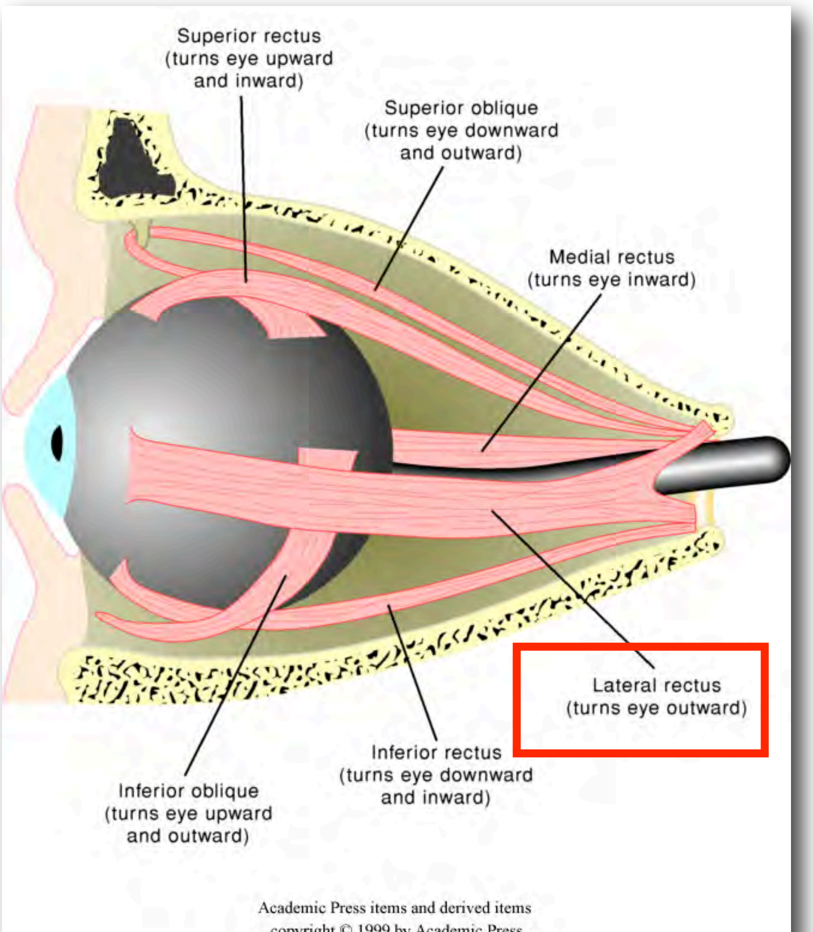
The ***Tochlear nerve*** (IV) originates in the midbrain. It innervates the ***superior oblique***.

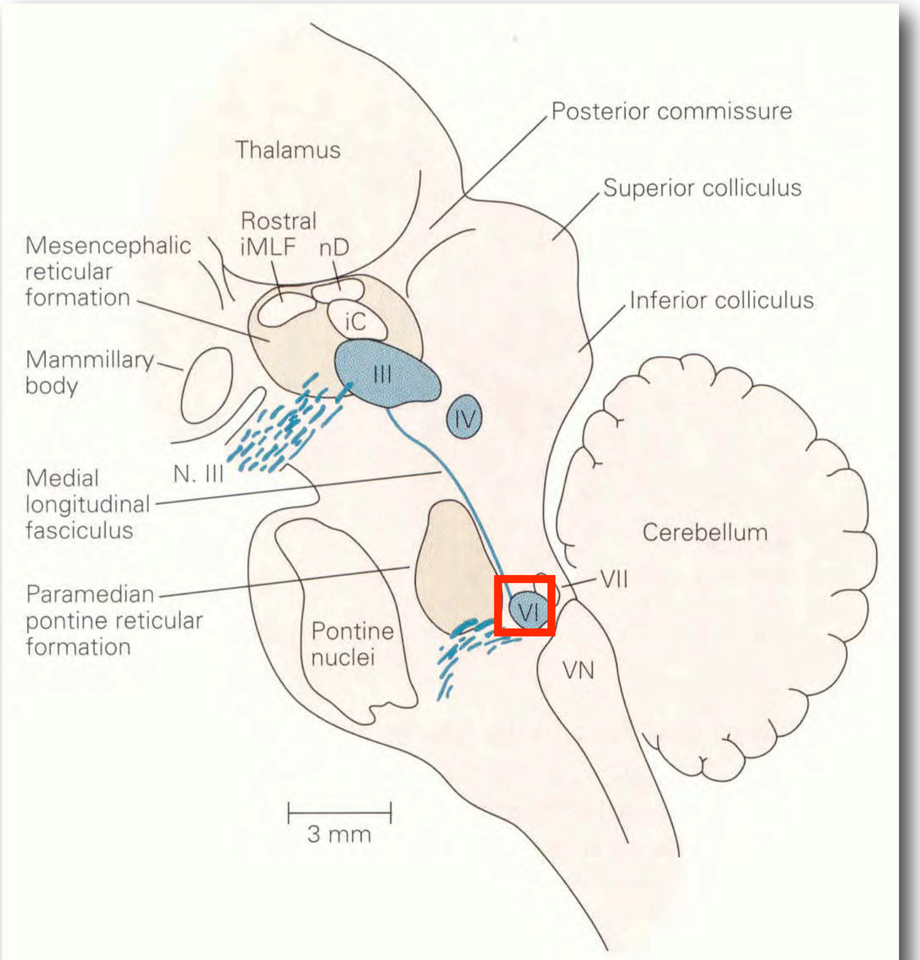




Extraocular Muscle Innervation

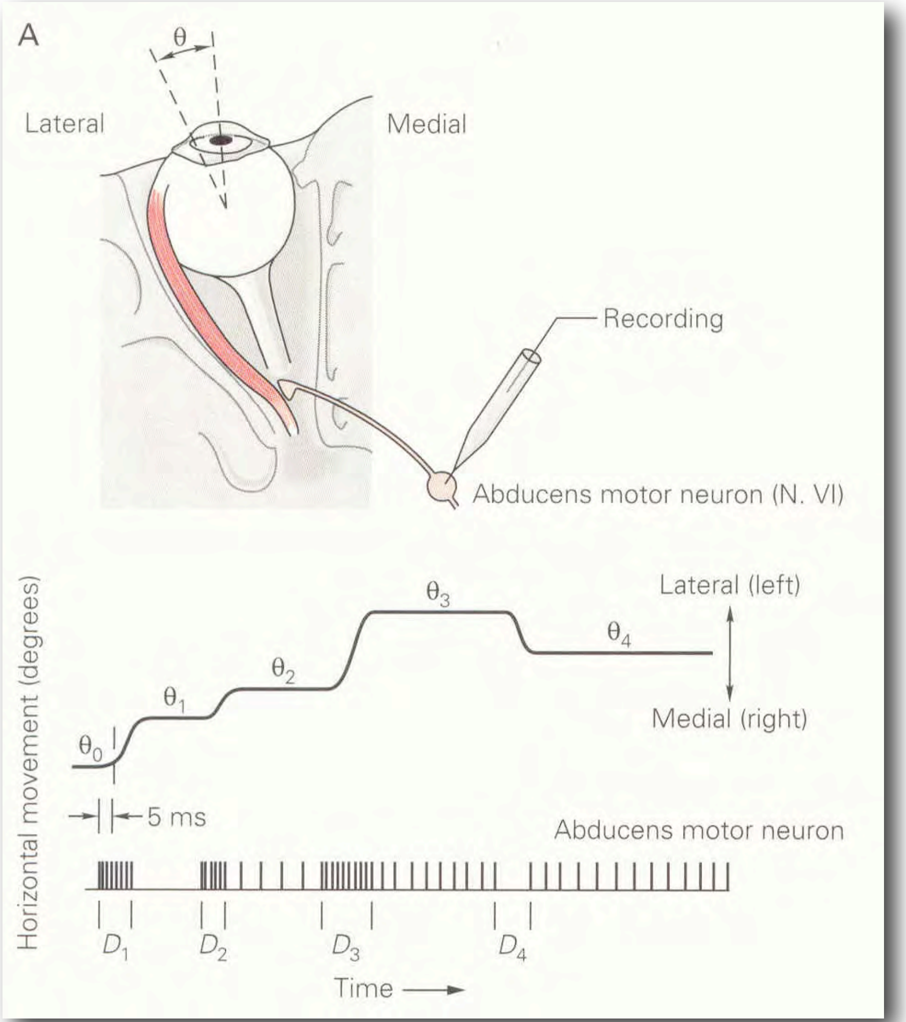
The ***Abducens nerve*** (VI) originates in the pons. It innervates the ***lateral rectus***.

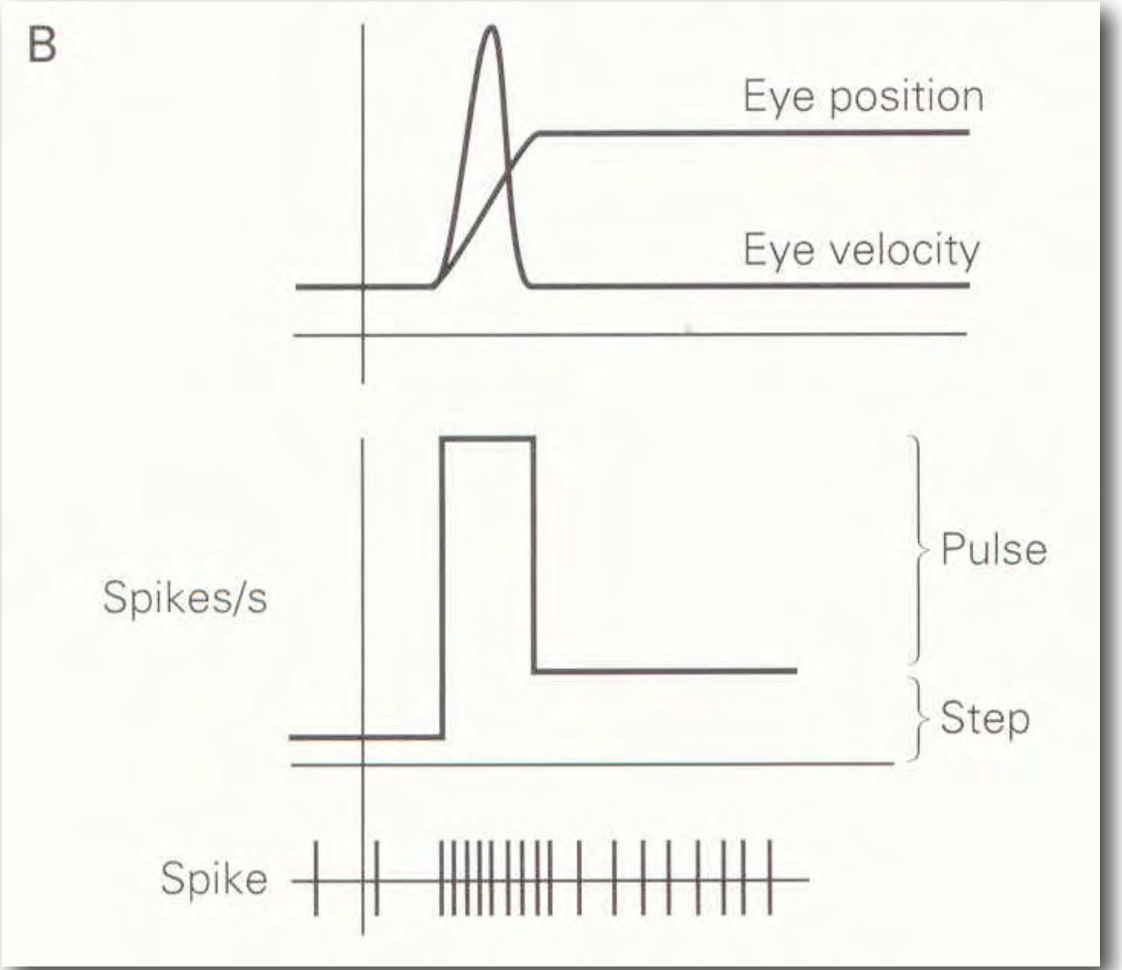




Neural Control of Saccades

The discharge property of extraocular motor neurons is directly proportional to the position and velocity of the eye.





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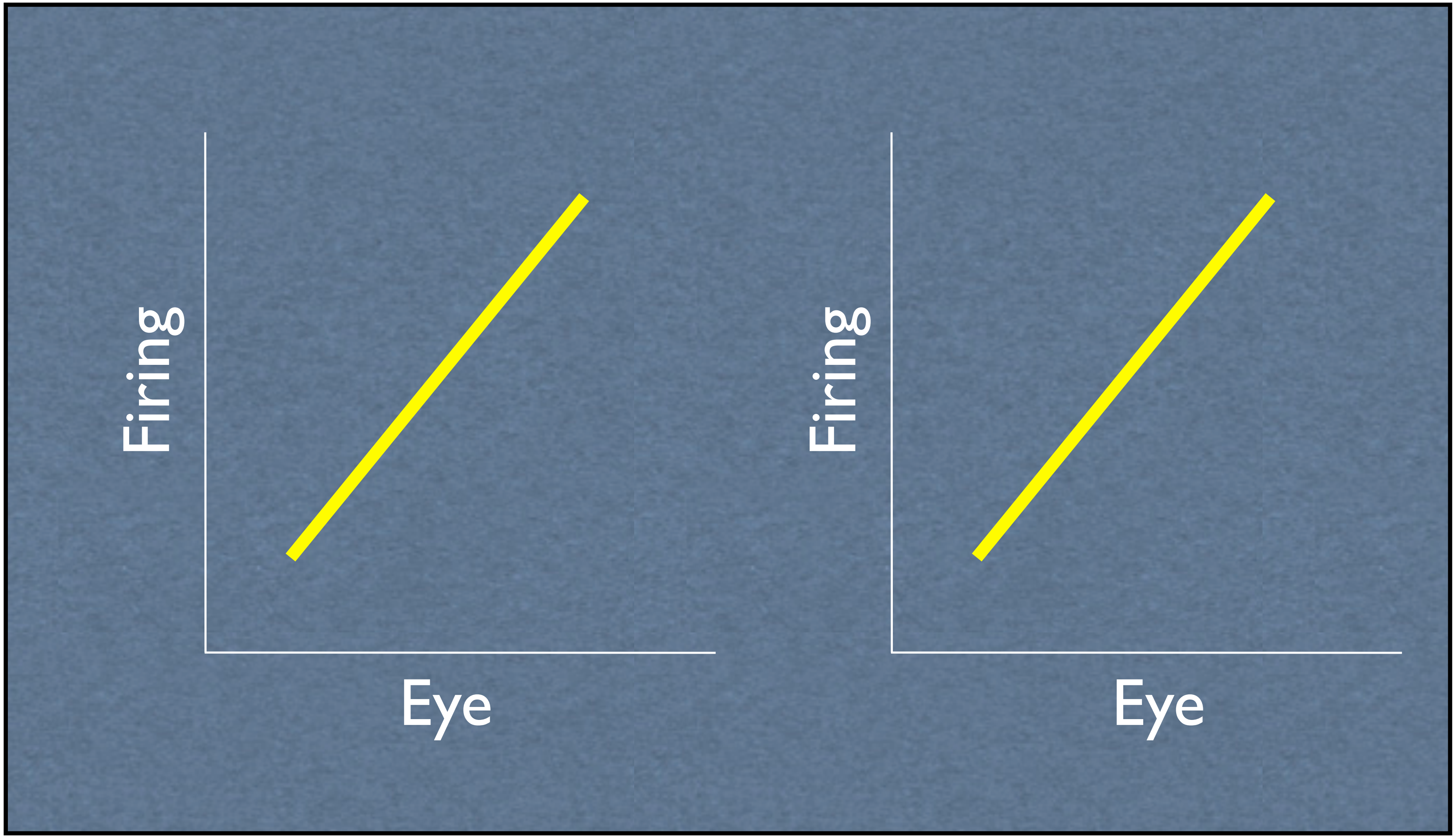
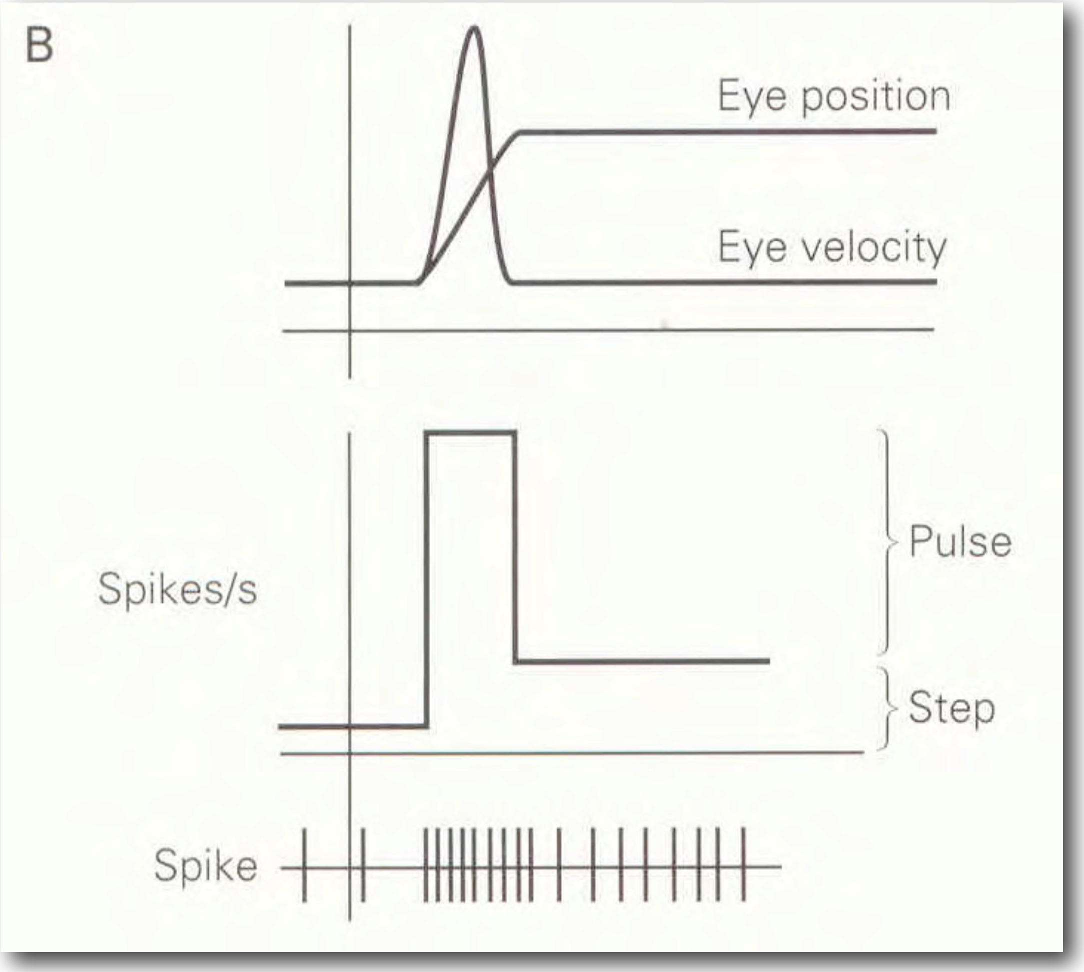


Neural Control of Saccades

The saccade signal of motor neurons has the form of a ***pulse-step.***

The height of the step determines the amplitude of the saccade, while the height of the pulse determines the speed of the saccade.

The duration of the pulse determines the duration of the saccade.

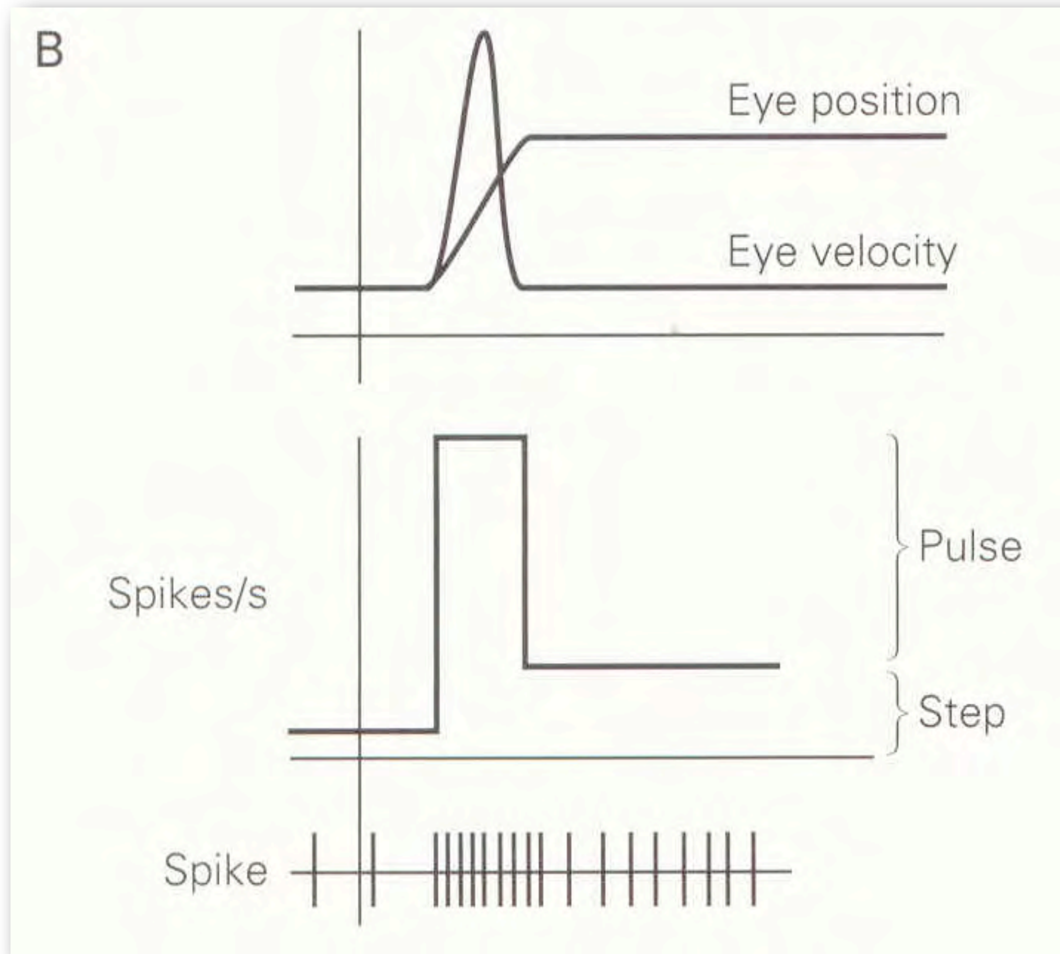


Neural Control of Saccades

The saccade signal of motor neurons has the form of a ***pulse-step.***

The pulse is the ***phasic*** signal that commands the eyes the move.

The step is the ***tonic*** signal that commands the eyes to hold in an eccentric position.

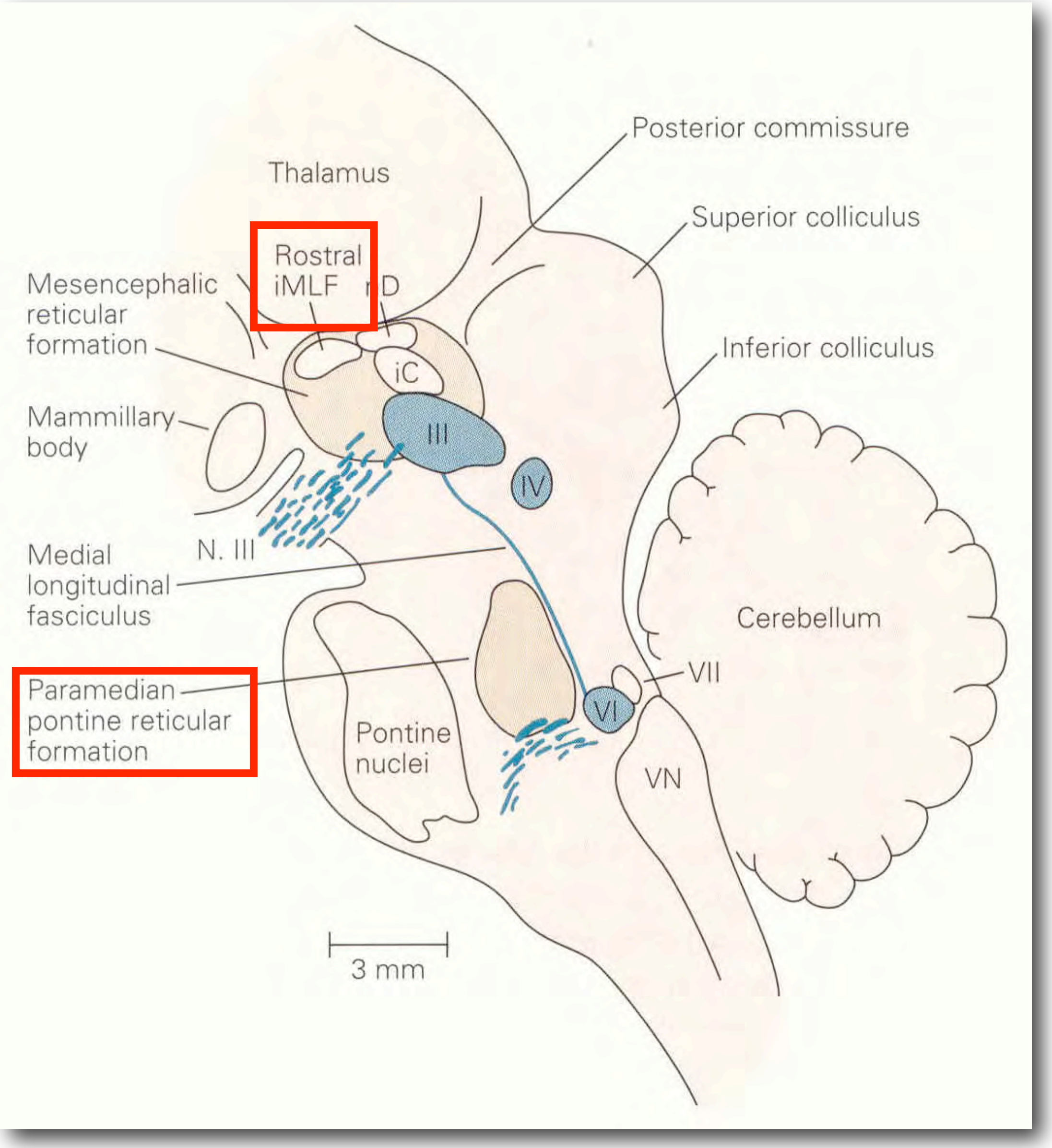


Neural Control of Saccades

The direction of saccades is controlled by premotor neurons in two gaze centers in the reticular formation:

The *paramedian pontine reticular formation (PPRF*) is the ***horizontal gaze center***.

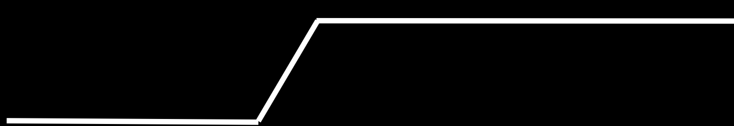
2) The *rostral interstitial nucleus (rostral iMLF***)** is the ***vertical gaze center***.

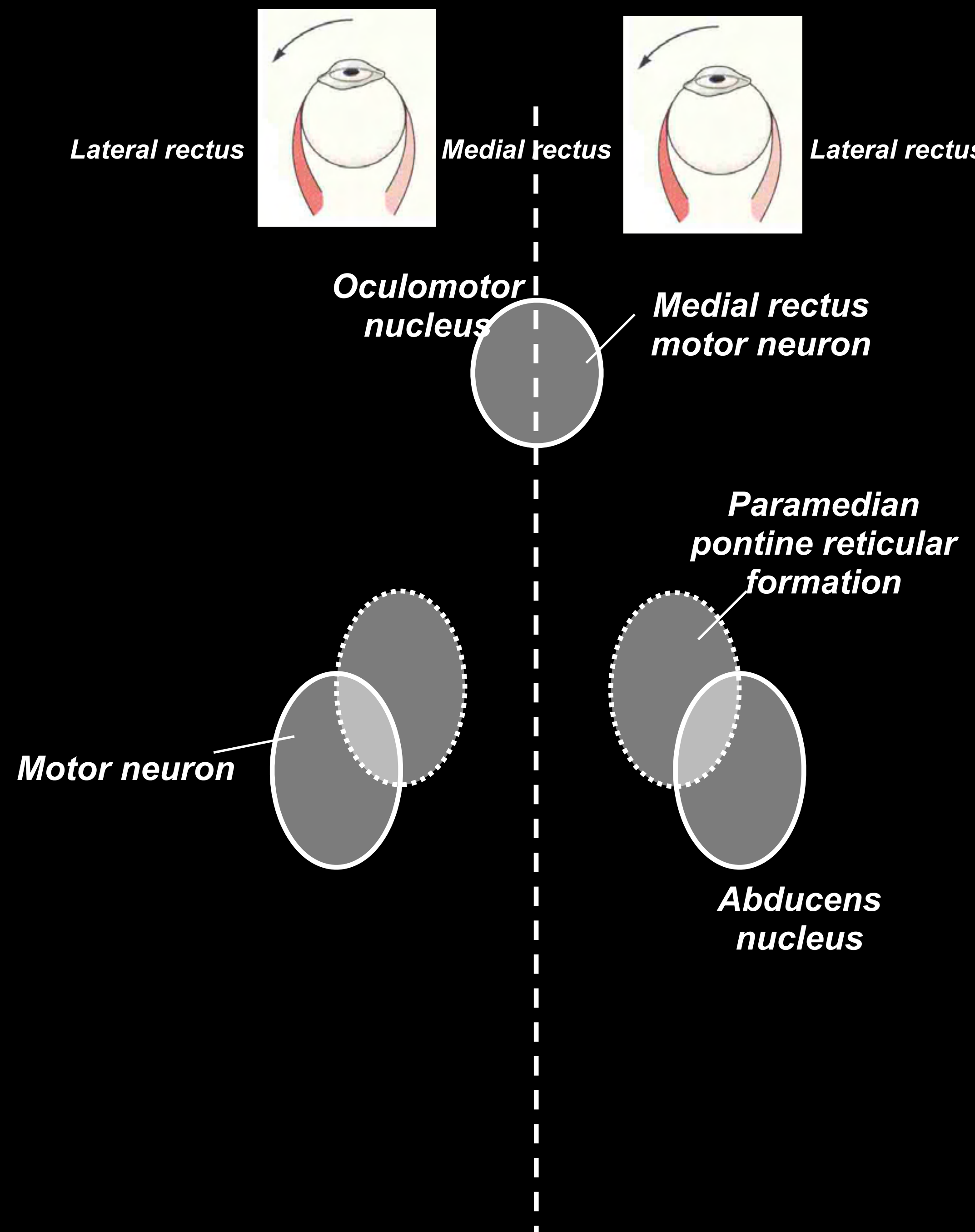


Circuit for Horizontal Saccades

Excitatory burst neurons in the PPRF provide the phasic signal to the abducens nucleus.

Eye





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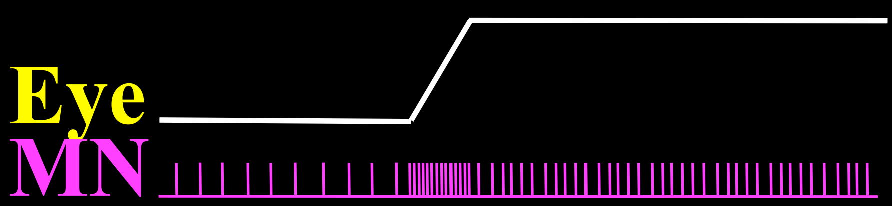

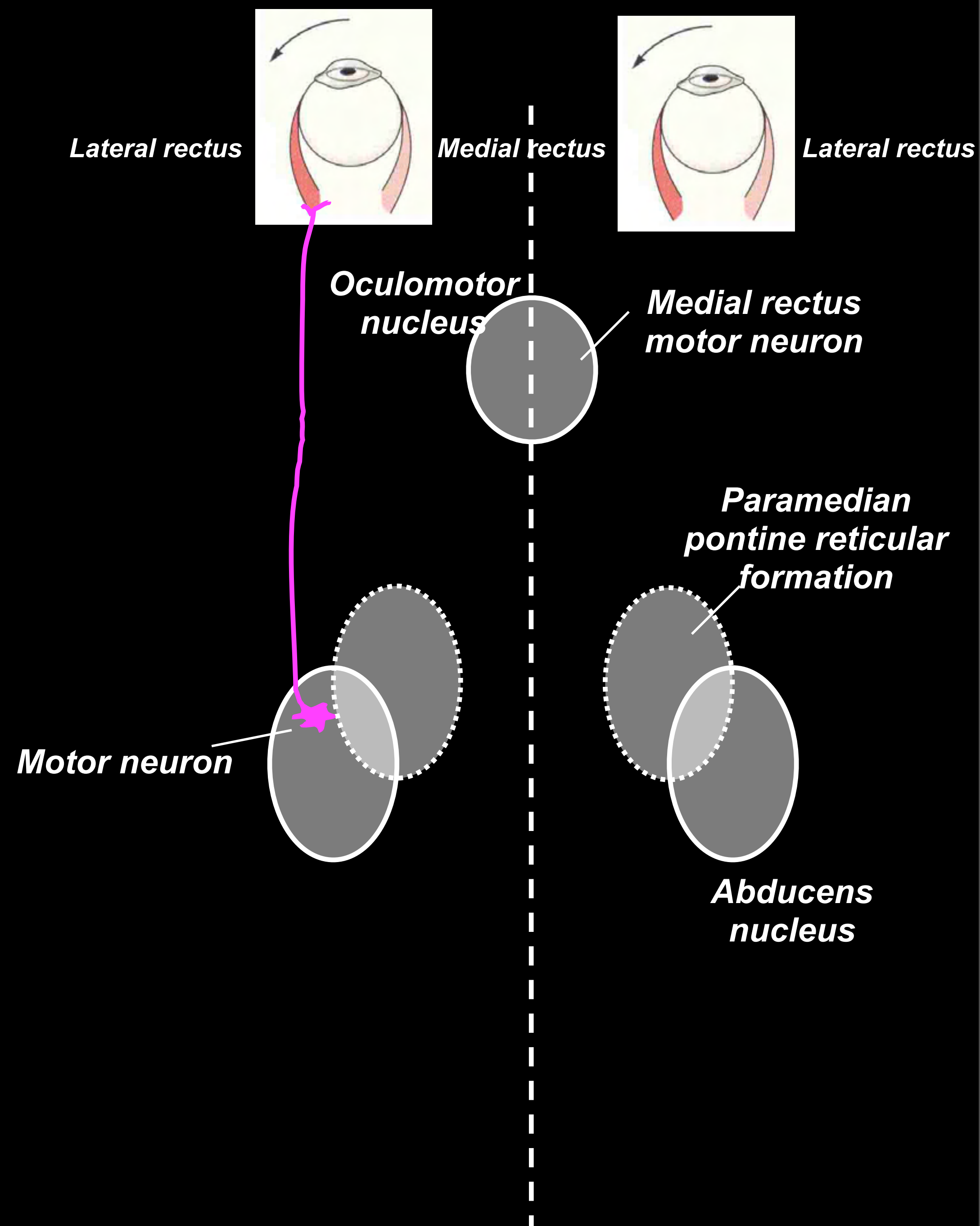

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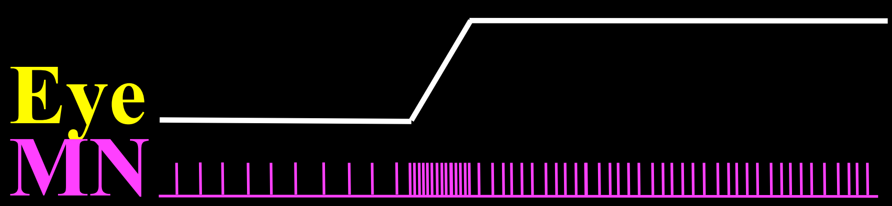

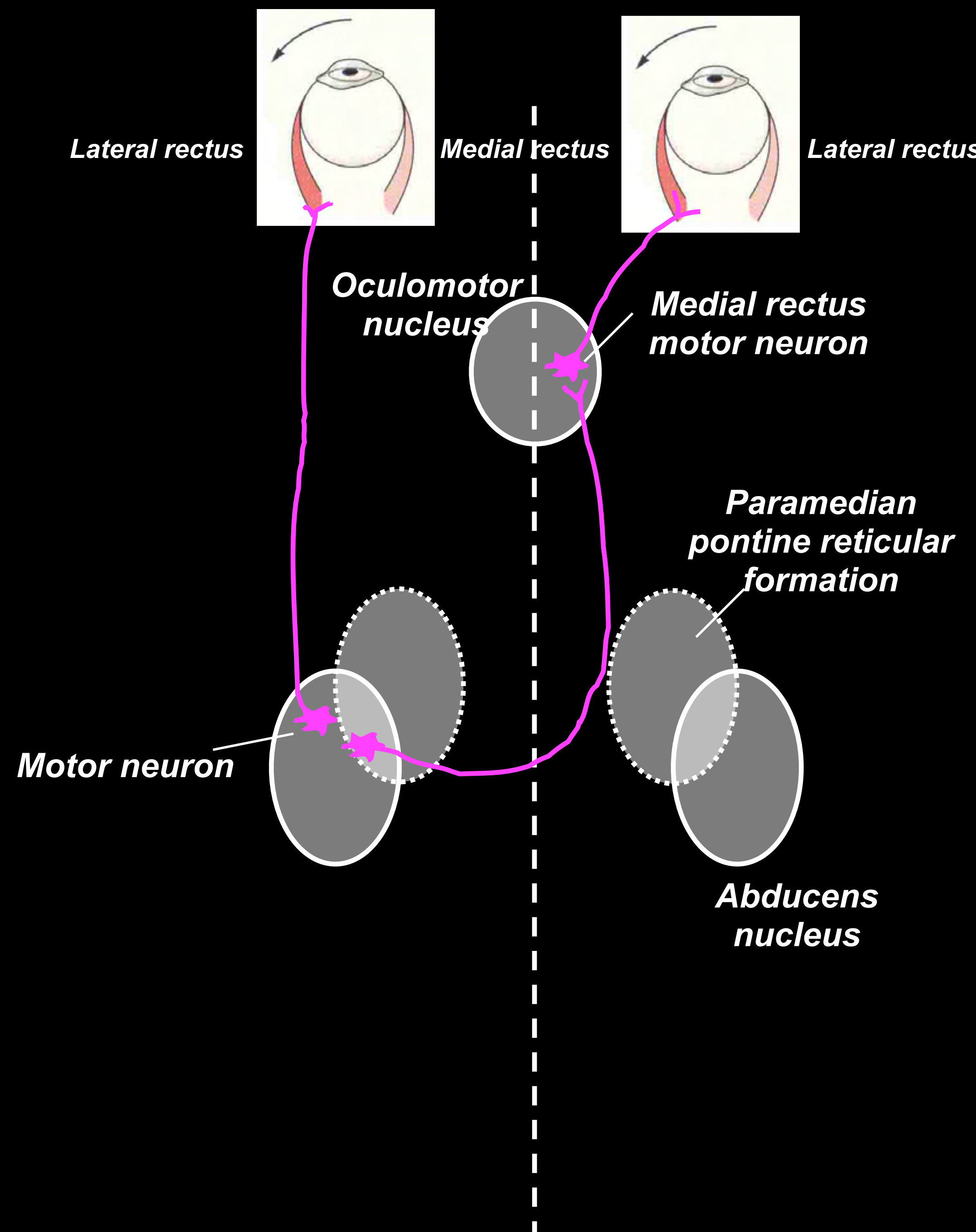

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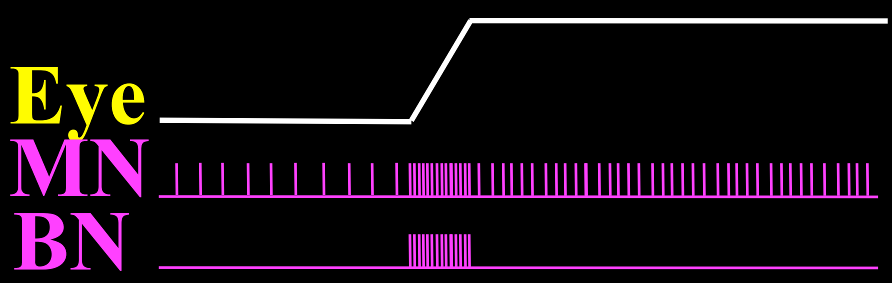
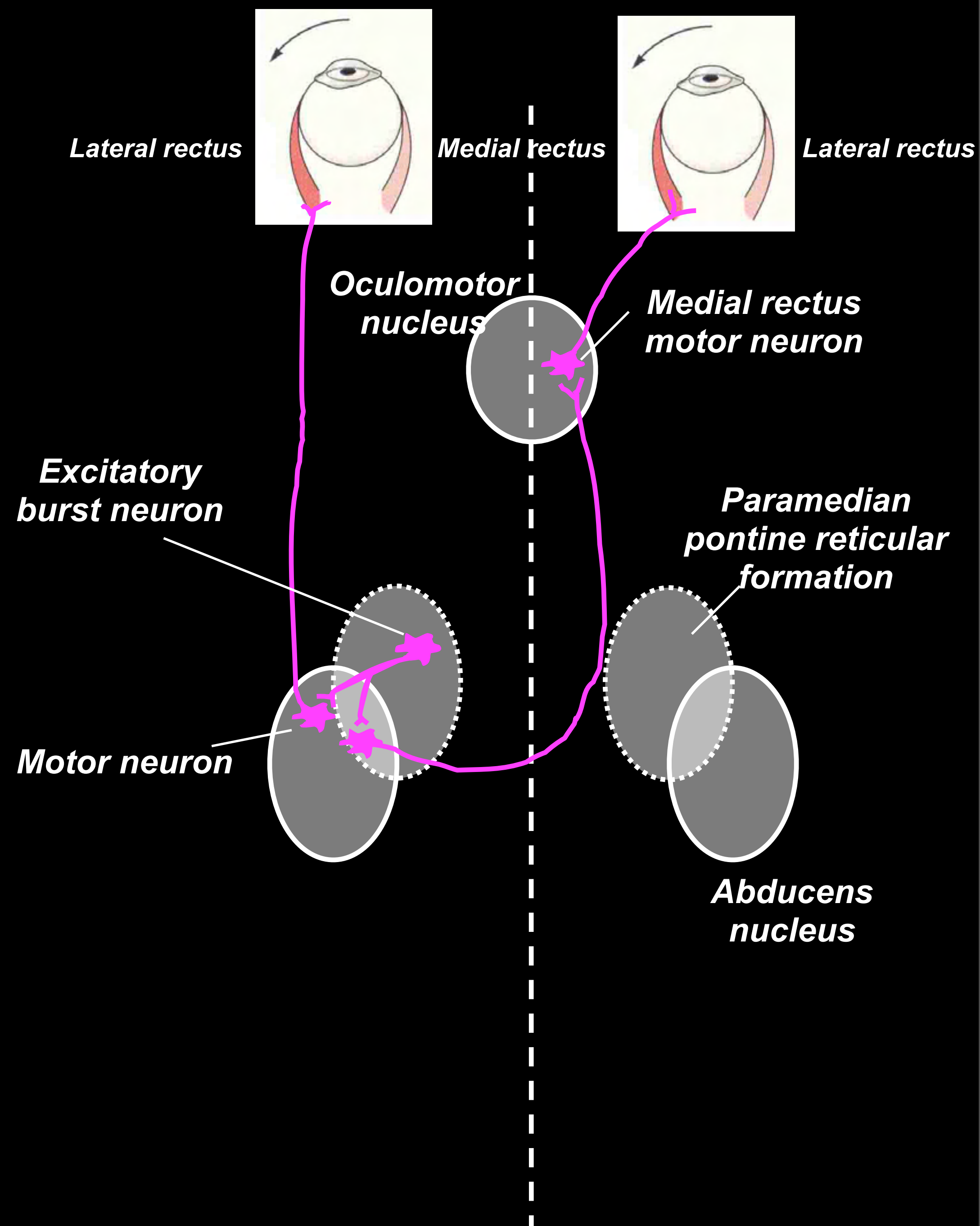
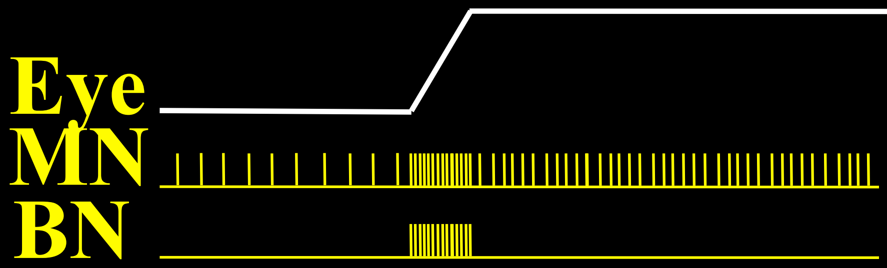
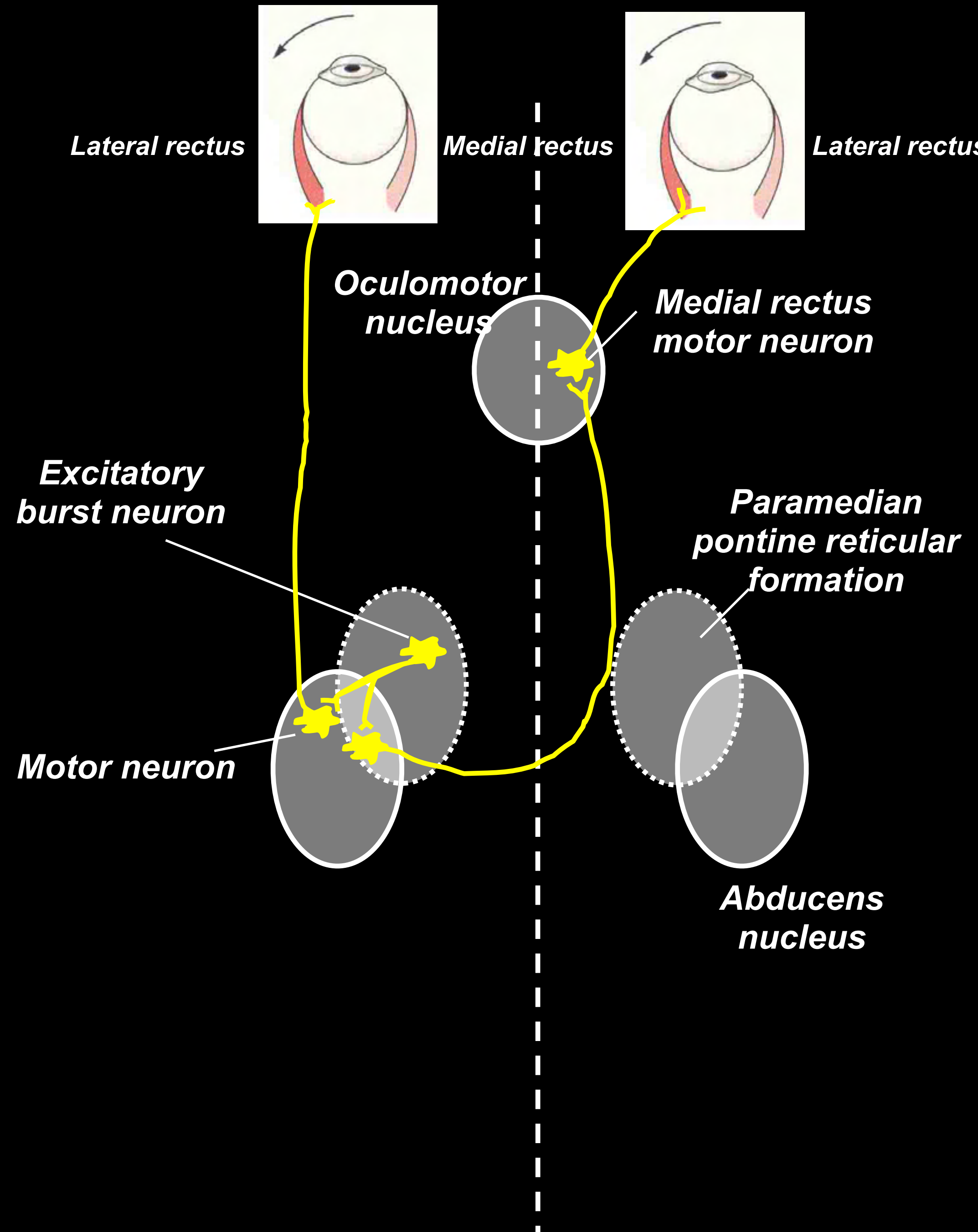




Circuit for Horizontal Saccades

Tonic neurons in the nucleus prepositus hypoglossi integrate the PPRF's phasic signal to provide the tonic signal to the abducens motor neurons.





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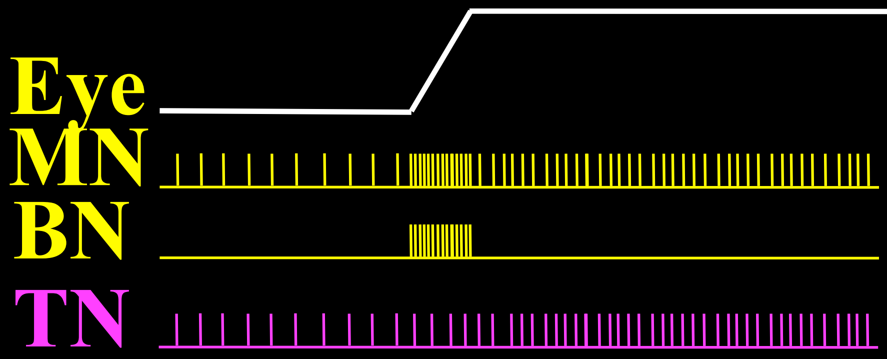
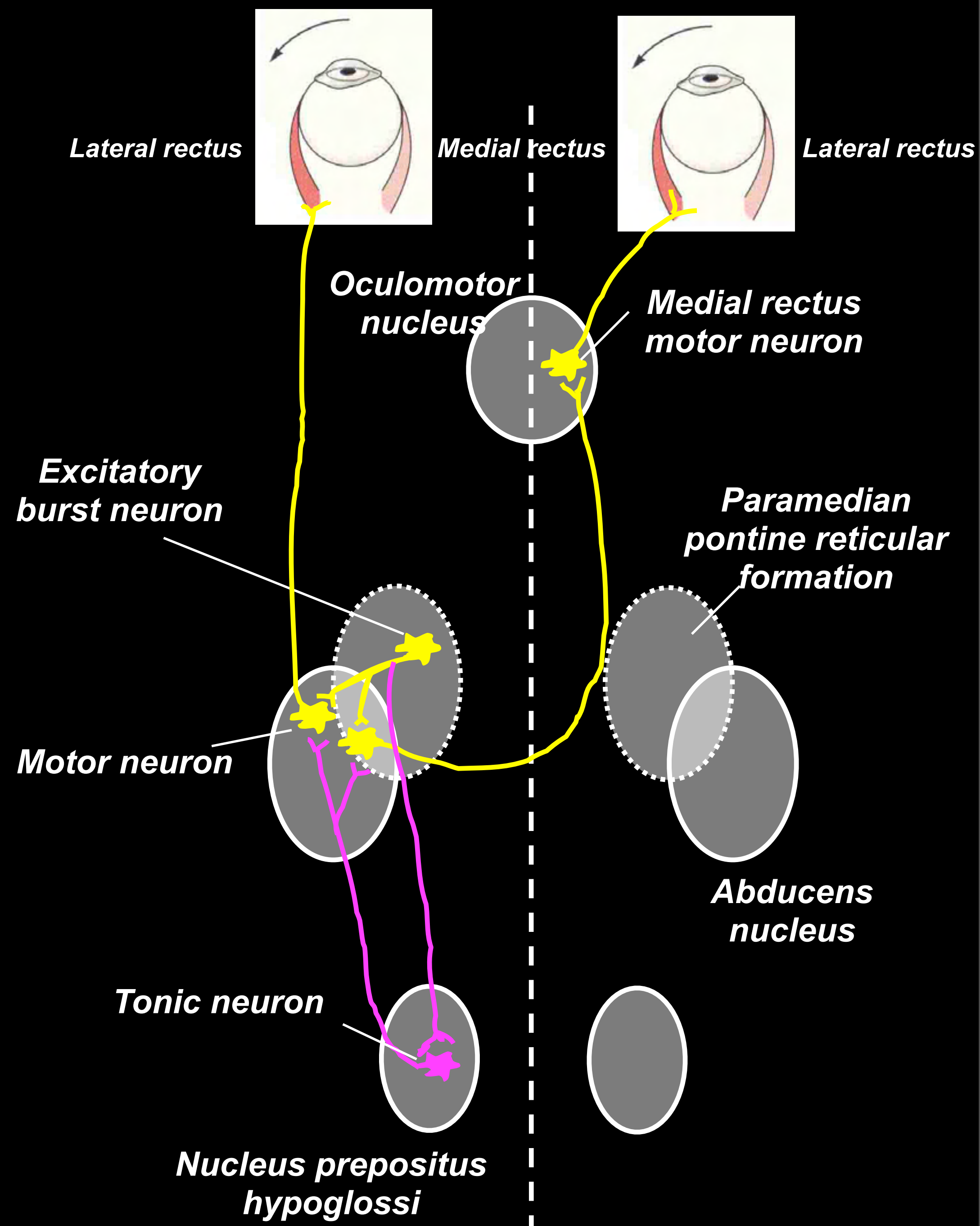
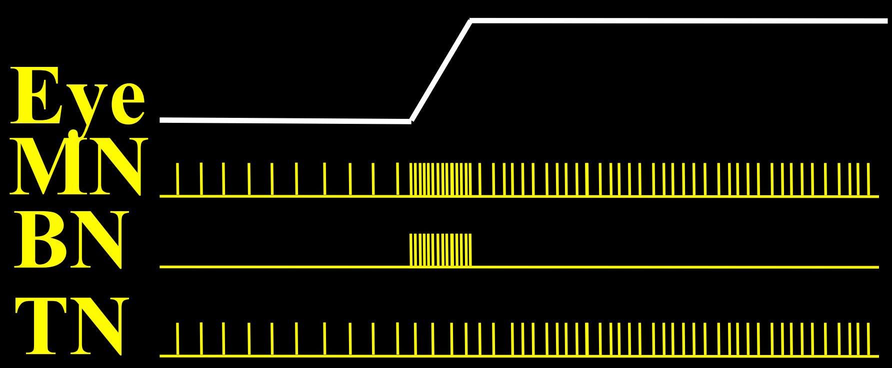
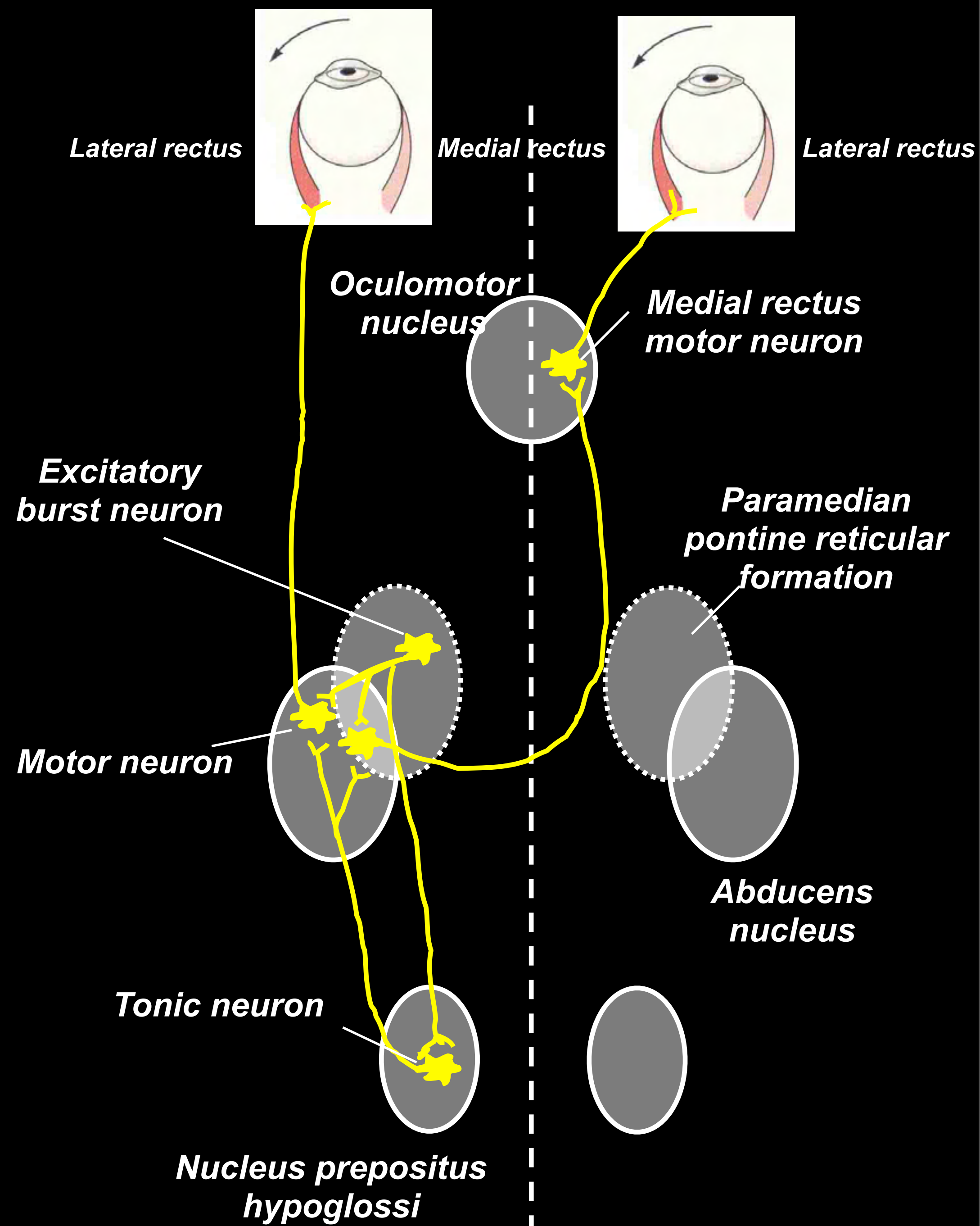




Circuit for Horizontal Saccades

Inhibitory burst neurons in the PPRF silence the contralateral abducens and oculomotor nucleus neurons to relax the antagonist muscles.





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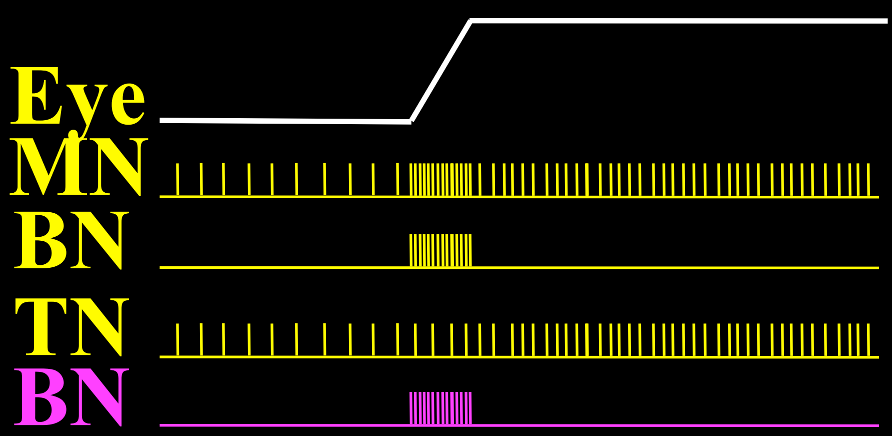

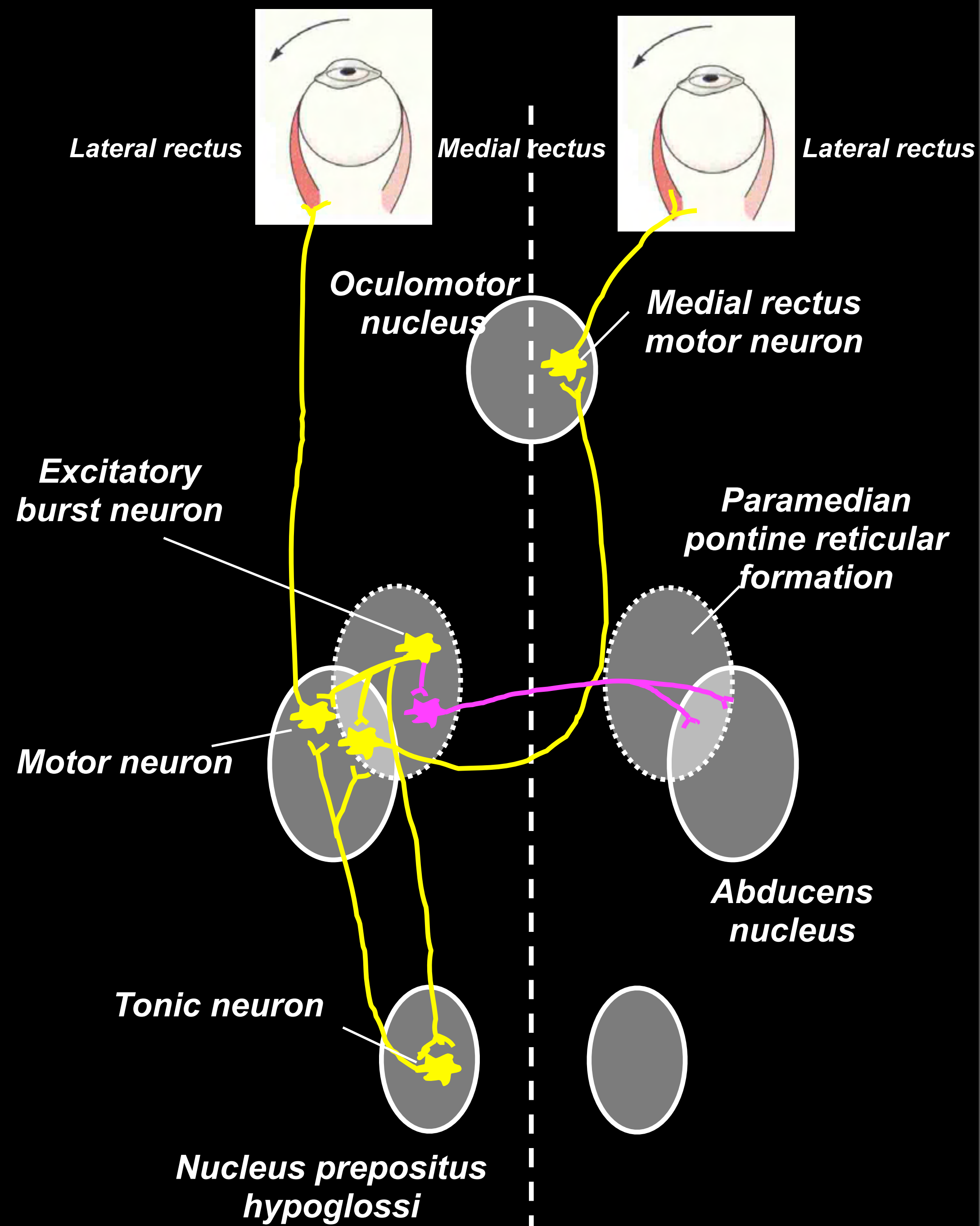

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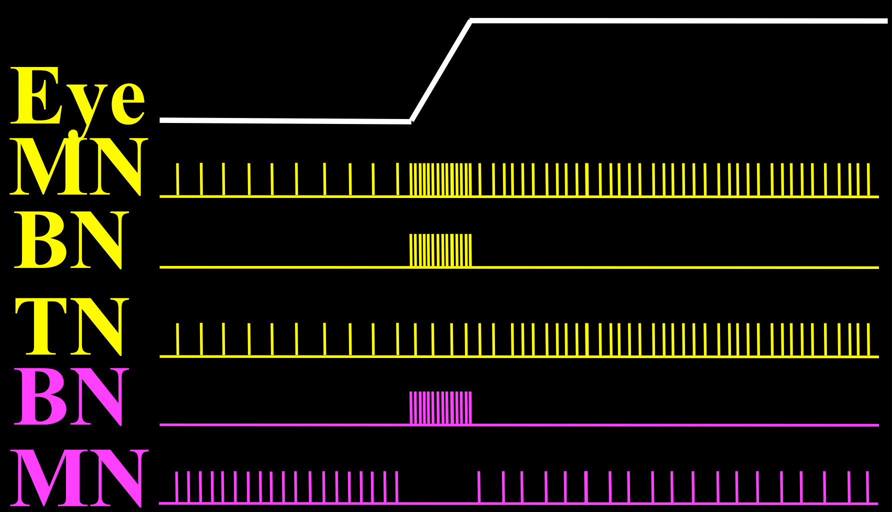
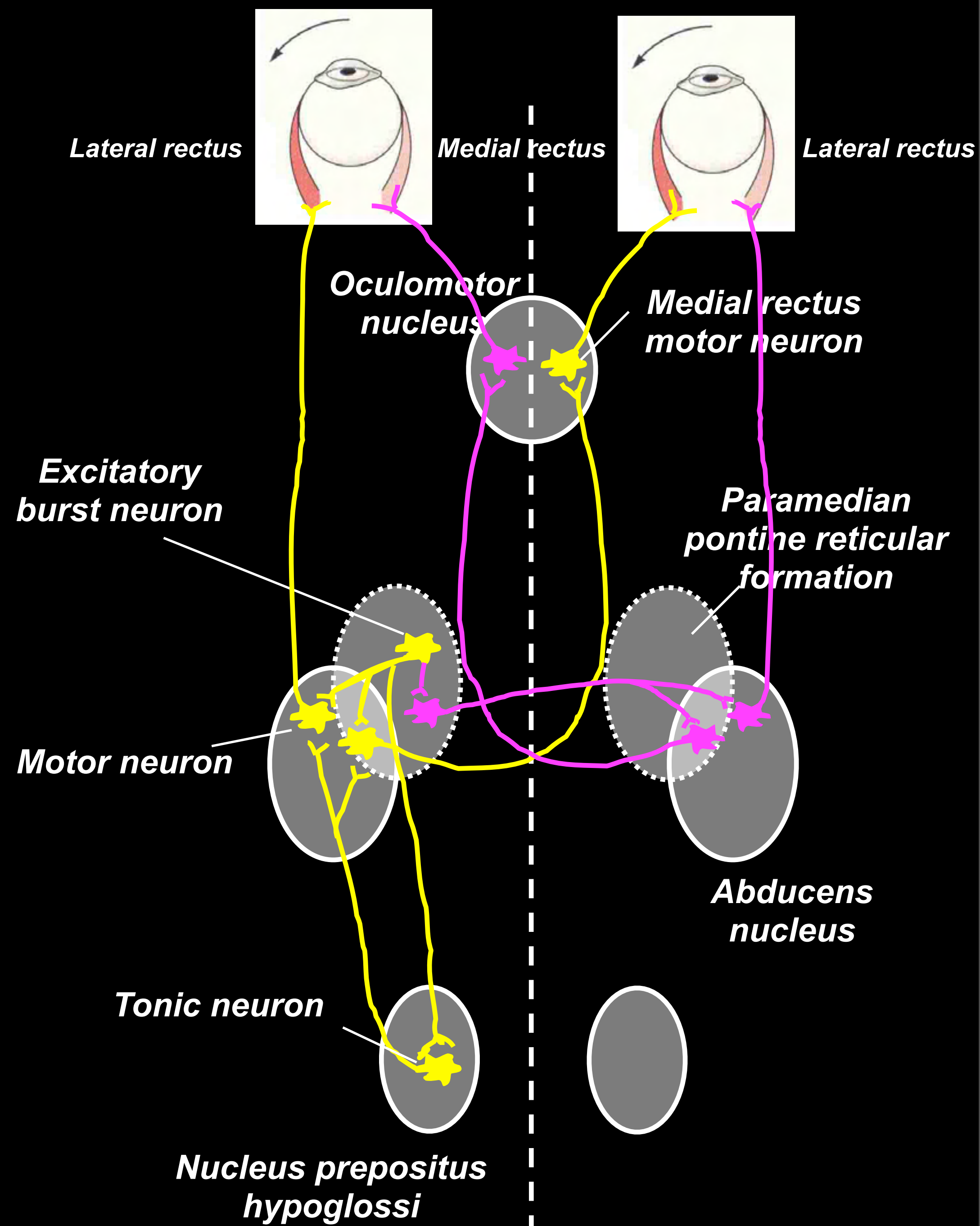
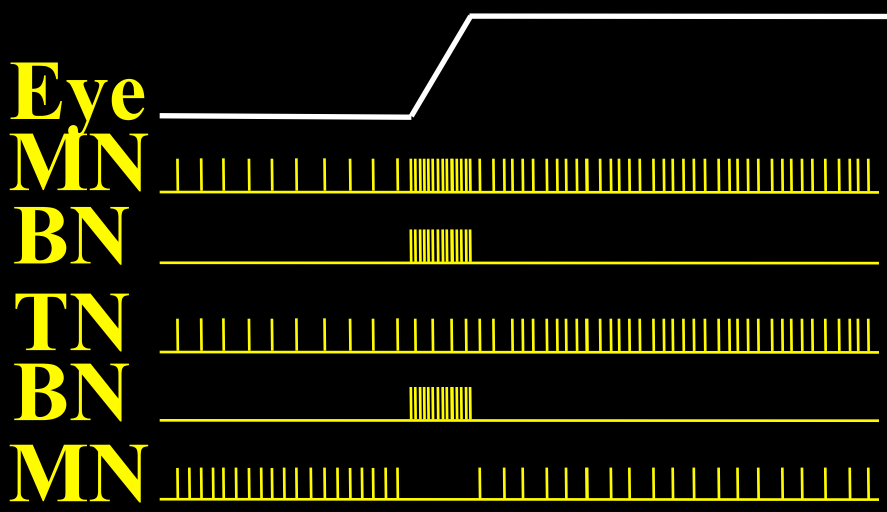
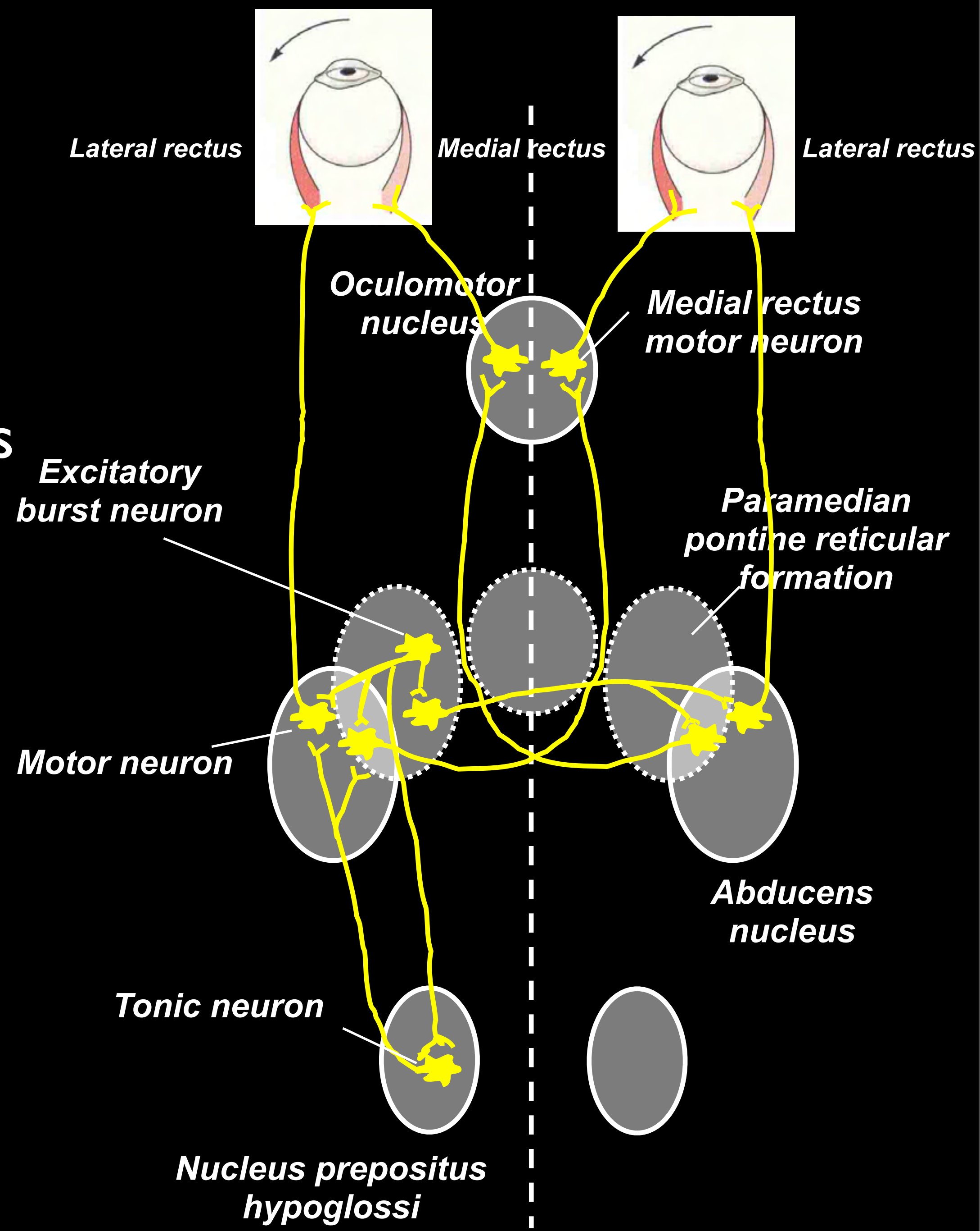




Circuit for Horizontal Saccades

Omnipause neurons inhibit burst neurons in the PPRF, thereby preventing saccades. A trigger command inhibiting these neurons is necessary to activate the saccade burst generator.





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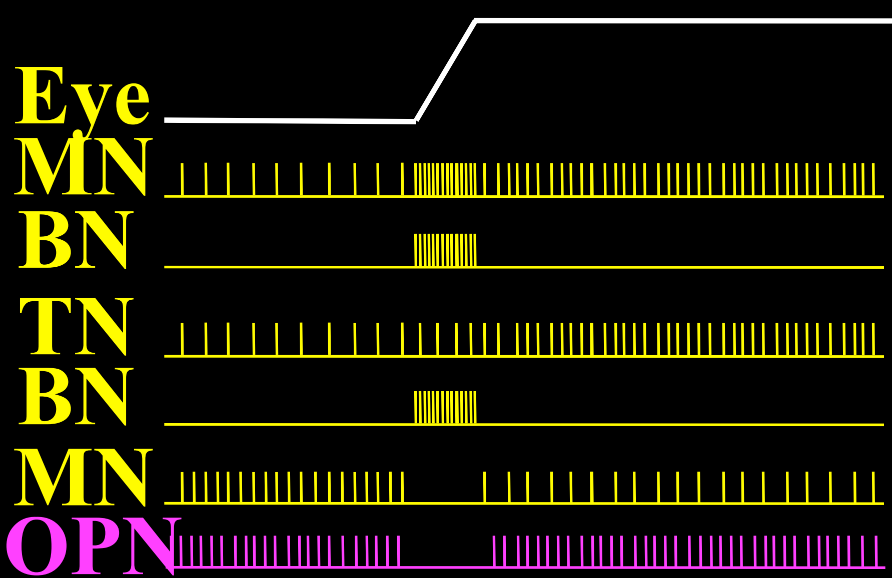
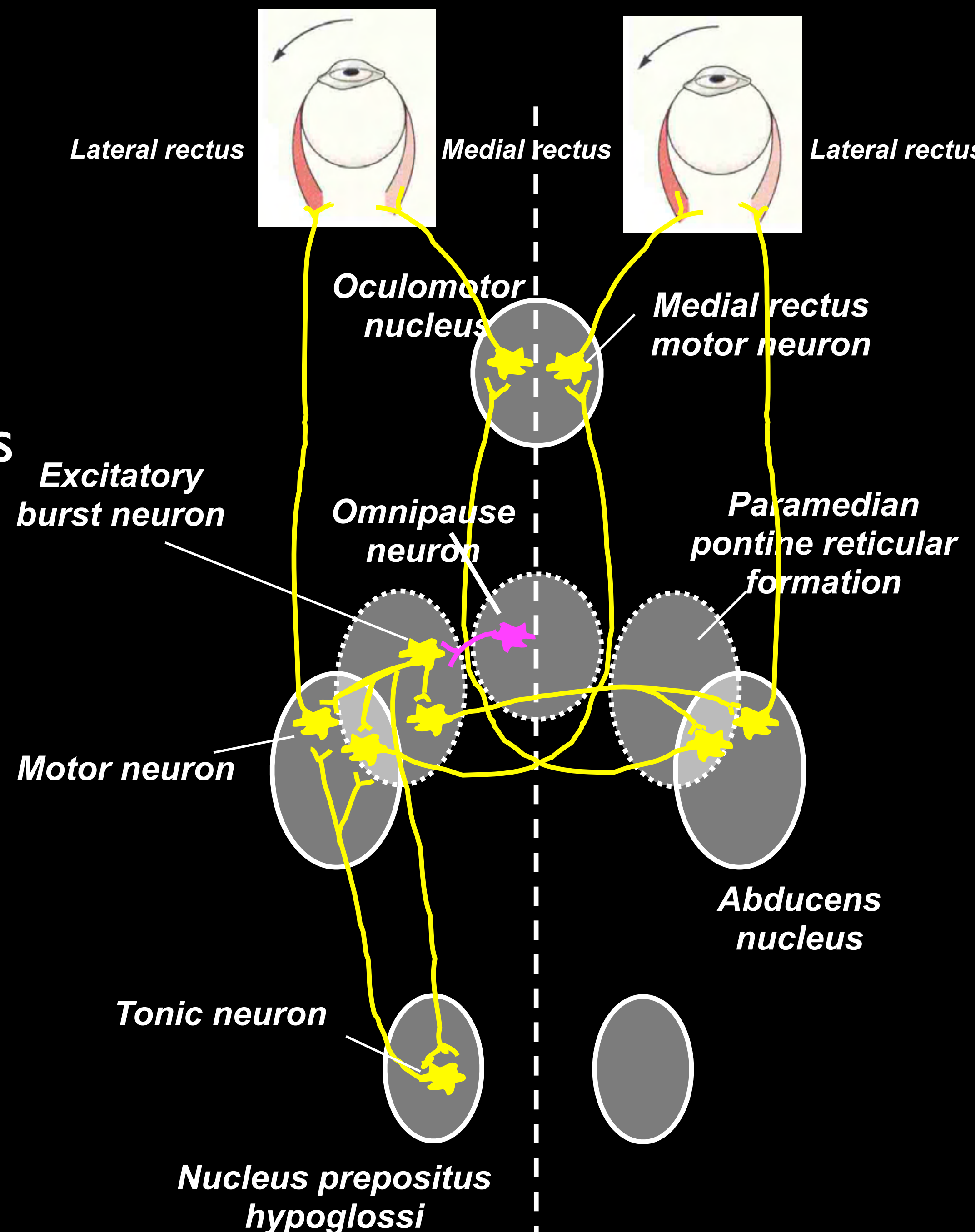
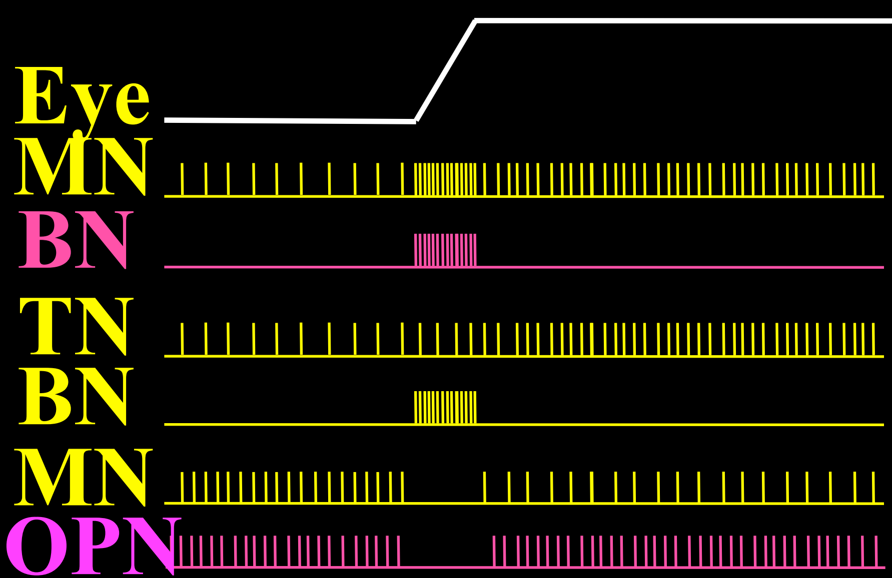
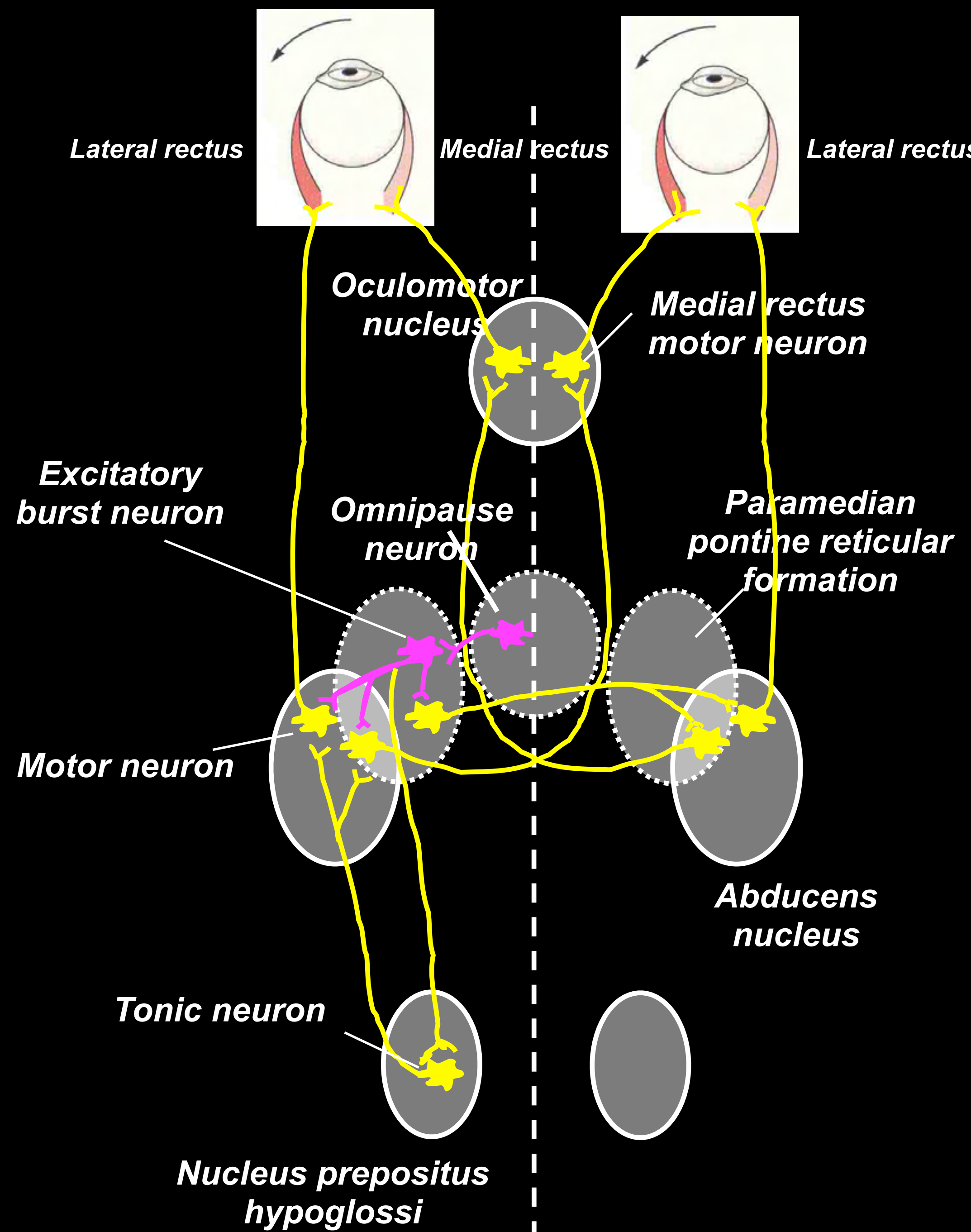




Circuit for Horizontal Saccades

The ***superior colliculus*** provides both the motor command to the PPRF's burst neurons and the trigger command to the omnipause neurons.

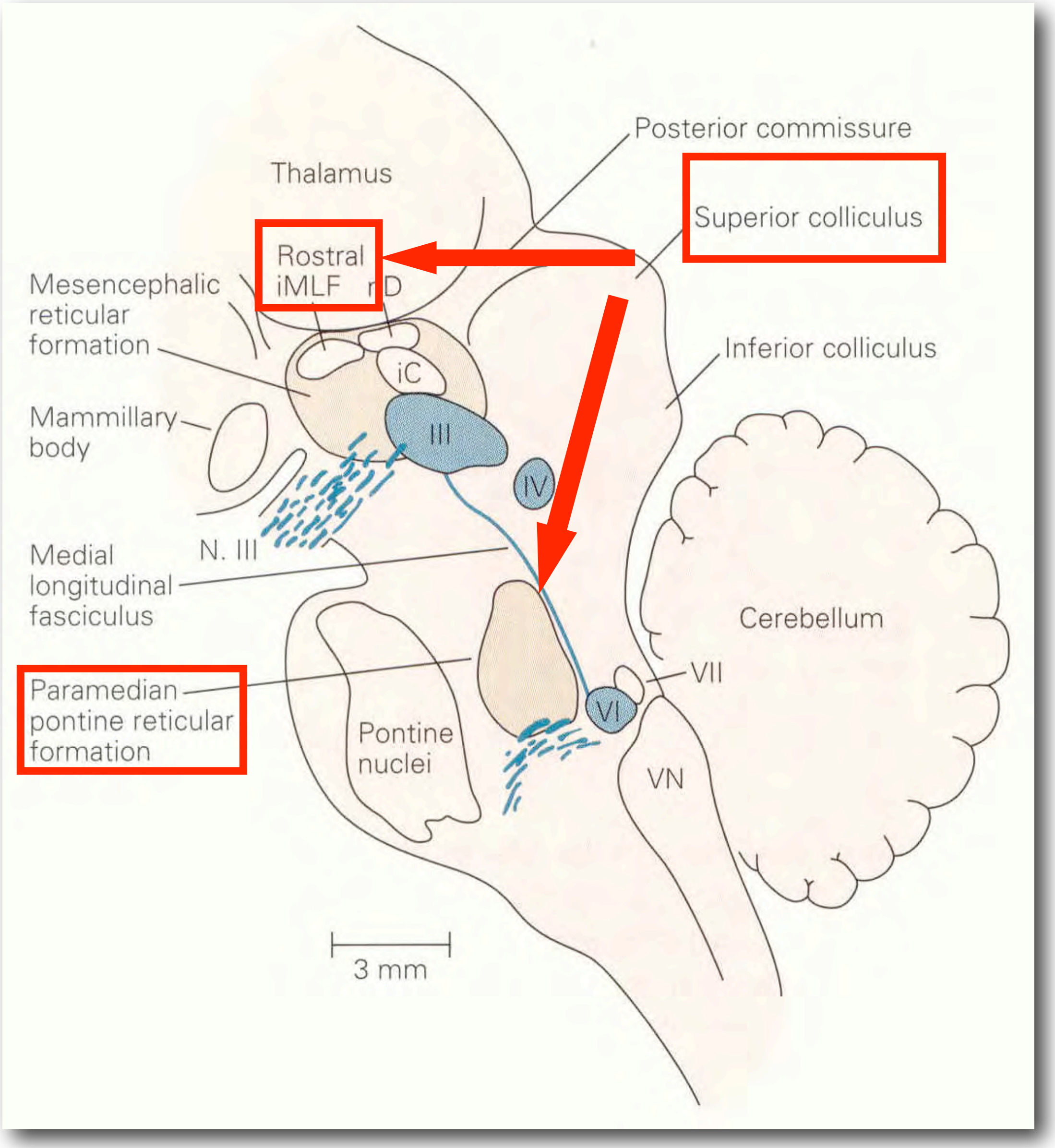




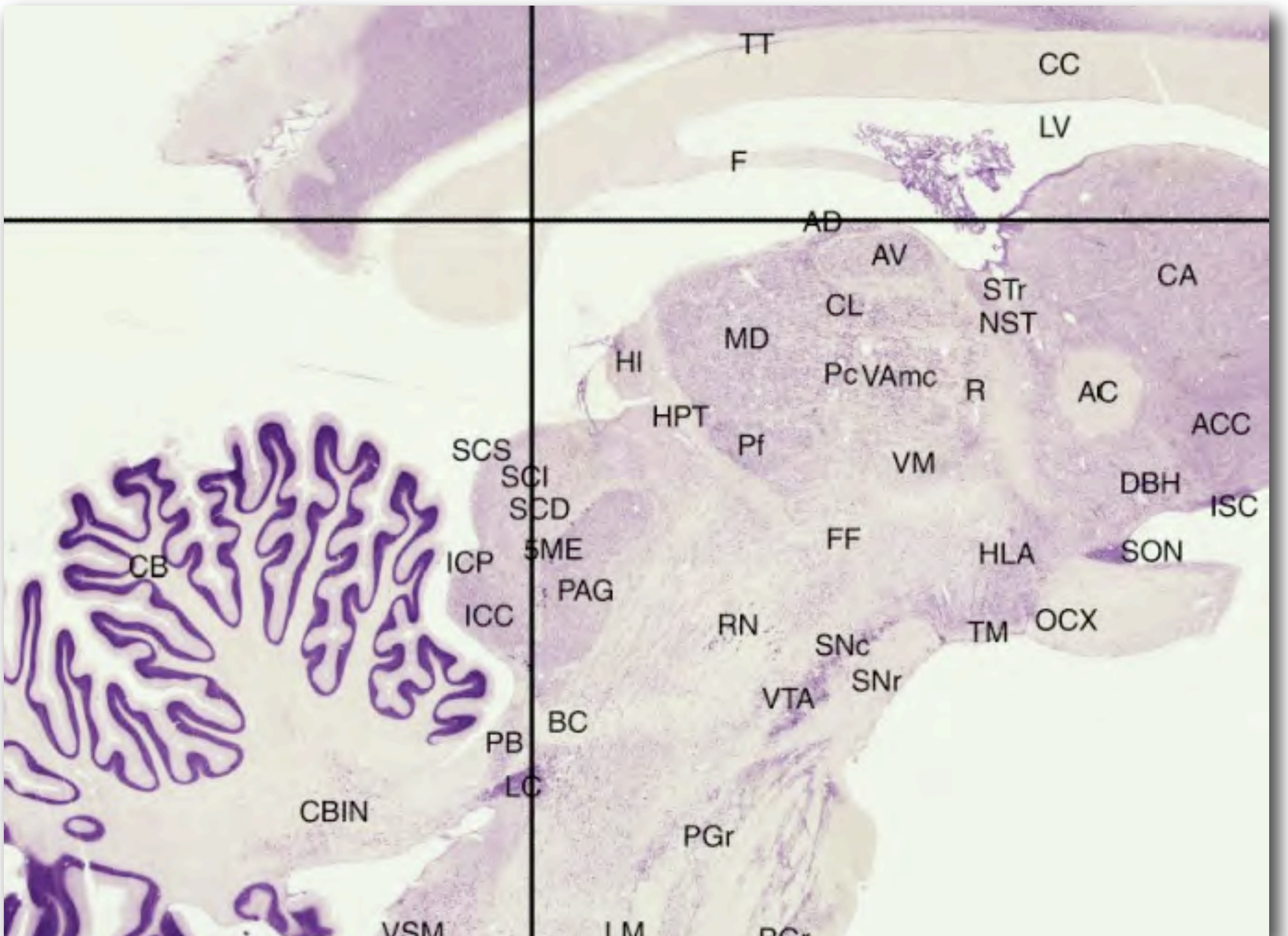
Superior Colliculus

The ***superior colliculus*** is located on the roof of the midbrain.

It sends projections to both the horizontal (PPRF) and vertical gaze centers (rostral iMLF), providing the motor command to move the eye to an intended new position.

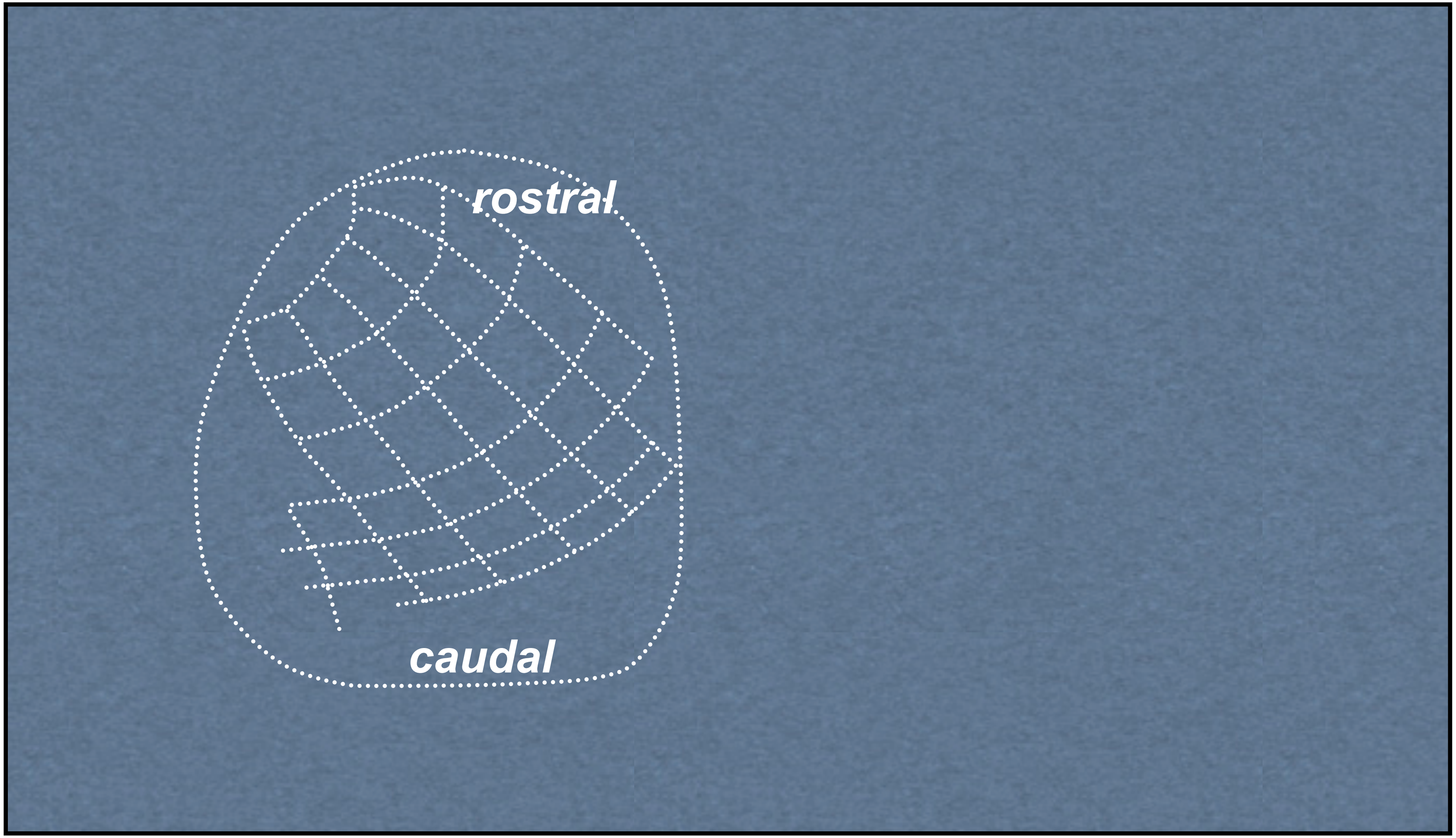


Superior Colliculus



Superior Colliculus

The superior colliculus contains a topographic motor map for saccadic eye movements that is independent of the initial position of the eyes in the orbit.



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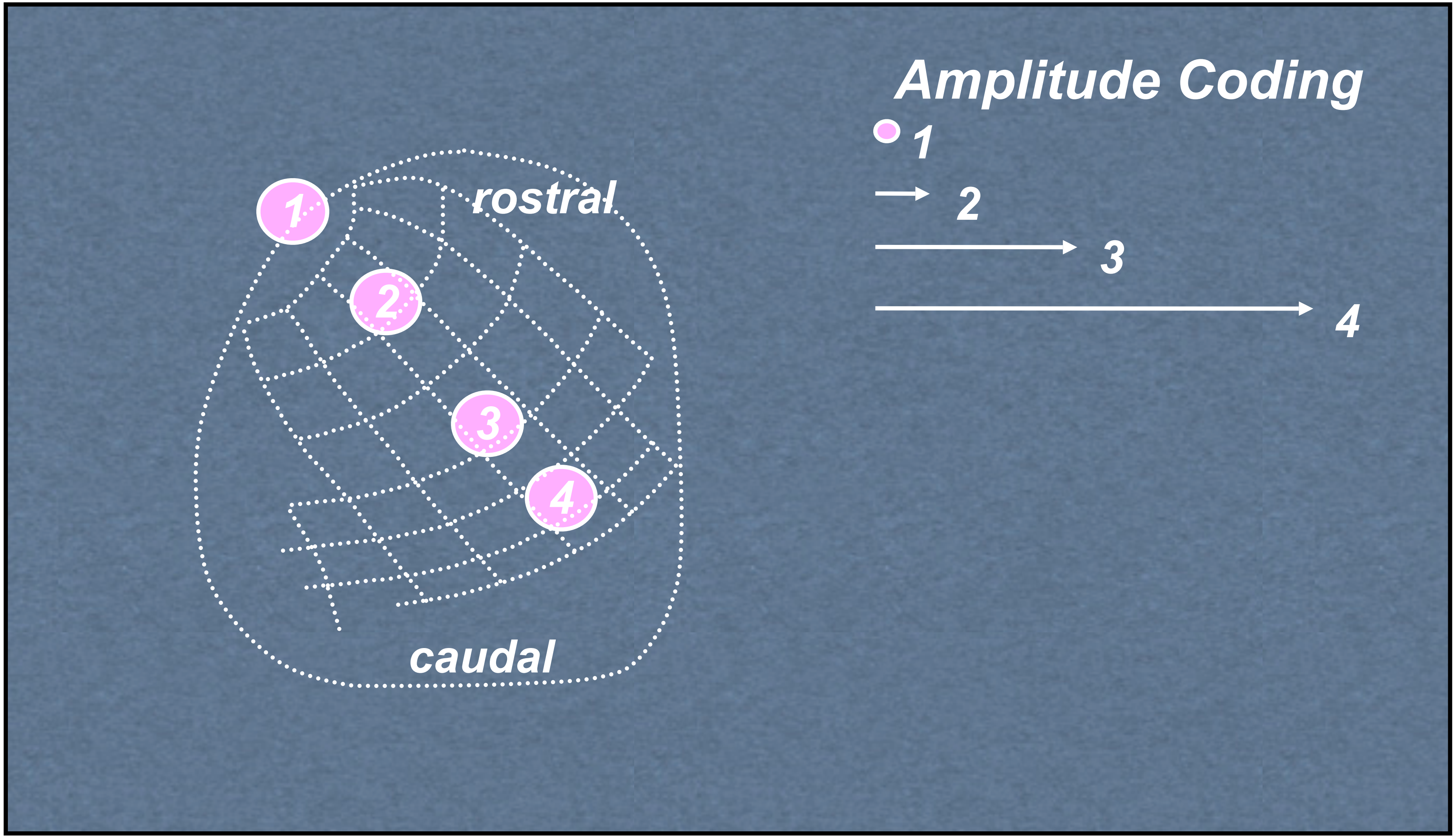

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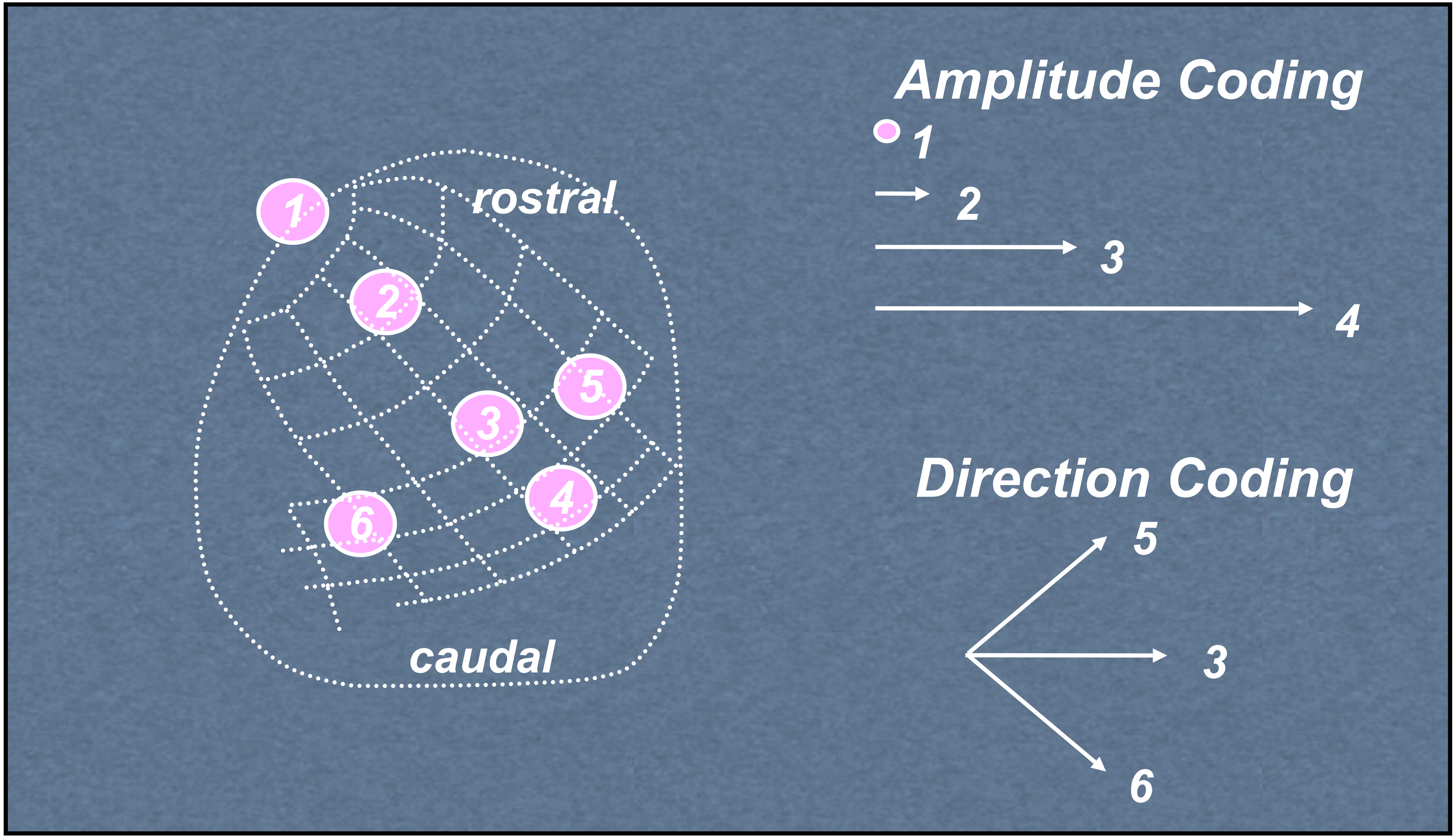
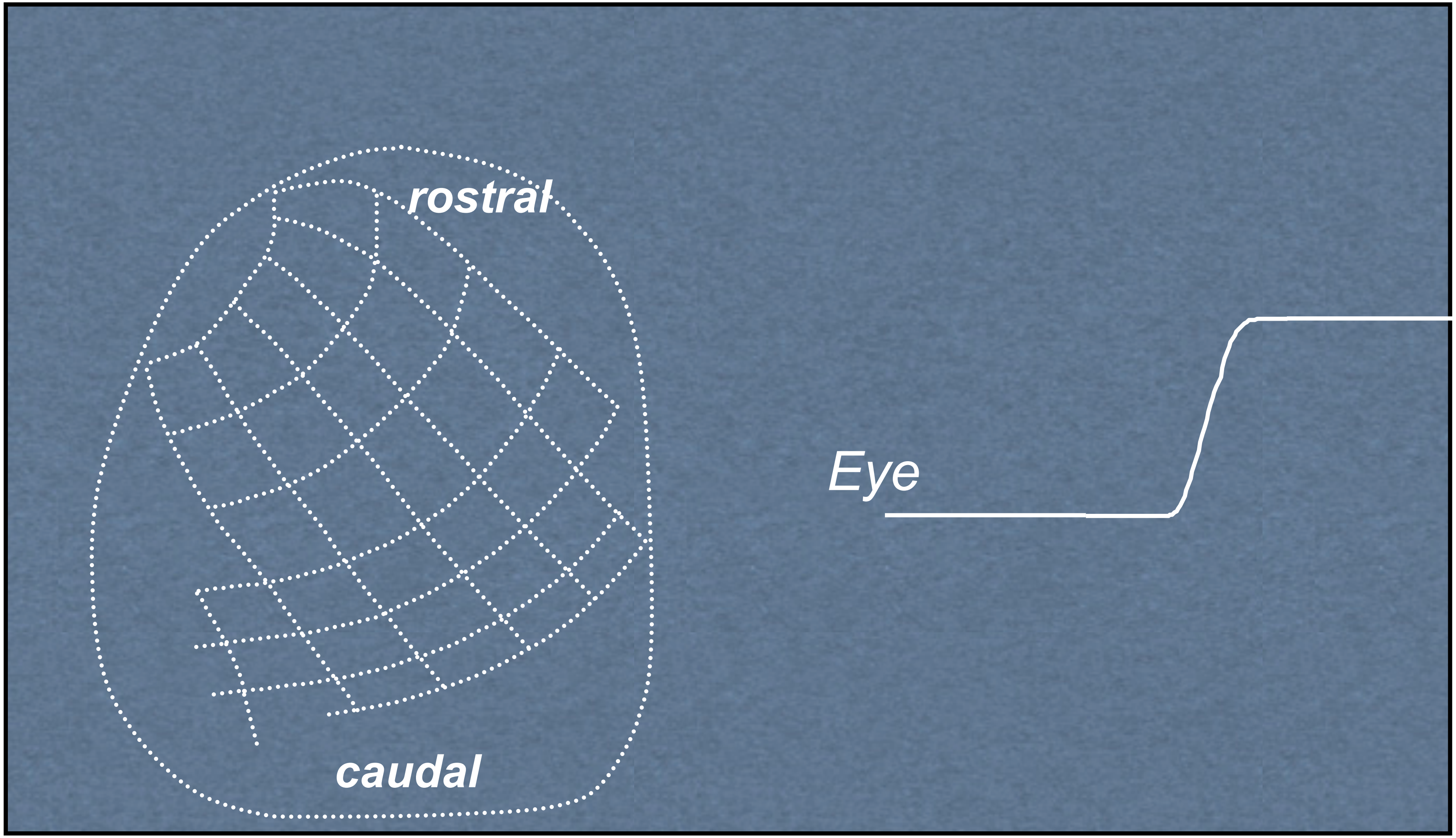


Superior Colliculus

Fixation neurons in the rostral pole of the SC pause before and during saccades and saccade neurons in the caudal pole discharge before and during saccades.



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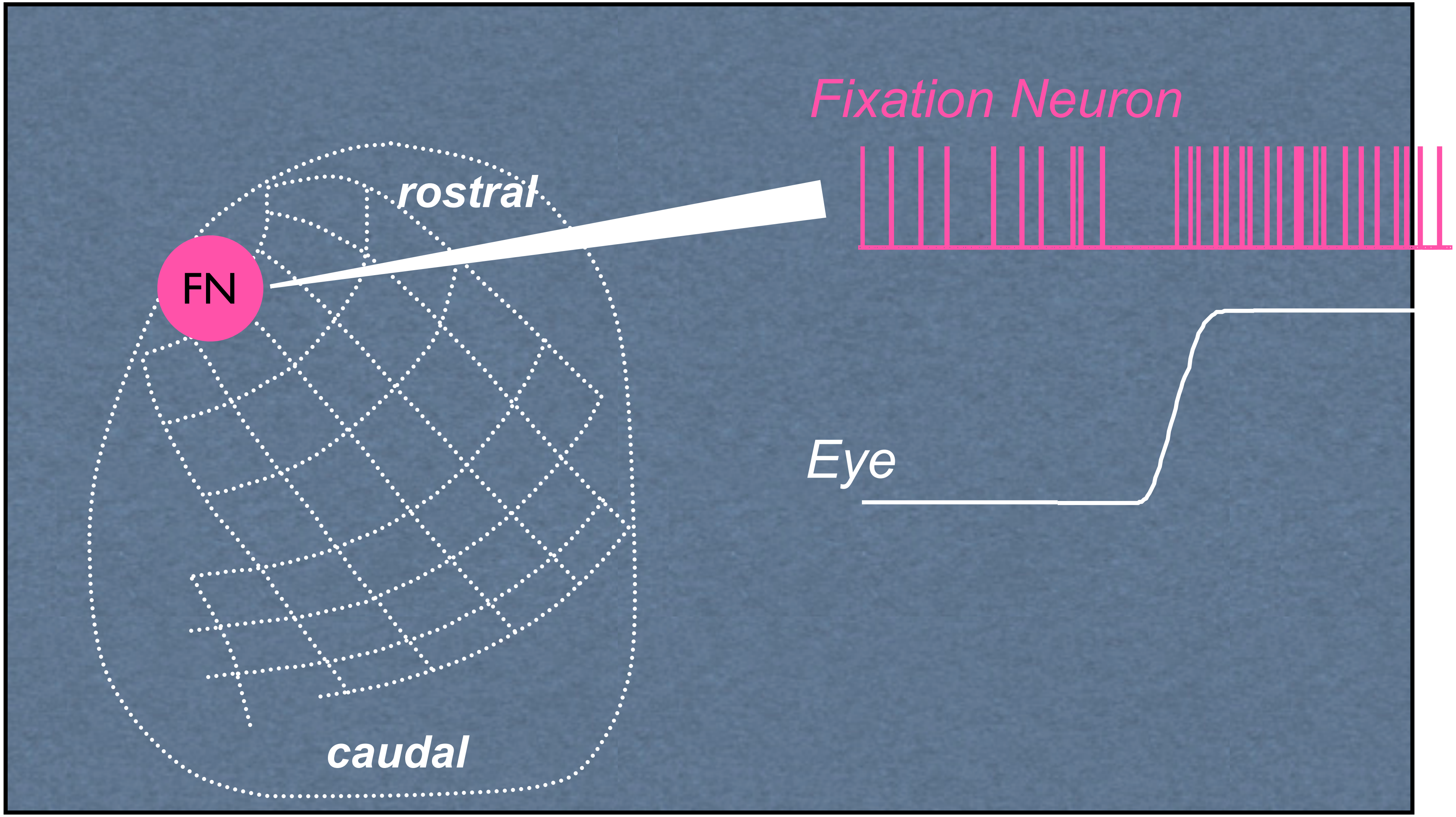

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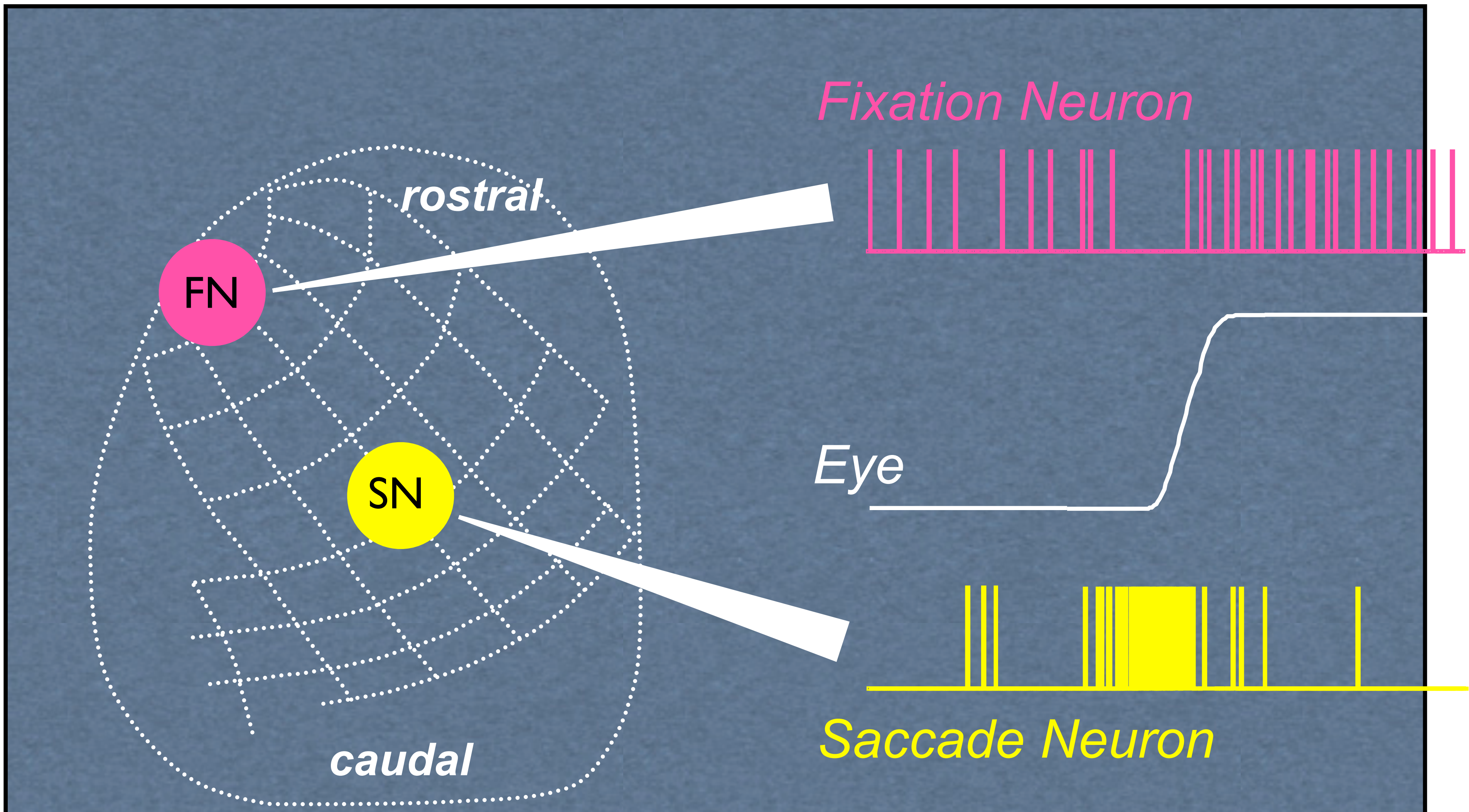
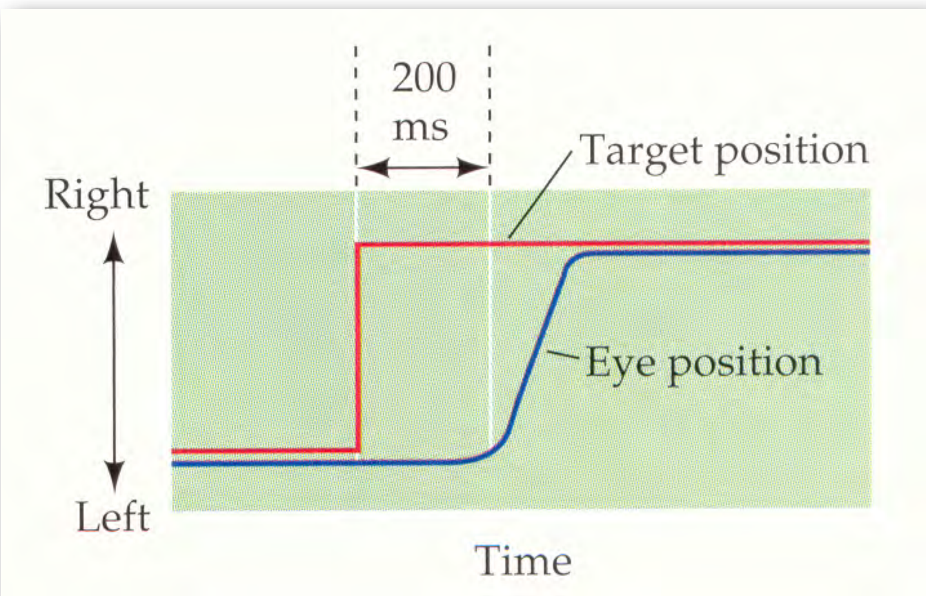
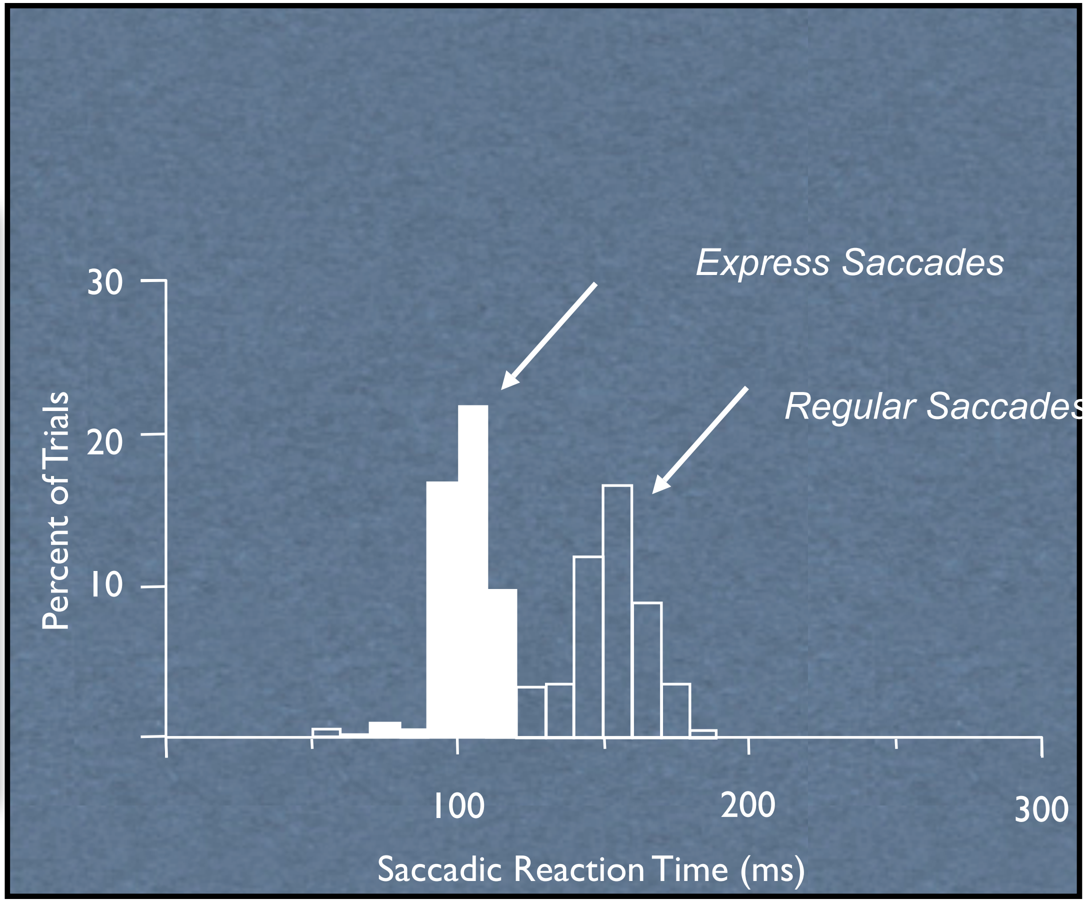


Superior Colliculus

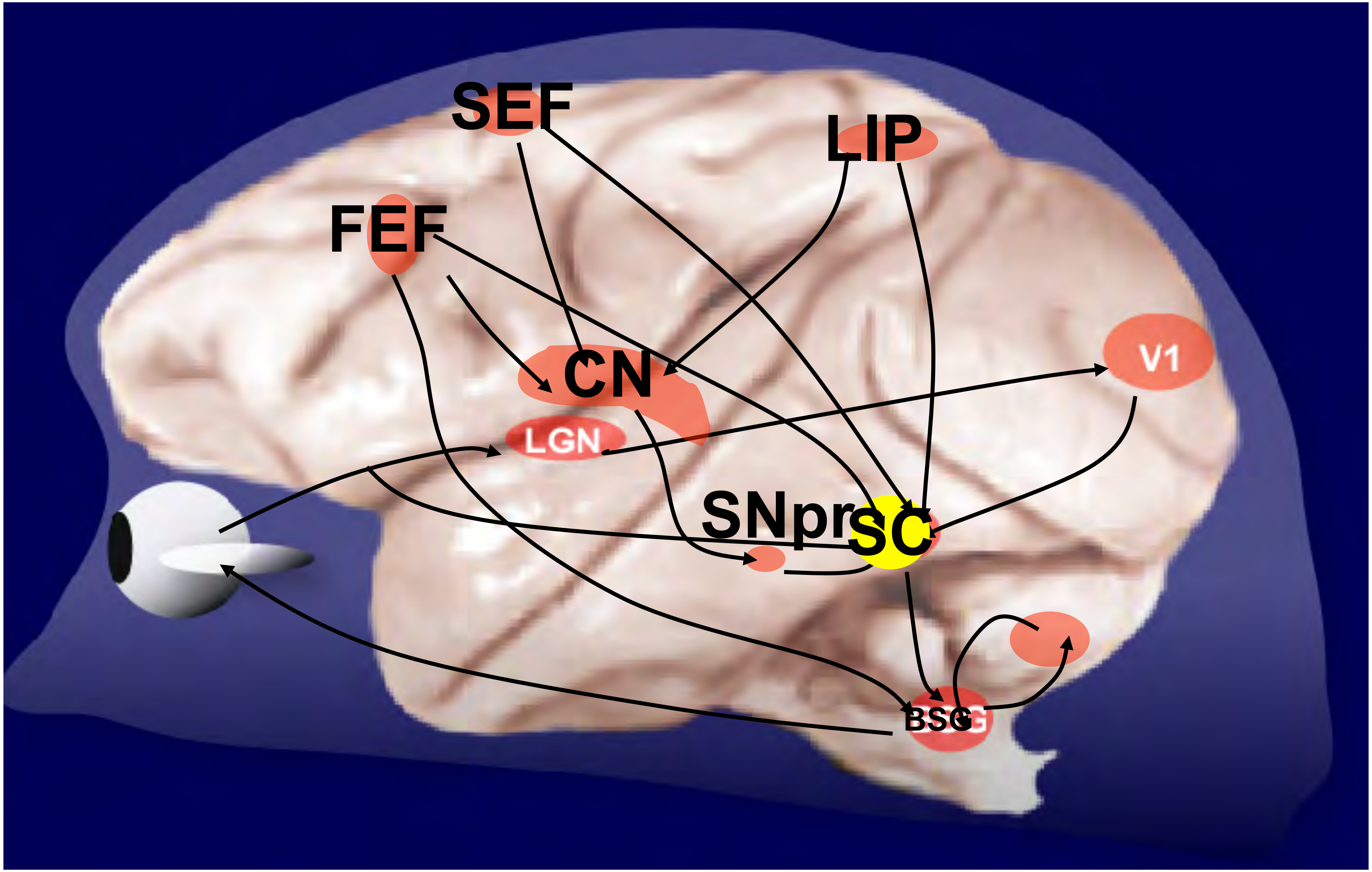
The integrity of the superior colliculus is crucial for the production of *reflexive* saccades, including "*express*" saccades whose latency approach the fastest time for visual signals to reach the oculomotor system and trigger a saccade.





Higher Saccadic Centers

The saccade-related activity of superior colliculus neurons is shaped by inputs from a variety of cortical areas through direct and indirect projections.



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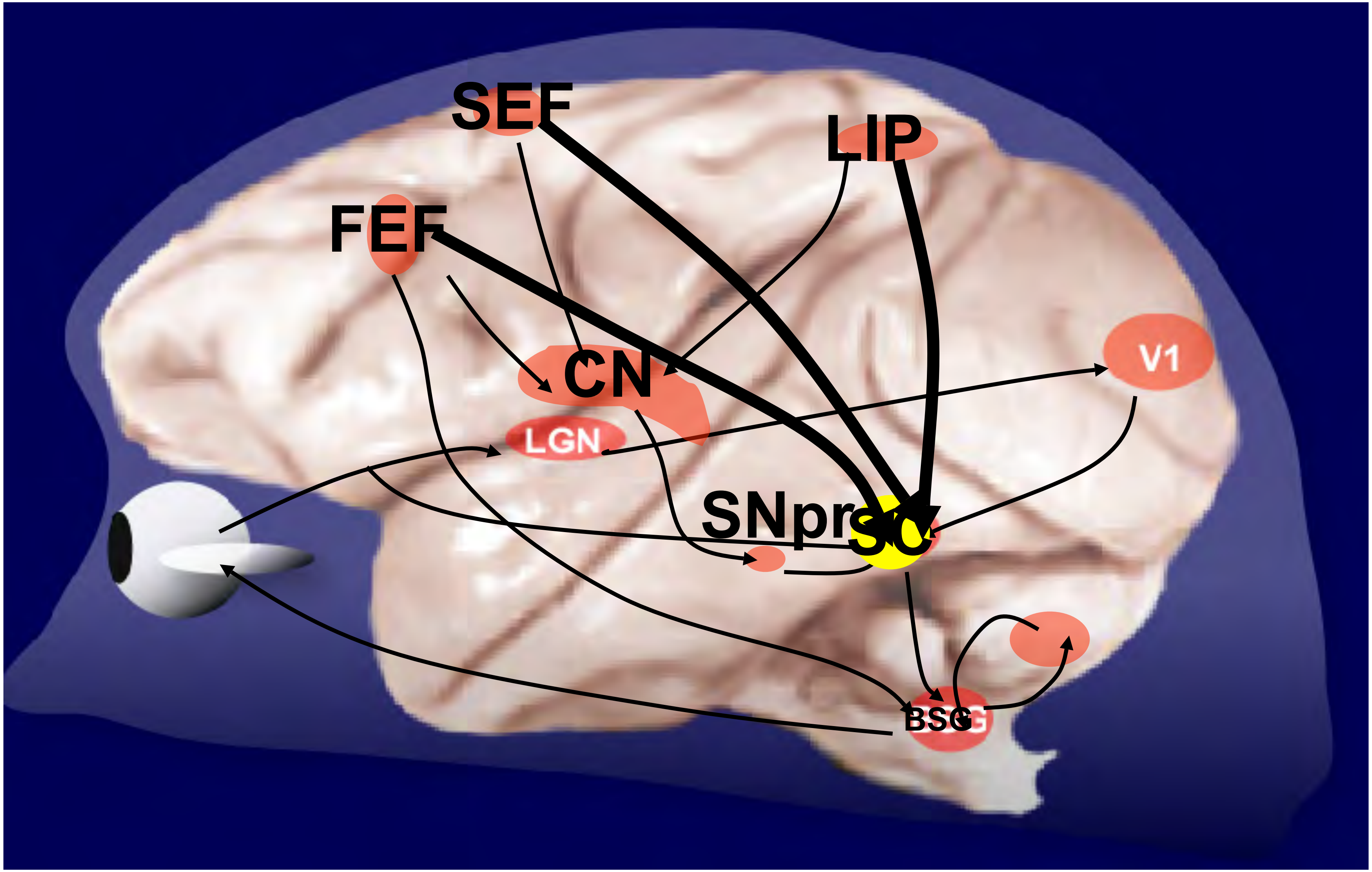

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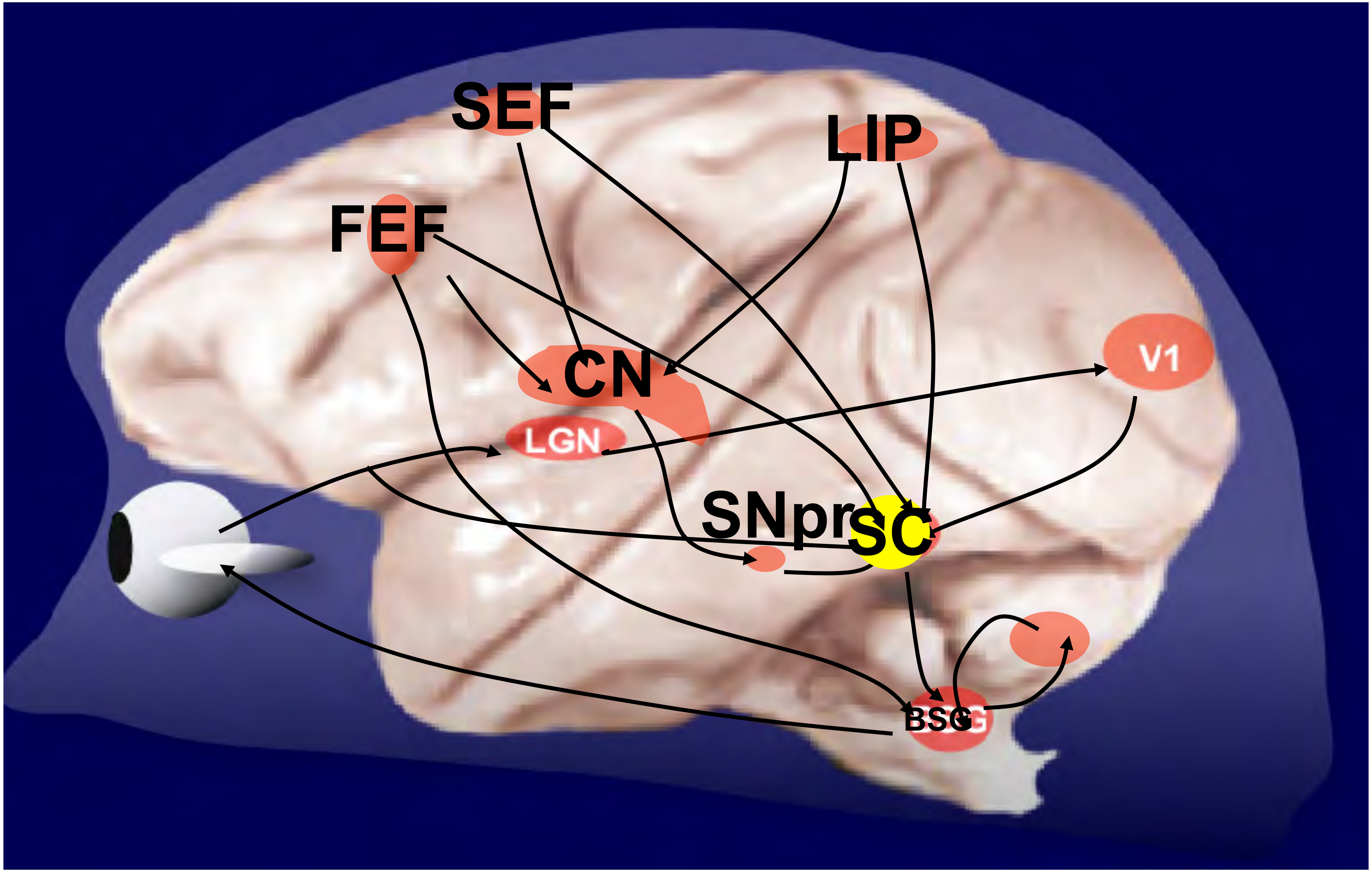

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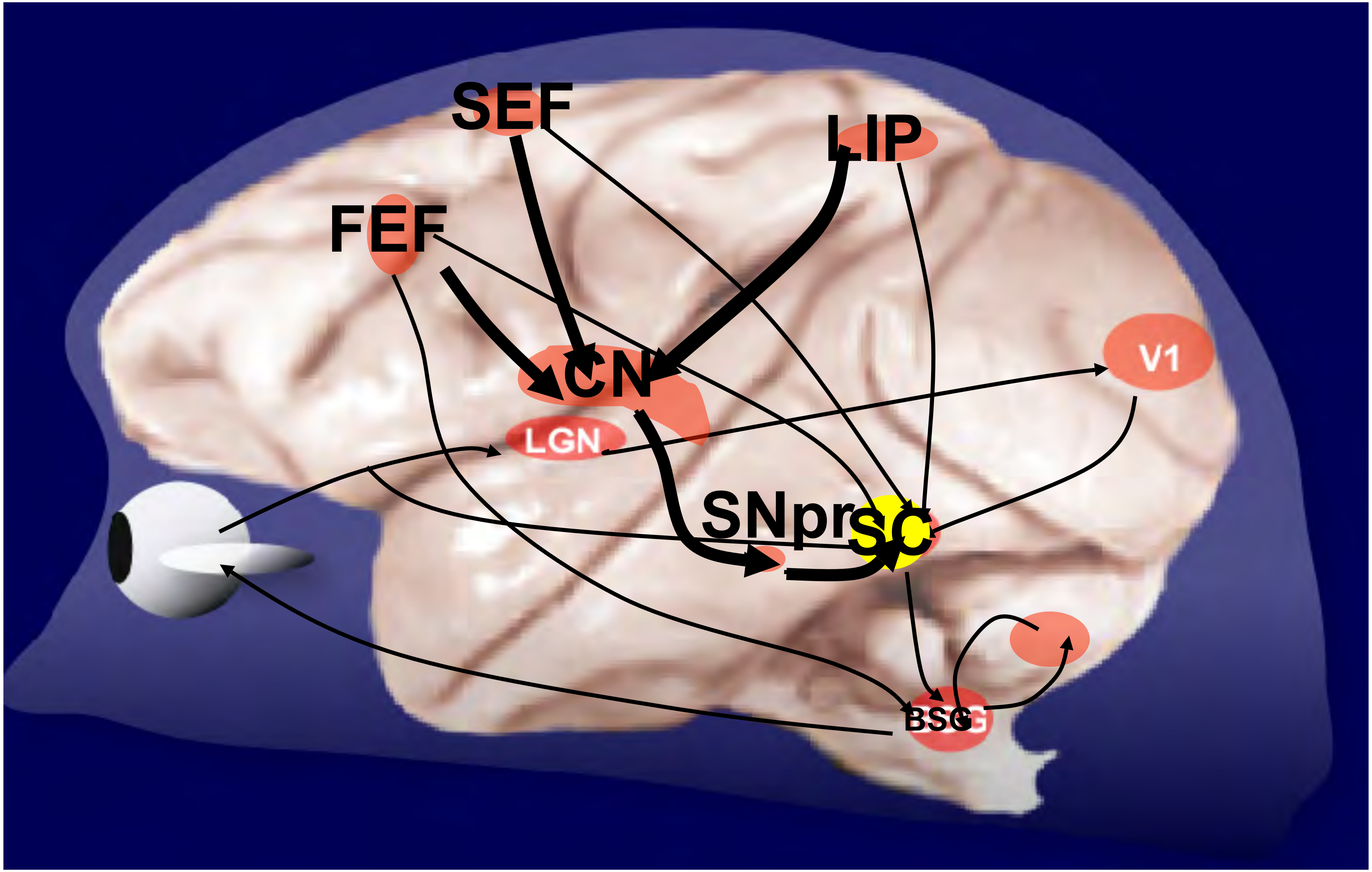

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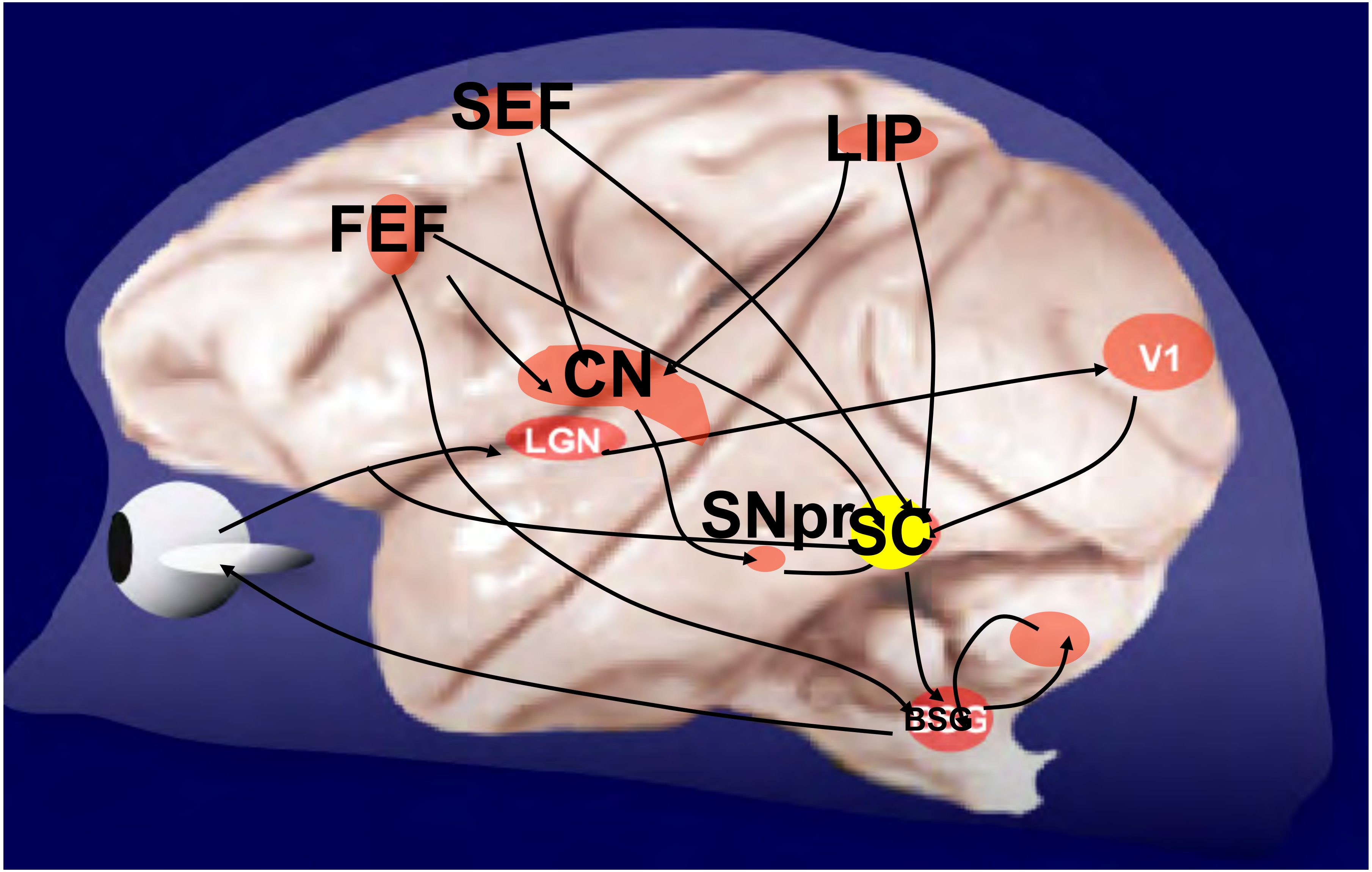
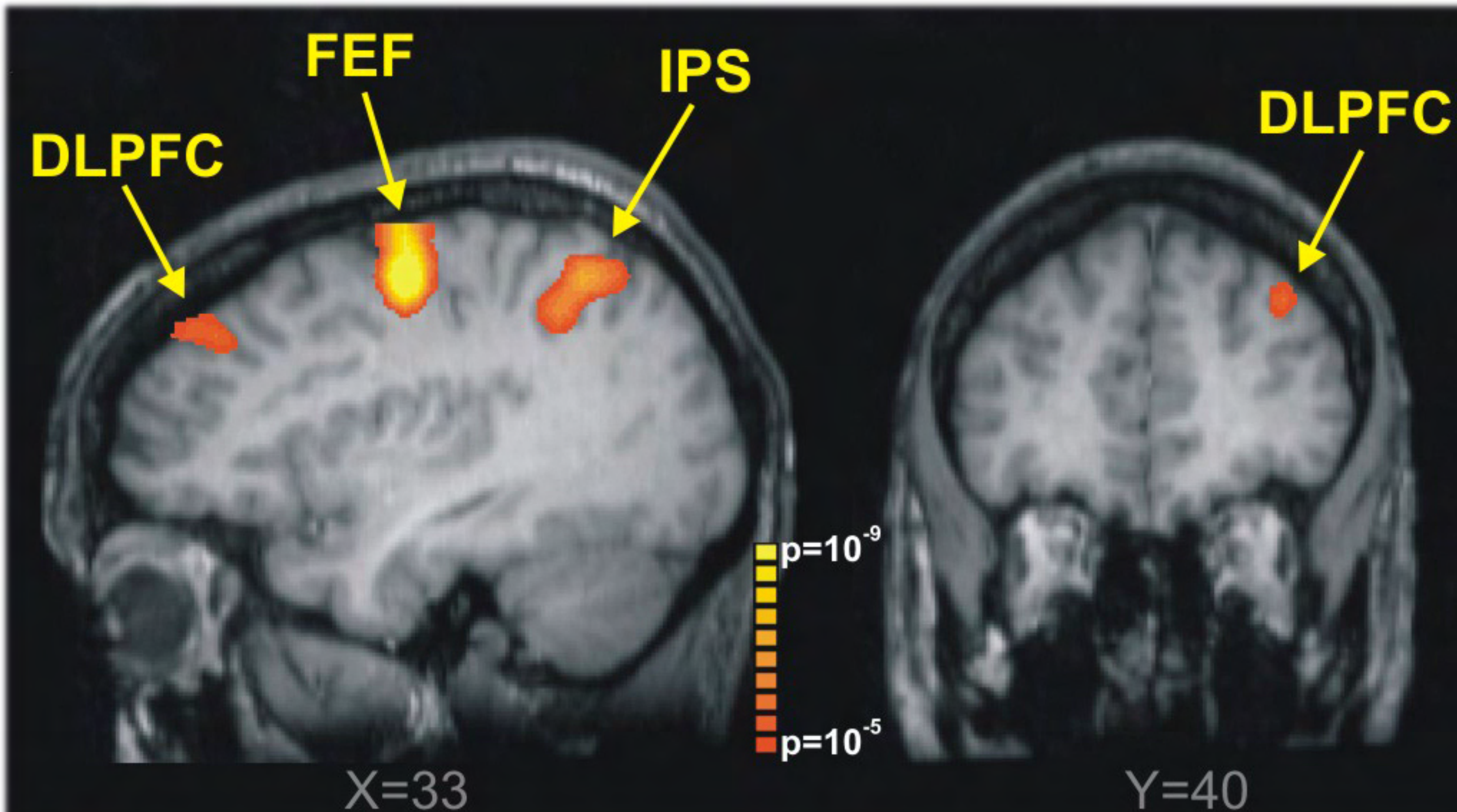


Higher Saccadic Centers

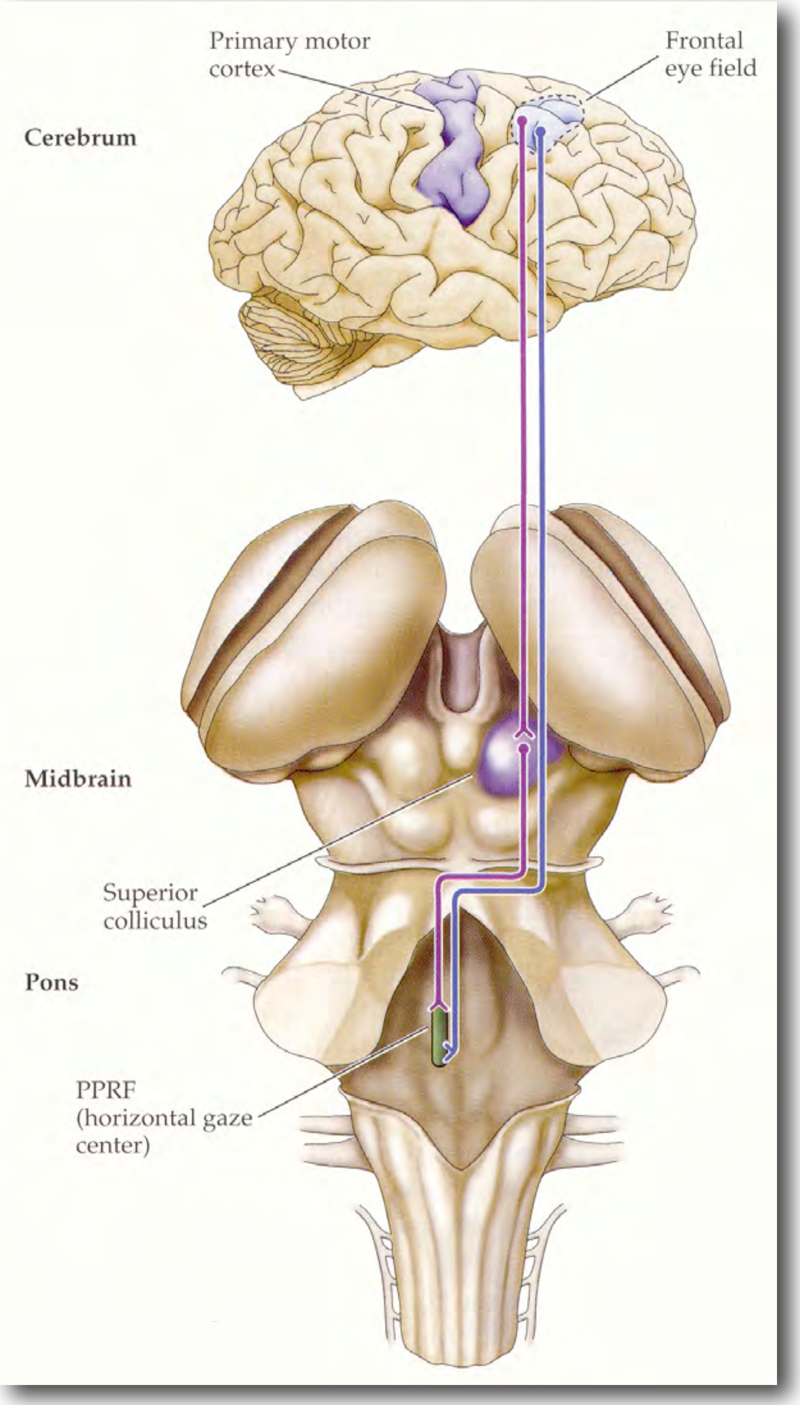
Functional magnetic resonance imaging (fMRI) has demonstrated that saccades in humans and monkeys activate similar cortical areas.



Frontal Eye Fields

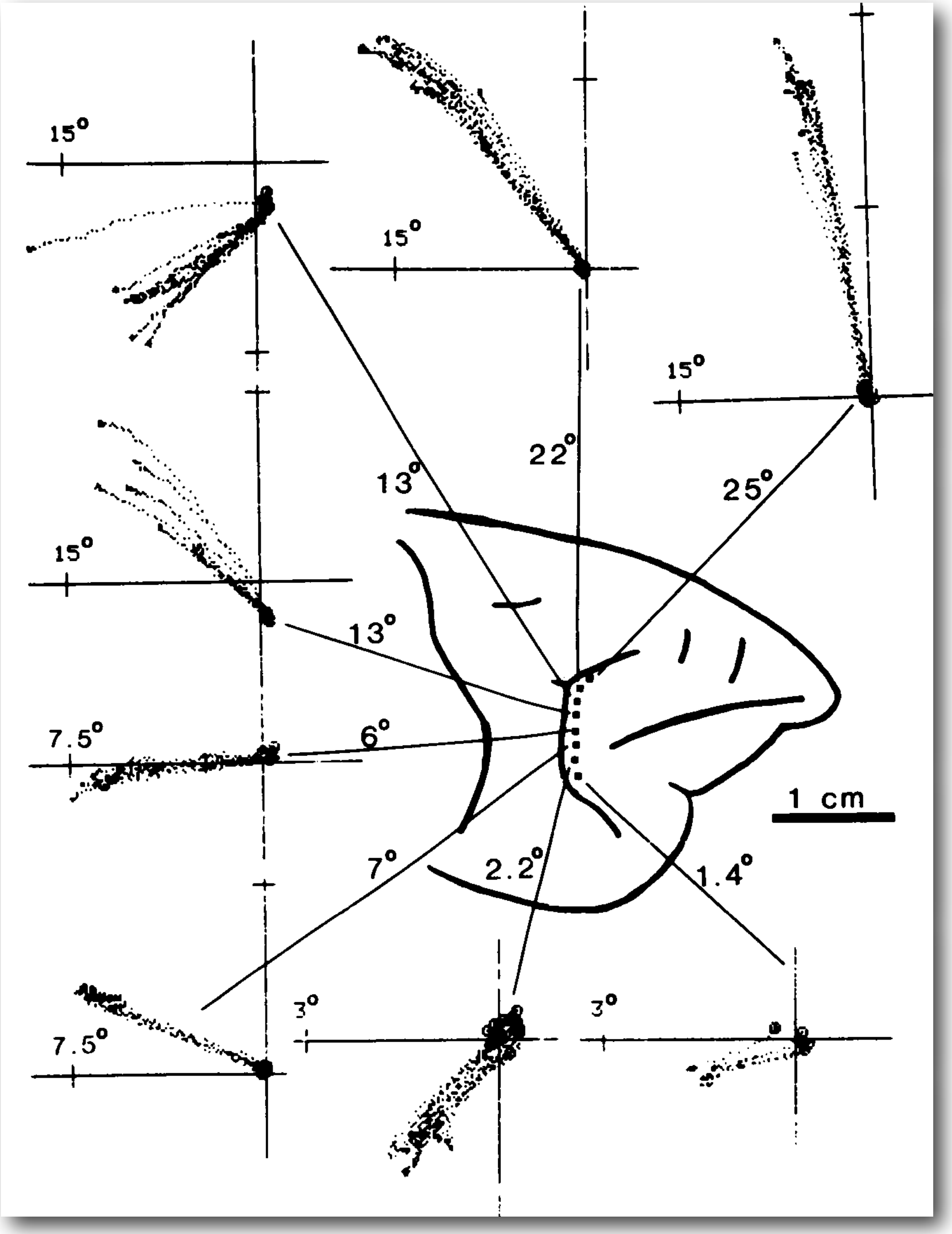
Upper motor neurons in the *frontal eye fields* can control the production of saccades via their projections to:

Superior colliculus
Brainstem pre-motor neurons.



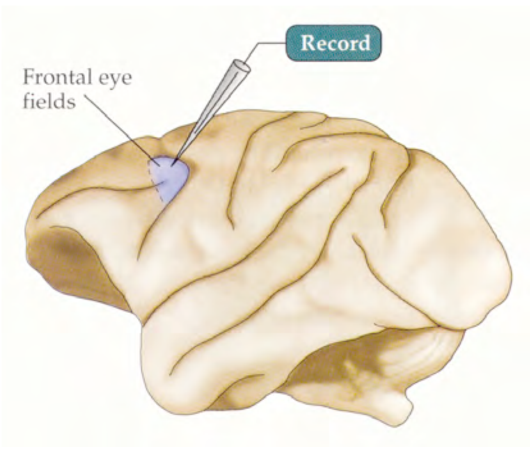
Frontal Eye Fields

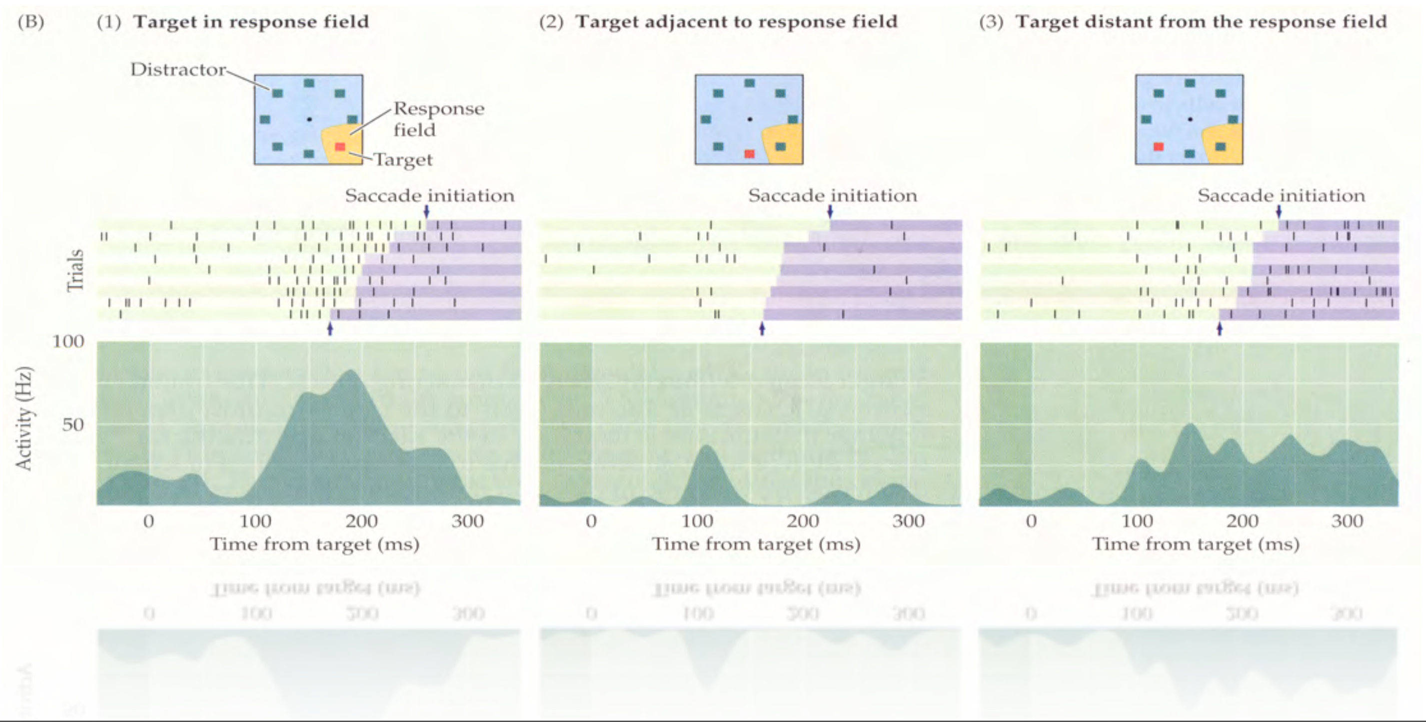
The frontal eye fields contain a topographic map of saccadic eye movements. The medial FEF codes large saccades and the lateral FEF codes small saccades.



Frontal Eye Fields

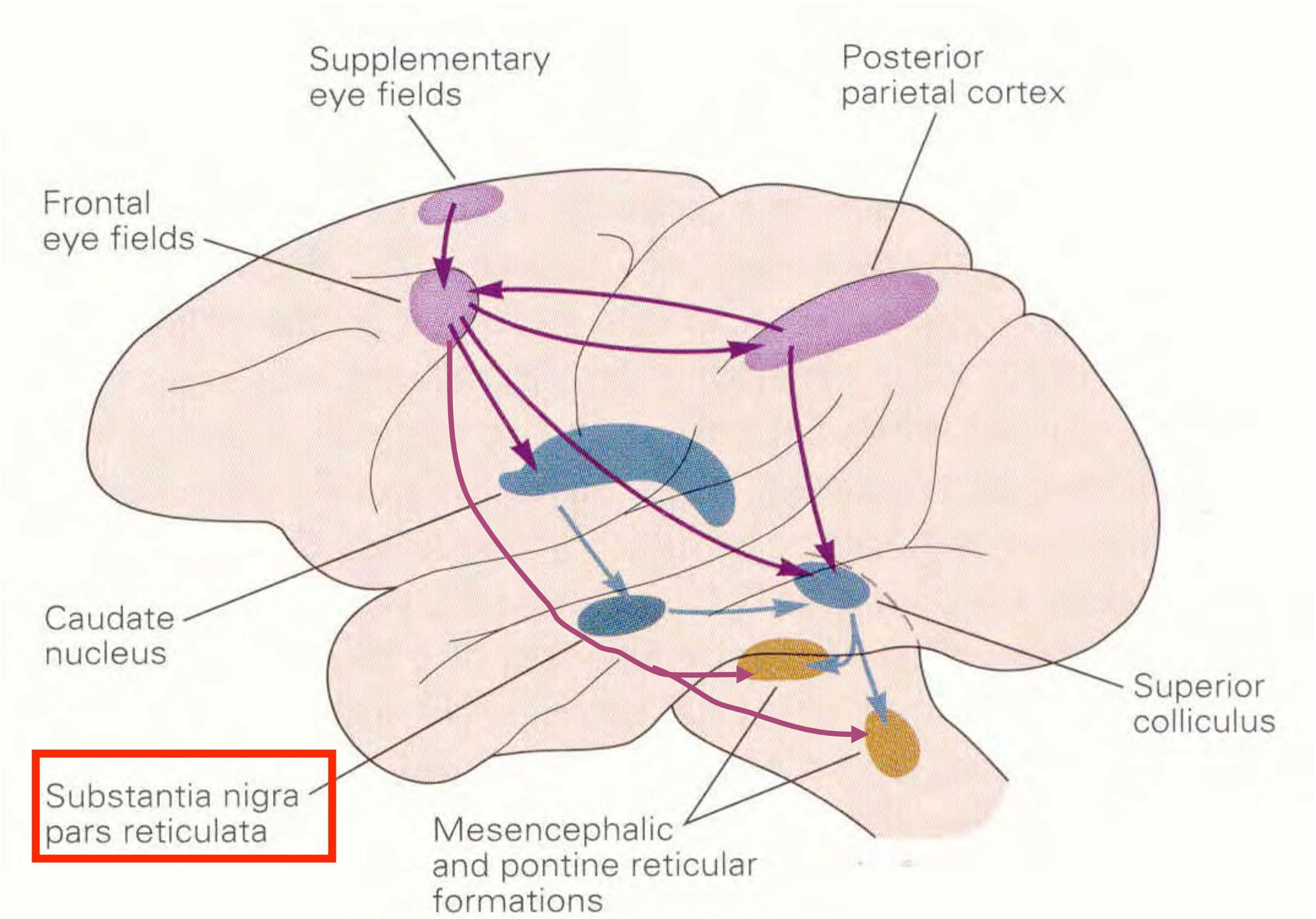
The activity of *frontal eye fields* neurons reflects the selection of the visual target for a saccadic eye movement when several potential goals for movements are available.





Basal Ganglia

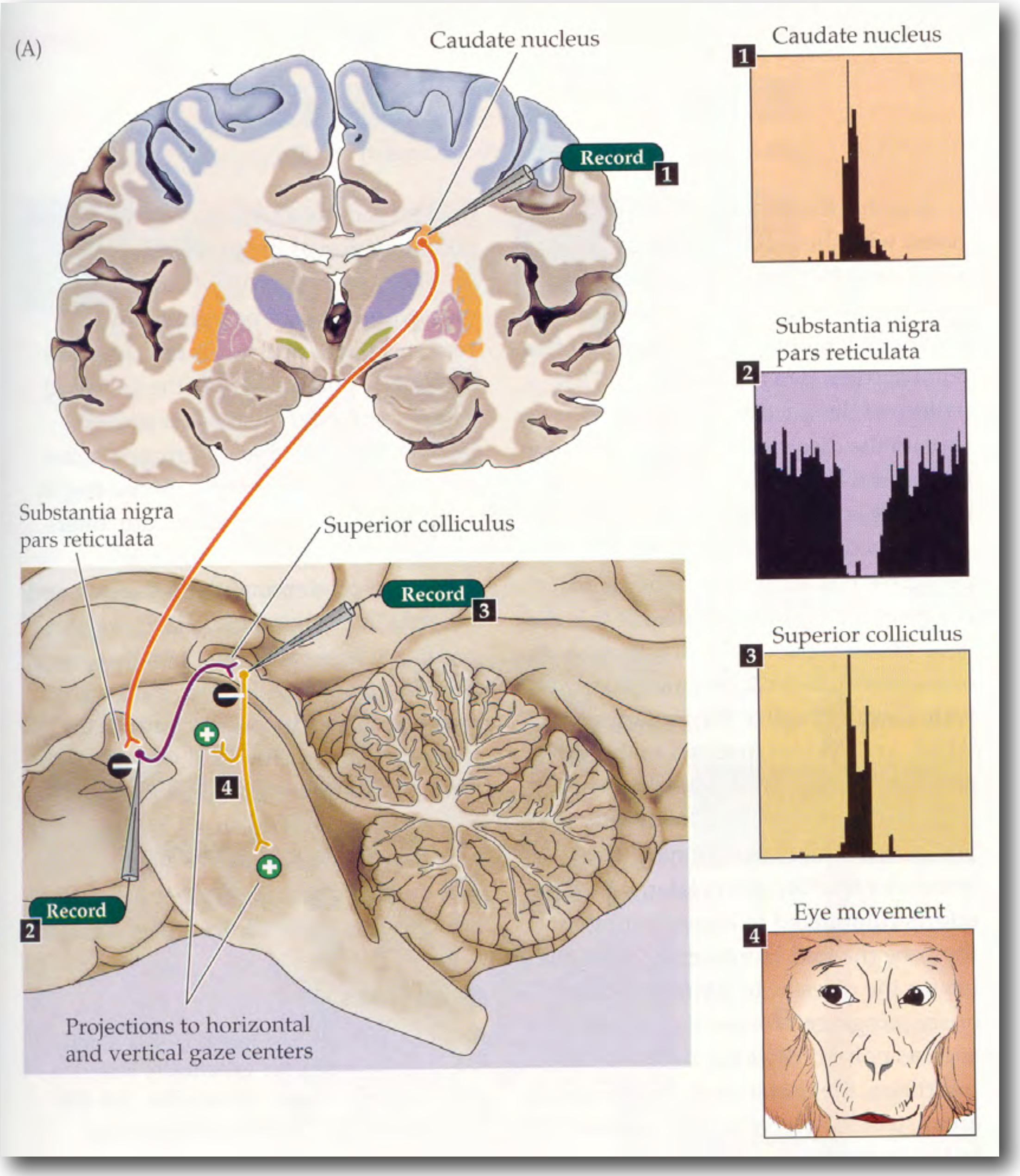
The substantia nigra pars reticulata funnels inputs from the frontal cortex and acts as a gate for the voluntary control of saccades, keeping the superior colliculus activity in check.



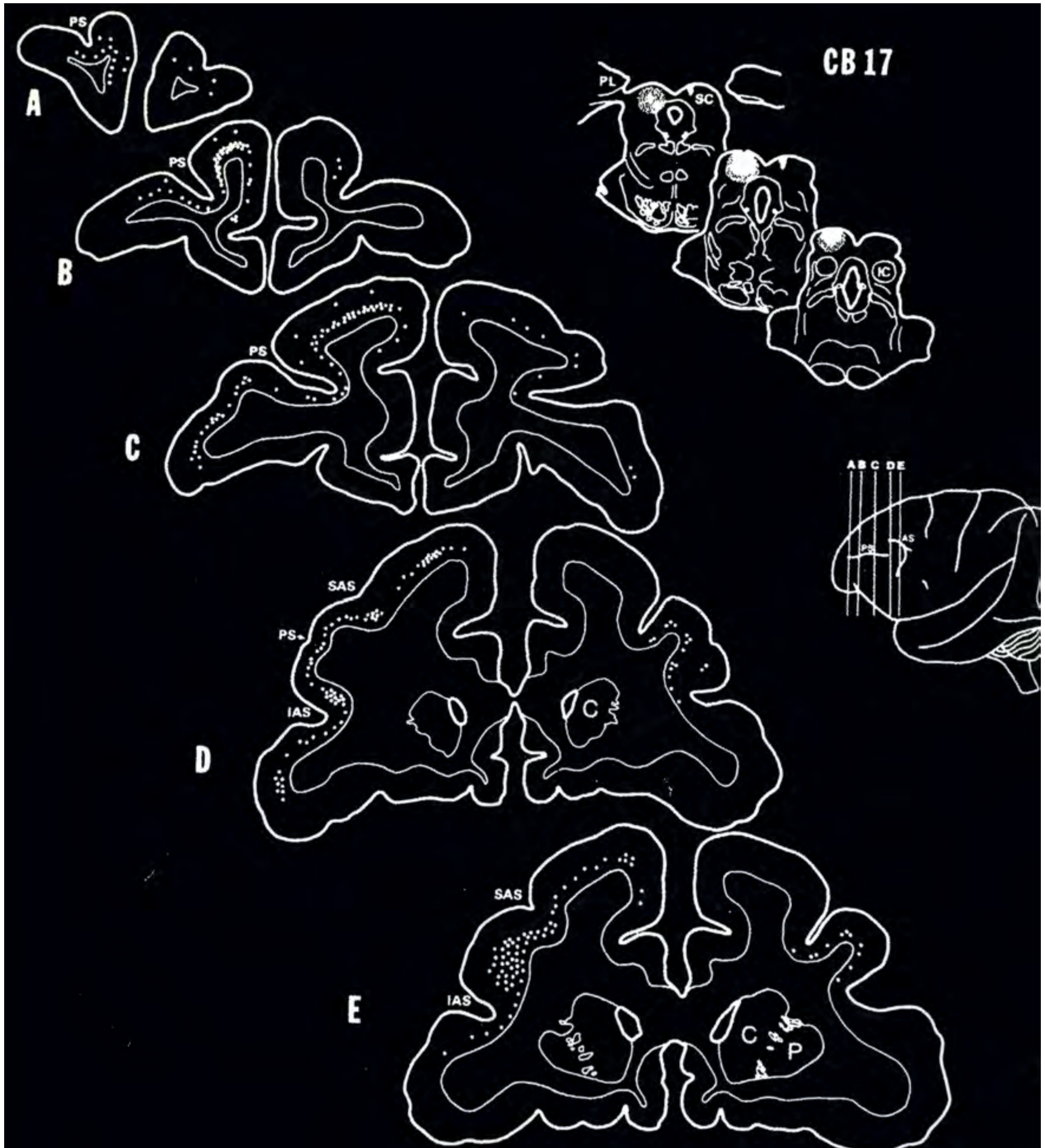
Basal Ganglia

The substantia nigra pars reticulata tonically inhibits the superior colliculus, thereby inhibiting unwanted reflexive saccades.

Prior to a voluntary saccade, this tonic inhibition is reduced by inhibitory inputs from the caudate which is activated by frontal cortical neurons.



Prefrontal Cortex projects to Superior Colliculus



Eye Movements and Psychiatric Disorder

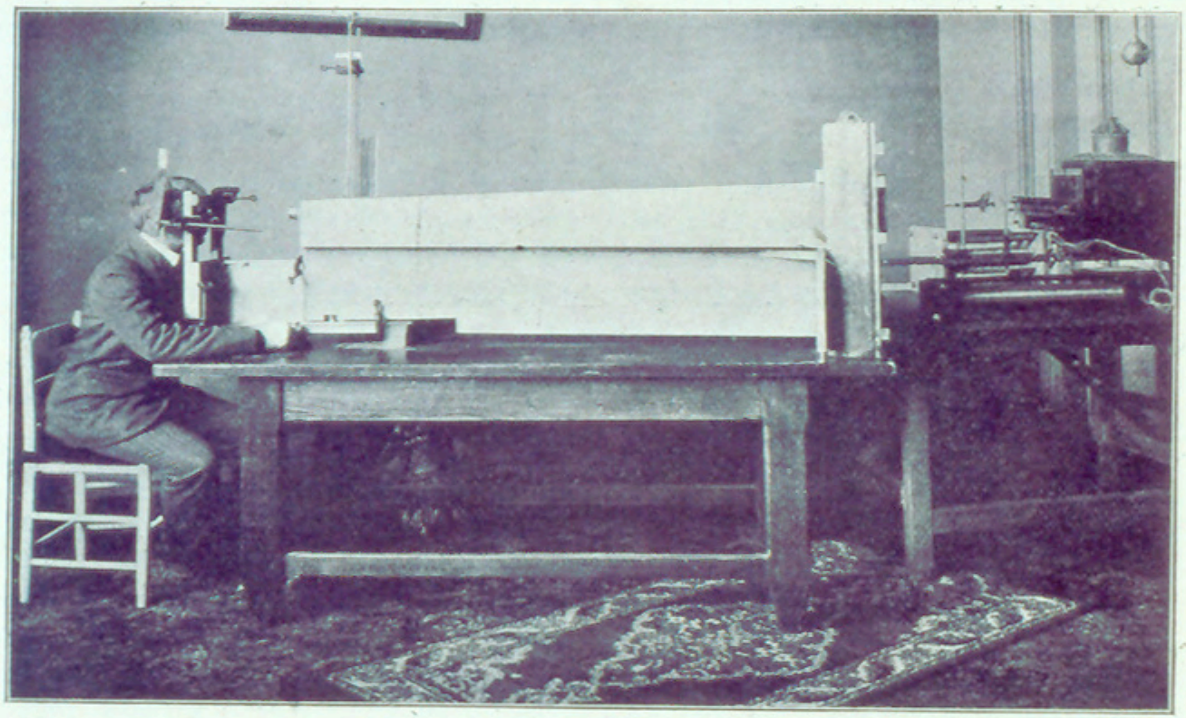
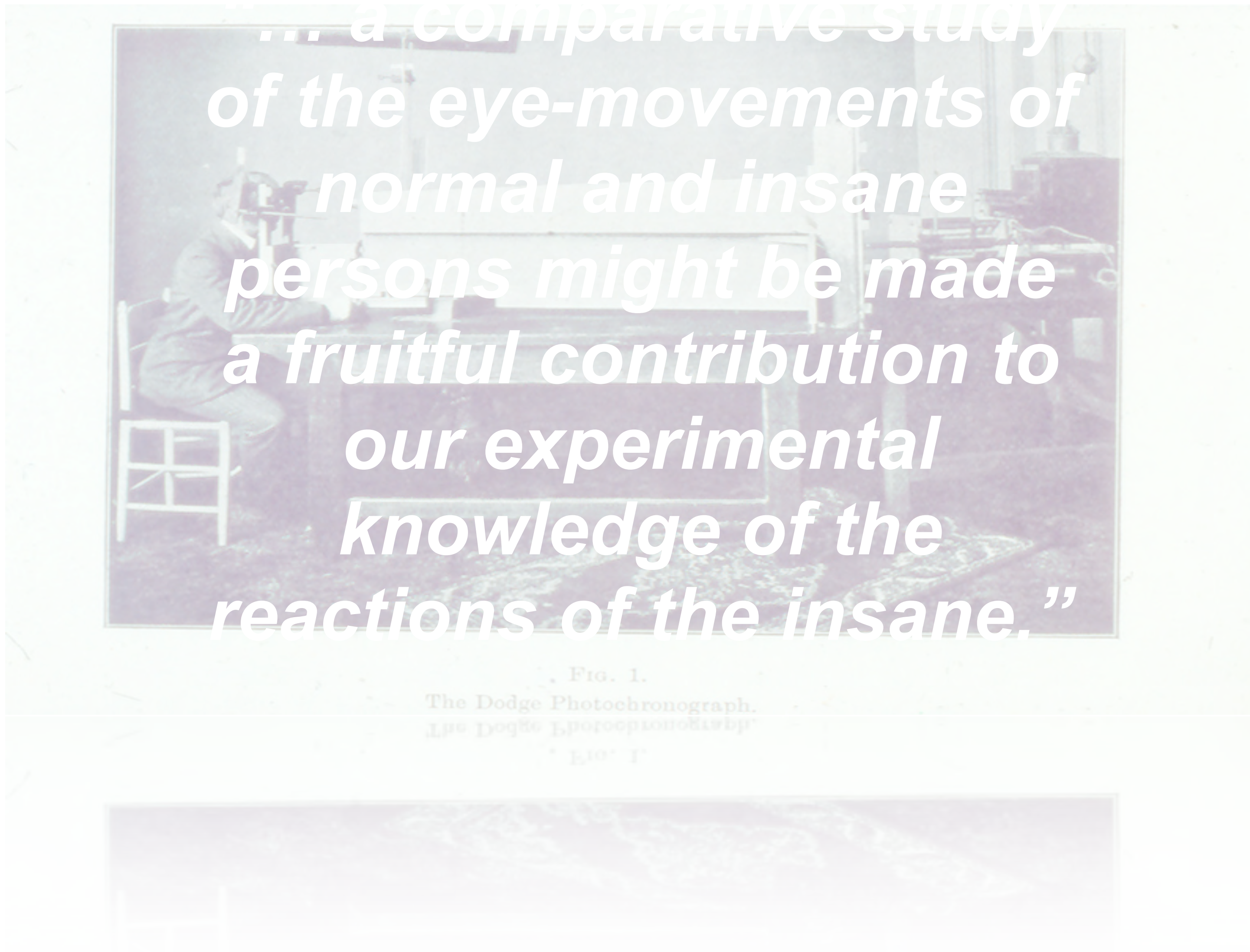


Fig. 1.
The Dodge Photochronograph.

Diefendorf & Dodge (1908). An experimental study of the ocular reactions of the insane from photographic records. Brain, 31: 451-389

Eye Movements and Psychiatric Disorder



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Eye Movements as a Clinical Tool

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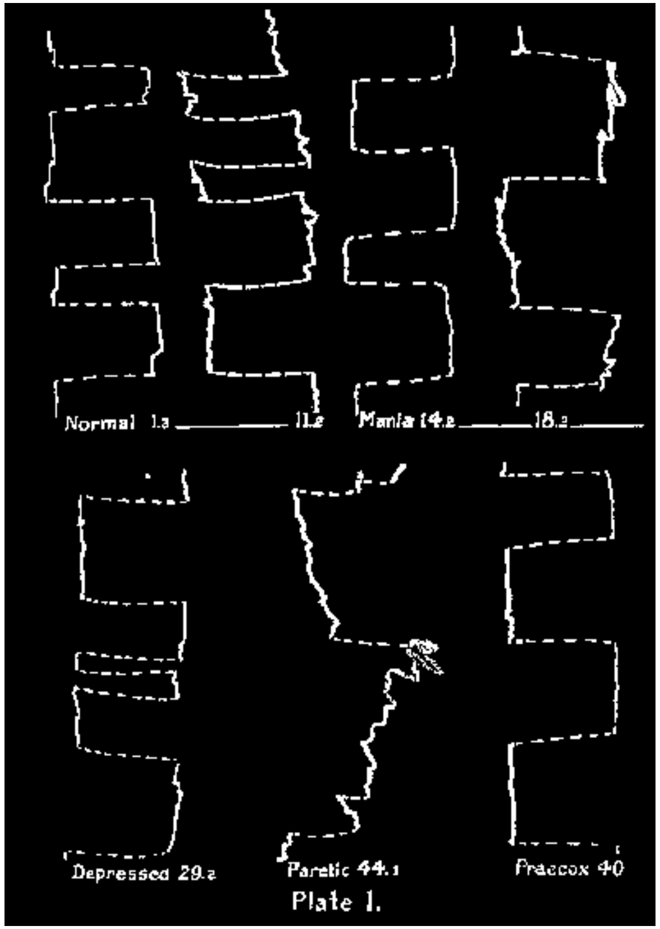

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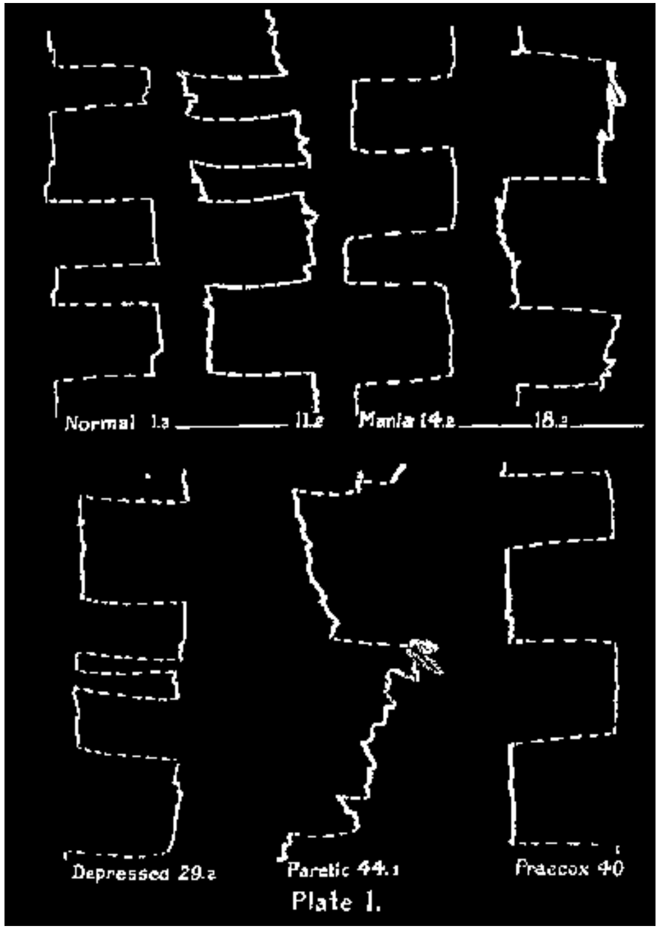

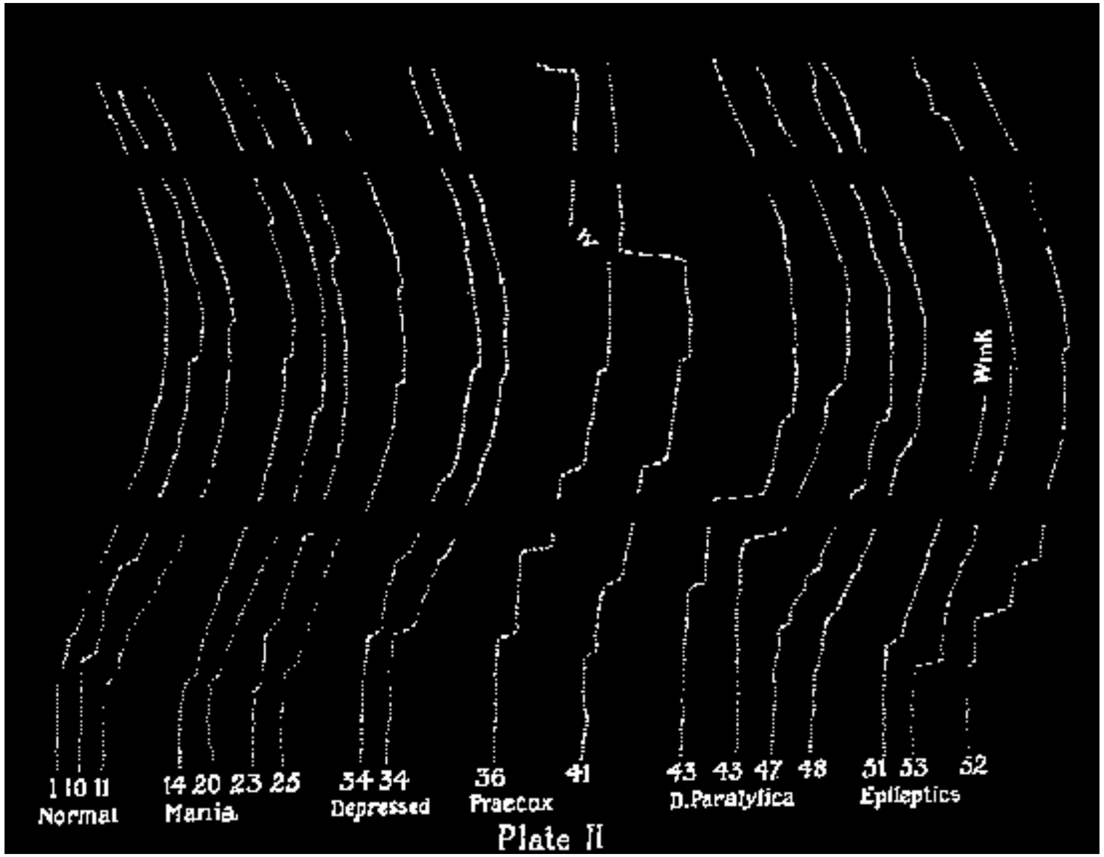

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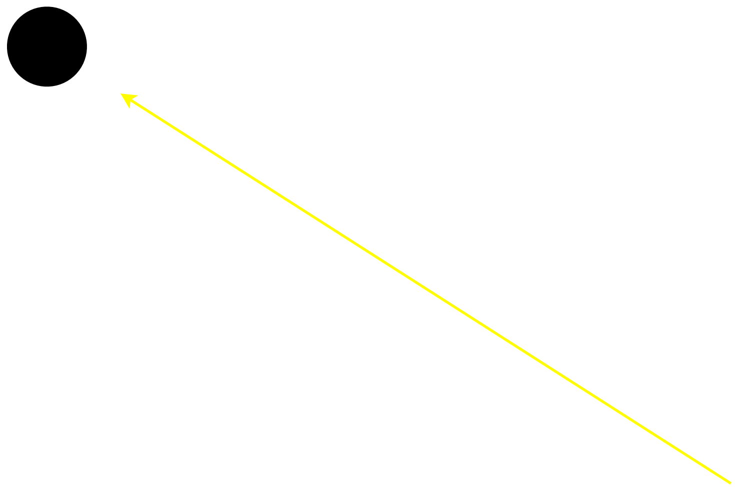
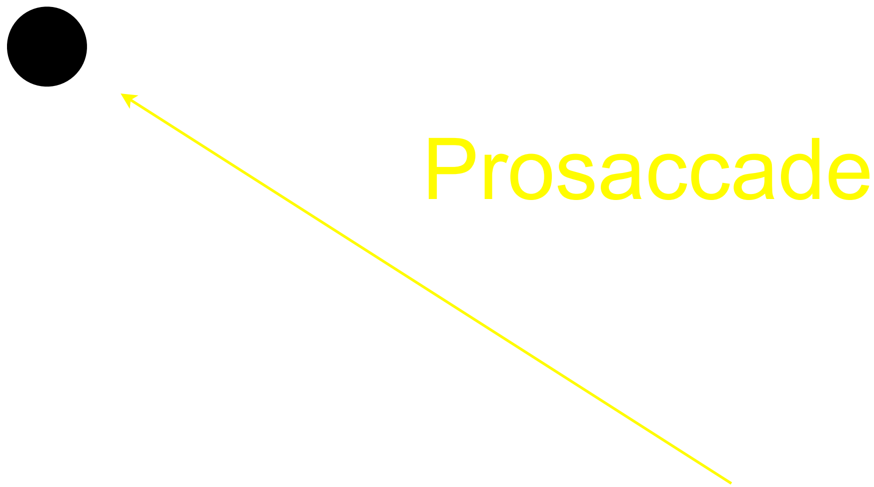
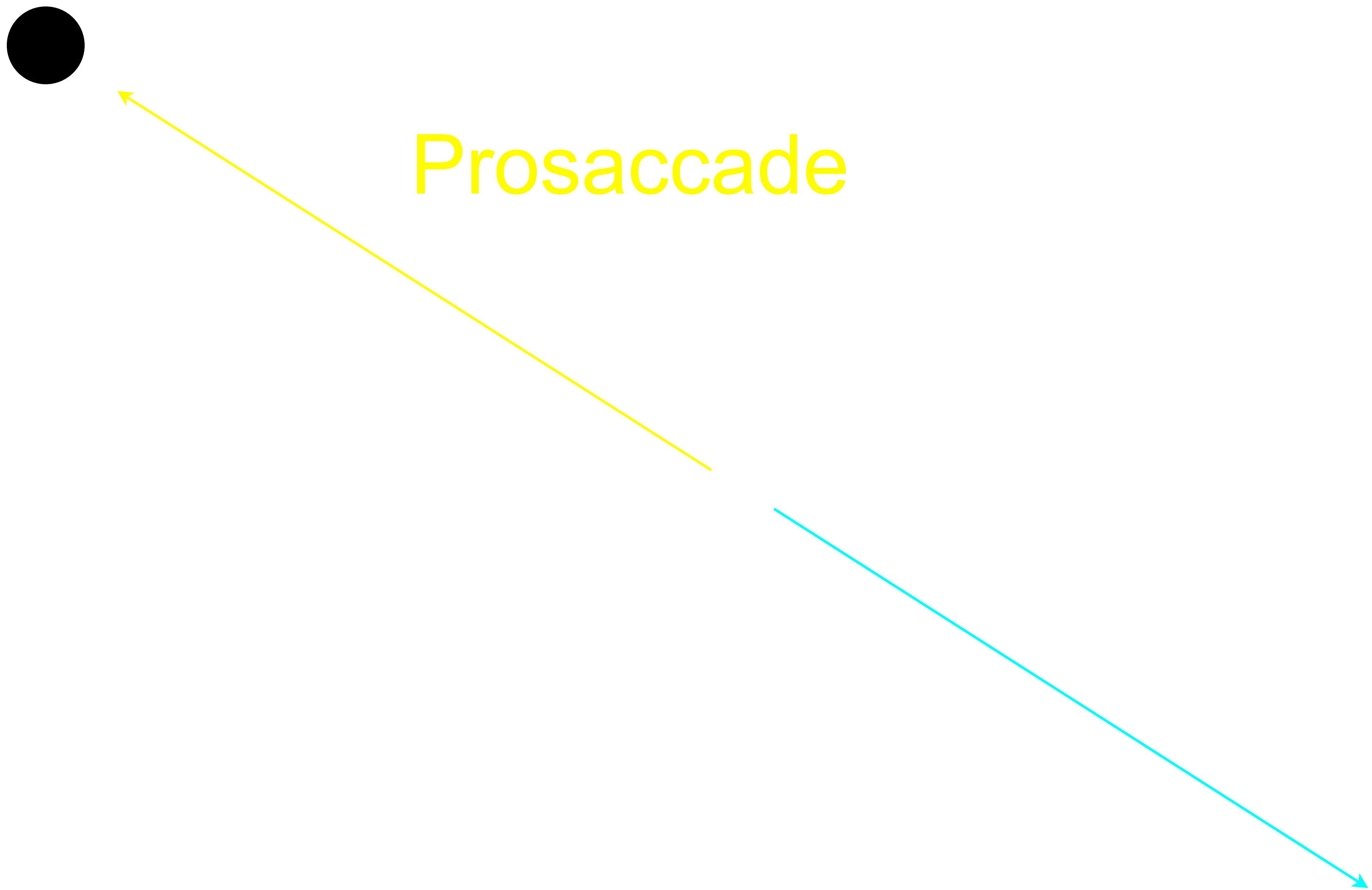
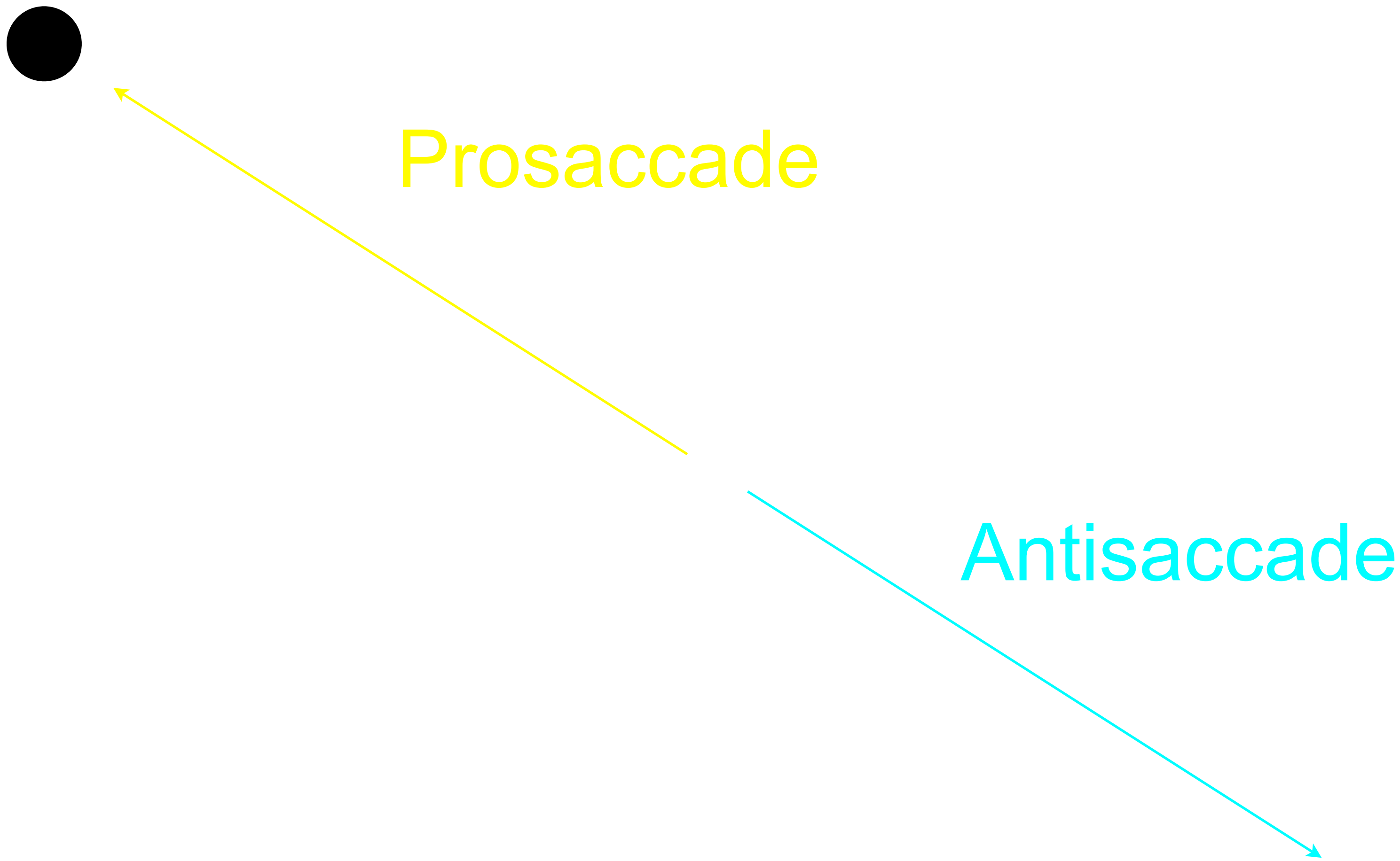



Prosaccade


Prosaccade


Prosaccade
Antisaccade

Increased Error Rates in the Antisaccade Task

Alzheimer's Disease

Attention Deficit Hyperactivity Disorder (ADHD)

Frontal Cortex Lesions

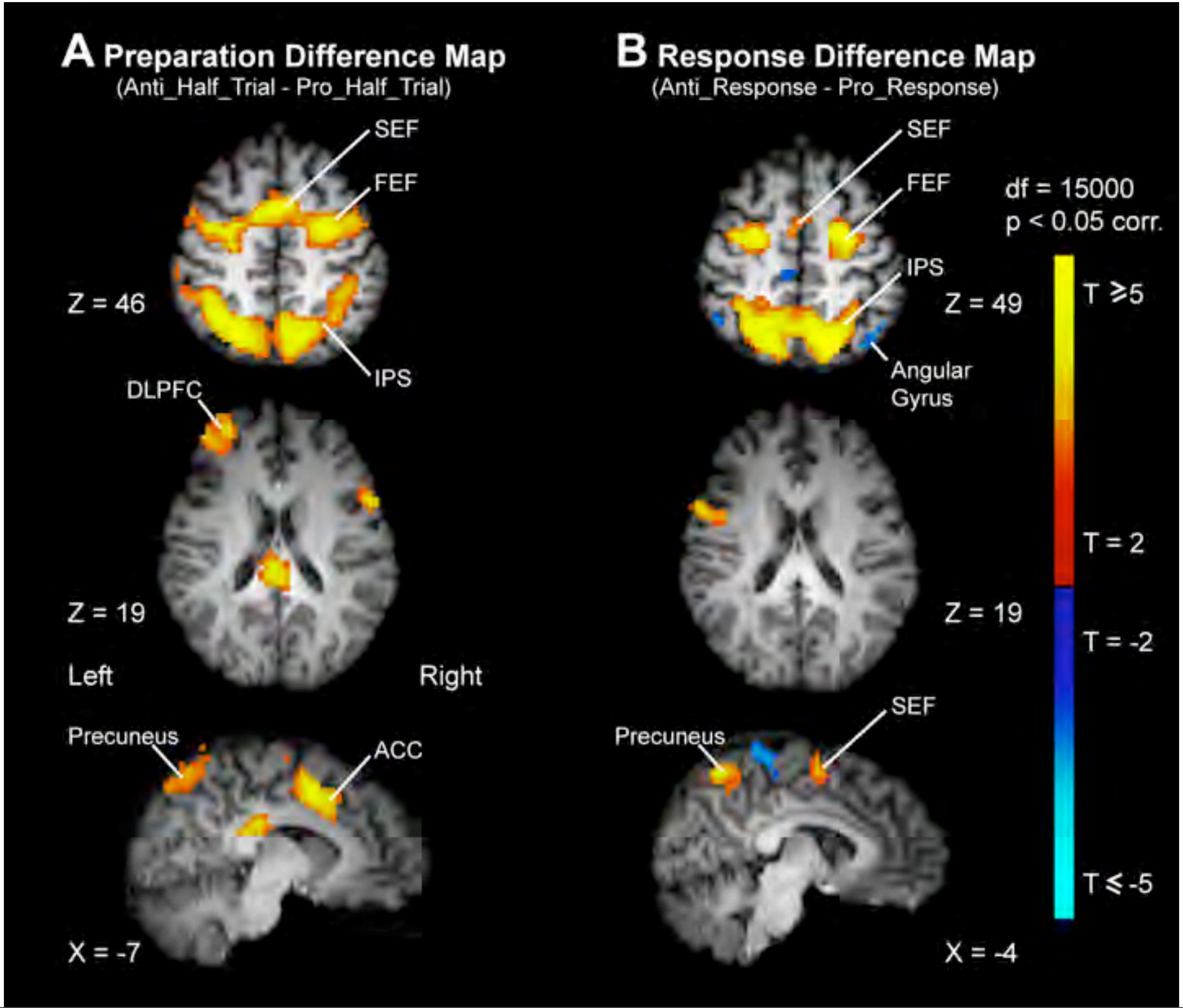
Huntington's Disease

Parkinson's Disease

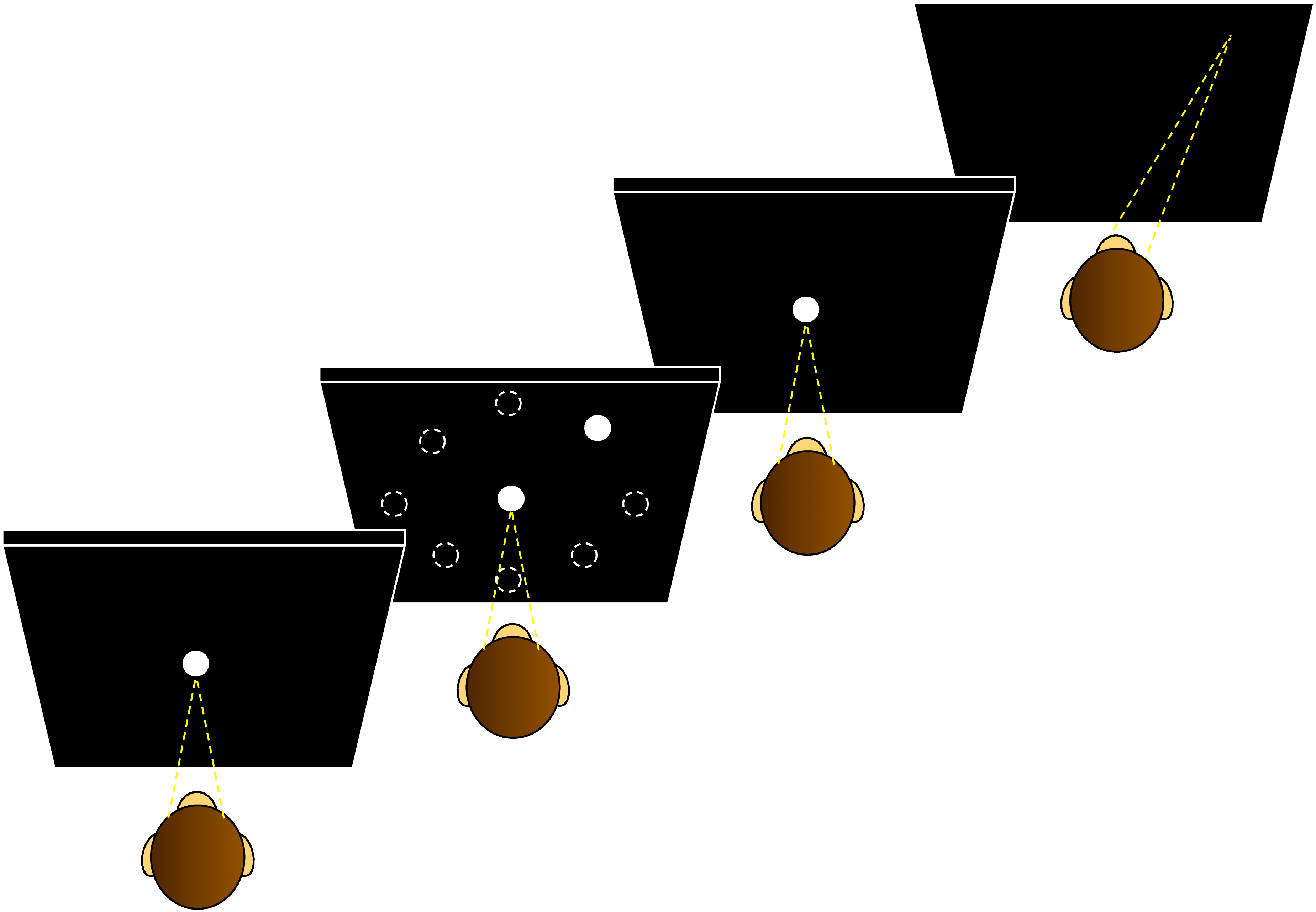
Progressive Supranuclear Palsy

Schizophrenia

Preparatory activation versus response activation

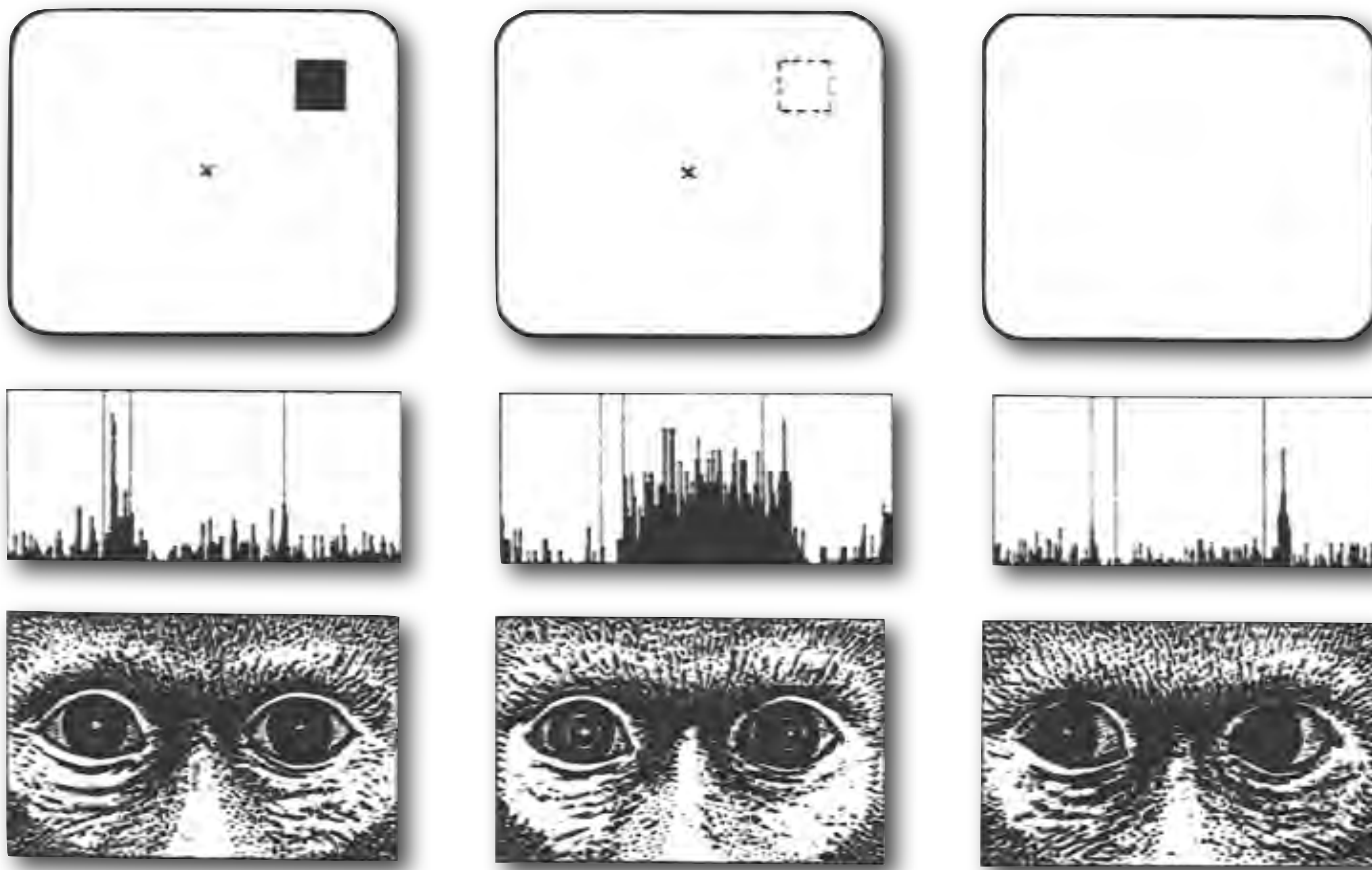


Memory – Guided Saccade Task



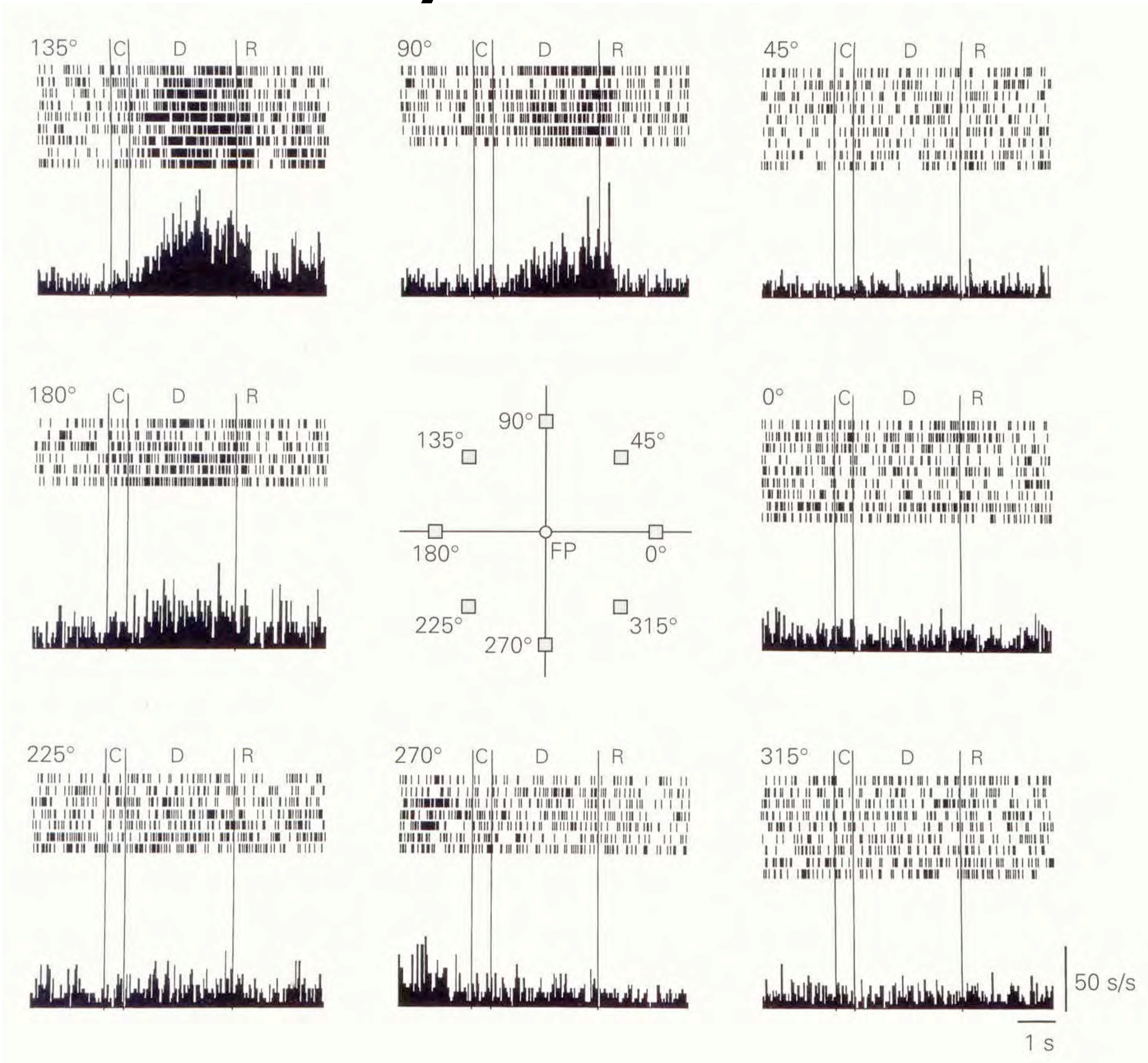
Prefrontal Cortex and Working Memory

Neurons in the dorsolateral prefrontal cortex show visual, delay, or movement-related activity or a combination.



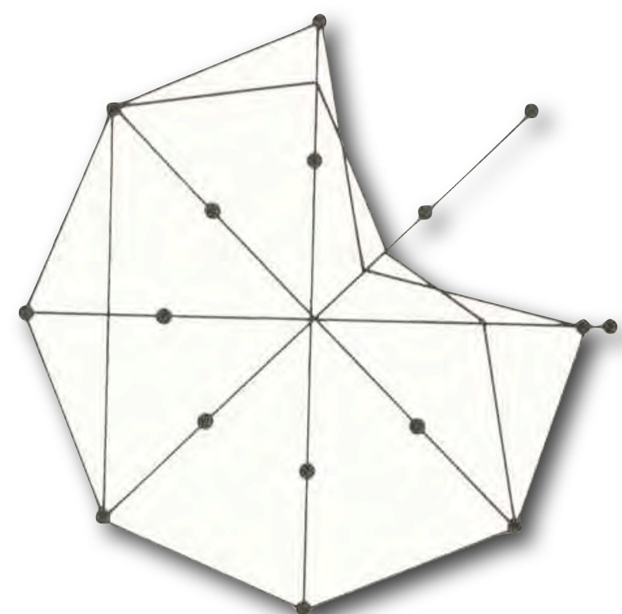
Prefrontal Cortex and Working Memory

Many prefrontal neurons show location-selectivity during the delay period. Different neurons code different spatial locations, providing a spatial map in working memory.



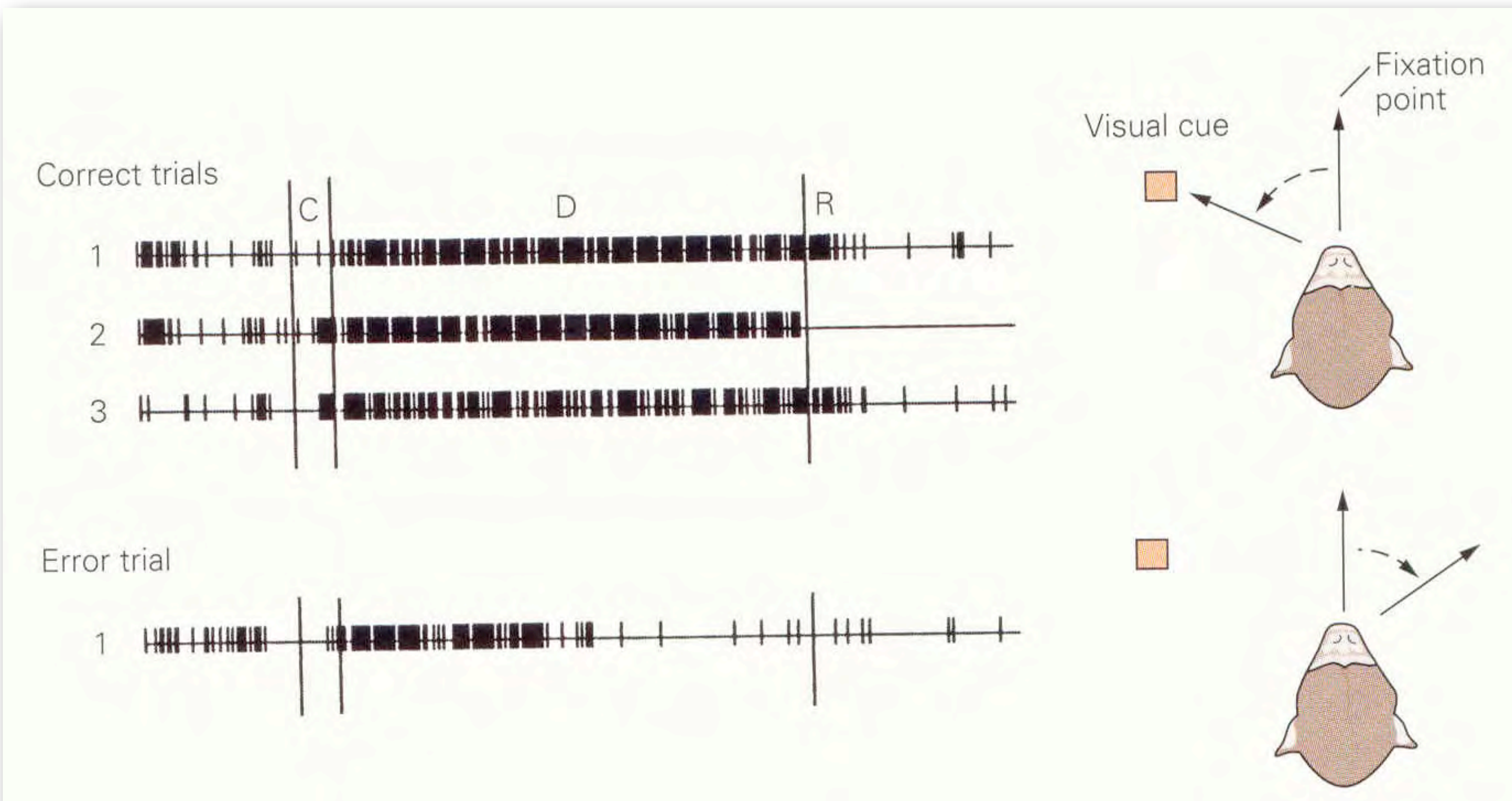
Prefrontal Cortex and Working Memory

Inactivation of small sites in the prefrontal cortex leads to spatially selective working memory deficits.



Prefrontal Cortex and Working Memory

Neurons in the dorsolateral prefrontal cortex track working memory and predict the animal's performance.



Further Reading

Purves D, Augustine GJ, Fitzpatrick D, Katz LA, LaMantia A-S, McNamara JO, Willams SM (2001). Neuroscience. 2nd edition, Chapter 20, Sinauer

Kandel ER, Schwartz JH, Jessell TM (2000). Principles of Neural Science. 4th edition, Chapter 39, McGraw-Hill