The oculomotor system

Or
Fear and Loathing at the Orbit

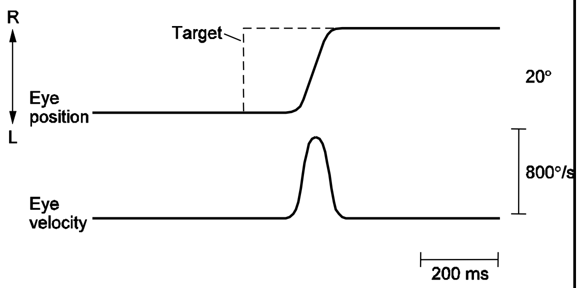
First you tell them what your gonna tell them

- The phenomenology of eye movements.
- The anatomy and physiology of the extraocular muscles and nerves.
- The supranuclear control of eye movements: motor control and cognitive plans.

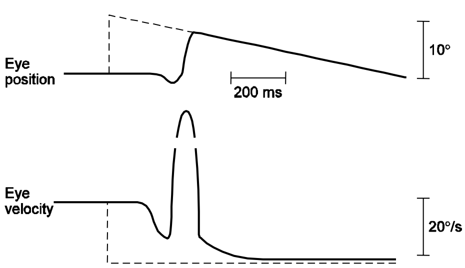
The purposes of eye movements

- Keep an object on the fovea
  - Fixation
  - Smooth pursuit
- Keep the eyes still when the head moves
  - Vestibulocular reflex
  - Optokinetic reflex
- Change what you are looking at (move the fovea from one object to another)
  - Saccade
- Change the depth plane of the foveal object
  - Vergence – eyes move in different directions

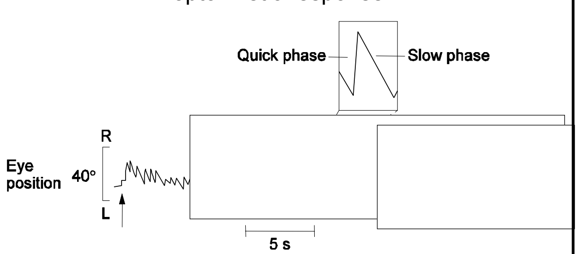
Saccades move the fovea to a new *position*



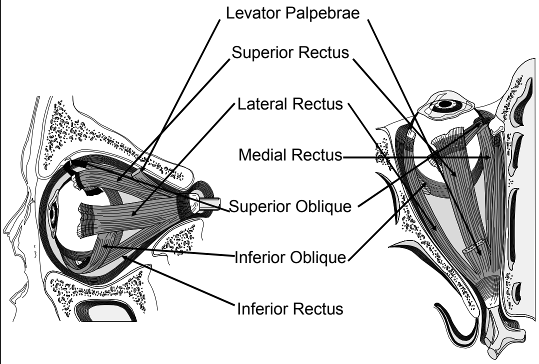
Smooth pursuit matches eye velocity to target velocity



The vestibuloocular reflex drives the eyes in the opposite direction of head movement – but the vestibular signal habituates, and is supplemented by vision – the optokinetic response

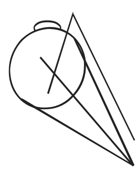


6 Muscles move the eyes



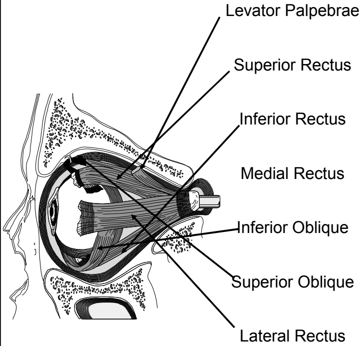
The obliques are counterintuitive

- Each oblique inserts behind the equator of the eye.
- The superior oblique rotates the eye downward and intorts it!
- The inferior oblique rotates the eye upward and intorts it.
- Vertical recti extort the eye as well as elevate or depress it.



Vertical movements are made by combination of obliques and vertical rectus muscles, each of which has a torsional and a vertical component which varies with the horizontal position of the eye in the orbit.

3 Cranial Nerves Control the Eye



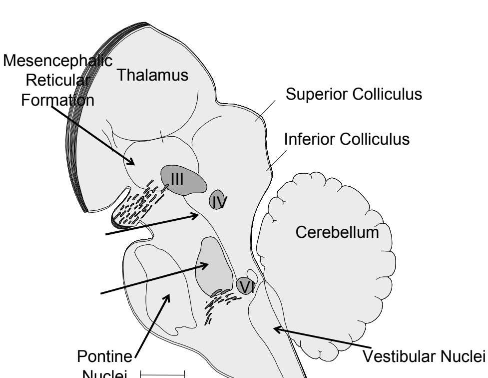
Nerve III: Oculomotor

Nerve IV: Trochlear

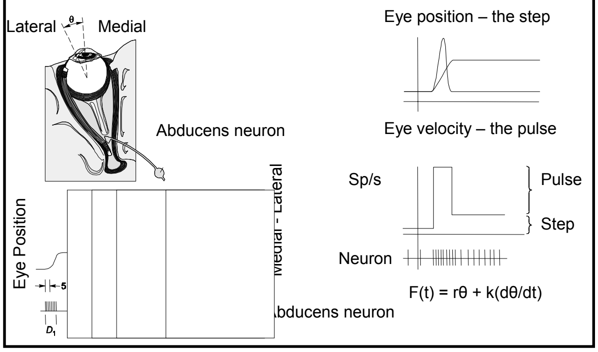
Nerve VI: Abducens

Left fourth nerve palsy

Eye muscle nuclei



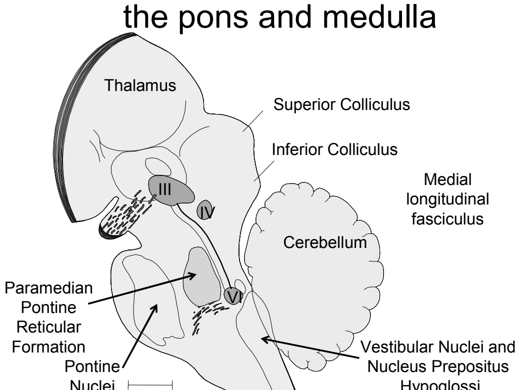
Oculomotor neurons describe eye position and velocity.



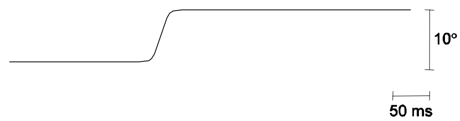
The transformation from muscle activation to gaze

- The pulse of velocity and the step of position are generated independently.
- For horizontal saccades the pulse is generated in the paramedian pontine reticular formation.
- The step is generated in the medial vestibular nucleus and the prepositus hypoglossi by a neural network that integrates the velocity signal to derive the position signal.

Horizontal saccades are generated in the pons and medulla

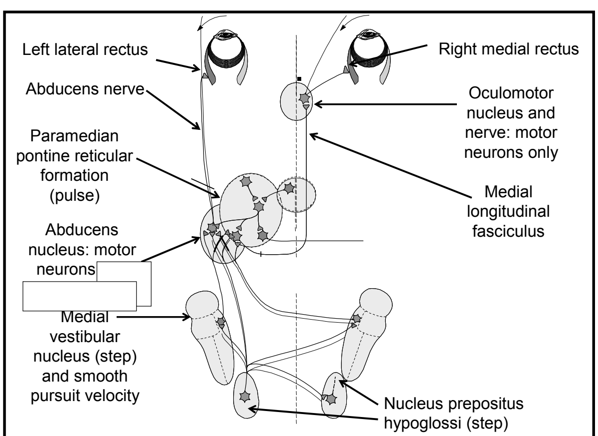


Neurons involved in the generation of a saccade



Generating the horizontal gaze signal

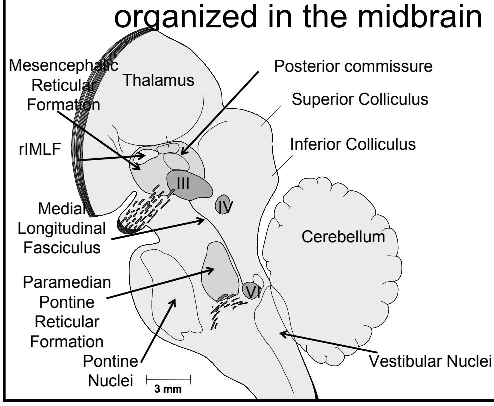
- The medial rectus of one eye and the lateral rectus of the other eye must be coordinated.
- This coordination arises from interneurons in the abducens nucleus that project to the contralateral medial rectus nucleus via the medial longitudinal fasciculus.



To reiterate

- Ocular motor neurons carry a step of position and a pulse of velocity.
- For horizontal saccades the pulse comes from the *ipsilateral* paramedian pontine reticular formation.
- For the VOR (and probably for smooth pursuit) the velocity signal comes from the *contralateral* medial vestibular nucleus.
- The step comes from the prepositus hypoglossi and medial vestibular nucleus, which integrate the velocity signal.
- Abducens interneurons send the pulse and step to the oculomotor nucleus via the medial longitudinal fasciculus.

Vertical movements and vergence are organized in the midbrain



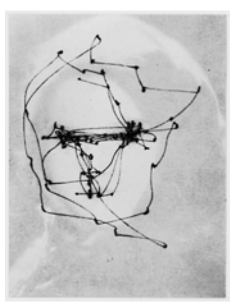
Internuclear ophthalmoplegia

- The medial longitudinal fasciculus is a vulnerable fiber tract.
- It is often damaged in multiple sclerosis and strokes.
- The resultant deficit is internuclear ophthalmoplegia
- The horizontal vergence signal cannot reach the medial rectus nucleus, but the convergence signal can.

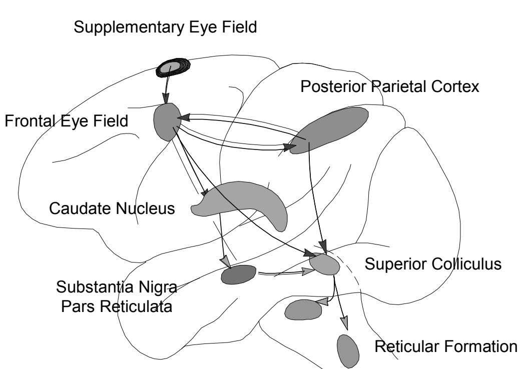
Supranuclear control of saccades

- The brainstem can make a rapid eye movement all by itself (the quick phase of nystagmus).
- The supranuclear control of saccades requires controlling the rapid eye movement for cognitive reasons.
- In most cases saccades are driven by attention

Humans look at where they attend



Supranuclear control of saccades



Supranuclear Control of Saccades

- Superior colliculus drives the reticular formation to make contralateral saccades.
- The frontal eye fields and the parietal cortex drive the colliculus.
- The parietal cortex provides an attentional signal and the frontal eye fields a motor signal.
- The substantia nigra inhibits the colliculus unless
- It is inhibited by the caudate nucleus
- Which is, in turn, excited by the frontal eye field.

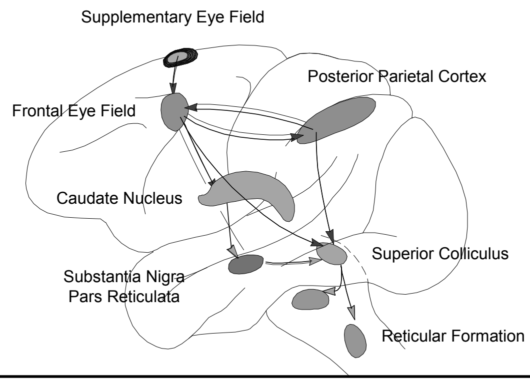
The effect of lesions

- Monkeys with collicular or frontal eye field lesions make saccades with a slightly longer reaction time.
- Monkeys with combined lesions cannot make saccades at all.
- Humans with parietal lesions neglect visual stimuli, but have no specific eye movement deficits. If they can see it they can make saccades to it.
- Humans with frontal lesions cannot make antisaccades.

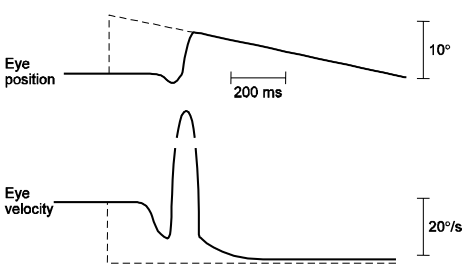
The Antisaccade Task

- Look away from a stimulus.
- The parietal cortex has a powerful signal describing the attended stimulus.
- The colliculus does not respond to this signal.
- The frontal motor signal drives the eyes away from the stimulus.
- Patients with frontal lesions cannot ignore the stimulus, but must respond to the parietal signal

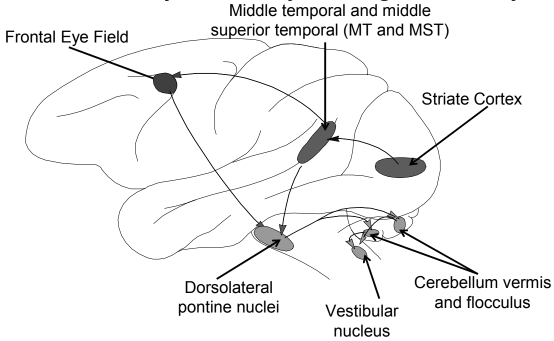
Antisaccades



Smooth pursuit matches eye velocity to target velocity



Supranuclear control of pursuit: pursuit matches eye velocity to target velocity



Smooth pursuit

- Requires cortical areas that compute target velocity, and the cerebellum.
- Utilizes many of the brainstem structures for the vestibuloocular reflex
- Requires attention to the target.

Clinical deficits of smooth pursuit

- Cerebellar and brainstem disease
- Specific parietotemporal or frontal lesions
- Any clinical disease with an attentional deficit – Alzheimer's or any frontal dementia, schizophrenia

Oh no, what do I really have to know about this stuff, he panicked

- The kinds of eye movements.
- What the muscles do.
- The separation, in the brainstem, or horizontal and vertical eye movement systems.
- The brainstem pathway for horizontal saccades.
- The cortical pathways for saccades and smooth pursuit.