LISC 322 Neuroscience

THE OCULOMOTOR SYSTEM

Anatomy & Physiology

Martin Paré

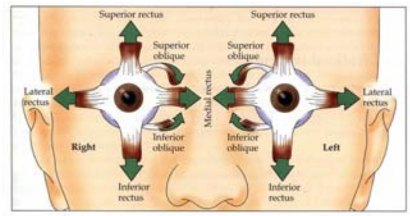
Assistant Professor

Physiology & Psychology

http://brain.phgy.queensu.ca/pare

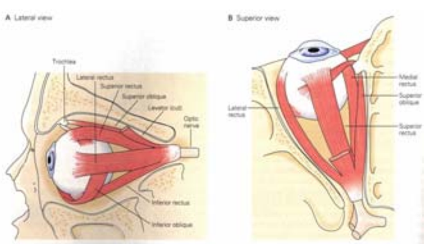
Extraocular Muscles

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



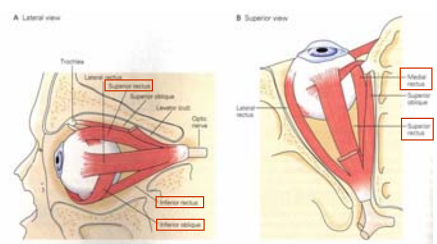
Extraocular Muscle Innervation

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



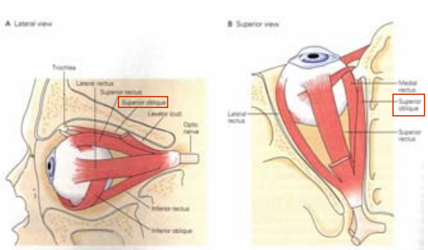
Extraocular Muscle Innervation

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



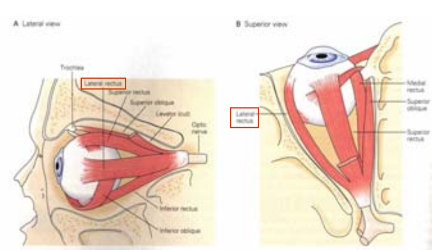
Extraocular Muscle Innervation

The ***Trochlear*** nerve (IV) innervates the ***superior oblique***.



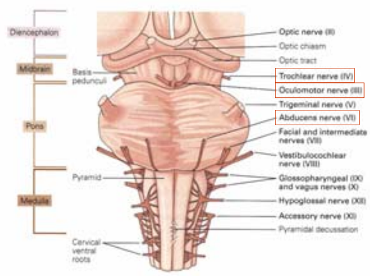
Extraocular Muscle Innervation

The ***Abducens*** nerve (VI) innervates the ***lateral rectus***.



Extraocular Muscle Innervation

Ventral view

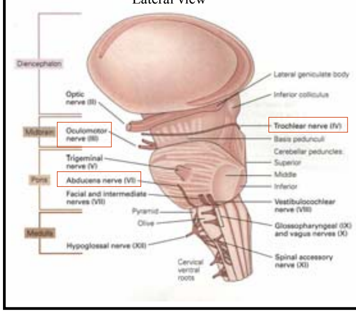


The ***Oculomotor*** and ***Trochlear*** nerves originate from the ***midbrain***.

The ***Abducens*** nerve originates from the ***pons***.

Extraocular Muscle Innervation

Lateral view

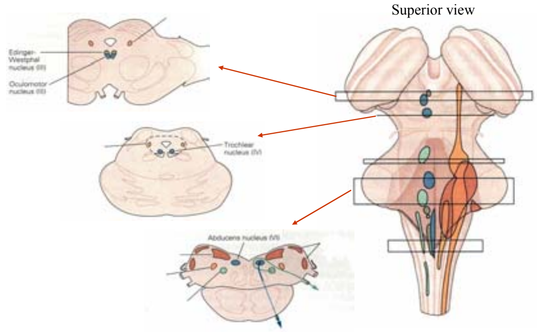


The ***Oculomotor*** and ***Trochlear*** nerves originate from the ***midbrain***.

The ***Abducens*** nerve originates from the ***pons***.

Nuclei of Ocular Motor Neurons

Superior view



Neural Control of Saccades

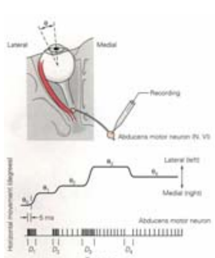
The problem of moving the eyes in the orbit entails two separate issues: controlling the *amplitude* of the movement (how far to go!), and controlling the *direction* of the movement (which way to go!).

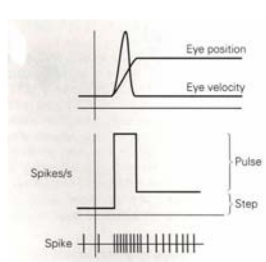
The amplitude of a saccade is determined by the activity in the *lower motor neurons* within the three oculomotor nuclei.

The direction of a saccade is determined by which muscles are activated, as dictated by the activity in the *premotor neurons* within two separate gaze centers in the brainstem.

Neural Control of Saccades

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



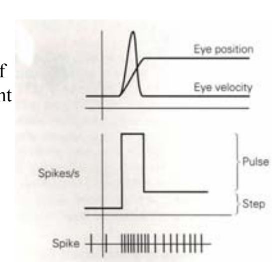


Neural Control of Saccades

Thus, 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.

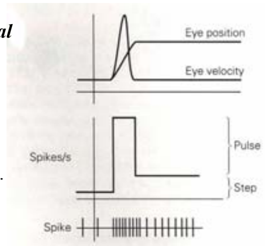


Neural Control of Saccades

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

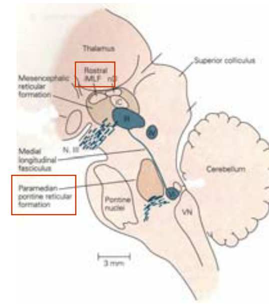
The pulse is the ***phasic signal*** that commands the eyes to move.

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



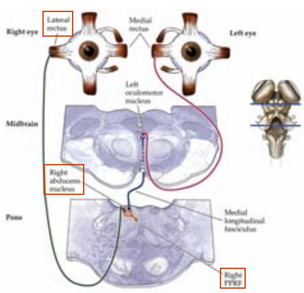
Neural Control of Saccades

The direction of saccades is dictated by premotor neurons in ***two gaze centers*** in the reticular formation:
1) The *paramedian pontine reticular formation* (PPRF) next to the abducens nucleus is the ***horizontal gaze center***.
2) The *rostral interstitial nucleus* (rostral iMLF) in the midbrain reticular formation near the oculomotor nucleus is the ***vertical gaze center***.



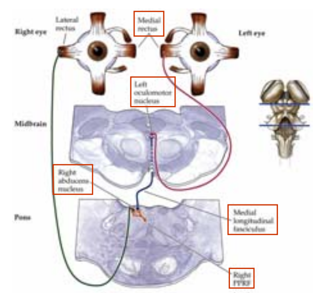
Circuit for Horizontal Saccades

To produce a rightward saccade, activation of premotor neurons in the right *PPRF* increases the activity of *lower motor neurons* in the right *abducens nucleus*, which innervate the *lateral rectus* muscle of the right eye.

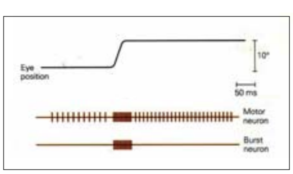


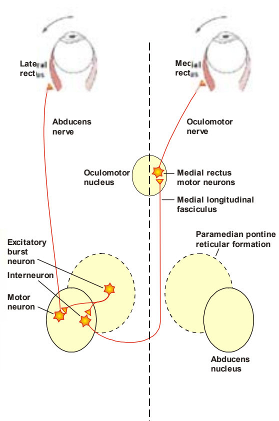
Circuit for Horizontal Saccades

Activation in the right *PPRF* also increases the activity of *internuclear neurons* in the same (right) *abducens nucleus*, which send their axons along the *medial longitudinal fasciculus* to innervate the lower motor neurons in the left *oculomotor nucleus*, which in turn innervate the *medial rectus* muscle of the left eye.

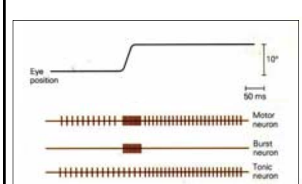


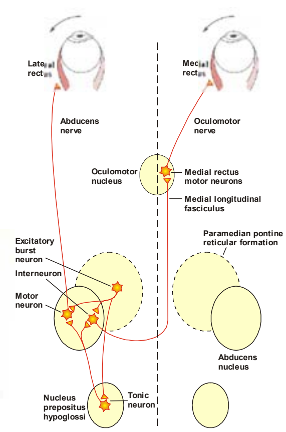
Excitatory burst neurons in the PPRF provide the ***phasic signal*** of the abducens motor neurons.



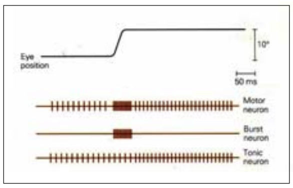


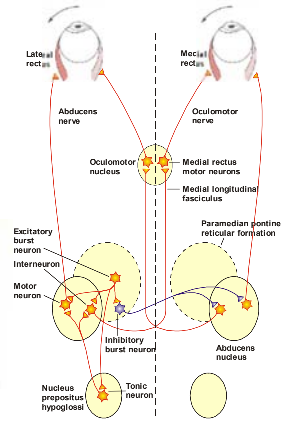
Tonic neurons in the nucleus prepositus hypoglossi integrate the PPRF's phasic signal to provide the ***tonic signal*** of the abducens motor neurons.



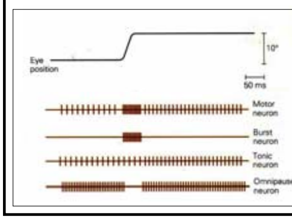


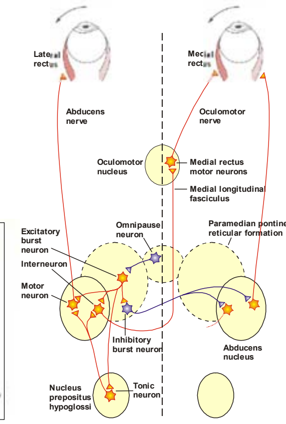
Inhibitory burst neurons in the PPRF silence the contra-lateral abducens internuclear and motor neurons to relax the antagonist muscles.



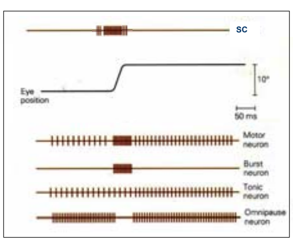


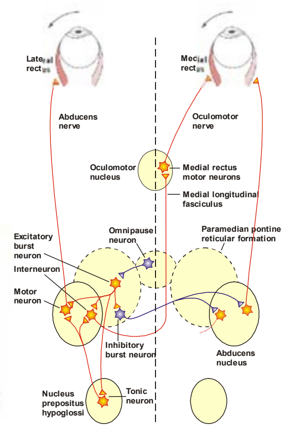
Omnipause neurons inhibit the burst neurons in the PPRF, thereby preventing saccades. A trigger command silencing these neurons is necessary to activate the saccade burst generator.



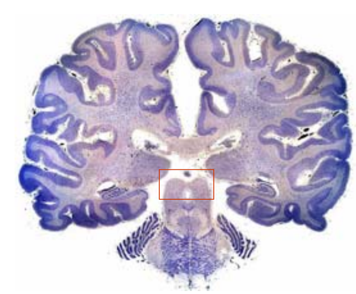


The ***Superior Colliculus*** provides both the motor command to the PPRF's burst neurons and the trigger command to the omnipause neurons.





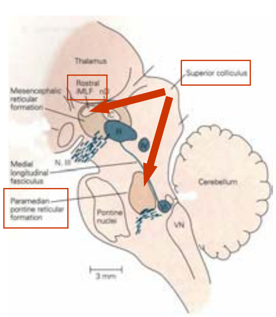
Superior Colliculus



Superior Colliculus

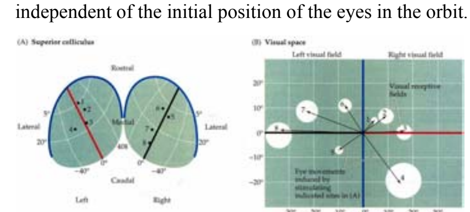
The superior colliculus is situated on the roof of the midbrain.

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 for the foveation of a visual stimulus.



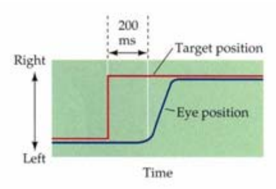
Superior Colliculus

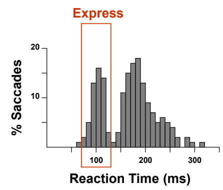
The superior colliculus contains a *topographic motor map* composed of neurons that discharge a high frequency burst of action potentials immediately prior to saccades that have a specific vector, i.e., a direction and amplitude that is independent of the initial position of the eyes in the orbit.



Superior Colliculus

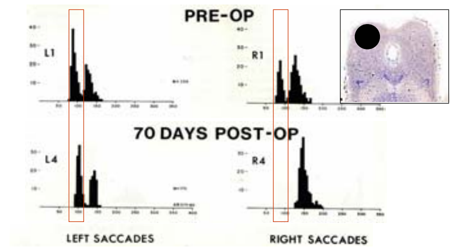
The integrity of the superior colliculus is crucial for the production of *reflexive* saccades, including the "*express*" saccades whose latency approach the fastest time for visual signals to reach the oculomotor system and trigger a saccade.





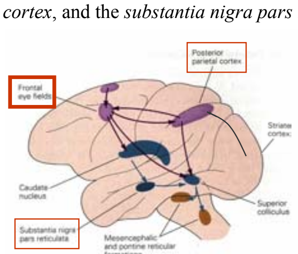
Superior Colliculus

Lesions of the superior colliculus permanently abolish the production of "*express*" saccades.



Higher Saccadic Centers

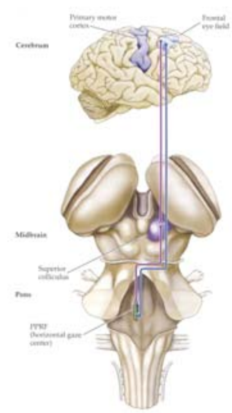
The saccade-related activity of superior colliculus neurons is shaped by inputs from the *frontal eye fields*, the *posterior parietal cortex*, and the *substantia nigra pars reticulata*.



Frontal Eye Fields

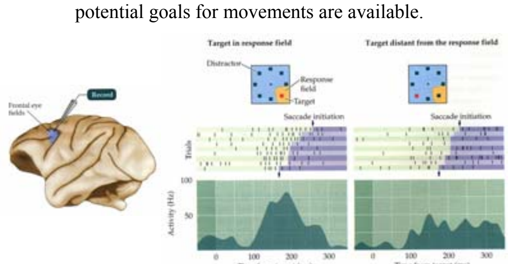
Upper motor neurons in the *frontal eye fields* can control the production of saccades via their projection to:

1) superior colliculus,
2) brain stem pre-motor neurons.



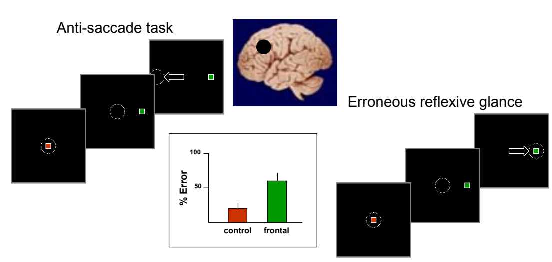
Frontal Eye Fields

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.



Frontal Eye Fields

The *frontal eye fields* are involved in suppressing reflexive saccades and generating *voluntary, non-visual* saccades.



Higher Saccadic Centers

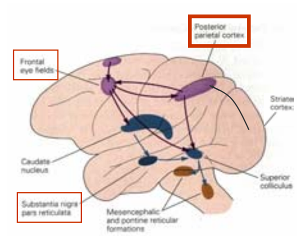
The *complementary executive control* exerted on saccade generation by the frontal eye fields and the superior colliculus is revealed by the effect of selective and combined ablation.

Lesions of the superior colliculus prevent the generation *short-latency reflexive* saccades, whereas the generation of *voluntary* saccades is disrupted by frontal eye fields lesions.

Although saccades can still be produced after the ablation of either the superior colliculus or the frontal eye fields, a combined ablation of these two structures results in t he *complete abolition* of saccadic eye movements.

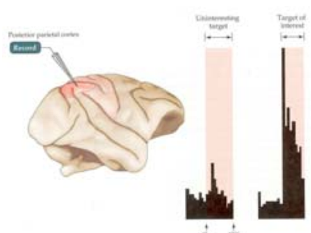
Posterior Parietal Cortex

The *posterior parietal cortex* is involved in the *visual guidance* of saccades by shaping the visual inputs to the superior colliculus.



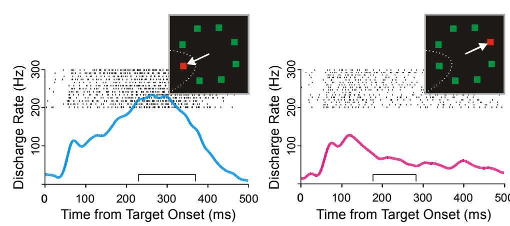
Posterior Parietal Cortex

Visual neurons in the *posterior parietal cortex* are selectively activated by stimuli that are behaviorally relevant, e.g., for actions, including saccadic eye movements.



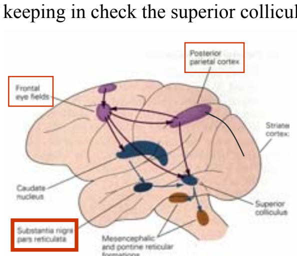
Posterior Parietal Cortex

The activation of *parietal cortex* neurons are particularly sensitive to salient visual stimuli and they respond most when a stimulus within their receptive field is a saccade target.

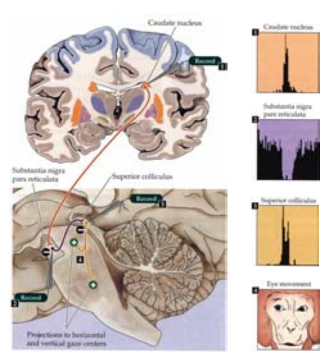


Basal Ganglia

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



Basal Ganglia



The neural activity in the *substantia nigra* maintains the superior colliculus tonically inhibited to *prevent* unwanted saccades.

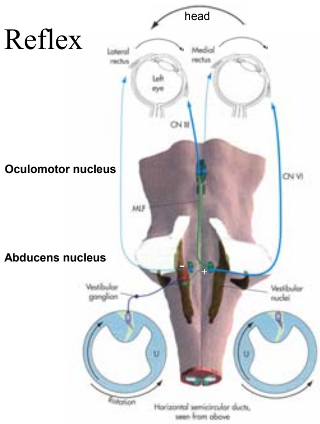
Prior to a voluntary saccade, this tonic inhibition is reduced by inputs from the caudate, which is activated by signals form the cortex.

Vestibulo-Ocular Reflex

The horizontal VOR is a short tri-synaptic reflex with synapses at:

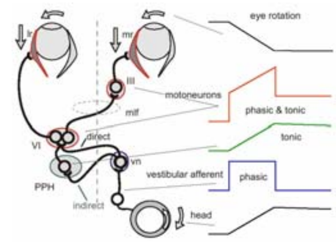
1) the vestibular nucleus,
2) the abducens nucleus,
3) the lateral rectus.

The medial rectus is concomitantly activated via the abducens inter-nuclear and oculomotor motor neurons.

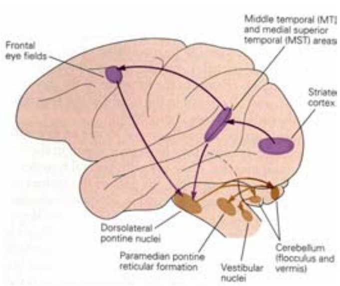


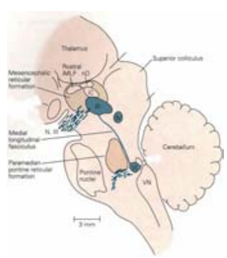
Vestibulo-Ocular Reflex

The VOR phasic command to the motor neurons comes directly from the vestibular nucleus, while the tonic command is provided by an indirect projection through the nucleus prepositus hypoglossi.



Smooth Pursuit Circuit





Oculomotor System: Anatomy & Physiology

Reference for this Lecture:

- Neuroscience, 2nd edition (2001) by Purves et al., Chapter 20.

Lectures are posted:

- http://brain.phgy.queensu.ca/pare

Office Time:

- Tuesday & Thursday (15:00-17:00)
  Botterell Hall, Room 438